# Biannual Report

**Department of Mathematics**
2019 and 2020

TECHNISCHE
UNIVERSITÄT
DARMSTADT

The cover illustration is by courtesy of Brice Loustau, postdoc at DAMS from Aug. 2018 to July 2020. It shows the Poincaré disk representing the hyperbolic plane tesselated with polygons which arise from the lift of a hyperbolic surface. The graphics illustrates the behaviour of harmonic maps between hyperbolic surfaces of the same genus.

Dear reader,

this biannual report provides a comprehensive overview of the research and teaching activities at the Department of Mathematics at TU Darmstadt during the years 2019 and 2020.
A characteristic of our department is the broad area of topics that are covered both in research and teaching. This is, for instance, reflected by the organization into eight diverse working groups: Algebra, Analysis, Applied Geometry, Didactics and Pedagogics of Mathematics, Logic, Numerical Analysis and Scientific Computing, Optimization, and Stochastics. The research activities are demonstrated by several joint research endeavors like Collaborative Research Centers, Graduate Schools, LOEWE centers and, last but not least, a large number of personal contacts. In particular, interdisciplinary work, for instance in cooperation with mechanical and electrical engineering, is one of the main pillars of research at our department. We are also very well connected to other research groups at the TU Darmstadt, in the Rhein-Main-Neckar area, within Germany, and far beyond. As such, our department is one of the largest and strongest departments of mathematics in Germany. The wealth of research areas is also represented in the different teaching activities. On the one hand, we provide several well established degrees in mathematics and, additionally, the English master in mathematics. On the other hand, our department offers a significant number of courses for thousands of students in each semester, mostly coming from other departments at the TU Darmstadt. In all of the these courses, we are dedicated to excellent and innovative teaching. The present report is meant to provide information about all research and teaching activities, about publications and prizes, presentations and events, from every single graduation thesis to our activities for high schools, and many other details that, taken together, represent our work in the last two years. We hope that this report forms an interesting and enjoyable reading experience.

With kind regards,

K. Große-Brauckmann

Prof. Dr. Karsten Große-Brauckmann
(Dean of the department)

## Contents

# 1 Research Groups

This section gives a brief overview of the research done in the eight research groups.

## 1.1 Algebra

The main research areas of this group are algebraic geometry, number theory and conformal field theory.
We are interested in Shimura varieties and automorphic forms and their applications in geometry and arithmetic. For example we investigate intersection and height pairings of special algebraic cycles on Shimura varieties and their connection to automorphic L-functions. We also study the relation between the representation theory of vertex operator algebras and automorphic forms.

**Members of the research group**

**Professors**

Jan Hendrik Bruinier, Yingkun Li, Anna von Pippich, Timo Richarz, Nils Scheithauer, Torsten Wedhorn

**Retired professors**

Karl-Heinrich Hofmann

**Postdocs**

Gabriele Bogo, Moritz Dittmann, Jolanta Marzec, Sven Möller, Michalis Neururer, Brandon Williams

**Research Associates**

Patrick Bieker, Johannes Buck, Thomas Driscoll-Spittler, Timo Henkel, Jens Hesse, Patrick Holzer, Paul Kiefer, David Klein, Jennifer Kupka, Priyanka Majumder, Ingmar Metzler, Sebastian Opitz, Maximilian Rössler, Can Yaylali

**Secretaries**

Ute Fahrholz, Anja Spangenberg

**Project: Higher automorphic Green functions**

In this project we investigate automorphic Green functions on orthogonal Shimura varieties at higher integral values of the spectral parameter.
Gross and Zagier conjectured that the CM values (of certain Hecke translates) of the automorphic Green function $G_s(z_1, z_2)$ for the elliptic modular group at positive integral spectral parameter $s$ are given by logarithms of algebraic numbers in suitable class fields. In joint work with S. Ehlen and T. Yang we prove a partial average version of this conjecture, where we sum in the first variable $z_1$ over all CM points of a fixed discriminant $d_1$ (twisted by a genus character), and allow in the second variable the evaluation at individual CM points of discriminant $d_2$. This result is deduced from more general statements for automorphic Green functions on Shimura varieties associated with the group $\mathrm{GSpin}(n, 2)$. We also use our approach to prove a Gross-Kohnen-Zagier theorem for higher Heegner divisors on Kuga-Sato varieties over modular curves.

**Partner:** S. Ehlen, Universität zu Köln; T. Yang, University of Wisconsin at Madison

**Support:** DFG, LOEWE

**Contact:** J. H. Bruinier, Y. Li

### References

[1] C. Alfes-Neumann and M. Schwagenscheidt. On a theta lift related to the Shintani lift. *Advances in Mathematics*, 328:858–889, 2018.

[2] J. H. Bruinier, S. Ehlen, and T. Yang. CM values of higher automorphic Green functions for orthogonal groups. Preprint, 2019.

[3] J. H. Bruinier and T. Yang. Faltings heights of CM cycles and derivatives of $L$-functions. *Inventiones mathematicae*, 177:631–681, 2009.


**Project: Arithmetic intersection theory on Shimura varieties**

We study special cycles on integral models of Shimura varieties associated with unitary similitude groups of signature $(n-1,1)$. In joint work with Howard and Yang we construct an arithmetic theta lift from harmonic Maass forms of weight $2-n$ to the first arithmetic Chow group of a toroidal compactification of the integral model of the unitary Shimura variety, by associating to a harmonic Maass form $f$ a suitable linear combination of Kudla-Rapoport divisors, equipped with the Green function given by the regularized theta lift of $f$. Our main result expresses the height pairing of this arithmetic Kudla-Rapoport divisor with a CM cycle in terms of a Rankin-Selberg convolution $L$-function of the cusp form of weight $n$ corresponding to $f$ and the theta function of a positive definite hermitian lattice of rank $n-1$. The proof relies on a new method for computing improper arithmetic intersections (among other things).

In joint work with Howard, Kudla, Rapoport, and Yang we proved that the generating series of arithmetic Kudla Rapoport divisors is an elliptic modular form of weight $n$ with values in the arithmetic Chow group. This can be used to define an arithmetic theta lift from weight $n$ cusp forms to the arithmetic Chow group. As applications, one obtains Gross-Zagier type formulas for heights of CM cycles in this setting as well as a proof of the Colmez conjecture in cases where the CM field is the compositum of a totally real field and an imaginary quadratic field.

In ongoing work with Howard, we compute arithmetic volumes of unitary Shimura varieties and the arithmetic degrees of Kudla-Rapoport divisors.

**Partner:** B. Howard, Boston College; S. Kudla, University of Toronto; M. Rapoport, Universität Bonn; T. Yang, University of Wisconsin at Madison

**Support:** DFG, NSF, AIM

**Contact:** J. H. Bruinier


### References

[1] J. H. Bruinier, B. Howard, S. Kudla, M. Rapoport, and T. Yang. Modularity of generating series of divisors on unitary Shimura varieties. *Astérisque*, 421:7–125, 2020.

[2] J. H. Bruinier, B. Howard, S. Kudla, M. Rapoport, and T. Yang. Modularity of generating series of divisors on unitary Shimura varieties II: arithmetic applications. *Astérisque*, 421:127–186, 2020.

[3] J. H. Bruinier, B. Howard, and T. Yang. Heights of Kudla-Rapoport divisors and derivatives of $L$-functions. *Inventiones Mathematicae*, 201:1–95, 2015.

[4] J. H. Bruinier and Y. Li. Heegner divisors in generalized Jacobians and traces of singular moduli. *Algebra and Number Theory*, 10:1277–1300, 2016.

**Project: Arithmetic Siegel-Weil formulas**

Let $V$ be a rational quadratic space of signature $(m, 2)$. A conjecture of Kudla relates the arithmetic degrees of top degree special cycles on an integral model of a Shimura variety associated with $SO(V)$ to the coefficients of the central derivative of an incoherent Siegel Eisenstein series of genus $m+1$.

In joint work with T. Yang we prove this conjecture for the coefficients of non-singular index $T$ when $T$ is not positive definite. We also prove it when $T$ is positive definite and the corresponding special cycle has dimension 0. To obtain these results, we establish new local arithmetic Siegel-Weil formulas at the archimedean and non-archimedian places.

**Partner:** T. Yang, University of Wisconsin at Madison

**Support:** DFG, LOEWE

**Contact:** J. H. Bruinier

**References**


[1] J. H. Bruinier and M. Westerholt-Raum. Kudla's modularity conjecture and formal Fourier-Jacobi series. *Forum of Mathematics, Pi*, 3:30pp., 2015.

[2] J. H. Bruinier and T. Yang. Arithmetic degrees of special cycles and derivatives of Siegel Eisenstein series. *Journal of the European Mathematical Society*, to appear.

[3] S. S. Kudla. Special cycles and derivatives of Eisenstein series. In *Heegner points and Rankin L-series*, volume 49 of *Math. Sci. Res. Inst. Publ.*, pages 243–270. Cambridge Univ. Press, Cambridge, 2004.


**Project: Arithmetic Riemann-Roch theorem for singular metrics**

A fundamental result in arithmetic intersection theory is the arithmetic Riemann–Roch theorem for arithmetic varieties by Gillet and Soulé. This theorem developed from previous versions by Faltings and Deligne, who treated the case of arithmetic surfaces. Deligne's isometry and the arithmetic Riemann-Roch theorem both require the vector bundles to be endowed with smooth hermitian metrics. However, many cases of arithmetic interest do not satisfy this assumption. This research project with G. Freixas i Montplet aims at establishing an arithmetic Riemann–Roch theorem for a certain type of singular metrics. Furthermore, we aim at deriving arithmetic application from this theorem, for instance, we want to compute special values of the Selberg zeta function. In the recent article [1], we developed a new method of extending Deligne's Riemann–Roch isometry to certain modular curves. One arithmetic application of the theorem consists in an exotic analytic class number formula for the Selberg zeta function for the modular group. In the next step, we plan to apply the developed method to more general situations.

**Partner:** G. Freixas i Montplet, CNRS Paris

**Contact:** A.-M. von Pippich

**References**


[1] G. Freixas i Montplet and A.-M. von Pippich. Riemann–Roch isometries in the non-compact orbifold setting. *J. Eur. Math. Soc. (JEMS)*, 22(11):3491–3564, 2020.


**Project: Generalized Eisenstein series**

Eisenstein series are an essential ingredient in the theory of automorphic forms with numerous applications to number theory and arithmetic geometry. This joint research project concerns the generalization of elliptic and hyperbolic Eisenstein series to more general settings. Here, one direction of research has been devoted to the study of special values of these Eisenstein series and to establish an analogue of Kronecker's limit formula. In the recent article [1], jointly with V. Völz and M. Schwagenscheidt, we realized averaged versions of these Eisenstein series for as regularized Borcherds lifts and we proved that the special value at $s = 0$ is given in terms of the corresponding Borcherds product. In the next step, we plan to define and study generalized Eisenstein series associated to special cycles for the orthogonal group, and we aim at realizing theses series in a similar way as generalized regularized theta lifts.

**Partner:** D. Klein (TU Darmstadt); M. Schwagenscheidt (ETH Zurich)

**Contact:** A.-M. von Pippich

#### References


[1] A.-M. von Pippich, M. Schwagenscheidt, and F. Völz. Kronecker limit formulas for parabolic, hyperbolic, and elliptic Eisenstein series via Borcherds products. *J. Number Theory*, 225:18–58, 2021.


### Project: Jensen–Rohrlich type formulas for hyperbolic spaces

The classical Jensen's formula is a well-known theorem of complex analysis which characterizes, for a meromorphic function $f$ on the unit disc, the value of the integral of $\log|f(z)|$ on the unit circle in terms of the zeros and poles of $f$ inside the unit disc. An important theorem of Rohrlich establishes a version of Jensen's formula for modular functions $f$ with respect to the full modular group $\mathrm{PSL}_2(\mathbb{Z})$ and expresses the integral of $\log|f(z)|$ over a fundamental domain in terms of special values of Dedekind's eta function. In this joint project, we plan to establish analogues of the Jensens's formula in higher dimensions. In the recent article [1], we were able to prove a Jensen–Rohrlich type formula for the hyperbolic 3-space.

**Partner:** S. Herrero (University of Gothenburg); Ö. Imamoḡlu (ETH Zürich); Á. Tóth (Eötvös Loránd University, Budapest)

**Contact:** A.-M. von Pippich

#### References


[1] S. Herrero, O. Imamoglu, A.-M. von Pippich, and A. Tóth. A jensen–rohrlich type formula for the hyperbolic 3-space. *Trans. Amer. Math. Soc.*, 371(9):6421–6446, 2019.


### Project: The Kodaira dimension of $A_6$

The Kodaira dimension of a complex smooth projective variety is an important birational invariant in algebraic geometry. It measures the size of the canonical model of the variety. The Siegel modular variety $A_n = \mathrm{Sp}_{2n}(\mathbb{Z})\backslash H_n$ parametrizes the principally polarized complex abelian varieties of dimension $n$. Tai, Freitag and Mumford proved that $A_n$ is of general type for $n \geq 7$, i.e. has maximal Kodaira dimension. In the other direction several authors showed that $A_n$ is unirational for $n \leq 5$ and therefore has Kodaira dimension $-\infty$. After more than 30 years, the case n=6 is still unsolved. In [1] we construct a non-zero Siegel cusp form of degree 6 and weight 14 with vanishing order 2 at the boundary from the Leech lattice. This function defines a non-trivial global section of the bicanonical bundle $\omega^2_{\overline{A_6}}$ which implies that the Kodaira dimension of $A_6$ is non-negative. This is the first partial result on the Kodaira dimension of $A_6$.

**Contact:** N. Scheithauer

**Partner:** M. Dittmann, R. Salvati Manni

**References**


[1] M. Dittmann, R. Salvati Manni, and N. R. Scheithauer. Harmonic theta series and the Kodaira dimension of $A_6$. *Algebra & Number Theory*, 15(1):271–285, 2021.


**Project: Construction and classification of holomorphic vertex operator algebras**

Vertex operator algebras give a mathematically rigorous description of 2-dimensional quantum field theories. The theory of these algebras is in many aspects similar to the theory of positive-definite even lattices. The analogue of Niemeier's classification of positive-definite even lattices of rank 24 is Schellekens' list. The $V_1$-subspace of a holomorphic vertex operator algebra of central charge 24 is a reductive Lie algebra. Schellekens showed that there are at most 71 possibilities for $V_1$ and conjectured that each occurs for a unique vertex operator algebra. By the work of many authors this is now proved for all cases with non-trivial $V_1$. The case of trivial $V_1$ is realised by the moonshine module. The uniqueness of this vertex operator algebra is one of the main open problems in the theory. The moonshine module can be constructed as an orbifold of the vertex operator algebra associated with the Leech lattice by an involution. In [2] we develop a general orbifold theory for automorphisms of finite order. A formula for the dimension of the $V_1$-space of an orbifold corresponding to a genus 0 group is derived in [3]. We show in [1] that this formula is an obstruction coming from Eisenstein series and generalize it to arbitrary orders. The formula implies an upper bound on the dimension of the $V_1$-space which we use to define the notion of a generalized deep hole. Then we show that each vertex operator algebra on Schellekens' list with non-trivial $V_1$ can be obtained by orbifolding the vertex operator algebra of the Leech lattice by such an automorphism. This generalizes the construction of the Niemeier lattices through deep holes of the Leech lattice by Conway, Parker and Sloane.

**Contact:** N. Scheithauer

**Partner:** J. van Ekeren, S. Möller

**References**


[1] S. Möller and N. R. Scheithauer. Dimension formulae and generalised deep holes of the Leech lattice vertex operator algebra. arxiv:1910.04947, submitted, 2019.

[2] J. van Ekeren, S. Möller, and N. R. Scheithauer. Construction and classification of holomorphic vertex operator algebras. *J. Reine Angew. Math.*, 759:61–99, 2020.

[3] J. van Ekeren, S. Möller, and N. R. Scheithauer. Dimension formulae in genus zero and uniqueness of vertex operator algebras. *Int. Math. Res. Not. IMRN*, (7):2145–2204, 2020.


## 1.2 Analysis

The research group Analysis consists of seven professors, D. Bothe, R. Farwig, R. Haller-Dintelmann (apl.), M. Hieber, S. Modena, S. Roch (apl.) and Chr. Stinner (apl.), and about

30 assistants as state employees or paid by third party funding. The field of research of this group covers theory and applications of partial differential equations and of integral equations as well as mathematical modeling. Having close contact to the departments of engineering and natural sciences, the analysis group at TU Darmstadt is open to new mathematical problems and scientific challenges.

One focal point of research activities is the investigation of nonlinear PDEs in fluid dynamics including methods from evolution equations, maximal regularity and harmonic analysis. Of particular interest are geophysical flows, nematic liquid crystals and complex fluids. Equations of fluid dynamics are also studied using methods of convex integration, which have been proven in recent years to be a fundamental tool in order to show "low-regularity" results and to explain mathematically longstanding open problems in the theory of turbulent fluids. A famous open problem concerning the existence of smooth solutions of the Navier-Stokes equations is one of the seven Millennium Problems of Clay Mathematics Institute.

A second focus point is put on the mathematical modeling and computational analysis of complex flow problems, in particular two-phase flows with transport processes occurring at fluid interfaces and dynamic wetting phenomena. The research builds on continuum mechanical modeling employing and further developing sharp-interface as well as diffuse interface models with increasing levels of physico-chemical interface properties. For a deep understanding of the elementary transport and transfer processes, direct numerical simulations with complementary numerical methods such as Volume-of-Fluid, Interface Tracking and combined Level Set / Front Tracking are employed and further developed.

Further focal points concern the analysis and numerical approximation techniques for singular integral equations which can be applied in fluid mechanics, computer tomography and image processing, the analysis of elliptic and parabolic equations on non-smooth domains with mixed boundary conditions as well as the investigation of various chemotaxis models and the analysis of small $BV$ solutions to hyperbolic systems of conservation laws.

The research group Analysis presents two "Research Seminars" on a regular weekly basis, introductory seminars on functional analytic tools in the theory of partial differential equations as well as graduate seminars on recent questions in the above-mentioned fields of research. In addition to basic courses on analysis, the research group offers lectures on analysis for majors in mathematics as well as advanced courses on partial differential equations and on related fields for graduate students.

Several members of the research group Analysis (Bothe, Farwig, Hieber) were Principal Investigators of the International Research Training Group (IRTG 1529) (Internationales Graduiertenkolleg) "Mathematical Fluid Dynamics" funded by DFG and JSPS and associated with TU Darmstadt, Waseda University in Tokyo and the University of Tokyo, which ended in December 2018. It initiated, however, further activities in the years 2019-20, as e.g., joint Japanese-German confererences at RIMS in Kyoto or ceremonies, where the presidents of the universities involved signed agreements concerning the further exhange of PhD students.

The research group Analysis also participates with Principal Investigators in various research networks such as the CRC 1194 (Bothe, Gründing, Marschall), the CRC-Transregio 75 (Bothe), the CRC-Transregio 150 (Marschall) and the Priority Programm 1740 (Bothe, Marschall), all funded by the DFG.

Several of our Postdocs obtained offers for a professorship or an assistant professorship. More specifically, Karoline Disser was appointed as Professor at the University of Kassel, Patrick Tolksdorf and Amru Hussein were appointed as assistant professors at the Univerisity of Mainz and Kaiserslautern, respectively. Martin Saal was awarded with a DFG scholarship to pursue research on stochastic analysis at the Scuola Normale in Pisa.

Matthias Hieber serves since 2020 as the vice director of the Mathematical Research Institute in Oberwolfach (MFO).

**Members of the research group**

**Professors**

Dieter Bothe, Reinhard Farwig, Robert Haller-Dintelmann, Matthias Hieber, Stefano Modena, Steffen Roch, Christian Stinner

**Postdocs**

Björn Augner, Tim Binz, Jorge Cardona, Anupam Pal Choudhury, Karoline Disser, Holger Marschall, Martin Saal, Amru Hussein, Patrick Tolksdorf

**Research Associates**

Heba Alkafri, Muhammad Hassan Asghar, Milad Bagheri, Francisco Bodziony, Aday Celik, Thomas Eiter, Mathis Fricke, Mathis Gries, Dirk Gründing, Dennis Hillenband, Klaus Kress, Johannes Kromer, Tomislav Maric, Jens-Henning Möller, Matthias Niethammer, Suraj Raju, Andreas Schmidt, Anton Seyfert, Miriam Schmitt, Tobias Tolle, André Weiner, Marc Wrona

**Scolarship holders**

Sebastian Bechtel, Martin Saal

**Secretaries**

Renate Driessler, Lilli Jundt-Becker, Anke Meier-Dörnberg

**Project: Modelling and analysis of heterogeneous catalysis systems**

In chemical engineering, catalytic processes play an extremly important role. In contrast to homogeneous catalysts (cf. enzymes) which are added as a catalytically active substance to a fluid mixture to accelerate required chemical reactions and to reduce the production of by-products, catalytic surface structures often have advantageous properties. For example, in contrast to homogeneous catalysts, no filtration technique is required to extract the catalyst from the product, as the chemical reactions typically take place mainly on the catalytic surface. Also some heterogeneous catalysts are more efficient than competing homogeneous catalysts by several orders of magnitude. The project consists of several sub-projects listed below:

- Modelling of multi-component fluids with cross-diffusion and bulk-surface-interaction: Modelling of physically relevant models from heterogeneous catalysis should be based on general thermodynamic principles as energy conservation and entropy production. For multi-component systems, closure relations following this modelling paradigma inevitably lead to cross-diffusion effects for diffusive fluxes $j_i = j_i(\vec{c})$ – in contrast to Fickean diffusion ($j_i = -d_i \nabla c_i$). Resulting models include, but are not limited to, Maxwell–Stefan diffusion and Fick–Onsager diffusion.

- Existence, uniqueness and long-time behaviour for heterogeneous reaction-diffusion-advection-sporption systems: By coupling a reaction-diffusion-advection system in the bulk phase of a chemical reactor with a reaction-diffusion-advection system on the catalytic surface of this reactor, on is faced with several mathematical challenges: Besides the quasi-linear (insted of semi-linear) nature of the Maxwell–Stefan diffusion, for maximal regularity of the linearised bulk-surface system, substantially more difficult conditions have to be checked. Currently we are working on an application of the mathematical theory developed in [10] and [11] to a prototype case of a chemical reactir with a dilute bulk and Maxwell-Stefan surface diffusion. We are, in particular, interested in the existence and uniqueness of strong solutions and their long-time behaviour (global-in-time existence, convergence to equilibria). Besides that using the *boundedness-by-entropy* method (which heavily relies on the thermodynamic consistent modelling), we seek to construct global-in-time weak solutions for heterogeneous catalysis systems, possibly also including a Navier–Stokes model for the advective flux.
- Modelling and analysis of heterogeneous catalysis systems with fast sorption and fast surface chemistry: Since for heterogeneous catalysis systems the surface chemistry, i.e. chemical reactions on the active surface, and ad- and desorption betwenn bulk phase and surface in best case are extremely fast, it makes sense to consider the fast sorption and fast surface chemistry limit of such systems where the surface chemistry and the sorption processes instantaneously attain a equililibrium configuration. Based on thermodynamic principles, in [5] we showed how (for a prototypical reactor) such a reduced fast limit system can be derived: Dynamic boundary conditions are thereby replaced by nonlinear equilibrium conditions on the surface chemistry and homogeneous boundary conditions for the flux corresponding to conserved quantities under chemical reactions. The resulting systems of reaction-diffusion equations with combined type boundary conditions constitute an interesting class of reaction-diffusion systems [5], [4].

**Partner:** R. Denk (Universität Konstanz), W. Dreyer (WIAS Berlin), P.-E. Druet (WIAS Berlin), A. Jüngel (TU Wien), J. Málek (Charles University Prague), R. Schnaubelt (Karlsruher Institut für Technologie)

**Contact:** Björn Augner, Dieter Bothe

### References


[1] B. Augner. $L_p$-maximal regularity for parabolic and elliptic boundary value problems with boundary conditions of varying differentiability orders. In preparation.

[2] B. Augner and D. Bothe. Analysis of a hetereogeneous catalysis model with Langmuir adsorption. In preparation.

[3] B. Augner and D. Bothe. Modelling and analysis of a heterogeneous catalysis system with site-conserving Maxwell-Stefan diffusion on the surface. In preparation.

[4] B. Augner and D. Bothe. Analysis of some heterogeneous catalysis models with fast sorption and fast surface chemistry. *https://arxiv.org/abs/2006.12098*, 2020.

[5] B. Augner and D. Bothe. The fast-sorption-fast-surface-reaction limit of a heterogeneous catalysis model. *Discrete and Continuous Dynamical Systems: Series S*, 14(2):533–574, 2021.

[6] D. Bothe. Sharp-interface continuum thermodynamics of multicomponent fluid systems with interfacial mass, 2020. Preprint.

[7] D. Bothe and W. Dreyer. Continuum thermodynamics of chemically reacting fluid mixtures. *Acta Mech.*, 226(6):1757–1805, 2015.

[8] D. Bothe and P.-E. Druet. On the structure of continuum thermodynamical diffusion fluxes – a novel closure scheme and its relation to the Maxwell-Stefan and the Fick-Onsager approach, 2020. Preprint.

[9] D. Bothe, M. Köhne, S. Maier, and J. Saal. Global strong solutions for a class of heterogeneous catalysis models. *J. Math. Anal. Appl.*, 445(1):677–709, 2017.

[10] R. Denk, J. Prüss, and R. Zacher. Maximal $L_p$-regularity of parabolic problems with boundary dynamics of relaxation type. *J. Funct. Anal.*, 255(11):3149–3187, 2008.

[11] R. Schnaubelt. Stable and unstable manifolds for quasilinear parabolic problems with fully nonlinear dynamical boundary conditions. *Adv. Differential Equations*, 22(7-8):541–592, 2017.

[12] O. Soucek, V. Orava, J. Málek, and D. Bothe. A continuum model of heterogeneous catalysis: thermodynamic framework for multicomponent bulk and surface phenomena coupled by sorption. *Internat. J. Engrg. Sci.*, 138:28–117, 2019.

**Project: Interconnection structures for infinite-dimensional systems of port-Hamiltonian type**

Starting from the 1960s a *port-based* modelling and analysis has been introduced to treat complex, multi-physics systems within a unified framework. These usually consist of many subsystems of mechanical, electrical or thermal type etc., which can be described by their inner dynamics, usually a system of ODEs or PDEs, and which may interact with other subsystems via ports, i.e. input and output variables. For *port-Hamiltonian systems* the notion of energy is highlighted, and usually subsystems are required to be either energy-preserving or energy-dissipating. We investigate well-posedness and stability properties for this class of systems, especially the effects of non-autonomous perturbations and of the structure of the system on existence, uniqueness and long-time behaviour of solutions [1], [2], [3], [4].

**Contact:** Björn Augner

**References**

[1] B. Augner. Well-posedness and stability of infinite-dimensional linear port-Hamiltonian systems with nonlinear boundary feedback. *SIAM J. Control Optim.*, 57(3):1818–1844, 2019.

[2] B. Augner. Uniform exponential stabilisation of serially connected inhomogeneous Euler-Bernoulli beams. *ESAIM: Control, Optimisation and Calculus of Variations*, 26:Art. No. 110, 2020.

[3] B. Augner. Well-posedness and stability for interconnection structures of port-Hamiltonian type. In J. Kerner, H. Laasri, and D. Mugnolo, editors, *Control Theory of Infinite-dimensional Systems.*, volume 277 of *Operator Theory: Advances and Applications. Linear Operators and Linear Systems*, pages 1–52. Birkhäuser/Springer, 2020.

[4] B. Augner and H. Laasri. Exponential stability for infinite-dimensional non-autonomous port-Hamiltonian systems. *Systems & Control Letters*, 144:Art. No. 104757, 2020.

**Project: The structure of continuum thermodynamical diffusion fluxes**

Multicomponent diffusion in fluid systems is commonly modeled via the Fick-Onsager or the generalized Maxwell-Stefan approach. The latter approach has the advantage that the resulting fluxes are consistent with non-negativity of the partial densities for non-singular and non-degenerate Maxwell-Stefan diffusivities. On the other hand, this approach requires computationally expensive matrix inversions since the fluxes are only implicitly given. We explore a novel and more direct closure which avoids the inversion of the Maxwell-Stefan equations. It is shown that all three closures are actually equivalent under natural positivity requirements, thus revealing the general structure of continuum thermodynamical diffusion fluxes. One additional aim is to provide a rigorous fundament for recent extensions of the Darken equation from so-called weakly associated constituents to the case of general mixtures.

**Partner:** Pierre-Étienne Druet

**Contact:** Dieter Bothe

### References

[1] D. Bothe and P.-E. Druet. On the structure of continuum thermodynamical diffusion fluxes – A novel closure scheme and its relation to the Maxwell-Stefan and the Fick-Onsager approach. *Preprint*, arXiv:2008.05327, 2020.

### Project: Mathematical modeling of the surfactant influence on mass transfer at fluid interfaces

Fluid interfaces in technical or industrial processes are often contaminated with surface active agents (surfactants), either on purpose or due to impurities. This has a strong influence on mass transfer because of (i) the back-effect of the adsorbed surfactant onto the hydrodynamics via changes in interfacial tension and (ii) the local hindrance of mass transfer due to interface coverage. We develop and investigate mathematical models which quantitatively capture these phenomena in a thermodynamically consistent way. Depending on the desciption of the interfacial free energy, these models can incorporate Langmuir's energy barrier effect in a consistent and local manner.

**Partner:** Akio Tomiyama

**Contact:** Dieter Bothe

### References

[1] D. Bothe. Sharp-interface continuum thermodynamics of multicomponent fluid systems with interfacial mass. *Preprint*, arXiv:2010.05989, 2020.

[2] Y. Hori, D. Bothe, K. Hayashi, S. Hosokawa, and A. Tomiyama. Mass transfer from single carbon-dioxide bubbles in surfactant-electrolyte mixed aqueous solutions in vertical pipes. *International Journal of Multiphase Flow*, 124.:103207, 2020.

### Project: Mathematical modeling and analysis of multicomponent fluids

Real world fluids like solutions, electrolytes, fluid mixtures, etc. are composed of several constituents, i.e. are multicomponent fluids. Their sound and quantitative description requires a consistent coupling of species advection, multicomponent diffusion, chemical reactions and further purely mechanical phenomena. We investigate the thermodynamically consistent mathematical modeling of multicomponent fluids, both in the compressible as well as incompressible case. For fluid mixtures, incompressibility is defined as the independence of the average volume on pressure at given temperature and composition. We rigorously study the incompressible limit, where it turns out that a weighted sum of the partial mass densities stays constant. We also analyse the resulting PDEs, which are of mixed parabolic-hyperbolic type. We study the well-posedness of the model in classes of strong solutions and obtain existence and uniqueness for short-times. If the initial data are sufficiently near to an equilibrium solution, well-posedness holds on arbitrary large, but finite time intervals. In the incompressible setting, non-solenoidal effects still affect the velocity field in the Navier-Stokes equations of multicomponent fluids and, due to different specific volumes of the species, the pressure remains connected to the densities by algebraic formula. By means of a carefully tailord change of variables, we reformulate the PDE system to eliminate positivity and incompressibility constraints. We again obtain well-posedness results in classes of strong solutions.

**Partner:** Wolfgang Dreyer, Pierre-Étienne Druet

**Contact:** Dieter Bothe

### References


[1] D. Bothe, W. Dreyer, and P.-E. Druet. Multicomponent incompressible fluids–an asymptotic analysis. *Preprint*, WIAS preprint 2825, 2021.

[2] D. Bothe and P.-E. Druet. Mass transport in multicomponent compressible fluids: local and global well-posedness in classes of strong solutions for general class-one models. *Preprint*, arXiv:2001.08970, 2020.

[3] D. Bothe and P.-E. Druet. Well-posedness analysis of multicomponent incompressible flow models. *Preprint*, arXiv:2005.12052, 2020.


**Project: Numerical simulation of binary droplet collisions** Binary collisions of droplets form a very important elementary process for many technical applications. In order to gain detailled insights into the rich physical phenomena, direct numerical simulations are employed to extract local instantaneous quantities, e.g. velocity and pressure. For head-on collisions of identical droplets, i.e. if the droplet trajectories admit no offset, one of the droplets can be numerically replaced with a mirror droplet by a collision plane to reduce the computational effort. Still, resolving the gas film directly remains infeasible, such that its effects are captured in terms of a subgrid-scale model for the pressure, based on the lubrication approximation. Employing a domain boundary with symmetry conditions as collision plane was shown to accurately reproduce the collision process for a prescribed collision outcome. However, artificial deceleration in the vicinty of the collision plane inhibits the gas film from reaching physically reasonable thicknesses. This project aims at predictive simulations by introducing an artificial interior collision plane that, besides the subgrid-scale model, does not interfer with the collision process. Contrary to the previous treatment as boundary condition for the bulk pressure, a direct coupling of the subgrid-scale pressure to the employed flow solver FS3D allows to reach physically reasonable film thicknesses, even with coarse resolution. Further refinement of the coupling, however, is subject of ongoing research.

**Support:** DFG TRR 75

**Contact:** Dieter Bothe

### References


[1] J. Kromer. *Towards a computer-assisted global linear stability analysis of fluid particles*. PhD thesis, TU Darmstadt, 2019.

### Project: Time-periodic viscous flow past a body

We investigate the time-periodic flow of an incompressible viscous fluid past an obstacle, which is governed by the Navier–Stokes equations in an exterior domain. In the case of a non-rotating body, existence of a solution was proved in [4] in a framework of homogeneous Sobolev space. We further developed this approach in [1] to obtain a solution in classical Sobolev spaces. For the flow past a rotating body, we showed existence of a solution in [3]. The proof requires compatibility of the angular velocity of the rotation and the time period of the prescribed external force. Further research aims at omitting this condition. Moreover, the spatially asymptotic properties of such time-periodic flows are studied. Based on the analysis of time-periodic fundamental solutions to the associated linearized systems from [6, 2] and the first results from [5], we develop asymptotic expansions of the velocity field decomposed into its (time-independent) mean over one period and a remaining part that decays faster. In particular, this yields sharp pointwise decay estimates of the velocity field as well as necessary and sufficient conditions for faster decay. Moreover, decay properties of the associated vorticity field are studied based on the introduction of a corresponding fundamental solution.

**Partner:** G.P. Galdi (University of Pittsburgh); M. Kyed (Hochschule Flensburg)

**Contact:** Thomas Eiter

#### References


[1] T. Eiter and G. P. Galdi. New results for the Oseen problem with applications to the Navier-Stokes equations in exterior domains. In *Mathematical Analysis of Viscous Incompressible Fluid*, number 2171 in RIMS Kôkyûroku, pages 1–15. Res. Inst. Math. Sci. (RIMS), Kyoto, 2020.

[2] T. Eiter and M. Kyed. Estimates of Time-Periodic Fundamental Solutions to the Linearized Navier–Stokes Equations. *Journal of Mathematical Fluid Mechanics*, 20:517–529, 2018.

[3] T. Eiter and M. Kyed. Viscous Flow Around a Rigid Body Performing a Time-periodic Motion. *J. Math. Fluid Mech.*, 23(1), 2021.

[4] G. P. Galdi and M. Kyed. Time-periodic flow of a viscous liquid past a body. In *Partial differential equations in fluid mechanics*, volume 452 of *London Math. Soc. Lecture Note Ser.*, pages 20–49. Cambridge Univ. Press, Cambridge, 2018.

[5] G. P. Galdi and M. Kyed. Time-periodic solutions to the Navier-Stokes equations in the three-dimensional whole-space with a non-zero drift term: asymptotic profile at spatial infinity. In *Mathematical analysis in fluid mechanics—selected recent results*, volume 710 of *Contemp. Math.*, pages 121–144. Amer. Math. Soc., Providence, RI, 2018.

[6] M. Kyed. A fundamental solution to the time-periodic Stokes equations. *J. Math. Anal. Appl.*, 437(1):708–719, 2016.


### Project: Time-periodic motion of liquid drops

We investigate the motion of a liquid drop emerged into another viscous fluid, both modeled by the Navier–Stokes equations with gravity as external force. In physical experiments, the drop performs a steady motion when the corresponding Reynolds number is small. In [1] we introduced a framework of suitable function spaces in which we showed the existence of solutions to this stationary free-boundary problem. When the Reynolds number exceeds a certain threshold, the physical experiment suggests that the drop undergoes a periodic motion despite the absence of external periodic forces. As a first step for an analytic validation of this Hopf bifurcation, the motion of a liquid drop inside a bounded container and subject to an external time-periodic force was studied in [2]. The analysis of the associated linearized problem was carried out with the help of the concept of $\mathcal{R}$-boundedness.

**Partner:** M. Kyed (Hochschule Flensburg); Y. Shibata (Waseda University, Tokyo)

**Contact:** Thomas Eiter

**References**


[1] T. Eiter, M. Kyed, and Y. Shibata. Falling drop in an unbounded liquid reservoir: Steady-state solutions. Preprint, 2019.

[2] T. Eiter, M. Kyed, and Y. Shibata. On periodic solutions for one-phase and two-phase problems of the Navier–Stokes equations. *J. Evol. Equ.*, 2020.


### Project: Maximal $L^1$-regularity

Maximal regularity in $L^q$ of a densely defined operator $A$ on a Banach space $X$ means that the abstract evolution problem $\partial_t u + Au = f$, $u(0) = 0$, has a unique solution $u$ such that $\partial_t u, Au(t) \in L^q(0,T;X)$ if $f \in L^q(0,T;X)$ and hence can be estimated by $f$ in the norm of $L^q(0,T;X)$. This property is widely known and used in parabolic equations for the Laplacian and the Stokes operator when $1 < q < \infty$; the underlying Banach space $X$ is of type $UMD$ and hence reflexive. The corresponding endpoint results in $L^\infty$, $BC$ and in $L^1$ are more involved. E.g., it is known that $BC$-maximal regularity will hold only if $X$ is neither reflexive nor weakly sequentially complete.

In this project we discuss maximal $L^1$-regularity which occurs in the analysis of density-dependent inhomogeneous Navier-Stokes equations when controlling the path of particle trajectories. Underlying results in the literature work in homogeneous Besov spaces $\dot{B}^s_{q,1}$ on special domains $\Omega \subset \mathbb{R}^n$ and are proved using properties of the heat kernel or the Littlewood-Paley characterization of Besov spaces. Now let $X$ be a reflexive Banach space and let $A$ with dense domain $D(A)$ be the generator of a bounded analytic semigroup. Then our general abstract result states maximal $L^1$-regularity in $(\theta,1)$-type real interpolation spaces $(X;D(A))_{\theta,1}$, $\theta \in (0,1)$. The proof is based on the dualities $(L^1(0,\infty;X))' = L^\infty(0,\infty,;X')$ and $(BC([0,\infty);X))' = \mathcal{M}(0,\infty;X')$ where $\mathcal{M}(0,\infty;X)$ is the space of all $X$-valued BV measures. As an application these results can be applied to the Laplacian and the Stokes operator on Besov spaces $B^s_{q,1}$, $q \in (1,\infty)$, $|s| < 2$, for smooth bounded as well as exterior domains.

**Partner:** Prof. Dr. Myong Hwan Ri (Institute of Mathematics, State Academy of Sciences, Pyongyang, DPR Korea)

**Contact:** Reinhard Farwig

**References**


[1] R. Farwig and M. H. Ri. Maximal $L^1$-regularity of sectorial operators in $(\theta,1)$-type real interpolation spaces. Preprint, arXiv:2004.12620, 2020.


### Project: The Navier-Stokes system in moving time-dependent exterior domains

The construction of strong solutions of the Navier-Stokes system in a time-dependent domain with prescribed motion is carried through by a reduction to the time-independent case by a $t$-dependent coordinate transform. By this means, a highly perturbed Navier-Stokes system with $t$-dependent coefficients will appear such that the resulting system is

non-autonomous even in the leading term. To construct local or global in time strong solutions this problem requires an analysis in the framework of maximal regularity combined with perturbation arguments. Whereas the first problem had been considered by J. Saal (J. Math. Soc. Japan 58, 617–641 (2006)) mainly for bounded domains, perturbation arguments applicable to non-autonomous systems were developed by Y. Giga–M. Giga–H. Sohr (Proc. Japan Acad. Ser. A Math. Sci. 67, 197–202 (1991)) for finite time intervals and under relatively strong assumptions.
The main aim of the project is to construct global in time strong solutions for exterior domains in which the Stokes operator is no longer invertible compared to the bounded domain case. Nevertheless, methods of J. Saal and Y. Giga–M. Giga–H. Sohr could be combined to get global strong solutions in $L^q$ provided the perturbation is sufficiently small as $t \to \infty$.

**Partner:** H. Kozono (Waseda University, Tokyo); D. Wegmann (TU Darmstadt)

**Contact:** R. Farwig

### References


[1] R. Farwig, H. Kozono, and D. Wegmann. Maximal regularity of the Stokes operator in an exterior domain with moving boundary and application to the Navier-Stokes equations. *Math. Ann.*, 375(3-4):949–972, 2019.


**Project: Global attractors for the surface quasi-geostrophic equations in 2D**

The surface quasi-geostrophic equation (SQGE) on $\mathbb{R}^2$ is a nonlinear and nonlocal equation for the so-called potential temperature $\theta$ with fractional dissipation. It is used in oceanography and atmospheric sciences as a model of fluid flow in the case of small Rossby and Ekman numbers. The nonlinear and nonlocal terms are due firstly to a transport term with a velocity which depends on the solution by Riesz transforms, and secondly due to a fractional Laplacian $(-\Delta)^\alpha$ acting as diffusion. Whereas the case $\alpha = 1$ has great similarity with the 2D Navier-Stokes system, the case $\alpha = \frac{1}{2}$ resembles the 3D Navier-Stokes system and the inviscid case $\alpha = 0$ poses difficulties as known for the 3D Euler system.
The aim is the study of the long-time behavior of solutions of (SQGE) in the subcritical case $\frac{1}{2} < \alpha < 1$ and to prove the existence of the compact so-called uniform attractor in the non-autonomous case when the external force $F(t, x, \theta)$ is $t$-dependent. Here we consider the case when $F(t, x, \theta) = f(t, x) + g(x, \theta)$; but $F$ should not include a typical damping term such as $-\lambda\theta$ for a positive $\lambda$ as in many results on compact attractors in unbounded domains. To this end, we follow techniques on non-autonomous equations developed by V.V. Chepyzhov and M.I. Vishik. In particular, estimates should be uniform with respect to time shifts in $\theta$ or - in other words - of the initial time. New technical difficulties appear in estimates of nonlinear terms of compositions of functions in Besov spaces. Due to the unboundedness of the domain $\mathbb{R}^2$ and lack of compactness the solution semigroup is only asymptotically compact so that for a priori estimates the problem is decomposed into a first part on bounded balls and a second part in exterior domains on which uniform smallness estimates for solutions are to be derived. In case that the external force is asymptotically almost periodic, the attractor can be written as the union of so-called kernel sections defined at time $t = 0$.

**Partner:** Chenyin Qian (Zhejiang Normal University, Jinhua, China)

**Contact:** Reinhard Farwig

### References

[1] R. Farwig and C. Qian. The uniform global attractor for non-autonomous quasi-geostrophic equations with fractional dissipation in $\mathbb{R}^2$. Manuscript, 2020.

### Project: Incompressible inhomogeneous fluids in bounded domains

This project deals with the existence of mild solutions to the inhomogeneous Navier-Stokes system for an incompressible fluid with an unknown nonconstant density $\rho \geq 0$. Most results on this nonlinear system of partial differential equations work in the whole space $\mathbb{R}^n$ or half space $\mathbb{R}^n_+$ in the framework of Besov spaces. To get similar results in bounded domains the technique of Besov spaces on $\mathbb{R}^n$ must be generalized to results on Besov spaces on domains. Here we keep to critical Besov spaces which are scale invariant with respect to the scaling of the Navier-Stokes system in order to get optimal results. In particular, embedding theorems for Besov spaces and maximal regularity of the Stokes operator on domains are crucial tools. With the results of H. Amann developed during the last 20 years on interpolation and extrapolation spaces and different characterizations of Besov spaces on domains the auxiliary results needed for the project are available. Another difficulty for the inhomogeneous setting is the control of particle trajectories in domains, i.e., a generalization of the theory of transport equations on $\mathbb{R}^n$ to domains.

**Partner:** Prof. Dr. Chenyin Qian (Zhejiang Normal University, Jinhua, China), Prof. Dr. Ping Zhang (The Chinese Academy of Sciences, Beijing)

**Contact:** Reinhard Farwig

### References

[1] R. Farwig, C. Qian, and P. Zhang. Incompressible inhomogeneous fluids in bounded domains of $\mathbb{R}^3$ with bounded density. *J. Funct. Anal.*, 278(5):108394, 2020.

### Project: Mathematical modeling and VOF-based simulation of dynamic wetting

Dynamic wetting phenomena are omnipresent in nature and technology. The ability to understand and control such processes is crucial for a variety of industrial and technical applications such as inkjet- or bioprinting or transport in microfluidic devices. On the other hand, the moving contact line problem, even in a largely simplified setting, still poses considerable challenges regarding fundamental mathematical modeling as well as numerical methods. The present work addresses both the fundamental modeling and the development of numerical methods based on the geometrical Volume-of-Fluid (VOF) method.

As one of the main results, we were able to prove a fundamental kinematic evolution equation describing the evolution of the *contact angle* within the advecting fluid velocity field [3]. Using this mathematical tool, we could show that physical solutions to one of the "standard models" of dynamic wetting have to be (weakly) singular at the moving contact line. This result holds in a quite general setting and extends the knowledge about the broadly discussed "moving contact line singularity". A compatibility analysis of the boundary conditions at the moving contact line shows that regular solutions are possible if surface mass densities are included in the modeling [2].

Besides the mathematical modeling, we also develop numerical methods based on the *geometrical Volume-of-Fluid method*, which is extended to allow for the simulation of dynamic wetting. In particular, we developed a novel interface reconstruction algorithm that works close to a boundary [4]. The latter method improves the accuracy of the method close to the contact line and allows for a kinematically consistent transport of the contact angle. Together with experimentalists within DFG CRC 1194 and the Profile Area Thermo-Fluids & Interfaces, we are able to validate our methods in realistic test cases. In particular, we investigate the rise of liquid in a capillary tube [5] and the breakup of droplets on chemically patterned surfaces [6].

**Partner:** Matthias Köhne (Universität Düsseldorf)

**Support:** DFG CRC 1194 "Interaction of Transport and Wetting Processes", Project B01

**Contact:** Mathis Fricke, Dieter Bothe

### References

[1] M. Fricke. *Mathematical modeling and Volume-of-Fluid based simulation of dynamic wetting*. PhD thesis, TU Darmstadt, 2021.

[2] M. Fricke and D. Bothe. Boundary conditions for dynamic wetting - A mathematical analysis. *The European Physical Journal Special Topics*, 229:1849–1865, 2020.

[3] M. Fricke, M. Köhne, and D. Bothe. A kinematic evolution equation for the dynamic contact angle and some consequences. *Physica D: Nonlinear Phenomena*, 394:26–43, 2019.

[4] M. Fricke, T. Marić, and D. Bothe. Contact Line Advection using the geometrical Volume of Fluid Method. *Journal of Computational Physics*, 407:109221, 2020.

[5] D. Gründing, M. Smuda, T. Antritter, M. Fricke, D. Rettenmaier, F. Kummer, P. Stephan, H. Marschall, and D. Bothe. A comparative study of transient capillary rise using direct numerical simulations. *Applied Mathematical Modelling*, 86:142–165, 2020.

[6] M. Hartmann, M. Fricke, L. Weimar, D. Gründing, T. Marić, D. Bothe, and S. Hardt. Breakup dynamics of capillary bridges on hydrophobic stripes. *International Journal of Multiphase Flow*, 138:103583, 2021.

**Project: Direct Numerical Simulation of Locally Coupled Transport Processes at Dynamic Contact Lines** The interaction between a liquid and a surface is basically omnipresent in our daily lives and every industrial application that involves liquids such as rain moving over the wind shield of a car or liquid drops in a lab-on-a-chip application. To numerically investigate wetting processes in a close vicinity to the three phase contact line, an arbitrary Lagrangian-Eulerian (ALE) method with moving meshes has been developed using the numerical platform OpenFOAM, see [5]. This approach allows to incorporate additional physical effects such as mass transfer across the interface or surface active substances that locally change the surface tension [8]. The implementation has been applied in an extensive study comparing three fundamentally different numerical approaches that are under development at the TU Darmstadt [5]. Additional developments include a novel algorithm for the analytic solution of a transient channel flow with slip [4] and the initialization of arbitrary level set and volume fraction fields from STL-data [7]. These developments allow us in cooperation with our theoretical and experimental partners inside the Collaborative Research Centre 1194 to investigate a variety of wetting processes. These include drop breakup with wall contact [6], surface tension driven movement of liquid in a capillary [5], quasi stationary surface shapes in rotating experimental devices [1], and behaviour of drops on swellable polymer surfaces [2].

**Support:** DFG CRC 1194 “Interaction between Transport and Wetting Processes”, Project B02

**Partner:** Max-Planck Institut for Polymer Research, Mainz, Leibnitz Institut für Polymerforschung, Dresden

**Contact:** Dirk Gründing, Dieter Bothe

### References

[1] D. Fickel, N. Postulka, H. Maximilian, D. Gründing, M. Nau, T. Meckel, and M. Biesalski. Changes of meniscus shapes and capillary rise heights under hypergravity. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 2020.

[2] M. Fricke, D. Fickel, M. Hartmann, D. Gründing, M. Biesalski, and D. Bothe. A geometry-based model for spreading drops applied to drops on a silicon wafer and a swellable polymer brush film. 2020. arXiv: 2003.04914.

[3] D. Gründing. *An Arbitrary Lagrangian-Eulerian Method for the Direct Numerical Simulation of Wetting Processes*. PhD thesis, TU Darmstadt, 2020.

[4] D. Gründing, S. Raju, and T. Marić. An arbitrarily accurate algorithm for the start up channel flow with slip, 2021. arxiv: 2103.06662.

[5] D. Gründing, M. Smuda, T. Antritter, M. Fricke, D. Rettenmaier, F. Kummer, P. Stephan, H. Marschall, and D. Bothe. A comparative study of transient capillary rise using direct numerical simulations. *Applied Mathematical Modelling*, 86:142–165, 2020.

[6] M. Hartmann, M. Fricke, L. Weimar, D. Gründing, T. Marić, D. Bothe, and S. Hardt. Breakup dynamics of capillary bridges on hydrophobic stripes. *International Journal of Multiphase Flow*, page 103582, 2021.

[7] T. Tolle, D. Gründing, D. Bothe, and T. Marić. Computing volume fractions and signed distances from arbitrary surfaces on unstructured meshes. 2021. arxiv: 2101.08511.

[8] A. Weiner, D. Gründing, and D. Bothe. Computing Mass Transfer at Deformable Bubbles for High Schmidt Numbers. *Chemie Ingenieur Technik*, 93(1-2):81–90, 2021.

**Project: Face-based Volume-of-Fluid interface positioning in arbitrary polyhedra**

For the numerical treatment of incompressible two-phase flows, especially if large deformations and topological changes occur, the Volume-of-Fluid (VOF) of [1] is commonly used. The respective phases are encoded by volume fractions, which, in the absence of phase change, are passively advected by the flow. In order to obtain reliable results, it is crucial to maintain a sharp interface throughout the simulation. This can be achieved by a geometric transport of the volume fractions, which requires an approximate reconstruction of the interface. Using the Piecewise Linear Interface Calculation of [3], in every time step and computational cell a plane is positioned to match the respective volume fraction, which substantiates the necessity for efficient algorithms. Hence, this project addresses the positioning of the planes in arbitrary polyhedral cells for a given normal, which translates to finding the unique root of a scalar monotonous function, namely the truncated cell volume. By exploiting the Gaussian divergence theorem, the volume is conveniently parametrized in terms of the signed distance as a sum of face-based quantities. This favourable in terms of general applicability and allows to restrain from the costly extraction of topological connectivity at runtime, which is predominant in literature. The derivatives of the volume can be obtained at negligible costs, which are exploited in a higher-order root finding scheme. The developed approach was shown to be highly efficient: on average, only one to two truncations are required to position the plane, outperforming exisiting methods. The numerical experiments show robustness for an extensive set of polyhedrons, volume fractions and normal orientations. Ongoing research aims at embedding the developed volume computation into a minimization-based scheme for the estimation of the normal fields from volume fraction data.

**Support:** DFG TRR 75

**Contact:** Johannes Kromer, Dieter Bothe

### References

[1] C. W. Hirt and B. D. Nichols. Volume of fluid (VOF) method for the dynamics of free boundaries. *Journal of Computational Physics*, 39:201–225, 1981.

[2] J. Kromer and D. Bothe. Face-based Volume-of-Fluid interface positioning in arbitrary polyhedra. *arXiv*, 2101.03861, 2021.

[3] W. J. Rider and D. B. Kothe. Reconstructing volume tracking. *Journal of Computational Physics*, 141:112–152, 1998.

**Project: Adaptive Lagrangian / Eulerian Interface Approximation (LEIA) methods for Direct Numerical Simulation of surface tension driven multiphase flows in complex geometries**

Many technical applications involve flows of fluids that do not mix and are driven by surface tension forces in geometrically complex domains. Two very timely and relevant examples are the Lab-On-a-Chip (LOC) devices used for fast disease detection and medication discovery and the simulation of the water management problem in Proton-Exchange Membrane (PEM) fuel cells. This project aims to develop numerical methods for multiphase hydrodynamics in geometrically complex domains. Several breakthroughs are required to achieve this aim, including accurate and robust tracking of fluid interfaces and the handling of high-density ratios.

The project consists of two methods that combine Eulerian and Lagrangian approaches and rely on geometrical approximations: the geometrical Volume-of-Fluid (VOF) and the Level Set / Front Tracking method. Both methods share some of their sub-algorithms, so developing both methods simultaneously exploits synergy effects and may lead to new and more accurate hybrid methods.

For the unstructured Level Set / Front Tracking method, new iso-surface reconstruction and signed-distance interpolation methods for unstructured meshes are researched. On the VOF side, a primary research question is the accurate and robust approximation of curvature of a piecewise-linear interface, discontinuous across cell boundaries. Improving the handling of high-density ratios is relevant for both methods. The key here is to ensure consistency between mass fluxes used in the momentum equation's discretization and the cell densities. Finally, as the simulation of industrial applications - the long-term aim of this project - is often only feasible on high-performance computers, efficient parallel implementation plays a crucial role in the project.

**Partner:** Seungwon Shin (Mechancial and System Design Engineering, Hongik University, South Korea), Damir Juric (Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur, CNRS, France), Jalel Chergui (Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur, CNRS, France), Douglas B. Kothe (Director Exascale Computing Project, Oak Ridge National Laboratory)

**Support:** DFG

**Contact:** Tomislav Marić, Tobias Tolle, Dieter Bothe

### References


[1] M. Fricke, T. Marić, and D. Bothe. Contact line advection using the geometrical volume-of-fluid method. *Journal of Computational Physics*, 407:109221, 2020.

[2] T. Marić, D. B. Kothe, and D. Bothe. Unstructured un-split geometrical volume-of-fluid methods–a review. *Journal of Computational Physics*, 420:109695, 2020.

[3] T. Marić, H. Marschall, and D. Bothe. lentfoam–a hybrid level set/front tracking method on unstructured meshes. *Computers & Fluids*, 113:20–31, 2015.

[4] T. Tolle, D. Bothe, and T. Marić. Saample: A segregated accuracy-driven algorithm for multiphase pressure-linked equations. *Computers & Fluids*, 200:104450, 2020.


**Project: CRC 1194 Z-INF: Improving the quality of scientific software and research data**

The question of the quality of scientific software and, more importantly, the reproducibility of research data is recently gaining importance in Computational Science and Engineering (CSE). Traditionally, the development of scientific (academic) CSE software faces many significant challenges: lack of direct funding by public funding organizations for increasing software quality and reproducibility of results, no dedicated person-hours for improving software quality, fluctuation of project developers (Ph.D. students and postdocs) with little or no overlap, the pressure of a "publish or perish" academic system that prioritizes publications over sustainable, high-quality research software and reproducible results.

A straightforward workflow is developed in this project, enabling university research groups to create continuously tested, documented, and sustainable scientific software with easily reproducible research results. The workflow combines established software engineering techniques (test-driven development, version control, continuous integration, containerization) with a straightforward research data management practice and applies this to scientific software in CSE.

**Partner:** B. Lambie (Managing Director, Thermo Fluids & Interfaces Profile Area, TU Darmstadt), C. Bischof, J.-P. Lehr (Scientific Computing Group, TU Darmstadt)

**Support:** DFG CRC 1194, Z-INF

**Contact:** Tomislav Marić, Dieter Bothe

**Project: Scale bridging simulation of dynamic wetting based on the phase field method**

Within the DFG Collaborative Research Centre SFB 1194 on "Interaction between Transport and Wetting Processes", the project B07 aims at the fundamental understanding of local transport processes at the contact line in multiscale, dynamic wetting processes on complex substrates. A two-phase flow solver based on the diffuse-interface phase-field method and developed in OpenFOAM is used. The method enables the description of imbibition and penetration processes in porous/structured substrates, especially during capillarity dominated wetting. Focus lies on the disclosure of the influence of local heterogeneities (pore size distribution, roughness, functionalization) as well as on a scale bridging methodology, to be realized by combining modern HPC techniques, DG methods and the hybrid atomistic-continuum method.

**Support:** DFG CRC 1194 “Interaction between Transport and Wetting Processes”, Project B07

**Contact:** Holger Marschall, Francisco Bodziony

### References

[1] M. Niethammer, G. Brenn, H. Marschall, and D. Bothe. An extended Volume of Fluid method and its application to single bubbles rising in a viscoelastic liquid. *J. Comput. Phys.*, 387:326–355, 2019.

[2] D. Rettenmaier, D. Deising, Y. Ouedraogo, E. Gjonaj, H. D. Gersem, D. Bothe, C. Tropea, and H. Marschall. Load balanced 2D and 3D adaptive mesh refinement in OpenFOAM. *SoftwareX*, 10:100317, 2019.

[3] T. Stark, T. Kiedrowski, H. Marschall, and A. F. Lasagni. Avoiding starvation in tribocontact through active lubricant transport in laser textured surfaces. *Lubricants*, 7(54):1–18, 2019.

## Project: Numerical simulation of the interaction between a drop and a liquid wall film

Within the DFG Collaborative Research Centre SFB/TRR 150 on "Turbulent, chemically reactive, multi-phase flows near walls", the subproject B08 contributes to a central scientific goal of the SFB: the understanding of the relevant physico-chemical processes in turbulent, chemical reacting multiphase flows near walls. By means of direct numerical simulation and in close cooperation with experimental subprojects, the droplet impact on a wall film is investigated. The impact of droplets on a wall film is investigated for different miscible liquids, which is highly relevant for the leading examples of the SFB/Transregio. This concerns fuel droplets on the oil film on the cylinder wall (engine) as well as wall film and drops of water-urea solution of different concentration (exhaust gas aftertreatment).

**Partner:** Martin Wörner (Karlsruhe Institute of Technology)

**Support:** DFG CRC TRR 150 “Turbulent, chemically reactive, multi-phase flows near walls”, Project B08

**Contact:** Holger Marschall, Milad Bagheri

### References

[1] F. Jamshidi, H. Heimel, M. Hasert, X. Cai, H. Marschall, and M. Wörner. On suitability of phase-field and algebraic Volume-Of-Fluid OpenFOAM solvers for gas-liquid microfluidic applications. *Comput. Phys. Commun.*, 236:72–85, 2019.

## Project: Development and Application of a Direct Numerical Method for Reactive Transport Processes in Bubble Systems

Within the DFG Priority Programme SPP 1740 on "Reactive Bubbly Flows", the sub-project addresses the following two key objectives: (i) elaboration of detailed knowledge regarding the complex interplay of two-phase hydrodynamics, local transport processes and chemical reactions on the basis of the analysis of local data from Direct Numerical Simulations (DNS), and (ii) the disclosure of qualitative mechanisms of above processes and their quantitative influence on enhancement, product distribution and selectivity for competitive (mixture-sensitive) prototype reactions.

**Support:** DFG Priority Program 1740 “Reactive Bubbly Flows"

**Contact:** Holger Marschall, Dennis Hillenbrand

### References


[1] D. Hillenbrand and H. Marschall. *Reactive Bubbly Flows*, chapter Development and Application of a Direct Numerical Method for Reactive Transport Processes in Bubble Systems, page 490. Advances in Mathematical Fluid Mechanics. Springer International Publishing – Birkhäuser Basel, 2021. ISBN 978-3-319-56601-6.

[2] A. Weiner, D. Hillenbrand, H. Marschall, and D. Bothe. Data-driven subgrid-scale modeling for convection-dominated concentration boundary layers. *Chem. Eng. Technol.*, 42(7):1349–1356, 2019.


**Project: Lagrangian representation for hyperbolic systems of conservation laws**

Systems of conservation laws are evolutionary nonlinear partial differential equations with several applications coming from both physics and engineering, in particular from fluid dynamics and traffic models. Global existence and uniqueness of solutions are known only for initial data with small total variation, and solutions are in general obtained in terms of vanishing viscosity approximations. Aim of the project is to construct a “Lagrangian representation” for such solutions, i.e., to describe solutions to hyperbolic conservation laws in terms of “particles” or “waves” moving along suitable characteristic curves, and to gain, in this way, a better understanding of the behavior and the fine structure of the solutions.

**Partner:** S. Bianchini (SISSA, Trieste (Italy))

**Contact:** S. Modena.

### References


[1] S. Bianchini and S. Modena. Quadratic interaction functional for general systems of conservation laws. *Communications in mathematical physics*, 338:1075–1152, 2015.

[2] S. Modena. Interaction functionals, glimm approximations and lagrangian structure of bv solutions for hyperbolic systems of conservation laws. *Ph.D. Thesis*, 2015.


**Project: Transport with rough vector fields**

The linear transport equation

$$\partial_t u + b \cdot u = 0,$$

for a given vector field $b : [0, T] \times \mathbb{R}^d \to \mathbb{R}^d$ and unknown $u : [0, T] \times \mathbb{R}^n \to \mathbb{R}$ is one of the most basic and (apparently) easiest PDEs in applied mathematics. Nevertheless, if the given vector field $b$ is non-smooth, the analysis of the associated Cauchy problem requires original ideas and technique. The first and still fundamental result by DiPerna and Lions in 1989 states that the Cauchy problem is well posed if the given vector fields is at least Sobolev (in the space variable). Such result was then extended by Ambrosio in 2004 for $BV$ vector fields. Several authors further developed the theory in the subsequent years. Aim of the project is to understand how much the well-posedness results available in the literature can further be extended, focusing in particular on the search for suitable counterexamples when some of the assumptions are not satisfied.

**Partner:** G. Sattig (Leipzig) L. Székelyhidi (Leipzig)

**Contact:** S. Modena.

### References


[1] S. Modena and G. Sattig. Convex integration solutions to the transport equation with full dimensional concentration. *Annales de l'Institut Henri Poincaré C, Analyse non linéaire*, 37(5):1075–1108, 2020.

[2] S. Modena and L. Székelyhidi. Non-renormalized solutions to the continuity equation. *Calculus of Variations and PDE*, 58:208, 2019.


### Project: Convex integration and turbulent fluids

The analysis of fluids in a turbulent regime is one of the greatest challenges in physics: a rigorous and complete mathematical theory for the equations of hydrodynamics (for incompressible fluids), the Euler ($\nu = 0$) and the Navier-Stokes ($\nu > 0$) equations

$$\partial_t u + u \cdot \nabla u + \nabla p = \nu \Delta u, \quad \div u = 0,$$

which agrees with experiments and with physical models, is still missing. In the recent years, starting from the groundbreaking works of C. De Lellis and L. Székelyhidi, it was noticed that a PDE technique named "convex integration", invented by J. Nash in 1954 to solve problems in differential geometry, can be successfully used to attack longstanding open problems in the theory of Euler and Navier-Stokes equations. In this spirit, the main goal of the project is to make use of convex integration techniques to advance the mathematical understanding of some physical models for turbulence.

**Partner:** J. Burczak (Leipzig), G. Sattig (Leipzig), L. Székelyhidi (Leipzig).

**Contact:** S. Modena.

### References


[1] J. Burczak, S. Modena, and L. Székelyhidi. Non Uniqueness of power-law flows. *Preprint*, 2020.


### Project: Direct numerical simulation of viscoelastic flows

Direct numerical simulation (DNS) of viscoelastic flows is challenging because all numerical methods tend to become unstable above some limiting degree of fluid elasticity, characterised by a critical Weissenberg number. The loss of convergence beyond the critical Weissenberg number is referred to as the so-called high Weissenberg number problem. This project is concerned with the stabilization of DNS methods for highly viscoelasic flows in order to numerically study rheological flow phenomena, stemming from the non-linear dependence of the stress on the deformation gradient history. Particular research focus is thereby put on rising bubbles in a viscoelastic fluid matrix, which exhibit several rheological flow phenomena that are poorly understood, such as the discontinuity in the steady-state rise velocity as the bubble volume exceeds a critical value and the so-called negative wake effect. By means of DNS of bubbles rising in a viscoelastic fluid, the project aims to contribute to a fundamental physical understanding of the rise velocity discontinuity and the negative wake.

Several project milestones were achieved, which include: (i) the development of a generic numerical framework for the transient simulation of viscoelastic flows in complex geometries at high Weissenberg number based on a finite volume method; (ii) the extension of the Volume-of-Fluid (VOF) method for direct numerical simulations (DNS) of two-phase flows with at least one viscoelastic phase; (iii) the extension of the generic numerical framework for non-isothermal viscoelastic flows. New benchmark results were obtained, e.g., with respect to the convergence property of different stabilization methods at high Weissenberg numbers. By means of the transient three-dimensional DNS of single rising bubbles in a viscoelastic medium it was shown that the extended VOF method captures characteristic flow phenomena such as the bubble rise velocity discontinuity. Ongoing research objectives are to describe the fundamental physical mechanism of the bubble rise velocity discontinuity and to contribute to the understanding of further rheological flow phenomena.

**Support:** Freudenberg SE; DFG CRC 1194

**Partner:** G. Brenn (TU Graz, Austria), S. Meburger, M. Schäfer (TU Darmstadt)

**Contact:** Matthias Niethammer, Holger Marschall, Dieter Bothe

#### References

[1] S. Meburger, M. Niethammer, D. Bothe, and M. Schäfer. Numerical simulation of non-isothermal viscoelastic flows at high Weissenberg numbers using a finite volume method on general unstructured meshes. *J. Nonnewton. Fluid Mech.*, 287(November 2020):104451, nov 2020.

[2] M. Niethammer. *A Finite Volume Framework for Viscoelastic Flows at High Weissenberg Number*. PhD thesis, TU Darmstadt, 2019.

[3] M. Niethammer, G. Brenn, H. Marschall, and D. Bothe. An extended volume of fluid method and its application to single bubbles rising in a viscoelastic liquid. *J. Comput. Phys.*, 387:326–355, 2019.

[4] M. Niethammer, H. Marschall, and D. Bothe. Robust Direct Numerical Simulation of Viscoelastic Flows. *Chemie Ing. Tech.*, 91(4):522–528, 2019.

### Project: $C^*$-Algebras in numerical analysis

For the numerical solution of an operator equation on an infinite-dimensional space, one discretizes the operator to obtain a sequence of $n \times n$ matrices $A_n$. Interesting asymptotic properties of the sequence $(A_n)$ can be studied by embedding this sequence into an appropriate $C^*$-algebra and by studying the structure of that algebra. Of particular interest are algebras of matrix sequences which own the following (self-similarity) property: Every sequence in the algebra can be rediscovered from each of its infinite subsequences modulo a sequence tending to zero in the norm. Examples of such algebras arise, for instance, from the finite sections method for Toeplitz or singular integral operators. Sequences $(A_n)$ in self-similar algebras are distinguished by their excellent asymptotic properties: for example, the pseudospectra of the $A_n$ converge with respect to the Hausdorff metric. A basic tool to analyse algebras of matrix sequences is a Fredholm theory of sequences, which has also found interesting applications: a proof of the Arveson dichotomy for self-adjoint sequences, a proof of the index formula for band-dominated operators, and the creation of an algorithm to determine partial indices of matrix functions numerically, for instance. We derived results along these lines for spatial discretizations of several classes of $C^*$-algebras including Cuntz algebras, reduced group $C^*$-algebras and algebras generated by truncated Toeplitz operators on model spaces, and we (still) plan to extend them to multi-dimensional disk algebras and other algebras generated by isometries. The final goal of this project is a comprehensive text on $C^*$-algebras arising in the field of numerical analysis.

### References


[1] S. Roch. Beyond fractality: piecewise fractal and quasifractal algebras. *Operator Theory: Advances and Applications*, 268:413–428, 2018.

[2] S. Roch. Extension-restriction theorems for algebras of approximation sequences. *Operator Theory: Advances and Applications*, 267:261–284, 2018.

[3] S. Roch. Compact sequences in quasifractal algebras. *Operator Theory: Advances and Applications*, 282, 2020 (accepted).


**Contact:** Steffen Roch

### Project: Multiscale models for tumor cell migration

Tumor cell migration is influenced by a plethora of processes taking place at different spatial scales which range from the subcellular level (microscopic scale) via the mesoscopic scale of cell interactions and up to the macroscopic scale of cell and tissue populations. We develop multiscale models based on the rather new approach of micro-macro models. In these models a system of partial differential equations for cell and tissue populations on the macroscopic scale is coupled to ordinary differential equations modeling particular aspects of subcellular dynamics. We model e.g., the influence of cell contractivity or acidity on tumor cell migration and show how this can be used to model therapy approaches. Thereby we combine modeling, analysis, and numerical simulations. Basic properties of the solutions to these models are proved analytically, while the precise behavior is illustrated by numerical simulations.

**Partner:** C. Surulescu (TU Kaiserslautern), M. Lukácová (Universität Mainz), N. Sfakianakis (University of St. Andrews).

**Contact:** C. Stinner.

### References


[1] N. Kolbe, N. Sfakianakis, C. Stinner, C. Surulescu, and J. Lenz. Modeling multiple taxis: tumor invasion with phenotypic heterogeneity, haptotaxis, and unilateral interspecies repellence. *Discrete Contin. Dyn. Syst. Ser. B*, to appear.

[2] G. Meral, C. Stinner, and C. Surulescu. A multiscale model for acid-mediated tumor invasion: therapy approaches. *J. Coupled Syst. Multiscale Dyn.*, 3:135–142, 2015.

[3] G. Meral, C. Stinner, and C. Surulescu. On a multiscale model involving cell contractivity and its effects on tumor invasion. *Discrete Contin. Dyn. Syst. Ser. B*, 20:189–213, 2015.

[4] C. Stinner, C. Surulescu, and G. Meral. A multiscale model for pH-tactic invasion with time-varying carrying capacities. *IMA J. Appl. Math.*, 80:1300–1321, 2015.

[5] C. Stinner, C. Surulescu, and A. Uatay. Global existence for a go-or-grow multiscale model for tumor invasion with therapy. *Math. Models Methods Appl. Sci.*, 26:2163–2201, 2016.


### Project: Chemotaxis systems with split population

We study chemotaxis systems with split population. In a particular model, the population is split into moving and static individuals and, apart from diffusion, the motion of the moving individuals is biased toward regions of high concentrations of a chemoattractant which in turn is produced by the static individuals. For this model, where the mass of the whole population is conserved, we establish a critical mass phenomenon distinguishing between global and bounded solutions for subcritical mass and the existence of solutions blowing up in infinite time for supercritical mass. We aim to study the behavior of solutions for more general models with split population.

**Partner:** Ph. Laurençot (University of Toulouse)

**Contact:** C. Stinner.

### References


[1] P. Laurençot and C. Stinner. Mass threshold for infinite-time blowup in a chemotaxis model with splitted population. Preprint, arXiv:2009.09655, 2020.


### Project: Features of taxis models

We study chemotaxis and haptotaxis systems which are connected to the Keller-Segel system. Our aim is to prove specific features which are either rarely observed in the context of taxis systems or connected with unusual variants of taxis systems. As a first example, in a haptotaxis model with a specific type of degenerate diffusion, called myopic diffusion, we refine the asymptotic behavior of the solutions based on proving improved regularity of the solution.

**Partner:** M. Winkler (Universität Paderborn)

**Contact:** C. Stinner.

### References


[1] M. Winkler and C. Stinner. Refined regularity and stabilization properties in a degenerate haptotaxis system. *Discrete Contin. Dyn. Syst.*, 40:4039–4058, 2020.


### Project: Numerical simulation of mass transfer at rising bubbles

The primary goal of this project is to supplement experimental groups within the priority program SPP 1740 with insightful simulation data, which help to understand transport processes in bubbly flows. One of the main challenges in comparing experimental and numerical results of the mass transfer at rising bubbles is the so-called high-Schmidt number problem. The main statement of this problem is that the transport of a diluted species, for example, the dissolved gas, happens on much smaller length scales than the momentum transport in the liquid phase. This leads to the formation of extremely thin boundary layers at the gas-liquid interface, which cannot be resolved directly with classical numerical methods. One way to mitigate the resolution requirements at the interface is the application of subgrid-scale models, which accurately approximate the species transport based on analytical solutions or machine learning models of simplified substitute problems. Over the last two years, such subgrid-scale models have been successfully applied to investigate the interplay between surface active agents, bubble hydrodynamics and reactive mass transfer. Future work will be concerned with the development and deployment of our models in even more complex scenarios like pseudo swarms of multiple bubbles.

**Support:** DFG Priority Program 1740 “Reactive Bubbly Flows"

**Contact:** Andre Weiner, Dieter Bothe

**References**


[1] A. Weiner, D. Gründing, and D. Bothe. Computing mass transfer at deformable bubbles for high Schmidt numbers. *Chemie Ingenieur Technik*, 93:81–90, 2021.

[2] A. Weiner, D. Hillenbrand, H. Marschall, and D. Bothe. Data-driven subgrid-scale modeling for convection-dominated reactive boundary layers. *Chemical Engineering Technology*, 42:1349–1356, 2019.

[3] A. Weiner, J. Timmermann, C. Pesci, J. Grewe, M. Hoffmann, M. Schlüter, and D. Bothe. Experimental and numerical investigation of reactive species transport around a small rising bubble. *Chemical Engineering Science: X*, 1:100007, 2019.


## 1.3 Applied Geometry

The research group “Geometry and Approximation” investigates geometric objects, typically surfaces, and ways to approximate them.

Classical *Differential Geometry* and *Geometric Analysis* studies surfaces minimizing geometric functionals for which examples arise in the sciences and engineering. In the simplest case, say for a biological cell, a bounding surface encloses a given volume in such a way that the area is minimized. Other interfaces minimize functionals involving curvatures, for instance the Willmore functional. Critical points are characterized by Euler equations which are non-linear partial differential equations. The mathematical goal is to establish new solutions or properties of solutions, not only in Euclidean 3-space but also in other Riemannian ambient spaces, using methods of analysis and Riemannian Geometry.

In *Geometric Modeling*, mathematical tools for the explicit description of geometric objects are developed and analyzed. Here the focus is on complex structures, as they arise in various applications: One may think of a car body, a piece of cloth, or a dinosaur in an animated film. The surfaces considered in Differential Geometry and Geometric Modeling typically have a fairly complicated structure. For processing, it is necessary to approximate them in a function space of reduced complexity, say a spline space. For that reason, the development of tools for efficient approximation of geometric objects is an important task, giving rise to interesting mathematical questions in the field of multivariate approximation theory.

### Members of the research group

**Professors**

Karsten Große-Brauckmann, Elena Mäder Baumdicker, Ulrich Reif

**Postdocs**

Florian Martin

**Research Associates**

Jerome Alex, Kai Bouaraba, Ba-Duong Chu, Alexander Dietz, Tobias Ewald, Ömer Genc, Philipp Käse, Ben Lambert, Melanie Rothe, Arthur Windemuth

**Secretary**

Tanja Douglas

## Project: Surfaces in homogeneous manifolds

Minimal and constant mean curvature surfaces are a traditional subject in Euclidean space, or in spheres, while the case of homogeneous 3-manifolds as ambient spaces is a further prominent case studied more recently. Using a direct Plateau method and Schwarz reflection we are also interested in the case of higher codimension. Generalizing results of a PhD thesis by Windemuth yet to be published there may be examples in higher dimensional spheres. Another project to be finished is in the codimension one homogeneous spaces, where examples using the Daniel construction may be constructed.

**Partner:** Rob Kusner (Amherst, MA), Arthur Windemuth (TU Darmstadt)

**Contact:** K. Große-Brauckmann

### References

[1] J. Alex and K. Grosse-Brauckmann. Periodic networks of fixed degree minimizing length. eprint, arXiv:1911.01792, 2019.

## Project: A posteriori error estimates for wave maps

The wave maps equation is the natural partial differential equation of hyperbolic nature in a geometric context. Our objective consists in studying stability properties of wave maps. In particular, these allow us to derive computable a posteriori error bounds for numerical schemes approximating wave maps. We treat the critical dimension which implies the possible appearance of singularities. The pointwise constraint of being manifold-valued and the possible blowup of the gradient due to singularities are challenging in this context. Questions of (non-)uniqueness are also of importance. First results can be found in [1].

**Contact:** Elena Mäder-Baumdicker, Jan Giesselmann

### References

[1] J. Giesselmann and E. Mäder-Baumdicker. A posteriori error estimates for wave maps into spheres. Preprint, arXiv:2010.07552, 2020.

## Project: Morse theoretical questions of Willmore surfaces

In a recent work [1] we computed the Morse Index of immersed Willmore spheres in the Euclidean three-space. It turned out that the size of the kernel of a certain partial differential equation on complete, non-compact minimal surfaces are crucial for this computation. Certain elements in that kernel with logarithmical growth are particularly of interest. In this project we study the relation of geometric properties of complete minimal spheres with finite total curvature to Morse theoretical questions of Willmore surfaces.

**Partner:** Jonas Hirsch (Universität Leipzig), Rob Kusner (University of Massachusetts at Amherst)

**Support:** German Research Association (DFG).

**Contact:** Elena Mäder-Baumdicker

### References

[1] J. Hirsch and E. Mäder-Baumdicker. On the Morse Index of Willmore Spheres. Preprint, arXiv:1905.04185, 2019.

**Project: Minimal surfaces with high codimension in spheres**

We would like to find examples of non-orientable, embedded minimal surfaces in spheres with low area. As such objects do not exist in the three-sphere, we have to deal with higher codimension. In a first step, we study whether known construction procedures such as bipolar surfaces in the five-sphere are useful to find the desired surfaces. High symmetry of the surfaces would be useful.

**Support:** German Research Association (DFG).

**Contact:** Elena Mäder-Baumdicker, Melanie Rothe

**Project: ABC Surfaces**

Non-Uniform Rational B-Splines (NURBS), the standard of industrial modeling, reveal severe drawbacks. In particular, the contact of neighboring patches is in general discontinuous due to the complicated structure of trimming curves. In this project, we develop new methods to represent Gk continuous composite surfaces for industrial use. A patent is pending.

**Partner:** Dr. Florian Martin

**Contact:** U. Reif

**Project: Geometric Hermite Subdivision**

In this project we develop and analyze nonlinear subdivision algorithms which generate smooth curves from point and normal data. Such schemes are useful in applications with highest demands concerning the fairness of the curves to be constructed, as appearing for instance in the automotive industry.

**Partner:** Prof. Andreas Weinmann

**Contact:** U. Reif

## 1.4 Didactics and Pedagogics of Mathematics

**The working group on subject didactics accommodates two lines of research**

The working group on subject didactics with Regina Bruder until 2019/09 and Katja Krüger since 2020/10 considers their focus to be on theoretically and empirically founded concepts of course development for secondary levels I and II.

Due to participation in various working groups of the GDM [Society for Didactics of Mathematics], major book projects, and through extensive teacher training activities, subject didactics has built a strong network throughout the German-speaking areas.

The implementation of preliminary mathematics courses (online and blended-learning) at the commencement of the engineering degree courses in four departments (VEMINT project in cooperation with Kassel, Paderborn and Hannover) and the project leadership of MINTplus connected with the center of teacher education (ZFL) in Darmstadt until 2019/09 demonstrate the broad networking and anchoring of the working group on subject didactics at Darmstadt Technical University. Since 2019/10 teaching statistics and probability with regard to statistical literacy becomes a new focus in this research field.

The further grown international connections led to a two year DAAD- project with the ACU in Brisbane (Australia) and Iresha Ratnayake from Sri Lanka worked with us as a postal doctoral candidate in the DAMS until summer 2020.

**Research Group in Operator Algebras and Mathematical Physics**

**Quantum probability** is an extension of classical probability theory that allows to treat also probabilistic effects of quantum systems. Operator algebras allow a unified treatment of both cases, classical probability as well as probability in quantum systems. All basic notions of probability like expectations, random variables, stochastic processes, martingales, etc. can be formulated in the language of operator algebras in such a way that they reduce to the notions of classical probability whenever the operator algebra is commutative.

Our **research interests** range from theoretical mathematical investigations to physical applications. Consequently, the members of our research group as well as our research partners range from pure mathematicians to physicists.

Common to most of our research is its focus on certain **dynamical behaviour**, be it the dynamics of classical and quantum stochastic processes (Markov processes, noise, quantum trajectories, filtering, etc.), be it the dynamics generated by completely positive maps (ergodic and spectral properties, existence and numerical computation of equilibrium states, quantum state preparation, etc.). The coupling representation of a Markov process has also opened the door to a scattering theory for such processes and to research on quantum coding. It links quantum probability in a new and unexpected way with the fields of quantum information and quantum control.

Recently the **geometry of entangled states** came into the focus of our research interests, in particular entanglement on infinite systems, multipartite entanglement, and criteria for entanglement by methods from convex algebraic geometry.

**Members of the research group**

**Professors**

Regina Bruder, Katja Krüger, Burkhard Kümmerer

**Research Associates**

Malte Brandy, Jan Herzog, Felix Johlke, Thomas Klein, Albrun Knof, Barbara Krauth, Sandra Lang, Iresha Ratnayake, Ulrike Roder, Marcel Schaub, Judith Schilling, Insa Schreiber, Felix Voigt

**Secretaries**

Sigrid Hartmann, Heike Müller

**Project: MINTplus (BMBF)**

Within the scope of the 'Qualitätsoffensive Lehrerbildung'(BMBF) an extension of the project MINTplus from 2019 for a further 5 years was approved.

The center of teacher education (ZfL) of the TU Darmstadt puts the aim to profile both courses for teacher students (LaG, LaB) with certified suitability consultation, specific profession-related, interdisciplinary study offers as well as graded practise phases at extracurricular learning places and at school. The teacher students should be strengthened in identification with the planned career and with the elective fields of teaching equally. They should be perceived as especially competent tutors at the university as knowledge mediators and be esteemed. With the interlinking area planned for all professional combinations innovative attempts are pursued in the study entrance phase. The common study entrance prepares the teacher students for the specialist demands in the subsequent semesters and supports them with the construction of a professional-connecting identification with the

MINT fields.
`https://www.qualitaetsoffensive-lehrerbildung.de/de/projekte-16.php`

**Support:** Federal Ministry of education and research (BMBF)

**Contact:** R.Bruder (project leader until 2019/09), C. Preuss, Y. Bachmann
**Details:** https://www.zfl.tu-darmstadt.de/projekte_2/mintplus/projekt_mintplus.de.jsp

**Project: ELMA (Factors of influence on achievement success in mathematics) Lower Saxony 2018-2019**

The aim of the ELMA project was to find possible causes for the phenomenon, that there are large performance differences in the central written exam in mathematics for the completion of secondary school in different regions of Lower Saxony. To this end, 15 schools with widely scattering examination results were examined. In the evaluation, qualitative and quantitative approaches were combined in order to obtain, within the framework of a reconstructive description paradigm, as holistic a picture as possible of the complex problem area of 'influencing factors on performance success'.
In order to check the fit of the 4 to 5 class tests per class with the curricular standards and the final central examination, the tasks were examined with regard to the content-related and process-related competences required therein. The task quality of the class tests was described by an analysis of the task structure and the cognitive requirements. This is a prognosis of the expected empirical task difficulty due to the presumed solution approaches. The degree of formalisation F, the degree of complexity K and the execution effort A of the individual tasks are included in the weighted assessment of the empirical task difficulty.
The analyses show that a broader spectrum of competences is addressed in the class tests of the classes that pass the 2018 examination more successfully than in the classes that tend to score worse.

**Support:** Ministry of Education Lower Saxony

**Contact:** R. Bruder, F. Johlke, U. Roder

### References


[1] F. Johlke, U. Roder, and R. Bruder. Project ELMA - an investigation of factors influencing achievement in the Realschulabschluss mathematics with the help of the analysis of class tests of the final years. In WTM-Verlag Münster, editor, *Beiträge zum Mathematikunterricht*, pages 1069–1072, 2019.


**Project: WTT Serious Games Information Center for technology and knowledge transfer between research, business and society in the field of Serious Games**

Serious games are games that not only entertain, but also make a playful contribution to education or health. In the WTT Serious Games project at the TU Darmstadt, knowledge about the characteristics of high-quality Serious Games is acquired, recorded and transferred to small and medium-sized enterprises (SMEs) such as game developers, IT service providers and users by means of studies, publications, recommendations for action and events in interdisciplinary cooperation. Targeted measures to promote start-ups are also intended to motivate young people to get involved in the serious games market with their innovative ideas. Overall, the project aims to sustainably strengthen Hessen as a games

location and to establish Hessen nationwide as #1 in the serious games market with the TU Darmstadt as the first point of contact for research and teaching in the field of serious games. Our project contribution here consists in the research and presentation of serious games in the field of education.
Details: http://www.wtt-serious-games.de

**Partner:** Dr. Stefan Göbel (project leader), Prof Dr. Josef Wiemeyer (TU Darmstadt), Sonja Bergsträßer (TU Darmstadt), Polona Casermann (TU Darmstadt), Philipp Müller (TU Darmstadt), Katrin Hoffmann (TU Darmstadt), Katharina Straßburg (TU Darmstadt), Thomas Lenz (TU Darmstadt)

**Contact:** R. Bruder, M. Schaub

**References**


[1] P. Caserman, K. Hoffmann, P. Müller, M. Schaub, K. Straßburg, J. Wiemeyer, R. Bruder, and S. Göbel. Quality Criteria for Serious Games: Serious Part, Game Part, and Balance. *JMIR serious games*, 8(3):e19037, 2020.

[2] M. Schaub, K. Straßburg, R. Bruder, P. Casermann, S. Göbel, K. Hoffmann, P. Müller, and E. Staub. Quality criteria for serious games shown on mathematical education games. In *EDULEARN 20 Proceedings*, pages 5882–5888, 2020.


**Project: Knowledge qualities for mathematical proof processes in the field of analysis in the first semester**

The project is located in the research area on the transition between school and university with a focus on the influence of mathematical knowledge and its quality on proving processes. The objectives of the project are the description and further development of the knowledge qualities derived from activity theory, which have already been adapted by Nora Feldt-Caesar and Oliver Schmitt for basic knowledge and basic skills, as well as conclusions for diagnostic instruments and acquisition materials for knowledge on the corresponding quality. An exemplary implementation of these instruments and materials is envisaged for one mathematical concept and one theorem. Based on theoretical considerations and known quantitative and qualitative studies on the influence of these qualities on evidence processes, the instruments and materials will be tested in a qualitative investigation, and the influence of the diagnosed knowledge qualities on proving processes will be examined more closely.

**Contact:** I. Apel

**References**


[1] I. Apel. Tätigkeitstheoretische Betrachtung von Kenntnisqualitäten für mathematische Beweisprozesse. In Andreas Frank and Stefan Krauss and Karin Binder, editor, *Beiträge zum Mathematikunterricht 2019*, pages 57–60. WTM Verlag, 2019.

[2] I. Apel. Zum Einfluss von Kenntnisqualitäten auf Beweisprozesse am Beispiel der $\epsilon$-$\delta$-Stetigkeit. In Hans-Stefan Siller and Wolfgang Weigel and Jan Franz Wörler, editor, *Beiträge zum Mathematikunterricht 2020*, pages 69–72. WTM Verlag, 2020.


**Project: EOM (E-Feedback to overcome Misconceptions)**

The aim of the dissertation project EOM (E-Feedback to overcome Misconceptions) is the optimization of feedback in digital online learning environments. Digitally designed, automated and error-adaptive feedback elements are intended to trigger learning processes

among pupils. Current studies and research work from feedback theory as well as media pedagogy and psychology are included.
This E-Feedback is used to take individual learning preferences into account and thus to increase the effectiveness of the feedback elements, as individual learning preferences can influence the acceptance and thus also the effect of feedback. Feedback on the performances of tasks is, next to diagnosis before and a supportive framework afterwards, on main part of learning environments. The concepts of learning styles, that are based on personality traits, are used to take into account potentially existing differences in learning behavior. This view from the perspective of the learners can serve as the basis for optimizing individual feedback elements.

**Contact:** F. Johlke

### References


[1] O. Genc, F. Johlke, M. Schaub, N. Feldt-Caesa, R. Fournier, U. Roder, and R. Bruder. Mathematikdidaktische Forschungsansätze und Entwicklungsarbeiten zu digitalen Diagnose und Förderangeboten an der TU-Darmstadt. In Kai Kaspar and Michael Becker-Mrotzek, Ssandra Hofhues and Johannes König and Daniela Schmeinck, editor, *Bildung, Schule, Digitalisierung*. Waxmann Münster, 2020.

[2] F. Johlke. E-Feedback to overcome Misconceptions. In Mellony Graven and Hamsa Venkat and Anthony Essien and Pamela Vale, editor, *Proceedings of the 43rd Conference of the International Group for the Psychology of Mathematics Education*, page 52. PME Pretoria, South Africa, 2019.

[3] F. Johlke. E-Feedback - Zur Relevanz individueller Fehler und Lernpräferenzen. In Hans-Stefan Siller and Wolfgang Weigel and Jan Franz Wörler, editor, *Beiträge zum Mathematikunterricht 2020*, pages 473–476. WTM Münster, 2020.


**Project: Quantum Control: Approach based on Scattering Theory for Non-commutative Markov Chains and Multivariate Operator Theory**

The aim of this project is to explore genuinely non-commutative versions of control theory with a view toward direct applications to the emergent discipline of quantum control.
A basic idea of this project is to make use of recent developments in multivariate operator theory. While in classical operator theory a single operator is analysed, in multivariate operator theory the joint action of a family of operators is studied. These operators may not commute with each other. Nevertheless, there are analogies to classical results in complex analysis such as the idea of multi-analytic operators. It turns out that many of the operator results which are relevant for classical control theory can be extended to this setting. We develop these tools with applications to quantum control.
Scattering theory for non-commutative Markov chains is a theory about open quantum systems with many relations to operator theory. Recently the wave operator occurring in this theory has been rewritten as a multi-analytic operator and it is possible to interpret it as a version of open-loop control. For example it has been successfully applied to the preparation of quantum states in a micromaser interacting with a stream of atoms.
It is thus promising to investigate multivariate operator theory and apply it to problems in quantum control where interesting engineering applications can be expected.

**Partner:** R. Gohm, J. Gough, Aberystwyth University; H. Maassen, University of Nijmegen

**Support:** Engineering and Physical Sciences Research Council (EPSRC), GB.

**Contact:** B. Kümmerer

### References

[1] R. Gohm, F. Haag, and B. Kümmerer. Universal Preparability of States and Asymptotic Completeness. *Communications in Mathematical Physics*, 352 (1):59 – 94, 2017.

[2] R. Gohm, B. Kümmerer, and T. Lang. Noncommutative Symbolic Coding. *Ergodic Theory and Dynamical Systems*, 26:1521 – 1548, 2006.

[3] B. Kümmerer and H. Maassen. Scattering Theory for Generalized Markov Chains. *Infinite Dimensional Analysis, Quantum Probability, and Related Topics*, 3:161 – 176, 2000.

### Project: Stationary States, Recurrence and Transience for Quantum Dynamics

Probabilistic Markovian behavior is described by semigroups of transition matrices or, more generally, by transition kernels. In quantum probability, this generalizes to semigroups of completely positive operators on the algebra of observables. As in classical probability, existence, uniqueness, and convergence to stationary states—states generalize probability distributions – are an important issue whenever one is interested in the long time behavior of such a dynamics. For finite systems a Perron-Frobenius type theory is available, for infinite systems, notions of recurrence and transience become crucial.
Starting from a noncommutative version of the Riesz decomposition theorem we develop a coherent approach to recurrence and transience. It leads to a classification of idempotent Markov operators, thereby identifying concretely the Choi-Effros product, and to an abstract Poisson integral. The paradigmatic case of semigroups on the algebra $\mathscr{B}(\mathscr{H})$ of all bounded operators on a Hilbert space was studied in more detail. These may be viewed as a quantum version of Markovian semigroups on countably many states.
Current activities regard the decomposition of the dynamics on finite system into irreducible components. A structure theorem for the asymptotically non-vanishing observables was derived by applying the aforementioned Perron-Frobenius theory. This leads to a transfer of the above results from the projection on the fix space to the projection on the space of non-decaying observables. Future work may include further understanding of the concrete applications of this new decomposition and the possibilities of generalizing to infinite systems.

**Partner:** R. Gohm (Aberystwyth)

**Contact:** M. Brandy, B. Kümmerer

### References

[1] A. Gärtner and B. Kümmerer. A Coherent Approach to Recurrence and Transience for Quantum Markov Operators. Preprint arXiv:1211.6876, TU Darmstadt, 2012.

### Project: Measures of Entanglement and Norms on Tensor Products

It is one of the basic problems of quantum information to measure degrees of entanglement for quantum states.
A quantum system is described by a state on a Hilbert space, i. e. a non-negative trace class operator with trace one. For the description of composed quantum systems one has to use a state on the tensor product of the corresponding Hilbert spaces. For example, a tensor product of states describes a joining of independent quantum systems. Since the state space of a quantum system is a convex set one can consider the convex hull of the product states: The set of *separable states*. But not all states on the tensor product Hilbert

space are separable. Such states are called *entangled*. Experiments show that only entangled states behave truely quantum mechanically as they may violate Bell's inequalities and can be used for quantum cryptography and quantum computation.
There exist various notions in the literature of how to measure the degree of entanglement: it should measure the usability of an entangled state for true quantum effects. But most of these notions are bound to bi-partite or finite dimensional systems. Recently, W. Arveson established a universal measure of entanglement which is geometrically motivated and may attain the value "infinity" for certain states. However, in the finite case this measure equals the maximal or projective tensor norm previously proposed by O. Rudolph. In this project we aim to gain a deeper understanding of the structure of Arveson's measure of entanglement. For example, we try to compute its value for some interesting states on multipartite systems or give better bounds for it. Moreover, we intend to apply Arveson's measure to more general notions of physical entanglement such as entanglement of fermionic or bosonic particles, genuine multipartite entanglement and others. Due to the existence of "infinitely entangled states" we also address the problem of explicitly characterizing this set and try to find concrete physical examples for such states.
More recently, by using methods from convex algebraic geometry we find new criteria for entanglement.

**Contact:** B. Kümmerer, S. Lang

### References


[1] F. Sokoli and G. Alber. Generalized Schmidt decomposability and its relation to projective norms in multipartite entanglement. *J. Phys. A*, 47, 2013.

[2] F. Sokoli and B. Kümmerer. Entanglement of Indistinguishable Particles and its Quantification. Preprint arXiv:1507.04615v1, TU Darmstadt, 2015.


### Project: Stationary Quantum Stochastic Processes, Unitary Cocycles, and Their Cohomology

We resume an older project (cf. [1]) on the structure of stationary quantum stochastic processes.
A stationary quantum stochastic process with values in the $n \times n$-matrices $M_n$ is given by a quadruple $(\mathscr{A}, \varphi, (T_t)_t, i)$, where $\mathscr{A}$ is a von Neuman algebra with a faithful normal state $\varphi$, $(T_t)_t$ is a stationary group of automorphisms of $(\mathscr{A}, \varphi)$ with time parameter $t \in \mathbb{Z}$ or $t \in \mathbb{R}$ (in the latter case we assume continuity in the pointwise strong operator topology), $i : M_n \to \mathscr{A}$ is a *-homomorphism such that there exists the conditional expectation from $(\mathscr{A}, \varphi)$ onto $i(M_n)$. The random variables are then given by the family $(i_t)_t$ with $i_t := T_t \circ i$. It follows that for every $t$ there is a unitary $u_t \in \mathscr{A}$ such that $i_t(x) = u_t^* i(x) u_t$ for $x \in M_n$.
Two problems are considered:
1. Under which conditions can $u_t$ be chosen in the centralizer of $(\mathscr{A}, \varphi)$?
2. In the case of continuous time, i.e. $t \in \mathbb{R}$, under which conditions can we choose the unitaries $(u_t)_t$ such that they form a strongly continuous cocycle of the automorphism group $(T_t)_t$, i.e., such that $u_{s+t} = u_s \cdot T_s(u_t)$?
If both conditions are fullfilled, then the automorphism group $(T_t)_t$ can be considered as a perturbation of an evolution $(S_t)_t$ of $(\mathscr{A}, \varphi)$ with $S_t(x) := u_t T_t(x) u_t^*$. It leaves the subalgebra $i(M_n) \subseteq \mathscr{A}$ pointwise fixed and hence can be considered as a *free* evolution

of the relative commutant of $i(M_n)$ in $\mathscr{A}$ which may be considered as a heat bath. If the stochastic process has the Markov property then the free evolution becomes a white noise.

**Contact:** B. Kümmerer, F. Voigt

### References


[1] B. Kümmerer. Stochastic Processes with Values in Mn as Couplings to Free Evolutions. Preprint, University of Tübingen, 1993.


### Project: Asymptotic Completeness and Synchronizing Words

Given finite sets $A$ and $C$ then a surjective map $\gamma : A \times C \to A$ may be identified with a road-coloured directed graph with vertices $A$ and $C$ a set of colours labeling its edges with a road-colouring. A probability distribution on $C$ induces transition probabilities between the vertices of $A$. Dually, $\gamma$ induces an injective *-homorphism $i : \mathscr{A} \to \mathscr{A} \otimes \mathscr{C}$ where $\mathscr{A}$ and $\mathscr{C}$ denote the commutative algebras of functions on $A$ and $C$. Iterating the map $i$ leads to an algebraic version of the Markov process for the given transition probabilities. In [3] we have shown that it is asymptotically complete if and only if the road coloured-graph admits a synchronizing word. Presently, the following two problems are considered:

1. For infinite sets $A$ and $B$ an analogous approach suggests the notion of synchronizing words for infinite graphs which is presently studied.
2. Admitting also non-commutative algebras $\mathscr{A}$ and $\mathscr{C}$ then an injective *-homomorphism $i : \mathscr{A} \to \mathscr{A} \otimes \mathscr{C}$ may be interpreted as a non-commutative version of a road-coloured graph, but the notion of asymptotic completeness makes still sense. A criterion for asymptotic completeness is provided by regularity of an associated extended transition operator ([3], [1]). Classically (i.e., for commutative algebras), this translates into regularity of the adjacency matrix of the road-colored graph's label product with itself. In this case the transition operator corresponds to a sum of tensor products and it exhibits strong positivity properties. The question arises, whether this structure can be transferred to the non-commutative case.

**Partner:** R. Gohm, Aberystwyth University

**Contact:** A. Knof, B. Kümmerer

### References


[1] R. Gohm, F. Haag, and B. Kümmerer. Universal Preparability of States and Asymptotic Completeness. *Communications in Mathematical Physics*, 352 (1):59 – 94, 2017.

[2] R. Gohm, F. Haag, and B. Kümmerer. Synchronizing for Infinite Road-Coloured Graphs. Preprint, TU Darmstadt, 2020.

[3] R. Gohm, B. Kümmerer, and T. Lang. Noncommutative Symbolic Coding. *Ergodic Theory and Dynamical Systems*, 26:1521 – 1548, 2006.

[4] B. Kümmerer and H. Maassen. Scattering Theory for Generalized Markov Chains. *Infinite Dimensional Analysis, Quantum Probability, and Related Topics*, 3:161 – 176, 2000.


### Project: Mathematics: The Common Language of Natural Sciences (Mathematik als gemeinsame Sprache der Naturwissenschaften)

In this project we develop an innovative multidisciplinary lecture course to be attended by all teacher students who study at least one of the subjects mathematics, physics, chemistry, biology, or informatics. It is a building block of the recently founded "interlinking

area" ("Vernetzungsbereich"), which is established as a part of the MINTplus initiative of the Technical University Darmstadt to profile the teachers education at our university. It is financially supported by German Bundesministerium für Bildung und Forschung as a part of the "Qualititätsoffensive Lehrerbildung".
The course supports the usage of mathematical language and the handling of mathematical formulas in the respective subjects, thereby reflecting the role of mathematics as common language of natural sciences, in particular, possibilities and limitations of mathematical modelling in natural sciences. The common mathematical language provides a link between different natural sciences and fosters crossover cooperations in school teaching. Examples from the history of mathematics illuminate the mutual dependence between the developments of mathematics and of natural sciences.

**Support:** BMBF (Bundesministerium für Bildung und Forschung, Ministry for Education and Research)

**Contact:** B. Kümmerer, S. Lang

### References

[1] R. Bruder and B. Kümmerer. Mathematik verbindet. Ein neuer Ansatz für das gymnasiale Lehramt im Darmstädter Projekt MINTplus in der Qualitätsoffensive Lehrerbildung. *GDM-Mitteilungen*, 107:27 – 32, 2019.

## 1.5 Logic

The research group in *Mathematical Logic and Foundations of Computer Science* represents the subject area of Mathematical Logic viewed as an applied foundational discipline between mathematics and computer science. Research activities focus on the application of proof theoretic, recursion theoretic, category theoretic, algebraic and model theoretic methods from mathematical logic to mathematics and computer science.
Besides classical mathematical logic (represented with proof theory, recursion theory and model theory) this involves constructive type theory, categorical logic, universal algebra, domain and lattice theory, finite model theory and complexity theory.
Within mathematics, a primary field of applications in the proof- and recursion-theoretic setting is the extraction of new information from proofs in classical mathematics (proof mining: Kohlenbach). This concerns qualitative aspects (e.g., independence of existence assertions from certain parameters) as well as quantitative aspects of computability and complexity of solutions, extraction of algorithms and bounds from proofs, and links with exact real arithmetic and computational mathematics (Kohlenbach, Streicher). Model theoretic investigations make intra-mathematical links with algebra and discrete mathematics, e.g., graphs and hypergraphs (Otto, Eickmeyer).
Concerning Logic in Computer Science and the mathematical foundations of computer science, major activities revolve around issues of semantics. On the one hand, this involves the mathematical foundation of the semantics and the logic of programming languages (Streicher); on the other hand, logics and formal systems are investigated in the sense of model theoretic semantics, w.r.t. expressiveness and definability, with an emphasis on computational aspects (algorithmic and finite model theory, descriptive complexity: Otto, Eickmeyer). Besides specific application domains in computer science, as, e.g., verification, data bases and knowledge representation, there is work on foundational issues in the areas of computability and complexity, as well as type theory and category theory (Streicher).

Overall, the logic group forms an internationally well connected cluster of expertise, with a characteristic emphasis on the connections that mathematical logic has to offer, both w.r.t. other areas within mathematics and w.r.t. the 'logic in computer science' spectrum.

**Members of the research group**

**Professors**

Ulrich Kohlenbach, Martin Otto, Thomas Streicher

**Retired professors**

Christian Herrmann, Peter Zahn

**Lecturers**

Kord Eickmeyer

**Postdocs**

Ulrik Buchholtz, Paolo Capriotti, Anton Freund, Emanuele Frittaion (Humboldt fellow), Pedro Pinto, Thomas Powell, Sam Sanders, Andrei-Valentin Sipoş

**Research Associates**

Julian Bitterlich, Felix Canavoi, Marius Tritschler, Jonathan Weinberger

**Secretaries**

Betina Schubotz

**Project: Proof Mining in Convex Optimization**

This project aims at using proof-theoretic methods from logic for the extraction of new data (such as effective bounds, 'proof mining') from prima facie noneffective proofs in convex optimization and related areas. We tailor the proof-theoretic methods to the specific domain of applications and will then apply them for the extraction of rates of asymptotic regularity, metastability (in the sense of T. Tao) and convergence of central iterative procedures used in convex optimization. In particular, we study convergence proofs which make use of facts from the abstract theory of set-valued operators (e.g., maximally monotone operators).

**Partner:** G. Lopéz-Acedo (U Sevilla), A. Nicolae (U Babeş-Bolyai, Cluj-Napoca)

**Support:** DFG Project KO 1737/6-1

**Contact:** U. Kohlenbach.

**References**


[1] U. Kohlenbach. On the reverse mathematics and Weihrauch complexity of moduli of regularity and uniqueness. *Computability*, 8:377–387, 2019.

[2] U. Kohlenbach. A polynomial rate of asymptotic regularity for compositions of projections in Hilbert space. *Foundations of Computational Mathematics*, 19:83–99, 2019.

[3] U. Kohlenbach. Quantitative analysis of a Halpern-type proximal point algorithm for accretive operators in banach spaces. *Journal of Nonlinear and Convex Analysis*, 21:2125–2138, 2020.

[4] U. Kohlenbach. Quantitative results on the proximal point algorithm in uniformly convex Banach spaces. *Journal of Convex Analysis*, 28:11–18, 2021.

[5] U. Kohlenbach, G. López-Acedo, and A. Nicolae. Moduli of regularity and rates of convergence for Fejér monotone sequences. *Israel Journal of Mathematics*, 232:261–297, 2019.

[6] U. Kohlenbach and T. Powell. Rates of convergence for iterative solutions of equations involving set-valued accretive operators. *Computers & Mathematics with Applications*, 80:490–503, 2020.

[7] U. Kohlenbach and A. Sipoş. The finitary content of sunny nonexpansive retractions. *Communications in Contemporary Mathematics*, 23:63 pages, 2021.

**Project: Viscosity methods in nonlinear analysis**

In the setting of hyperbolic spaces, we show that the convergence of Browder-type sequences and Halpern iterations respectively entail the convergence of their viscosity version with a Rakotch map. We also show that the convergence of a hybrid viscosity version of the Krasnoselskii-Mann iteration follows from the convergence of the Browder type sequence. Our results follow from proof-theoretic techniques (proof mining). From an analysis of theorems due to T. Suzuki, we extract a transformation of rates for the original Browder type and Halpern iterations into rates for the corresponding viscosity versions. We show that these transformations can be applied to earlier quantitative studies of these iterations. From an analysis of a theorem due to H.-K. Xu, N. Altwaijry and S. Chebbi, we obtain similar results. Finally, in uniformly convex Banach spaces we study a strong notion of accretive operator due to Brezis and Sibony and extract an uniform modulus of uniqueness for the property of being a zero point. In this context, we show that it is possible to obtain Cauchy rates for the Browder type and the Halpern iterations (and hence also for their viscosity versions).

**Support:** TU Darmstadt Future Talent Fellowship (P. Pinto), DFG Project KO 1737/6-1 (U. Kohlenbach, P. Pinto)

**Contact:** U. Kohlenbach.

### References

[1] U. Kohlenbach and P. Pinto. Quantitative translations for viscosity approximation methods in hyperbolic spaces. Preprint, arXiv:2102.03981, 2021.

**Project: The 'Lion-Man game'**

In this project we analyze, based on an interplay between ideas and techniques from logic and geometric analysis, a pursuit-evasion game. More precisely, we focus on a uniform betweenness property and use it in the study of a discrete lion and man game with an $\varepsilon$-capture criterion. In particular, we prove that in uniformly convex bounded domains the lion always wins and, using ideas stemming from proof mining, we extract a uniform rate of convergence for the successive distances between the lion and the man. As a byproduct of our analysis, we study the relation among different convexity properties in the setting of geodesic spaces.

**Partner:** G. Lopéz-Acedo (U Sevilla), A. Nicolae (U Babeş-Bolyai, Cluj-Napoca)

**Support:** Oberwolfach Research in Pairs 1911p, DFG Project KO 1737/6-1 (Kohlenbach), DGES Grant MTM2015-65242-C2-1P (López-Acedo), CNCS-UEFISCDI (Nicolae)

**Contact:** U. Kohlenbach.

### References

[1] U. Kohlenbach, G. López-Acedo, and A. Nicolae. A uniform betweenness property in metric spaces and its role in the quantitative analysis of the Lion-Man game. *Pacific Journal of Mathematics*, 319:181–212, 2021.

**Project: Inquisitive Modal Logic**

Inquisitive logic provides a formal framework for dealing with knowledge representation issues including information updates. It can thus model cognitive and linguistic phenomena related not just to assertions but also to questions [1]. Model-theoretic aspects of corresponding extensions of modal logics are closely related to team semantics and have been at the core of a co-operation with Ivano Ciardelli. This co-operation, since around 2016, has led to the proposal and analysis of corresponding notions of inquisitive bisimulation [2, 3]. Key results obtained so far concern natural characterisations of inquisitive modal logics as fragments of two-sorted first-order logic. Related work with Silke Meißner starting from [4] has further illuminated the relationship between inquisitive modal logic and classical logic, including recent applications of classical model-theoretic tools in [5].

**Partner:** Ivano Ciardelli, Munich Center for Mathematical Philosophy, Ludwig-Maximilaians-Universität München

**Contact:** M. Otto.

### References


[1] I. Ciardelli. *Questions in Logic*, volume DS-2016-01 of *ILLC Dissertation Series*. Institute for Logic, Language and Computation, Amsterdam, 2015.

[2] I. Ciardelli and M. Otto. Bisimulation in inquisitive modal logic. In J. Lang, editor, *Theoretical Aspects of Rationality and Knowledge (TARK) 16*. EPTCS, 2017.

[3] I. Ciardelli and M. Otto. Inquisitive bisimulation. *Journal of Symbolic Logic*, 2020. To appear.

[4] S. Meißner. On the model theory of inquisitive modal logic, 2018. Bachelor Thesis.

[5] S. Meißner and M. Otto. A first-order framework for inquisitive modal logic. Under review, TU Darmstadt, 2020. arxiv:1906.04981.


**Project: Quantitative studies on strongly convergent variants of the proximal point algorithm**

The proximal point algorithm is a well-known method to approximate zeros of maximal monotone operators. Since this algorithm only converges weakly, several variants were developed to ensure strong convergence. In this project, we investigate several such algorithms, Halpern-type, Mann-type, multi-parameter, etc., from a finitary perspective (proof mining). Using proof-theoretical methods, we give quantitative analyses of various non-effective mathematical proofs and obtain effective information like rates of metastability (in the sense of T. Tao) and rates of asymptotic regularity. Moreover, in several instances it was possible to bypass more complicated theoretical principles (like countable choice or weak compactness) which played an essential role in the original proofs and are shown to not be needed in our quantitative results. This work follows from recent quantitative studies on the proximal point algorithm and on the elimination of weak compactness in proof mining.

**Partner:** B. Dinis (University of Lisbon); U. Kohlenbach (TU Darmstadt); L. Leuştean (University of Bucharest).

**Support:** 'Future Talents' Short-term Scholarship (Ingenium)

**Contact:** P. Pinto.

## References


[1] B. Dinis and P. Pinto. On the convergence of algorithms with Tikhonov regularization terms. *Optimization Letters*, pages 1–14, 2020.

[2] B. Dinis and P. Pinto. Quantitative results on the multi-parameters proximal point algorithm. *Journal of Convex Analysis*, 28(3), 2021.

[3] L. Leuştean and P. Pinto. Quantitative results on the Halpern type proximal point algorithm. *Computational Optimization and Applications*, pages 1–25, 2021.

[4] P. Pinto. A rate of metastability for the Halpern type Proximal Point Algorithm. *Numerical Functional Analysis and Optmization*, pages 1–24, 2021.


**Project: Finitary content on generalizations of proximal point algorithms to two operators**

The method of alternating resolvents, which generalizes the well-known proximal point algorithm to two monotone operators, gives a weak approximation to a common zero of the operators. Several generalizations have been considered that are strongly convergent (Halpern-type, multi-parameter, etc.). In the context of the proof mining program, we investigate the quantitative features of such algorithms using proof-theoretical methods. Rates of metastability (in the sense of T. Tao), rates and quasi-rates of asymptotic regularity are obtained, and we argue that certain complex principles can be removed from the original non-effective proofs – namely, countable choice and weak compactness. This project follows naturally from previous studies on variants of the proximal point algorithm and from results on proof-theoretic tameness.

**Partner:** B. Dinis (University of Lisbon).


**Support:** DFG Project KO 1737/6-1.


**Contact:** P. Pinto.

## References


[1] B. Dinis and P. Pinto. Effective metastability for a method of alternating resolvents. Preprint, TU Darmstadt, 2021.


## 1.6 Numerical Analysis and Scientific Computing

The research focus of the group for *Numerical Analysis and Scientific Computing* lies in the development, analysis, and implementation of novel, efficient, accurate, and reliable numerical methods for the solution of complex problems of practical interest. This includes the derivation and simplification of models, their analysis, the construction of appropriate numerical schemes for their simulation, the analysis of these numerical methods, the derivation of a-posteriori error estimates, the adaptive solution, and the consideration of related optimization and inverse problems.

The long-term goal of the group is to contribute to the fundamental research topics in the area of numerical mathematics and scientific computing, but also to provide software and expertise for the tackling of specific problems in engineering and the natural sciences. The group is currently engaged in projects in various application areas, e.g., in computational medicine and biology, in simulation and optimal control of gas and water supply networks, in inverse problems for fluid dynamics and non-destructive testing, in modeling and simulation of radiative transfer phenomena, in acoustic and optical tomography, in multiscale modeling and numerical approximation of soft matter systems, in simulation of transient acoustic and electromagnetic phenomena, in modeling and simulation in energy science and in modeling and simulation of compressible single- and multi-phase flows.

Particular research directions in the area of numerical mathematics that are pursued along these applications are, e.g., the development and numerical analysis of novel discretization schemes, the design and analysis of *a posteriori* error estimates, the uncertainty quantification for problems with variable inputs, and the structure preserving model reduction as well as the design and the analysis of model-adaptive schemes.

The research group *Numerical Analysis and Scientific Computing* has been and is engaged among others in various coordinated research activities, e.g., in the Graduate Schools (Excellence Initiative) GSC 233 Computational Engineering and GSC 1070 Energy Science and Engineering, the Transregional Collaborative Research Centers (Transregio/SFB) TRR 154 Mathematical Modelling, Simulation and Optimization Using the Example of Gas Networks and TRR 146 Multiscale Simulation Methods for Soft Matter Systems, the International Research Training Group IGK 1529 Mathematical Fluid Dynamics, and the German Research Foundation (DFG) Priority Program SPP 1748 Reliable Simulation Techniques in Solid Mechanics — Development of Non-Standard Discretisation Methods, Mechanical and Mathematical Analysis. In addition, the group has various industry partners, including cooperations with Robert Bosch GmbH Stuttgart, BASF Ludwigshafen, and Infineon München.

**Members of the research group**

**Professors**

Herbert Egger, Christoph Erath, Jan Giesselmann, Martin Kiehl, Jens Lang

**Retired professors**

Peter Spellucci

**Postdocs**

Neelabja Chatterjee, Jürgen Dölz, Pia Domschke, Alf Gerisch, Hadi Minbashian, Christopher Müller, Mania Sabouri, Kersten Schmidt, Adrien Semin, Mirjam Walloth

**Research Associates**

Anke Böttcher, David Frenzel, Oliver André Habrich, Hrishikesh Joshi, Thomas Kugler, Teresa Kunkel, Richard Franz Löscher, Axel Lukassen, Nora Marie Philippi, Bogdan Radu, Moritz Schneider, Lucas Schöbel-Kröhn, Vsevolod Shashkov, Philipp Steinbach, Elisa Strauch, Erik Laurin Strelow, Gabriel Teschner, Dimitrios Zacharenakis

**Secretaries**

Elke Dehnert, Dagmar Thies

**Project: Convergence Analysis of Fractional Conservation Laws using Discontinuous Galerkin Method**

Fractional conservation laws encompass a large number of applicable models, ubiquitous in natural, physical or biological processes. Standard examples include Black–Scholes model from finance or Burgers equation with *fractional Laplacian* source term. Fractional conservation laws can be viewed as natural nonlocal generalization of the viscous conservation law. There is a plethora of research work available, conducted to explore the construction and convergence of different numerical methods approximating the actual equation. One of them being a certain class of discontinuous Galerkin methods, which takes into account the effects of the convective term and the fractional term. The aim of this project is to discretize the fractional conservation law model using the discontinuous Galerkin method with forward Euler time discretization and obtain an *a priori* error estimate which will determine rate of convergence of the numerical solution to the smooth exact solution. This desired error estimate consists of contributions from two different quantities. First contribution is due to the error between the numerical solution and the appropriate projection of the exact solution on the finite element space of piecewise polynomials. We are going to estimate this quantity by using the *stability* of the scheme, with the help of properly chosen CFL condition. Second contribution has its origin in the error between the exact solution and the appropriate projection of it on the finite element space of piecewise polynomials. This quantity will be estimated using the regularity of the exact solution and an application of Bramble–Hilbert Lemma.

**Contact:** Jan Giesselmann, Neelabja Chatterjee

**References**


[1] N. Alibaud. Entropy formulation for fractal conservation laws. *J. Evol. Equ.*, 7(1):145–175, 2007.

[2] S. Cifani and E. R. Jakobsen. Entropy solution theory for fractional degenerate convection-diffusion equations. *Ann. Inst. H. Poincaré Anal. Non Linéaire*, 28(3):413–441, 2011.

[3] S. Cifani, E. R. Jakobsen, and K. H. Karlsen. The discontinuous Galerkin method for fractional degenerate convection-diffusion equations. *BIT*, 51(4):809–844, 2011.

[4] B. Cockburn and C.-W. Shu. The local discontinuous Galerkin method for time-dependent convection-diffusion systems. *SIAM J. Numer. Anal.*, 35(6):2440–2463, 1998.

[5] J. Droniou and C. Imbert. Fractal first-order partial differential equations. *Arch. Ration. Mech. Anal.*, 182(2):299–331, 2006.

[6] Q. Zhang and C.-W. Shu. Error estimates to smooth solutions of Runge-Kutta discontinuous Galerkin methods for scalar conservation laws. *SIAM J. Numer. Anal.*, 42(2):641–666, 2004.


**Project: Uncertainty quantification for forward and inverse problems**

We study the numerical solution of forward and inverse acoustic scattering problems by randomly shaped obstacles in three-dimensional space using a fast isogeometric boundary element method. We show that the knowledge of the deformation field's expectation and covariance at the surface of the scatterer are already sufficient to compute the surface Karhunen-Loève expansion. Multilevel quadrature methods are then used for the efficient approximation of quantities of interest, such as the scattered wave's expectation and variance. Computing the wave's Cauchy data at an artificial, fixed interface enclosing the random obstacle, we can also directly infer quantities of interest in free space. Adopting the Bayesian paradigm we also compute the expected shape and the variance of the scatterer from noisy measurements of the scattered wave at the artificial interface. Numerical results for the forward and inverse problem are given to demonstrate the feasibility of the proposed approach.

**Partner:** H. Harbrecht (Universität Basel); C. Jerez-Hanckes (Universidad Adolfo Ibanez, Santiago, Chile); M. Multerer (USI Lugano)

**Contact:** Jürgen Dölz

### References


[1] J. Dölz, H. Harbrecht, C. Jerez-Hanckes, and M. Multerer. Isogeometric multilevel quadrature for forward and inverse random acoustic scattering. arXiv:2010.14613, 2020.


### Project: Adaptive dynamical multiscale methods

The aim of this project is the development of an integrated, dynamic multiscale approach for the numerical solution of the compressible instationary Euler equations on network structures. These methods will be used for the description of the stochastic behavior of practically relevant outputs relative to randomized parameters in hyperbolic differential equations (quantification of uncertainty), the construction of reduced order models and an adaptive multilevel optimization for gas networks.
In the first project period, modelling aspects and the development of adaptive discretizations were of primary importance. Adaptive spatial and temporal discretizations are controlled and combined with models from a newly established model hierarchy such that an efficient simulation of gas networks over the whole time horizon relative to a prescribed tolerance becomes available.
In the second project period, the influence of dynamic market fluctuations, which can be described by randomized initial and boundary values, on objective functions and scopes for the optimal control of gas networks in the framework of an uncertainty quantification will be investigated. Therefore, adaptive stochastic collocation methods with multilevel-like strategies for the reduction of the variance will be used. The integrated application of multilevel methods in space, time, and model as well as stochastic components lead to a reduction of computing time if resolution hierarchies in the corresponding approximations (space, time, model, stochastics) are employed. The stochastic collocation is realised by means of anisotropic sparse Smolyak grids. The inherent sampling strategy allows for the use of reduced, structure-preserving models in order to further reduce the computing time even perspectively for large scaled networks. It is the goal to combine adaptive grid and model refinements with adaptive collocation methods to improve the multilevel methods and to achieve rigorous quality requirements for expectations and variances of solution functionals for the uncertainty quantification at reduced computing time.


**Support:** Project B01 within DFG TRR 154


**Contact:** Elisa Strauch, Pia Domschke, Jens Lang

### References


[1] P. Domschke, O. Kolb, and J. Lang. Fast and reliable transient simulation and continuous optimization of large-scale gas networks. arXiv:2012.02737, 2020.

[2] J. Lang, P. Domschke, and E. Strauch. Adaptive single- and multilevel stochastic collocation methods for uncertain gas transport in large-scale networks. arXiv:2012.03565, 2020.

[3] P. Mindt, J. Lang, and P. Domschke. Entropy-preserving coupling of hierarchical gas models. *SIAM Journal on Mathematical Analysis*, 51:4754–4775, 2019.


### Project: Model order reduction for inverse problems

We study the efficient numerical solution of linear inverse problems with operator valued data which arise, e.g., in seismic exploration, inverse scattering, or tomographic imaging.

The high-dimensionality of the data space implies extremely high computational cost already for the evaluation of the forward operator, which makes a numerical solution of the inverse problem, e.g., by iterative regularization methods, practically infeasible. To overcome this obstacle, we develop a novel model reduction approach that takes advantage of the underlying tensor product structure of the problem and which allows to obtain low-dimensional certified reduced order models of quasi-optimal rank. A complete analysis of the proposed model reduction approach is given in a functional analytic setting and the efficient numerical construction of the reduced order models as well as of their application for the numerical solution of the inverse problem is discussed. In summary, the setup of a low-rank approximation can be achieved in an offline stage at essentially the same cost as a single evaluation of the forward operator, while the actual solution of the inverse problem in the online phase can be done with extremely high efficiency. The theoretical results are illustrated using a typical model problem in fluorescence optical tomography.

**Partner:** J. Dölz (Uni Bonn); M. Schlottbom (U Twente)

**Support:** DFG TRR 146, DFG TRR 154

**Contact:** Herbert Egger

### References


[1] J. Dölz, H. Egger, and M. Schlottbom. A model reduction approach for inverse problems with operator valued data. arXiv:2004.11827, 2020.


### Project: Domain decomposition with rotating geometries

Engineering problems sometimes involve static and rotating geometries, e.g., propellers and ambient space or stators and rotors. It is then natural to introduce a domain decomposition with different coordinate systems rotating relative to each other. A typical example of such problems arises in electric machines. We propose and analyze a mortar method based on finite element or isogeometric analysis discretization of the individual subdomains which are coupled by a Lagrange multiplier technique. Trigonometric polynomials (harmonics) are chosen for the space of Lagrange-multipliers to take into account the rotational symmetry. We study the numerical stability of such discretization schemes and, in particular, derive simple criteria guaranteeing the relevant inf-sup stability condition. The validity and sharpness of the theoretical results is demonstrated by numerical tests.

**Partner:** M. Haruntyunyan; M. Merkel; S. Schöps (TEMF, TU Darmstadt)

**Support:** GSC 233

**Contact:** Herbert Egger, Richard Löscher

### References


[1] H. Egger, M. Harutyunyan, M. Merkel, and S. Schöps. On the stability of harmonic mortar methods with application to electric machines. arXiv:2005.12020, 2020. To appear in Proceedings of SCEE 2020.


### Project: dGFEM-BEM coupling for the Helmholtz equation

As a model problem we consider the Helmholtz equation in an interior and the corresponding exterior domain. This problem can be considered as a scattering problem. Therefore, the coupling of two different numerical methods is of highest interest to simulate the possible different behaviour of the model problem in the different domains. In this project we consider a novel approach, namely the coupling of a discountinous Galerkin method with the boundary element method. We develop a rigorous analysis of our approach as well as some convincing numerical examples.

**Partner:** Jens Markus Melenk (TU Wien); Lorenzo Mascotto (University of Vienna); Ilaria Perugia (University of Vienna); Alexander Rieder (University of Vienna)

**Contact:** Christoph Erath

**Project: Non-symmetric isogeometric FEM-BEM couplings**

The project considers the coupling of the finite element and the boundary element method in an isogeometric framework to approximate either two-dimensional Laplace interface problems or boundary value problems consisting in two disjoint domains. We consider the finite element Method in the bounded domains to simulate possibly non-linear materials. The boundary element method is applied in unbounded or thin domains where the material behavior is linear. The isogeometric framework allows us to combine different design and analysis tools: first, we consider the same type of NURBS parameterizations for an exact geometry representation and second, we use the numerical analysis for the Galerkin approximation. Moreover, it facilitates to perform $h$- and $p$-refinements. Practical examples (e.g., magneto static field of engines) will show the effectiveness of our numerical coupling approach.

**Partner:** Mehdi Elasmi (TU Darmstadt); Stefan Kurz (TU Darmstadt)

**Support:** Graduate School Computational Engineering, DFG

**Contact:** Christoph Erath

### References

[1] M. Elasmi, C. Erath, and S. Kurz. Non-symmetric isogeometric FEM-BEM couplings. arXiv:2007.09057, 2020.

**Project: Mathematical modelling of and numerical methods for time-dependent PDE problems arising in mathematical biology**

Biological processes like the invasion of tissue by cancer cells, the adhesion-driven reorganization of tissue, the healing of tissue wounds, and the cascade of steps in fracture healing can be modeled as time-dependent PDEs. We develop structured population models for the dedicated modelling of cellular surface-bound processes at the tissue scale, include cross-diffusion processes in different models, study the effect of multiple adhesion terms of different form in wound healing models, consider mechanochemial models of pattern formation, and justify continuous non-local adhesion models from a spatial stochastic random walk.

For the reliable, efficient and accurate simulation of these models, dedicated numerical schemes are required. We focus on general methods for taxis-diffusion-reaction systems and on particular schemes for the evaluation of the spatially nonlocal terms in models of cellular adhesion. In our approach, we follow the method of lines with finite volumes in space and linearly-implicit methods in time.

**Partner:** Mark A. J. Chaplain (University of St. Andrews, UK); Kevin J. Painter (Heriot-Watt University, Edinburgh, UK); Jonathan Sherratt (Heriot-Watt University, Edinburgh, UK); Dumitru Trucu (University of Dundee, UK); Andreas Buttenschön (University of British Columbia, Canada); Thomas Hillen (University of Alberta, Canada)

**Contact:** Alf Gerisch, Pia Domschke

#### References

[1] A. Voss-Böhme and A. Gerisch. Multi-scale analysis of contact-dependent interaction in tissue aggregation and invasion. In O. Wolkenhauer, editor, *Systems Medicine*, pages 156–168. Academic Press, Oxford, 2021, published online August 2020.

### Project: Cross-diffusion in models from mathematical biology

Cross-diffusion terms are nowadays widely used in reaction-diffusion equations encountered in models from mathematical biology and in various engineering applications. In this project we study the underlying model equations of such systems and investigate analytically their properties with an emphasis on pattern formation and positivity preservation. We also investigate and apply suitable numerical simulation techniques for applications from mathematical biology.

**Partner:** Anotida Madzvamuse (University of Sussex, UK); Raquel Barreira (Polytechnic Institute of Setubal, Portugal)

**Contact:** Alf Gerisch

### Project: Regularized moment methods for kinetic equations

Moment equations employing entropy closures are an interesting method for solving kinetic equations since they lead to equations that are very close to compressible fluid mechanics equations and posses a natural entropy structure. However, solving these equations numerically is rather delicate since the entropy closure makes it necessary to solve constrained minimization problems and numerical errors might make these problems unfeasible. This difficulty can be overcome using regularized minimization problems, as introduced in [1]. The goal of our research is to show convergence of solutions to the regularized moment system to solutions of the non-regularized moment system in case the regularization parameter goes to zero.

**Partner:** Martin Frank (KIT), Graham W. Alldredge (RWTH Aachen)

**Contact:** Jan Giesselmann

#### References

[1] G. W. Alldredge, M. Frank, and C. D. Hauck. A regularized entropy-based moment method for kinetic equations. *SIAM J. Appl. Math.*, 79(5):1627–1653, 2019.

### Project: Reduced basis construction via snapshot calibration

Standard model reduction techniques using proper orthogonal decomposition of snapshot matrices are not very efficient when applied to hyperbolic partial differential equations due to slow singular value decay. Our goal is to induce a faster singular value decay by computing snapshots on a transformed spatial domain, or the so-called snapshot calibration/transformation. We are particularly interested in problems involving shock collision, shock rarefaction-fan collision, shock formation, etc. For such problems, we propose spatial transformation using monotonic feature matching. We consider discontinuities and kinks as features, and by carefully partitioning the parameter domain. We prove that our method results in a fast $m$-width decay of a so-called calibrated manifold. It turns out, that calibration induces dependence of the $m$-width on the accuracy of the full order model, which is in contrast to elliptic and parabolic problems that do not require calibration. Our method is "data-driven" in the sense that it uses only solution snapshots and not the underlying partial differential equation.

**Partner:** Martin Frank (KIT), Graham W. Alldredge (RWTH Aachen)

**Contact:** Jan Giesselmann

### References


[1] N. Sarna, J. Giesselmann, and P. Benner. Data-driven snapshot calibration via monotonic feature matching. arXiv:2009.08414, 2020.


### Project: Spinodal decomposition of polymer-solvent systems

The goal of the project is to obtain stable and consistent descriptions of flow dynamics on multiple scales in a class of systems exhibiting highly complex non-equilibrium dynamics, namely phase-separating polymer solutions. This is done by combining (i) the derivation, analysis, and simulation of macroscopic two-fluid models describing the dynamics of viscoelastic phase separation, (ii) the mesoscopic simulation of viscoelastic phase separation by extension of a coupled Lattice-Boltzmann / Molecular Dynamics method, and (iii) the calibration of the macroscopic models to results from mesoscopic simulations by means of parameter estimation and inverse problems methodology.

**Partner:** Mária Lukácová-Medvidová, Aaron Brunk (Universität Mainz); Burkhard Dünweg, Dominic Spiller (Max-Planck-Institut für Ploymerforschung Mainz)

**Support:** DFG TRR 146

**Contact:** Herbert Egger, Oliver Habrich

### References


[1] A. Böttcher and H. Egger. Structure preserving discretization of Allen-Cahn type problems modeling the motion of phase boundaries. *Vietnam J. Math.*, 48:847–863, 2020.

[2] A. Brunk, B. Dünweg, H. Egger, O. Habrich, M. Lukacova-Medvidova, and D. Spiller. Analysis of a viscoelastic phase separation model. arXiv:2012.04234, 2020.

[3] H. Egger, O. Habrich, and V. Shahskov. Energy stable Galerkin approximation of Hamiltonian and gradient systems. *Comput. Meth. Appl. Math.*, 2020. in press.


### Project: Spatial model adaptation of compressible chemically reacting flows based on a posteriori error estimates

Simulation of some physical phenomena poses challenges as the interaction between different physics at a range of time and length scales needs to be resolved. One example is chemically reacting flows, where chemical reactions and convection interact. Computational resources can be better utilized by carrying out local mesh and model adaptation. The aim of this project is spatial model adaptation for hyperbolic balance laws based on a posteriori error estimates. We apply the proposed approach to compressible chemically reacting flows. In this example, the governing equations can be simplified by assuming chemical equilibrium which we denote as the simple system. We derive a posteriori error estimates using the relative entropy framework. The error estimates account for the modeling and the discretization errors, which can be used to perform the model and mesh adaptation. The model adaptation is done by decomposing the computational domain and locally choosing the full system where necessary and the simplified system where sufficient. The resulting system is numerically solved using discontinuous Galerkin method with multiresolution analysis on a hierarchy of nested grids with coarse data on a uniform grid. The component of the numerical solution on the nested grids is referred to as the details. The magnitude of the details decay as you increase the number of refinement levels when the numerical solution is locally smooth. We compare the mesh adaptation done based on the thresholding of the details and the residual. To this end we use *Multiwave*, which is a library designed for simulations of nonlinear hyperbolic balance laws.

**Support:** DFG Gi 1131/1-1 (up to 09.2020)

**Partner:** Siegfried Müller (RWTH Aachen), Aleksey Sikstel (Universität Erlangen-Nürnberg)

**Contact:** Jan Giesselmann, Hrishikesh Joshi

### References

[1] N. Gerhard, F. Iacono, G. May, S. Müller, and R. Schäfer. A high-order discontinuous Galerkin discretization with multiwavelet-based grid adaptation for compressible flows. *J. Sci. Comput.*, 62:25–52, 2015.

[2] J. Giesselmann and H. Joshi. Model adaptation of balance laws based on a posteriori error estimates and surrogate fluxes. *Finite volumes for complex applications IX – methods, theoretical aspects, examples (FVCA 9)*, pages 375–383, 2020.

[3] J. Giesselmann and T. Pryer. A posteriori analysis for dynamic model adaptation problems in convection dominated problems. *Math. Models Methods Appl. Sci.*, 27:2381–2432, 2017.

[4] S. Müller and A. Sikstel. Multiwave. https://www.igpm.rwth-aachen.de/forschung/multiwave, Institut für Geometrie und Praktische Mathematik, RWTH Aachen, 2018.

### Project: Simulation of reactive flows by projection onto time- and space-variable quasi-steady states

The simulation of a reactive flow leads to a partial differential equation, which usually contains a large number of unknown variables. Furthermore, the time scales of the different chemical reactions cover several orders of magnitude. In addition to the size the obtained partial differential equation is also very stiff and solving the partial differential equation is very time consuming. However, the fastest chemical reactions have small timescales and eventually reach their equilibrium in a period of time shorter than the timestep of the solver. In this case we can replace these chemical reactions by an algebraic equation. This approach leads to simulation of the chemical reaction system on a lower dimensional manifold describing the partial equilibrium of the fast reactions. Though, the state of the system can differ in time and space, the reaction rates depend on the state. For this reason the manifold changes in time and space. The goal of the project is to develop a model, which dynamically switches in space and time between the description of the chemical reactions via the kinetic model and the partial thermodynamic equilibrium.

**Contact:** Martin Kiehl


#### References

[1] A. Lukassen and M. Kiehl. Operator splitting for stiff chemical reaction systems. *J.Comput. Appl. Math.*, 344:495–511, 2018.


### Project: Stability and structure preserving approximation of hyperbolic problems on networks

We study the exponential stability of damped wave propagation problems on one-dimensional networks which arise in in the modeling of gas-transport processes on acoustic time- and length scales. Exponential stability of the problems is proven and the structure-preserving discretization by mixed finite elements and implicit time-stepping schemes is investigated. In addition, the application of model order reduction schemes is discussed.

**Partner:** B. Liljegren-Sailer, N. Marheineke (Uni Trier); V. Mehrmann (TU Berlin)

**Support:** DFG TRR 154

**Contact:** T. Kugler, Herbert Egger


#### References

[1] H. Egger and T. Kugler. Uniform exponential stability of Galerkin approximations for damped wave systems. In *Advanced Finite Element Methods with Applications, Selected papers from the 30th Chemnitz Finite Element Symposium*. Springer, 2019.

[2] H. Egger, T. Kugler, and B.-L. Sailer. Stability preserving approximations of a semilinear hyperbolic gas transport model. Springer, 2019. in press.

[3] H. Egger, T. Kugler, and V. Shashkov. An inexact Petrov-Galerkin approximation for gas transport in pipeline networks. In *Proceedings of ICOSAHOM 2018*. Springer.

[4] T. Kugler. *Galerkin methods for simulation of wave propagation on a network of pipes*. PhD thesis, 2020.


### Project: Boundary observers for flow in gas networks

We consider the flow of gas through networks, where measurements are available at certain vertices. Based on these nodal observations we set up an observer system in order to recover the original system state.

We model the gas flow through pipes by a system of semilinear hyperbolic partial differential equations based on Riemann invariants, which is an approximation of the isothermal Euler equations in the case of small velocities. For the observer system the algebraic node conditions are replaced by terms depending on the difference between the exact solution and the state of the observer system. We can show that the observer converges exponentially to the original system state.

**Partner:** Martin Gugat (Universität Erlangen-Nürnberg)

**Support:** Project C05 within DFG TRR 154

**Contact:** Jan Giesselmann, Teresa Kunkel


#### References

[1] M. Gugat and J. Giesselmann. Boundary feedback stabilization of a semilinear model for the flow in star-shaped gas networks. submitted to ESAIM: Control, Optimisation and Calculus of Variations, 2020.

**Project: Relative energy estimates, asymptotic stability and structure preserving discretization for isentropic flow in gas networks**

Gas transport in one-dimensional pipe networks can be described as an abstract dissipative Hamiltonian system, for which quantitative stability bounds can be derived by means of relative energy estimates. This allows us to conclude stability of solutions to subsonic flow problems with respect to perturbations in initial and boundary data as well as model parameters. In addition, we can prove convergence to the parabolic limit problem in the practically relevant high friction regime. Furthermore, the stability estimates are inherited almost verbatim by variational discretization schemes, like mixed finite elements in space and the implicit Euler method in time, leading to quantitative convergence rates and asymptotic stability in the limiting high friction regime. The results are first derived for the flow on a single pipe, but in the spirit of the port-Hamiltonian formalism, they naturally extend to pipe networks.

**Support:** Projects C04 and C05 within DFG TRR 154

**Contact:** Herbert Egger, Jan Giesselmann, Teresa Kunkel, Nora Philippi

#### References

[1] H. Egger and J. Giesselmann. Stability and asymptotic analysis for instationary gas transport via relative energy estimates. arXiv:2012.14135, 2020.

**Project: Adaptive Multilevel Stochastic Collocation Strategy for Solving Elliptic PDEs with Random Data**

We propose and analyse a fully adaptive strategy for solving elliptic PDEs with random data in this work. A hierarchical sequence of adaptive mesh refinements for the spatial approximation is combined with adaptive anisotropic sparse Smolyak grids in the stochastic space in such a way as to minimize the computational cost. The novel aspect of our strategy is that the hierarchy of spatial approximations is sample dependent so that the computational effort at each collocation point can be optimised individually. We outline a rigorous analysis for the convergence and computational complexity of the adaptive multilevel algorithm and we provide optimal choices for error tolerances at each level. Two numerical examples demonstrate the reliability of the error control and the significant decrease in the complexity that arises when compared to single level algorithms and multilevel algorithms that employ adaptivity solely in the spatial discretisation or in the collocation procedure.

**Partner:** Robert Scheichl (Universität Heidelberg); David Silvester (University of Manchester)

**Contact:** Jens Lang

#### References

[1] J. Lang, R. Scheichl, and D. Silvester. A fully adaptive multilevel stochastic collocation strategy for solving elliptic pdes with random data. *Journal of Computational Physics*, 419:109692, 2020.

**Project: A Third-Order Weighted Essentially Non-Oscillatory Scheme in Optimal Control Problems Governed by Nonlinear Hyperbolic Conservation Laws**

The weighted essentially non-oscillatory (WENO) methods are popular and effective spatial discretization methods for nonlinear hyperbolic partial differential equations. Although these methods are formally first-order accurate when a shock is present, they still have uniform high-order accuracy right up to the shock location. In this project, we propose a novel third-order numerical method for solving optimal control problems subject to scalar nonlinear hyperbolic conservation laws. It is based on the first-disretize-then-optimize approach and combines a discrete adjoint WENO scheme of third order with the classical strong stability preserving three-stage third-order Runge-Kutta method SSPRK3. We analyze its approximation properties and apply it to optimal control problems of tracking-type with non-smooth target states. Comparisons to common first-order methods such as the Lax-Friedrichs and Engquist-Osher method show its great potential to achieve a higher accuracy along with good resolution around discontinuities.

**Contact:** David Frenzel, Jens Lang

### References


[1] D. Frenzel. *Weighted Essentially Non-Oscillatory Schemes in Optimal Control Problems Governed by Nonlinear Hyperbolic Conservation Laws*. PhD thesis, TU Darmstadt, 2020.

[2] D. Frenzel and J. Lang. A third-order weighted essentially non-oscillatory scheme in optimal control problems governed by nonlinear hyperbolic conservation laws. arXiv:2009.12392, 2020.


### Project: POD model order reduction with space-adapted snapshots for flow problems

We consider model order reduction based on proper orthogonal decomposition (POD) for unsteady incompressible Navier-Stokes problems, assuming that the snapshots are given by spatially adapted finite element solutions. We propose two approaches of deriving stable POD-Galerkin reduced-order models for this context. In the first approach, the pressure term and the continuity equation are eliminated by imposing a weak incompressibility constraint with respect to a pressure reference space. In the second approach, we derive an inf-sup stable velocity-pressure reduced-order model by enriching the velocity reduced space with supremizers computed on a velocity reference space. For problems with inhomogeneous Dirichlet conditions, we show how suitable lifting functions can be obtained from standard adaptive finite element computations. We provide a numerical comparison of the considered methods for a regularized lid-driven cavity problem.

**Partner:** Carmen Gräßle; Michael Hinze (Universität Koblenz-Landau)

**Contact:** Jens Lang, Sebastian Ullmann

### References


[1] C. Gräßle, M. Hinze, J. Lang, and S. Ullmann. POD model order reduction with space-adapted snapshots for incompressible flows. *Advances in Computational Mathematics*, 45:2401–2428, 2019.

[2] C. Gräßle, M. Hinze, J. Lang, S. Ullmann, and J. Lang. Model order reduction for space-adaptive simulations of Navier-Stokes. volume 19 of *Proceedings of Applied Mathematrics and Mechanics*, doi:10.1002/pamm.201900435, 2019. Wiley-VCH Verlag GmbH & Co. KGaA Weinheim.


### Project: Entropy-Preserving Coupling of Hierarchical Gas Models

This project is concerned with coupling conditions at junctions for transport models which differ in their fidelity to describe transient flow in gas pipelines. It also includes the integration of compressors between two pipes with possibly different models. A hierarchy of three one-dimensional gas transport models is built through the $3 \times 3$ polytropic Euler equations, the $2 \times 2$ isentropic Euler equations, and a simplified version of it for small velocities. To ensure entropy preservation, we make use of the novel entropy-preserving coupling conditions recently proposed by Lang and Mindt [1] and require the continuity of the total enthalpy at the junction and that the specific entropy for pipes with outgoing flow equals the convex combination of all entropies that belong to pipes with incoming flow. We prove the existence and uniqueness of solutions to generalized Riemann problems at a junction in the neighborhood of constant coupling functions and stationary states which belong to the subsonic region. This provides the basis for the well-posedness of certain Cauchy problems for initial data with sufficiently small total variation.

**Partner:** Pia Domschke (Frankfurt School of Finance & Management)

**Contact:** Jens Lang, Pascal Mindt

### References


[1] J. Lang and P. Mindt. Entropy-preserving coupling conditions for one-dimensional Euler systems at junctions. *Netw. Heterog. Media*, 13:177–190, 2018.

[2] P. Mindt, J. Lang, and P. Domschke. Entropy-preserving coupling of hierarchical gas models. *SIAM Journal on Mathematical Analysis*, 51:4754–4775, 2019.


### Project: Modeling of Osteoarthritis

Understanding the pathophysiological processes of cartilage degradation requires adequate model systems to develop therapeutic strategies towards osteoarthritis (OA). Although different in vitro or in vivo models have been described, further comprehensive approaches are needed to study specific disease aspects. This study aimed to combine in vitro and in silico modeling based on a tissue-engineering approach using mesenchymal condensation to mimic cytokine-induced cellular and matrix-related changes during cartilage degradation. Thus, scaffold-free cartilage-like constructs (SFCCs) were produced based on self-organization of mesenchymal stromal cells (mesenchymal condensation) and (i) characterized regarding their cellular and matrix composition or secondly (ii) treated with interleukin-1$\beta$ (IL-1$\beta$) and tumor necrosis factor $\alpha$ (TNF$\alpha$) for 3 weeks to simulate OA-related matrix degradation. In addition, an existing mathematical model based on partial differential equations was optimized and transferred to the underlying settings to simulate the distribution of IL-1$\beta$, type II collagen degradation and cell number reduction. By combining in vitro and in silico methods, we aimed to develop a valid, efficient alternative approach to examine and predict disease progression and effects of new therapeutics.

**Partner:** Marie-Christin Weber, Alexandra Damerau, Moritz Pfeiffenberger, Timo Gaber, Frank Buttgereit, Annemarie Lang (Charite Berlin); Lisa Fischer, Sebastian Götschel, Rainald Ehrig (ZIB Berlin); Igor Ponomarev (Research Center of Medical Technology and Biotechnology, Bad Langensalza); Susanna Röblitz (University of Bergen)

**Contact:** Jens Lang

### References


[1] M.-C. Weber, L. Fischer, A. Damerau, I. Ponomarev, M. Pfeiffenberger, T. Gaber, S. Götschel, J. Lang, S. Röblitz, F. Buttgereit, R. Ehrig, and A. Lang. Macroscale mesenchymal condensation

to study cytokine-driven cellular and matrix-related changes during cartilage degradation. *Biofabrication*, 12:045016, 2020.

**Project: Adaptive Moving Finite Element Method for Steady Low Mach Number Compressible Combustion Problems**

This work surveys an $r$-adaptive moving mesh finite element method for the numerical solution of premixed laminar flame problems. Since the model of chemically reacting flow involves many different modes with diverse length scales, the computation of such a problem is often extremely time-consuming. Importantly, to capture the significant characteristics of the flame structure when using detailed chemistry, a much more stringent requirement on the spatial resolution of the interior layers of some intermediate species is necessary. Here, we propose a moving mesh method in which the mesh is obtained from the solution of so-called moving mesh partial differential equations. Such equations result from the variational formulation of a minimization problem for a given target functional that characterizes the inherent difficulty in the numerical approximation of the underlying physical equations. Adaptive mesh movement has emerged as an area of intense research in mesh adaptation in the last decade. With this approach points are only allowed to be shifted in space leaving the topology of the grid unchanged. In contrast to methods with local refinement, data structure hence is unchanged and load balancing is not an issue as grid points remain on the processor where they are. We will demonstrate the high potential of moving mesh methods for effectively optimizing the distribution of grid points to reach the required resolution for chemically reacting flows with extremely thin boundary layers.

**Partner:** Malte Braack (Christian-Albrechts-Universität Kiel)

**Contact:** Jens Lang, Zhen Sun

### References

[1] Z. Sun, M. Braack, and J. Lang. An adaptive moving finite element method for steady low Mach number compressible combustion problems. *International Journal for Numerical Methods in Fluids*, 92:1081–1095, 2020.

**Project: Fast and Reliable Transient Simulation and Continuous Optimization of Large-Scale Gas Networks**

We are concerned with the simulation and optimization of large-scale gas pipeline systems in an error-controlled environment. The gas flow dynamics is locally approximated by sufficiently accurate physical models taken from a hierarchy of decreasing complexity and varying over time. Feasible work regions of compressor stations consisting of several turbo compressors are included by semiconvex approximations of aggregated characteristic fields. A discrete adjoint approach within a first-discretize-then-optimize strategy is proposed and a sequential quadratic programming with an active set strategy is applied to solve the nonlinear constrained optimization problems resulting from a validation of nominations. The method proposed here accelerates the computation of near-term forecasts of sudden changes in the gas management and allows for an economic control of intra-day gas flow schedules in large networks. Case studies for real gas pipeline systems show the remarkable performance of the new method.

**Partner:** Pia Domschke (Frankfurt School of Finance & Management); Oliver Kolb (Universität Mannheim)

**Contact:** Jens Lang

#### References

[1] P. Domschke, O. Kolb, and J. Lang. Fast and reliable transient simulation and continuous optimization of large-scale gas networks. arXiv:2012.02737, 2020.

### Project: Discrete Adjoint Implicit Peer Methods in Optimal Control

It is well known that in the first-discretize-then-optimize approach in the control of ordinary differential equations the adjoint method may converge under additional order conditions only. For Peer two-step methods we derive such adjoint order conditions and pay special attention to the boundary steps. For $s$-stage methods, we prove convergence of order $s$ for the state variables if the adjoint method satisfies the conditions for order $s-1$, at least. We remove some bottlenecks at the boundaries encountered in an earlier paper of Schröder et al. [2] and discuss the construction of 3-stage methods for the order pair (3,2) in detail including some matrix background for the combined forward and adjoint order conditions. The impact of nodes having equal differences is highlighted. It turns out that the most attractive methods are related to BDF. Three 3-stage methods are constructed which show the expected orders in numerical tests.

**Partner:** Bernhard A. Schmitt (Universität Marburg)

**Contact:** Jens Lang

#### References

[1] J. Lang and B. A. Schmitt. Discrete adjoint implicit peer methods in optimal control. arXiv:2002.12081, 2020.

[2] D. Schröder, J. Lang, and R. Weiner. Stability and consistency of discrete adjoint implicit peer methods. *Journal of Computational and Applied Mathematics*, 262:73–86, 2014.

### Project: Analysis and numerical approximation of nonlinear evolution equations on network structures

We study nonlinear evolution problems on one-dimensional network structures. Typical applications involve, e.g., the transport of gas in pipeline systems, the movement of cells or bacteria in biological networks, or heat transfer in electronic circuits. The modeling of such systems is presented and the systematic analysis and numerical approximation is studied in a common framework.

**Support:** DFG TRR 154

**Contact:** Lucas Schöbel-Kröhn, Herbert Egger

#### References

[1] H. Egger and L. Schöbel-Kröhn. Chemotaxis on networks: analysis and numerical approximation. *ESAIM: Math. Model. Numer. Anal.*, 54:1339–1372, 2020.

[2] L. Schöbel-Kröhn. *Analysis and numerical approximation of nonlinear evolution equations on network structures*. PhD thesis, 2020.

### Project: Reduced order models for parametric convection-diffusion-reaction equations with random data based on adaptive snapshots

This project is concerned with the efficient solution of convection-diffusion-reaction equations with sets of deterministic and stochastic input data. We are particularly interested in the multi-query context where the stochastic problem must be solved for a large number of values of the deterministic parameters. In order to solve this task we consider a two step approach: we compute snapshots of the solution using adaptively constructed stochastic Galerkin finite element discretizations and use these snapshots to set up a Galerkin reduced order model based on proper orthogonal decomposition or a greedy procedure. Using adaptive discretizations reduces the computational costs in the offline phase of the reduced order model but also has some important consequences for its functionality. We investigate these influences and derive an error etsimator for the reduced solution which reveals all error sources involved.

**Contact:** Christopher Müller, Jens Lang

#### References


[1] S. Ullmann, C. Müller, and J. Lang. Stochastic Galerkin reduced basis methods for parametrized linear elliptic partial differential equations. arXiv:1812.08519, 2020.


### Project: Galerkin methods for simulation, calibration, and control of partial differential equations on networks

This project is part of the Transregional Collaborative Research Centre TRR 154 *Mathematical modelling, simulation and optimization using the example of gas networks*, and deals with the construction, analysis and efficient realization of numerical methods for partial differential equations on networks. We derive thermodynamically consistent models for gas transport on pipe networks under consideration of coupling conditions at pipe junctions. The focus is on the transport of gas mixtures and non-isothermal models as the one-dimensional Euler equations with friction. A structure preserving discretization based on a variational formulation of corresponding problems allows an efficient numerical approximation using Galerkin schemes. Basic properties like conservation of mass and dissipation of energy are inherited. Furthermore, we investigate singularly perturbed problems on networks and derive asymptotic preserving schemes. Our Galerkin methods are then used in the context of inverse problems, more precisely for state and parameter estimation by measurements at vertices, as well as for the efficient realization of control strategies on gas networks.

**Partner:** Michael Hintermüller (HU Berlin)

**Support:** Project C04 within DFG TRR 154

**Contact:** Herbert Egger, Nora Philippi

#### References


[1] H. Egger and J. Giesselmann. Stability and asymptotic analysis for instationary gas transport via relative energy estimates. arXiv:2012.14135, 2020.

[2] H. Egger and N. Philippi. A hybrid discontinuous galerkin method for transport equations on networks. In *International Conference on Finite Volumes for Complex Applications*, pages 487–495. Springer, 2020.

[3] H. Egger and N. Philippi. On the transport limit of singularly perturbed convection–diffusion problems on networks. *Mathematical Methods in the Applied Sciences*, 2020.

**Project: Mass lumping strategies for the efficient implementation of acoustic and electromagnetic wave propagation**

The study of wave propagation is an important topic in the field of engineering and it finds application in various fields such as in antenna design, radar detection, noise cancellation, fiber optics, signal filtering, seismic prospection and many others. Therefore, the efficient and accurate simulation of wave phenomena is of big relevance from a practical point of view. Our goal is to design efficient mixed finite element approximations by means of mass lumping, which involves replacing the mass matrix by a block-diagonal approximation. This allows to efficiently apply explicit time stepping schemes. We look at different types of discretizations and provide thorough error analysis.

**Support:** GSC 233

**Contact:** Herbert Egger, Bogdan Radu

**References**

[1] H. Egger and B. Radu. A second order finite element method with mass lumping for wave equations in H(div). arXiv:1912.07057, 2019.

[2] H. Egger and B. Radu. A mass-lumped mixed finite element method for acoustic wave propagation. *Numer. Math.*, 145:239–269, 2020.

[3] H. Egger and B. Radu. A mass-lumped mixed finite element method for Maxwell's equations. In *Proceedings of SCEE 2018*. Springer, 2020. in press.

[4] H. Egger and B. Radu. A second order finite element method with mass lumping for Maxwell's equations on tetrahedra. *SIAM J. Numer. Analysis*, 2020. accepted.

[5] H. Egger and B. Radu. A second order multipoint flux mixed finite element method on hybrid meshes. *SIAM J. Numer. Anal.*, 58:1822–1844, 2020.

**Project: Numerical approximation of poroelastic phenomena**

We consider the systematic numerical approximation of Biot's quasistatic model for the consolidation of a poroelastic medium. Various discretization schemes have been analysed for this problem and inf-sup stable finite elements have been found suitable to avoid spurious pressure oscillations in the initial phase of the evolution. In this paper, we first clarify the role of the inf-sup condition for the well-posedness of the continuous problem and discuss the choice of appropriate initial conditions. We then develop an abstract error analysis that allows us to analyse some approximation schemes discussed in the literature in a unified manner. In addition, we propose and analyse the high-order time discretization by a scheme that can be interpreted as a variant of continuous-Galerkin or particular Runge-Kutta methods applied to a modified system. The scheme is designed to preserve both the underlying differential-algebraic structure and the energy-dissipation property of the problem. In summary, we obtain high-order Galerkin approximations with respect to space and time and derive order-optimal convergence rates. The numerical analysis is carried out in detail for the discretization of the two-field formulation by Taylor-Hood elements and a variant of a Runge-Kutta time discretization. Our arguments can however be extended to three- and four field formulations and other time discretization strategies.

**Partner:** M. Lymbery; J. Kraus (Universität Duisburg/Essen)

**Support:** GSC 233, TU Darmstadt

**Contact:** Mania Sabouri, Herbert Egger

## References

[1] H. Egger and M. Sabouri. On the structure preserving high-order approximation of quasistatic poroelasticity. arXiv:1912.13086, 2019. Accepted.

### Project: Coupling of dynamical systems with convolution quadrature methods

Integrated circuits with smaller and smaller conducting structures lead to drastically faster processor generators in the last years. With the miniaturization there is more coupling of the signals between different conductors that is not anymore described by circuits. In this project we aim for coupled modelling of the dynamical behaviour of circuits and discretized 3D electromagnetic field equations through ports. We follow the convolution quadrature approach that leads to a model reduction based on precomputations for the electromagnetic field equations in frequency domain with a series of frequencies and to much reduced effort of the coupled dynamical simulation.

**Support:** Graduate School Computational Engineering, DFG

**Contact:** Herbert Egger, Kersten Schmidt, Vsevolod Shashkov

## References

[1] H. Egger, K. Schmidt, and V. Shashkov. Multistep and Runge-Kutta convolution quadrature methods for coupled dynamical systems. *Comput. Appl. Math.*, 2019.

### Project: Interaction between boundary layers and domain singularities

In this project singularly perturbed partial differential equations including microperforated layers with emphasis on corner singularities shall be analyzed. Singularly perturbed partial differential equations are characterized by microscopic solution behaviour, especially boundary layers. Such a solution behaviour is caused by small (material) parameters in front of the leading order differential operator, like small viscosities, or equivalently large parameters in front of lower order terms as for highly conductive media in electromagnetism. Also, geometrically small features like for thin layers or sheets that may even possess a microstructure leads to boundary layers in the solution. Solution representations taking into account the interaction of boundary layers and domain singularities can be used to construct efficient numerical schemes.

**Partner:** Bérangère Delourme (University of Paris 13, France); Monique Dauge (University of Rennes 1, France); Ralf Hiptmair (ETH Zürich)

**Contact:** Adrien Semin, Kersten Schmidt

## References

[1] A. Semin, B. Delourme, and K. Schmidt. On the homogenization of the Helmholtz problem with thin perforated walls of finite length. *ESAIM: Math. Model. Numer. Anal.*, 52(1):29–67, 2018.

### Project: Impedance conditions for visco-acoustic models

The acoustic damping in gas turbines and aero-engines relies to a great extent on acoustic liners that consist of a cavity and a perforated face sheet. The prediction of the impedance of the liners by direct numerical simulation is nowadays not feasible due to the hundreds to thousands of repetitions of tiny holes. We aim to obtain impedance conditions in viscous gases, especially for multiperforated acoustic absorbers, based on higher order asymptotic expansions and matched asymptotic expansion techniques.

**Partner:** Friedrich Bake, Anita Schulz (DLR Berlin)

**Contact:** Kersten Schmidt, Adrien Semin

#### References


[1] K. Schmidt and A. Semin. Surface homogenization of an array of Helmholtz resonators for a viscoacoustic model using two-scale convergence. arXiv:2003.11965, 2020.

[2] K. Schmidt, A. Semin, A. Thöns-Zueva, and F. Bake. On impedance conditions for circular multiperforated acoustic liners. *J. Math. Industry*, 8(1):15, 2018.

[3] A. Semin and K. Schmidt. On the homogenization of the acoustic wave propagation in perforated ducts of finite length for an inviscid and a viscous model. *Proc. R. Soc. Lond. A*, 474(2210), 2018.


### Project: Model reduction techniques for biomechanical devices

Biomechanical devices like stents are used to recover the blood flow in arteria when they are blocked due to a disease. With optimizing stent designs they remain comfortable at position and guarantee a permanent blood flow for longer times. The modeling of the mechanical properties is challenging due to their structure as a network of struts and their interaction with the blood vessel as a contact problem. We aim for a model reduction based on homogenization of systems of differential equations on edges of a periodic graph.

**Partner:** Josip Tambača, Luka Grubišić, Matko Ljulj, Marko Hajba (University of Zagreb, Croatia)


**Support:** German Academic Exchange Service in the “Programm für projektbezogenen Personenaustausch mit Kroatien” (Project-ID 57334847), Graduate School Computational Engineering


**Contact:** Kersten Schmidt, Adrien Semin, Herbert Egger

#### References


[1] M. Ljulj, K. Schmidt, A. Semin, and J. Tambača. Homogenization of the time-dependent heat equation on planar one-dimensional periodic structures. arXiv:1912.12989, 2019.


### Project: Shape optimization in acoustic-structure interaction

Acoustic-structure interaction is an emerging field in industry and mathematical modelling, with important applications in reducing the noise emitted by machines, vehicles, constructions, etc. In particular in the car industry, there is a huge interest to optimize and tailor the sound amplitudes within the car by changing the shape of parts of the elastic structure. We are interested in the minimization of the sound pressure by variation of the shape of the structure. For this we derive the shape derivative for the acoustic-structure interaction modelled by Helmholtz equation for the acoustic part, the equations of linear elasticity and coupling conditions and consider a closed optimization process in 3D using a high-order finite element discretization on hexahedral meshes.

**Partner:** Antoine Laurain (University of São Paulo, Brazil); Philipp Kliewe (TU Berlin)

**Contact:** Kersten Schmidt

### References

[1] P. Kliewe, A. Laurain, and K. Schmidt. Shape optimization in acoustic-structure interaction. In preparation.

### Project: Contour integration methods for nonlinear eigenvalue problems

Nonlinear eigenvalue problems (NEVPs) arise in many modern physical calculations. For linear eigenvalue problems all or a number of largest or smallest eigenvalues can be computed together with well-known techniques. For NEVPs eigenvalues can be computed separately with techniques like Newton or linearization based algorithms. With contour integration methods, several hundred of eigenvalues of a nonlinear eigenvalue problem inside a closed region of the complex plane can be computed together. For this complex integrals contours are approximated by quadrature rules leading to small matrices from which the eigenvalues are extracted. We are interested to analyze contour integration methods for the efficient computation of the spectrum in electromagnetic devices, using the filter functions as tools and contours adapted to the presence of singular points like branch cuts.

**Partner:** Luka Grubišić (University of Zagreb, Croatia), Rolf Schuhmann (TU Berlin)

**Contact:** Kersten Schmidt

### References

[1] P. Jorkowski, K. Schmidt, C. Schenker, L. Grubišić, and R. Schuhmann. Adapted contour integration for nonlinear eigenvalue problems in wave-guide coupled resonators. Submitted, 2020.

### Project: Super-convergent IMEX Peer methods with variable step sizes

The spatial discretization of certain time-dependent PDEs (e.g., advection-reaction-diffusion systems) yields large systems of ODEs where the right-hand side admits a splitting into a stiff and non-stiff part. We construct time integrators that combine the favorable stability properties of implicit methods and the low computational costs of explicit schemes. In order to guarantee consistency and, thus, convergence, the implicit and explicit integrator must fit together. A natural way to construct these implicit-explicit (IMEX) Peer methods is to start with an appropriate implicit scheme and extrapolate it in a suitable manner. We follow the approach developed by Lang and Hundsdorfer in [1]. Peer methods have the advantage that all stage values have the same order and, hence, order reduction for stiff systems is avoided. Further, there remain enough free parameters such that additional properties can be guaranteed. This includes optimal zero-stability, A-stability of the implicit part and, in particular, super-convergence. In [2], we derive necessary and sufficient conditions on the coefficient matrices to construct new super-convergent IMEX schemes for $s = 2, 3, 4$ stages. When solving dynamical systems with sub-processes evolving on many different time scales, efficiency is greatly enhanced by automatic time step variation. Therefore, we investigate the theory, construction and application of IMEX Peer methods that are super-convergent even for variable step sizes. To construct schemes that keep their higher order for variable step sizes and exhibit favorable linear stability properties, we adapt our approach for constant step sizes and, eventually, derive additional necessary and sufficient conditions on the nodes and coefficient matrices. New super-convergent IMEX Peer methods which maintain the super-convergence property independent of step size changes are constructed for $s = 2, 3, 4$ stages in [3].

**Partner:** Rüdiger Weiner (Universität Halle-Wittenberg)

**Contact:** Moritz Schneider, Jens Lang

#### References


[1] J. Lang and W. Hundsdorfer. Extrapolation-based implicit-explicit Peer methods with optimised stability regions. *J. Comp. Phys.*, 337:203–215, 2017.

[2] M. Schneider, J. Lang, and W. Hundsdorfer. Extrapolation-based super-convergent implicit-explicit Peer methods with A-stable implicit part. *J. Comp. Phys.*, 367:121–133, 2018.

[3] M. Schneider, J. Lang, and R. Weiner. Super-convergent implicit-explicit peer methods with variable step sizes. *J. Comput. Appl. Math.*, 2019. Available online 26 September 2019, 112501.


### Project: Well-balanced and asymptotic preserving IMEX Peer methods

Peer methods are a comprehensive class of time integrators offering numerous degrees of freedom in their coefficient matrices that can be used to ensure advantageous properties, e.g., A-stability or super-convergence. In [1], we show that the super-convergent implicit-explicit (IMEX) Peer methods recently designed in [2, 3] are well-balanced and asymptotic preserving by construction without additional constraints on the coefficients. These properties are relevant when solving (the space discretisation of) hyperbolic systems of balance laws, for example.

**Contact:** Moritz Schneider, Jens Lang

#### References


[1] M. Schneider and J. Lang. Well-Balanced and Asymptotic Preserving IMEX-Peer Methods. Numerical Mathematics and Advanced Applications ENUMATH 2019, doi:10.1007/978-3-030-55874-1, 2021. Springer International Publishing.

[2] M. Schneider, J. Lang, and W. Hundsdorfer. Extrapolation-based super-convergent implicit-explicit Peer methods with A-stable implicit part. *J. Comp. Phys.*, 367:121–133, 2018.

[3] M. Schneider, J. Lang, and R. Weiner. Super-convergent implicit-explicit peer methods with variable step sizes. *J. Comput. Appl. Math.*, 2019. Available online 26 September 2019, 112501.


### Project: Structure preserving simulation in nonlinear evolution problems

The main aim of this project is to develop novel discretization schemes that preserve the inherent geometric structure of underlying physical models, e.g., conservation or dissipation of energy or the production of entropy. Such systems arise in a variety of applications, e.g., in nonlinear wave propagation problems, in acoustics or electromagnetics, but also in nonlinear partial differential equations describing phase transformation. Two classes of such systems are identified and appropriate variational space- and time discretization schemes are developed. The applicability of the new methods is demonstrated in several applications.

**Partner:** Prof. Bai-Xiang Xu (TU Darmstadt)

**Support:** DFG GSC 233, SPP 2256

**Contact:** Herbert Egger, Vsevolod Shashkov


**References**

[1] H. Egger. Structure preserving approximation of dissipative evolution problems. *Numer. Math.*, 143:85–106, 2019.

[2] H. Egger. Energy stable Galerkin approximation of Hamiltonian and gradient systems. *Comput. Meth. Appl. Math.*, 2020. in press.

[3] H. Egger, T. Kugler, and V. Shashkov. An inexact Petrov-Galerkin approximation for gas transport in pipeline networks. In *Proceedings of ICOSAHOM 2018*. Springer.

[4] H. Egger and V. Shashkov. On energy preserving high-order discretizations for nonlinear acoustics. In *Proceedings ENUMATH 2019*. Springer, 2019. in press.

[5] Y. Yang, P. Kühn, M. Yi, H. Egger, and B.-X. Xu. Non-isothermal phase-field modeling of heat-melt-microstructure-coupled processes during powder bed fusion. *JOM*, 72:1719–1733, 2020.


**Project: Efficient discretization of memory kernels**

This project is devoted to the numerical solution of Volterra integro-differential equations arising in a variety of problems, e.g., multiscale models, dispersive media, boundary element methods for wave propagation, or field-circuit coupled problems. The main challenge consists in the efficient evaluation of memory terms, represented as Volterra integral operators. For a problem with $N$ time-steps, a naive realization leads to algorithms with $O(N^2)$ complexity and requiring $O(N)$ active memory. For the efficient realization, we consider a convolution quadrature approach having $O(N \log N)$ complexity and $O(\log N)$ active memory, and we present a further improvement leading to an algorithm with optimal $O(N)$ complexity. The latter is based on $\mathcal{H}^2$-matrix compression techniques, which we make suitable for a successive evaluation needed for evolutionary problems. We further discuss the application to typical model problems in electromagnetics.

**Support:** EXC GSC 233, DFG TRR 146

**Partner:** J. Dölz (Uni Bonn)

**Contact:** Herbert Egger, Vsevolod Shashkov


**References**

[1] J. Dölz, H. Egger, and V. Shashkov. Fast and oblivious evolutionary evaluation of volterra integral operators. *in preparation*.

[2] J. Dölz, H. Egger, and V. Shashkov. A convolution quadrature method for Maxwell's equations in dispersive media. In *Proceedings SCEE 2020*. Springer, 2020.

[3] H. Egger, K. Schmidt, and V. Shashkov. Multistep and Runge-Kutta convolution quadrature methods for coupled dynamical systems. *Comput. Appl. Math.*, 2019.


**Project: Simulation, optimization and uncertainty quantification for borehole thermal energy storage systems based on adaptive finite elements**

Borehole heat exchanger (BHE) arrays have become a common implement for extracting and/or storing heat energy from and into the soil. Building these facilities is expensive and their performance is subject to various sources of uncertainty, such as deviating borehole paths and unknown soil conditions. To examine this, we work on simulating BHE arrays and performing uncertainty quantifications, where we study the influence of geometries

deviating from the planned layout and other sources of uncertainty.
We make use of a 3D simulation model for BHE arrays in a patch of soil with optional groundwater flow, designed as a system of partial differential equations (PDEs). Continuing our work from [2], the system is solved with a simulation toolkit, which was programmed as an extension for the finite element method solver KARDOS. The toolkit builds on previous work for the simulation tool BASIMO [1] and was validated with benchmarks calculated with the commercial software FEFLOW, which specializes in heat transfer in porous media among other things. For the uncertainty quantification, we utilize an adaptive, anisotropic stochastic collocation method, which uses solutions of the PDE system as samples.
In our research, we investigated the influence of deviating borehole paths on BHE arrays in a heat extraction application. We performed a case study for a specific facility and were able to generalize our findings to show that facilities of this type and operation are surprisingly robust to introduced sources of uncertainty disturbing the array geometry [3].

**Partner:** Ingo Sass, Daniel O. Schulte, Bastian Welsch (Institut für Angewandte Geowissenschaften, TU Darmstadt)

**Support:** Darmstadt Graduate School of Excellence Energy Science and Engineering, GSC 1070

**Contact:** Philipp Steinbach, Jens Lang

### References


[1] D. O. Schulte, W. Rühaak, B. Welsch, and I. Sass. Basimo - borehole heat exchanger array simulation and optimization tool. *Energy Procedia*, 97:210–217, 2016.

[2] P. Steinbach. Adaptive Finite-Elemente-Verfahren für Erdwärmesondenspeicher. Masterarbeit, TU Darmstadt, 2018.

[3] P. Steinbach, D. O. Schulte, B. Welsch, I. Sass, and J. Lang. Quantification of bore path uncertainty in borehole heat exchanger arrays. arXiv:2103.00271, 2021.


### Project: Probabilistic constraints in optimization problems on flow network

Optimization under uncertainties can be realized using probabilistic constraints so that inequality constraints are satisfied with a predefined probability level. In order to compute the probability in the constraints, we analyze two methods: the spheric radial decomposition and the kernel density estimation. The second approach provides approximations of probability density functions which we integrate to approximate the corresponding probability. We consider stationary and transient flow models with uncertain boundary data on networks. As constraint we consider the probability that the solution at specific nodes meet some given bounds. In both settings, we compute derivatives of the probabilistic constraints using the kernel density estimation and derive necessary optimality conditions for the approximated optimization problem. Both approaches are applied to a realistic stationary gas network and provide similar results. Further, we investigate a realistic transient setting, a water contamination problem, for which we extend both methods.

**Partner:** Michael Schuster; Martin Gugat (Universität Erlangen-Nürnberg)

**Support:** DFG TRR 154

**Contact:** Elisa Strauch, Jens Lang

## References

[1] M. Schuster, E. Strauch, M. Gugat, and J. Lang. Probabilistic constrained optimization on flow networks. arXiv:2009.00352, 2020.

**Project: Physics informed neural networks applied to gas pipeline systems**

Physics informed neural networks emerged from the machine learning community and offer a new way to approximate solutions of partial differential equations. Based on them, we want to develop a reduced order model for gas pipeline systems. Because of the underlying transport equations which describe the gas flow, this task is not well suited for common reduced order methods like the reduced basis method. Further, we want to analyze the method mathematically and investigate how well-established ideas from other PDE solvers can be applied to physics informed neural networks.

**Partner:** Marc Pfetsch (TU Darmstadt)

**Support:** DFG TRR 154

**Contact:** Erik Laurin Strelow, Jens Lang, Alf Gerisch

**Project: Wall shear stress measurements using magnetic resonance imaging**

The flow of blood in human vessels is of great interest in medicine. A very important physical quantity is the wall-shear stress (WSS) and its distribution along the wall, that can be computed from the geometry and the velocity therein. The goal of this project is to use both the magnetic resonance imaging (MRI) and a fluid dynamical model to provide accurate values of the WSS. In a first step the inverse problem of reconstructing the smooth flow domain and the velocity profile inside the flow domain from the MRI measurements is analyzed and solved. In a recent collaboration with the project partners from the cardiology group of the Klinik für Radiologie (Universität Freiburg), we have discovered, that this procedure already provides reasonable estimates of the wall-shear stress in the case of well registered geometry. However, due to lower signal respective contrast to noise ratio (SNR/CNR) in practice and due to the present boundary layers high sensitivity of the wall-shear stress estimates with respect to accurate geometry identification there is need of further development. Therefore, the focus is on the data assimilation problem to enhance both, the reconstructions of the geometry and the velocity by utilizing knowledge of the governing fluid dynamics. The investigations of the collaborators from the Fachgebiet Strömungslehre und Aerodynamik (TU Darmstadt) have revealed that a laminarization of typical physiologically pulsating flows, rendering the classical Navier-Stokes equation is a suitable fluid dynamical model. We have developed a framework based on a parametric description and a localization strategy, that allows attacking the reconstruction problem with methods of shape optimization and optimal control in a computationally feasible manner.

**Partner:** Andreas Bauer, Cameron Tropea (TU Darmstadt); Axel Krafft, Nina Shokina, Jürgen Hennig (Universität Freiburg)

**Support:** DFG Eg-331/1-1

**Contact:** Gabriel Teschner, Herbert Egger

**References**


[1] H. Egger and B. Hofmann. Tikhonov regularization in Hilbert scales under conditional stability assumptions. *Inverse Problems*, 34:115015, 2018.

[2] H. Egger, T. Seitz, and C. Tropea. Enhancement of flow measurements using fluid-dynamic constraints. *J. Comp. Phys.*, 344:558–574, 2017.

[3] H. Egger and G. Teschner. On the stable estimation of flow geometry and wall shear stress from magnetic resonance images. *Inverse Problems*, 35:095001, 2019.

[4] N. Shokina, G. Teschner, A. Bauer, C. Tropea, H. Egger, J. Hennig, and A. Krafft. Parametric sequential method for mri-based wall shear stress quantification. *IEEE Transactions on Medical Imaging*, 2020.


**Project: Structure preserving adaptive enriched Galerkin methods for pressure-driven 3D fracture phase-field models (subproject of priority program 1748)**

The project is concerned with the development of innovative enriched Galerkin methods for the reliable simulation of pressure-driven fracture problems. Within this project, convergent adaptive mesh-refinement schemes based on new efficient error estimators for the variational inequality associated with the fracture irreversibility are developed.

**Partner:** Katrin Mang; Thomas Wick; Winnifried Wollner

**Support:** DFG Priority Program 1748

**Contact:** Mirjam Walloth

## 1.7 Optimization

The research group **Optimization** consists of the two directions **Discrete Optimization** and **Nonlinear Optimization**, which cooperate closely. Mathematical Optimization considers the development, analysis, and application of efficient numerical methods for minimizing (or maximizing) a function under constraints. While Discrete Optimization studies mainly linear or convex combinatorial problems involving integer variables, Nonlinear Optimization focuses on nonlinear problems with continuous variables. The research group covers both research topics in a comprehensive way and cooperates in particular in the challenging field of Mixed Integer Nonlinear Programming, which considers nonlinear optimization with mixed discrete-continuous variables.

**Discrete Optimization** has become an important component in modern applied mathematics. Many problems from business and industry can be modeled as discrete optimization problems. The development of solution methods for these problems is the main focus of the group Discrete Optimization. This includes the development of mathematical models of real-world problems, the theoretical analysis (using methods mainly from graph theory, polyhedral combinatorics, and integer programming), and the design and implementation of fast algorithms as well as their evaluation in practice.
Experiences of the group are, for instance, in the following applied areas: public mass transportation (line planning, disruption management), energy optimization (gas transport), or optimization in mechanical engineering (truss topology optimization), see the projects for details.

**Nonlinear Optimization** is nowadays an important technology in applied mathematics, science, and engineering. Nonlinear optimization problems appear in many applications,

e.g., shape optimization in engineering, robust portfolio optimization in finance, parameter identification, optimal control, etc. Nonlinear Optimization has emerged as a key technology in modern scientific and industrial applications. Challenging are in particular optimization problems with partial differential equations as constraints (PDE-constraints), for example optimization problems for flows, transport problems, diffusion processes, wave propagation, or mechanical structures. An efficient solution of such problems requires highly developed optimization methods, which use modern adaptive multilevel techniques of scientific computing.
The research group Nonlinear Optimization considers the development, theory, implementation, and application of efficient algorithms for nonlinear optimization. Particular research topics are PDE-constrained optimization, large scale optimization, adaptive multilevel techniques, discretization error for PDE-constrained optimization, preconditioning, global optimization, and relaxation of discrete problems.

The research group Optimization is or was engaged among others in the Darmstadt Graduate School of Excellence GSC 233 *Computational Engineering: Beyond Traditional Sciences*, the Darmstadt Graduate School of Excellence GSC 1070 *Energy Science and Engineering*, the Collaborative Research Centre (SFB) 805 *Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering*, the Collaborative Research Centre (SFB) 1194 *Interaction of Transport and Wetting Processes*, the Transregional Collaborative Research Centre (Transregio/SFB) 154 *Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks*, the German Research Foundation (DFG) Priority Programme (SPP) 1748 *Reliable Simulation Techniques in Solid Mechanics. Development of Non-standard Discretization Methods, Mechanical and Mathematical Analysis*, the German Research Foundation (DFG) Priority Programme (SPP) 1798 *Compressed Sensing in Information Processing* and the German Research Foundation (DFG) Priority Programme (SPP) 1962 *Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization*.

### Members of the research group

**Professors**

Yann Disser, Marc Pfetsch, Alexandra Schwartz, Stefan Ulbrich, Winnifried Wollner

**Postdocs**

Christopher Hojny, Christina Karousatou, Masoumeh Mohammadi, Andreas Paffenholz

**Research Associates**

Christoph Becker, Jan Becker, Johanna Biehl, Alexander Birx, Elisabeth Diehl, Sarah Essert, Tristan Gally, Maximilian Gläser, Ilhan Gören, Oliver Habeck, Christine Herter, Alexander Hopp, Benjamin Horn, Isabel Jacob, Kristina Janzen, Philipp Kolvenbach, Alexander Matei, Frederic Matter, Daniel Nowak, Björn Polenz, Anne-Therese Rauls, Seshadri Reddy-Basava, Lea Rehlich, Paloma Schäfer Aguilar, Andreas Schmitt, Johann Michael Schmitt, Cedric Sehrt, Nicolai Simon, Marcel Steinhardt, Anna Walter, David Michael Weckbecker, Ann-Kathrin Wiertz

**Secretaries**

Constanze Drechsel, Monika Kammer

**Project: Numerical approximation of optimal control problems for hyperbolic conservation laws (Subproject A02 of Transregio/SFB 154, phase 2)**

A lot of continuum models for physical problems, such as traffic modeling and fluid mechanics, are described by hyperbolic conservation laws. Some of these networks include switching processes like traffic flow models and water/gas network models. This motivates an analytic study and numerical approximation of optimal control problems of nonlinear hyperbolic conservation laws on networks under modal switching, where switchings are considered in the source terms as well as at boundary nodes and junctions. The main difficulty in the analysis of conservation laws arises from the fact that even in the case of a single scalar conservation law and smooth data the entropy solution usually develops shocks, which causes the solution operator to not be differentiable in the usual sense. However, encouraging progress has been achieved recently for the optimal control of conservation laws by using a generalized notion of differentiability (so called shift-differentiability). It was shown by Pfaff and Ulbrich that under weak assumptions tracking-type objective functionals are differentiable with respect to the initial and boundary control and that the reduced gradient can be represented by the reversible solution of a suitable adjoint equation. The goal of this project is a precise study of the associated adjoint and sensitivity equations and their solutions. Moreover, the project derives a detailed numerical analysis of optimal control problems for switched networks of conservation laws on bounded domains.

**Partner:** Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks"; speaker Prof. Dr. Alexander Martin (Department of Mathematics, FAU Erlangen-Nürnberg)

**Support:** DFG

**Contact:** P. Schäfer Aguilar, S. Ulbrich

### References


[1] S. Pfaff. *Optimal control of hyperbolic conservation laws on bounded domains with switching controls*. Verlag Dr. Hut, 2015.

[2] S. Ulbrich. Optimal control of nonlinear hyperbolic conservation laws with source terms. Habilitation, Zentrum Mathematik, TU München, Germany, 2001.


**Project: Structure preserving adaptive enriched Galerkin methods for pressure-driven 3D fracture phase-field models (Project in SPP 1748)**

This project is focused on numerically stable treatment of incompressible and quasi-incompressible materials within a quasi-static fracture growth problem. At a given time-step the discretization of the incompressible material by standard mixed methods will introduce an error of the displacement depending on the pressure; a situation that is highly problematic in hydraulic equilibria where the pressure error can be large despite the fact that the displacement is easy to calculate. Therefore, a pressure-robust discretization technique for incompressible quasi static damage evolutions has been investigated to overcome the above mentioned problem. A pressure-robust technique of interpolating discrete divergence free functions to divergence free functions has been implemented in deal.II and DOpElib libraries for stationary stokes and linear elasticity problems. The extension to the quasi-incompressible case is currently under investigation.

**Partner:** Katrin Mang, Thomas Wick (Universität Hannover), Mirjam Walloth (TU Darmstadt), DFG Priority Programme (SPP) 1748: “Reliable Simulation Techniques in Solid Mechanics. Development of Non-standard Discretization Methods, Mechanical and Mathematical Analysis”; speaker Prof. Dr. Jörg Schröder (Universität Duisburg-Essen)

**Support:** DFG

**Contact:** S. Basava, W. Wollner

### References


[1] S. Basava, K. Mang, M. Walloth, T. Wick, and W. Wollner. Adaptive and pressure-robust discretization of incompressible pressure-driven phase-field fracture. *arXiv:2006.16566*, 2020.

[2] K. Mang, M. Walloth, T. Wick, and W. Wollner. Mesh adaptivity for quasi-static phase-field fractures based on a residual-type a posteriori error estimator. *GAMM Mitteilungen*, 43(1), 2019. Early-Access.

[3] K. Mang, M. Walloth, T. Wick, and W. Wollner. Adaptive numerical simulation of a phase-field fracture model in mixed form tested on an L-shaped specimen with high poisson ratios. Preprint, arXiv:2003.09459, 2020.

[4] K. Mang, T. Wick, and W. Wollner. A phase-field model for fractures in incompressible solids. *Computational Mechanics*, 65(1):61–78, 2020.

[5] J. Schröder, T. Wick, S. Reese, P. Wriggers, R. Müller, S. Kollmannsberger, M. Kästner, A. Schwarz, M. Igelbüscher, N. Viebahn, H. R. Bayat, S. Wulfinghoff, K. Mang, E. Rank, T. Bog, D. D’Angella, M. Elhaddad, P. Hennig, A. Düster, W. Garhuom, S. Hubrich, M. Walloth, W. Wollner, C. Kuhn, and T. Heister. A selection of benchmark problems in solid mechanics and applied mathematics. *Archives of Computational Methods in Engineering*, 2020.


**Project: Multi-leader-follower games in function space (Project P21 in SPP 1962)**

This project aims to design efficient and problem tailored theoretical and numerical solution methods for certain classes of multi-leader-follower games (MLFGs) in function space accompanied by the theoretical analysis of these problems. While in a classical Nash equilibrium problem (NEP) we have several players that simultaneously make a decision which influences their own outcome and that of the others, in a MLFG the group of players is split into the so-called leaders deciding first and followers reacting to this. This hierarchical game has various applications in finite dimensions, e.g., in telecommunications, traffic networks and electricity markets as well as in infinite dimensions, e.g., the pursuit problem, autonomous driving and a multi-leader optimal control of the obstacle problem. By reducing the hierarchical structure, we end up with an equilibrium problem with equilibrium constraints (EPEC). In this framework, the existence of corresponding equilibrium points is hardly provable. In this context, we consider a sequence of more tractable auxiliary equilibrium problems and verify the convergence towards weaker types of Nash equilibria that are motivated by results referring to mathematical programs with equilibrium constraints (MPEC).

**Partner:** Sonja Steffensen, Anna Thünen (RWTH Aachen), DFG Priority Programme (SPP) 1962: “Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization”; speaker Prof. Dr. Michael Hintermüller (HU Berlin / WIAS Berlin)

**Support:** DFG

**Contact:** J. Becker, A. Schwartz

**Project: Multilevel optimization based on reduced order models with application to fluid-structure interaction**

In this project we derive and implement a multilevel optimization algorithm based on reduced order models with application to fluid-structure interaction (FSI) problems. The interaction of fluid flows with elastic deformation of structures is a problem occurring in many problems in engineering applications.
We build our work on a finite element discretisation of the fluid flow modelled with the 2D Navier-Stokes equations for incompressible fluids and a hyperelastic material.
The model reduction is done with help of the Proper Orthogonal Decomposition (POD) technique and the inf-sup stability is ensured by the enrichment of the POD spaces with supremizers. We further derive error control criteria and a convergence analysis under suitable assumptions.
The project builds on the work of Sarah Essert within GSC CE, who derives and implements adjoint-based derivative computations for fluid-structure interaction problems.

**Partner:** Darmstadt Graduate School of Excellence Computational Engineering (GSC 233); speaker Prof. Dr. Michael Schäfer (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** J. Biehl, S. Ulbrich

**Project: Competitive Analysis of online Dial-a-Ride**

Online optimization deals with settings where algorithmic decisions have to be made over time without knowledge of the future. A prominent problem of this type arises when controlling a transportation system, where requests to transport objects arrive over time and the system needs to decide online how to adapt its trajectory over time, e.g., the problem of controlling an elevator, a conveyor system, an autonomous vehicle fleet, etc. In terms of competitive analysis, the central question in this context is how much we lose in solution quality in the worst-case, compared to an optimum offline solution that knows all requests ahead of time, i.e., we ask for solutions with good competitive ratio.
From an abstract point of view, the goal of this project is to tightly analyze variants of online DIAL-A-RIDE and provide best-possible online algorithms. The initial focus is on providing a comprehensive analysis for the one-dimensional case. We conducted a complete analysis of the Smartstart algorithm [1] and improved the best known upper bound of the competitive ratio in the open setting (i.e., the server does not need to return to the origin after serving the final request) of online DIAL-A-RIDE on the line first to 2.94 [2] and later further to 2.66 [3]. For the future we intend to tighten the competitive ratios of the classical online DIAL-A-RIDE problem, and expand our considerations to more involved variants. The goal is to provide a complete analysis of modifications of online DIAL-A-RIDE that model settings beyond personal elevators, such as autonomous delivery and ride sharing.

**Partner:** Darmstadt Graduate School of Excellence Computational Engineering (GSC 233); speaker Prof. Dr. Michael Schäfer (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** A. Birx, Y. Disser

## References


[1] N. Ascheuer, S. Krumke, and J. Rambau. Online Dial-a-Ride problems: Minimizing the completion time. In *Proceedings of the 17th Annual Symposium on Theoretical Aspects of Computer Science (STACS)*, pages 639–650, 2000.

[2] A. Birx and Y. Disser. Tight analysis of the smartstart algorithm for online dial-a-ride on the line. *SIAM Journal on Discrete Mathematics*, 34(2):1409–1443, 2020.

[3] A. Birx, Y. Disser, and K. Schewior. Improved bounds for open online dial-a-ride on the line. In *Proceedings of the 22nd International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX)*, volume 145, pages 21:1–21:22, 2019.


### Project: Simulation-based optimization and optimal design of experiments for wetting processes (Subproject B04 of Collaborative Research Centre (SFB) 1194)

This project is part of the Collaborative Research Centre (SFB) 1194: "Interaction of Transport and Wetting Processes" and considers the development of a simulation based optimization approach for multiphase flow in the context of wetting phenomena. We use gradient-based multilevel optimization methods for shape optimization and parameter identification problems. The aim is to optimize the geometry of surfaces as well as material properties of fluids or surfaces to design wetting processes with desirable properties. Based on $L_p$-maximal regularity of the underlying linear twophase problem we also investigate the differentiability of the control-to-state-mapping, arising from resulting optimal control problems, with respect to initial and distributed controls for appropriate spaces. Moreover, optimization-based approaches for the optimal design of experiments will be developed, such that the resulting experiments allow the estimation of non-measurable parameters with minimal error variance. The results of this project should be particularly valuable for the future selection of generic experimental setups and will make available quantities which are difficult to measure experimentally.

**Partner:** Collaborative Research Centre (SFB) 1194: "Interaction of Transport and Wetting Processes"; speaker Prof. Dr.-Ing. Peter Stephan (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** E. Diehl, S. Ulbrich

### Project: Adaptive multigrid methods for fluid-structure interaction optimization

Strong fluid structure coupling is part of many technical systems. The aim of this project is to develop an efficient adaptive multilevel algorithm to solve an optimization problem governed by Fluid-Structure Interaction (FSI).

This algorithm should combine modern techniques of PDE-constrained optimization, adaptivity and Fluid-Structure Interaction simulation. Since for elliptic as well as for parabolic partial differential equations an adjoint based Trust-Region SQP method has shown good results, we want to adapt this method. We aim for an adjoint based algorithm that refines the spatial as well as the temporal grid adaptively during the optimization process.

The Fluid-Structure Interaction problem is considered in the weak form in an Arbitrary-Lagrangian-Eulerian (ALE) framework. The coupling of the two different parts of the partial differential equation is done via strong coupling.

Suitably the adjoint equation is considered in an ALE framework and in a strongly coupled way.

**Partner:** Darmstadt Graduate School of Excellence Computational Engineering (GSC 233); speaker Prof. Dr. Michael Schäfer (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** S. Essert, S. Ulbrich, M. Schäfer

**Project: Global methods for stationary and instationary gastransport (Subproject A01 of Transregio/SFB 154)**

This project is part of the Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks". Adaptive methods for the global solution of nonlinear mixed-integer optimization problems subject to ODE or PDE constraints are developed. We designed a new approach for the global solution for a class of ODE constrained optimization problems using the example of stationary gas networks. In this approach spatial and variable branching are combined with appropriate discretizations of the differential equations to construct relaxations of the original problem. Therefore, sufficient conditions under which numerical methods yield lower and upper bounds on the ODE solutions are derived. Moreover, convexity or concavity of the obtained under- and overestimators for specific numerical methods can be obtained under certain conditions. A key property of this approach is that the solutions of the ODEs only need to be known at a finite number of points due to the underlying network structure. This property enables us to adaptively refine discretizations without introducing new variables in the optimization problem. Furthermore, we proved that using these relaxations in a spatial branch-and-bound process yields an algorithm which terminates finitely under some natural assumptions [3].

We are currently extending this approach to PDE constrained optimization problems, now using the example of instationary gas networks. One step is to extend the approach of Burlacu et al. [1] for maximizing the storage of gas networks in the instationary case.

One further line of research is the exploitation of acyclicity of stationary gas flows. In [2], we investigate combinatorial models for such acyclic flows that use binary variables modeling flow direction. Some of these models can be used to significantly speed-up the solution of optimization problems for gas transport.

**Partner:** Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization using the Example of Gas Networks"; speaker Prof. Dr. Alexander Martin (Department of Mathematics, FAU Erlangen-Nürnberg)

**Support:** DFG

**Contact:** D. Gabriel, O. Habeck, M. E. Pfetsch, S. Ulbrich

### References


[1] R. Burlacu, H. Egger, M. Gross, A. Martin, M. E. Pfetsch, L. Schewe, M. Sirvent, and M. Skutella. Maximizing the storage capacity of gas networks: a global MINLP approach. *Optimization and Engineering*, 20:543–573, 2019.

[2] O. Habeck and M. E. Pfetsch. Combinatorial acyclicity models for potential-based flows. *Networks*, 2021. To appear.

[3] O. Habeck, M. E. Pfetsch, and S. Ulbrich. Global optimization of mixed-integer ODE constrained network problems using the example of stationary gas transport. *SIAM Journal of Optimization*, 29(4):2949–2985, 2019.

**Project: Mathematical models and methods for optimal combinations of passive and active components (Subproject A4 of Collaborative Research Centre (SFB) 805)**

This project is part of the Collaborative Research Centre (SFB) 805: "Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering". The project deals with the optimal design of mechanical trusses under uncertainty. Trusses are important in many applications (undercarriages of airplanes, bicycles, electrical towers, etc.) and are often overdimensioned to withstand given forces under several uncertainties in loads, material and production processes. Active parts can react to these uncertain effects and reduce the dimension of trusses. The Collaborative Research Centre 805 introduces new technologies to handle uncertainty in load-carrying systems. The aim of this project is to find optimal combinations of active and passive parts in a mechanical truss under uncertain loads. Mathematically, this leads to mixed-integer linear and nonlinear semidefinite problems. For the linear case, we have been developing the solver SCIP-SDP (`http://www.opt.tu-darmstadt.de/scipsdp/`). For the nonlinear case, there exists no solver that exploits the structure of the problem efficiently. Besides the development of an appropriate solvers, another focus lies in a mathematical handling of the upcoming uncertainties. Ellipsoidal and polyhedral sets are used to integrate uncertainty in different loading scenarios. The focus of the third funding period lies in the detection of model uncertainty and in the design of resilient trusses. Since mathematical models can only describe reality up to a certain degree, it is important to investigate the uncertainty caused by inadequacy of mathematical models. Within subproject A4, this is done by combining techniques from parameter estimation and optimal design of experiments to optimally place sensors to ensure that model uncertainty can be detected. Resilient trusses should be able to sustain certain forces even after the failure of a subset of bars. This leads to mixed-integer semidefinite programs with large numbers of semidefinite constraints, which should be generated dynamically to still allow for the solution of practically-relevant instances. All of this includes interdisciplinary communication to mechanical engineers to achieve realistic models.

**Partner:** Collaborative Research Centre (SFB) 805: "Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering"; speaker Prof. Dr.-Ing. Peter Pelz (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** T. Gally, M. E. Pfetsch, S. Ulbrich

**Project: Eigenvalue optimization with respect to shape variations in electro-magnetic systems**

The goal of particle accelerators cavities is to transfer energy to a charged particle beam by applying an electric field. To achieve accurate simulation results an exact representation of the geometry of electro-magnetic devices is crucial because even small changes can have a non-negligible effect on the final performance. The field distribution and its frequency in a radio-frequency (RF) cavity are governed by Maxwell's eigenvalue problem.

Within this project, we consider the optimization of these eigenvalues by means of shape optimization. To this end, we utilize a mixed formulation by (Kikuchi (1987)) and a discretization by means of Nédelec elements. The shape optimization is based on the method of mappings, where a Piola transformation is utilized to assert conformity of the mapped spaces. The derivation of derivatives is based on adjoint calculus for the constraining Maxwell eigenvalue problem.

**Partner:** Prof. Dr. Sebastian Schöps (TU Darmstadt)

**Contact:** C. Herter, W. Wollner

### Project: The complexity of Zadeh's pivot rule

Zadeh's LEAST-ENTERED pivot rule [4] is a memorizing pivot rule applicable to a wide range of algorithms. The most prominent example is the Simplex Algorithm since, for over thirty years, it was not clear if Zadeh's pivot rule might be the first polynomial time pivot rule for the Simplex Algorithm. In a breakthrough result, Friedmann [3] eventually was able to construct a super-polynomial lower bound via a connection to parity games and Markov decision processes.
As our first contribution, we first highlighted a fundamental flaw in the work of Friedmann, and later corrected this flaw while recovering his quantitative result [2]. We later, together with Friedmann, constructed a fully exponential lower bound [1], thus effectively eliminating Zadeh's pivot rule as a candidate for a sub-exponential rule, up to tie-breaking. Our bound holds for the discrete Strategy Improvement Algorithm for solving parity games, the Policy Iteration Algorithm for Markov Decision Processes, as well as for the Simplex Algorithm. The main goal for the future of this project is the pursuit of generalized and unified families of lower bounds that exclude large classes of algorithms at once.

**Partner:** Darmstadt Graduate School of Excellence Computational Engineering (GSC 233); speaker Prof. Dr. Michael Schäfer (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** Y. Disser, A. V. Hopp

#### References


[1] Y. Disser, O. Friedmann, and A. V. Hopp. An exponential lower bound for Zadeh's pivot rule. Preprint, arXiv:1911.01074, 2019.

[2] Y. Disser and A. V. Hopp. On Friedmann's subexponential lower bound for Zadeh's pivot rule. In *Proceedings of the 20th Conference on Integer Programming and Combinatorial Optimization (IPCO)*, pages 168–180, 2019.

[3] O. Friedmann. A subexponential lower bound for Zadeh's pivoting rule for solving linear programs and games. In *Proceedings of the 15th International Conference on Integer Programming and Combinatorial Optimization (IPCO)*, pages 192–206, 2011.

[4] N. Zadeh. What is the worst case behavior of the simplex algorithm? Technical Report 27, Departments of Operations Research, Stanford, 1980.


### Project: Optimal design of an energy network

In this project we derive a quasi-stationary optimization model for a decentralized energy network involving the energy carriers gas, heat and electricity, as well as renewable energies for a newly designed decentralized settlement.
For solving the resulting mixed-integer non-convex optimization problem we use the spatial branch-and-bound algorithm.

Moreover, we further investigate the dynamic behavior of the energy network regarding the energy carrier gas. We derive and implement over- and under estimators for the isothermal semilinear Euler equations for a single pipeline.

**Partner:** Darmstadt Graduate School of Excellence Energy Science and Engineering (GSC 1070); speakers Prof. Dr. Wolfram Jaegermann and Prof. Dr. Johannes Janicka (TU Darmstadt)

**Support:** DFG

**Contact:** K. Janzen, S. Ulbrich

**Project: Mathematical optimization in robust product design (Subproject A3 of Collaborative Research Centre (SFB) 805)**

The objectives of this subproject are the optimal design of load-carrying systems under uncertainty based on complex finite-element methods for system components and the determination of optimal excitations and sensor positions such that model uncertainty during production and usage can be identified reliably. The first goal is achieved by the development and application of novel mathematical methods for the robust optimization of geometry, topology and for actuator placement. For an efficient numerical treatment, first- and second-order approximations with respect to the uncertain parameters were used and reduced-order models with a-posteriori error control were implemented [1]. In order to detect model uncertainty after production or during usage, we developed a novel algorithm [2]. Therein, parameter estimation problems are solved in real time to estimate specific model parameters based on collected sensor data. In order to keep the estimation variance low, methods of optimal experiment design are applied that determine optimal sensor positions as well as optimal excitation positions and signals. A hypothesis test with the estimated parameters which are obtained from different test sets is constructed to quantify the quality of the employed model and the risk of its rejection.

**Partner:** Collaborative Research Centre (SFB) 805: "Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering"; speaker Prof. Dr.-Ing. Peter Pelz (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** A. Matei, S. Ulbrich

### References


[1] A. Alla, M. Hinze, P. Kolvenbach, O. Lass, and S. Ulbrich. A certified model reduction approach for robust parameter optimization with PDE constraints. *Advances in Computational Mathematics*, 45(3):1221–1250, 2019.

[2] T. Gally, P. Groche, F. Hoppe, A. Kuttich, A. Matei, M. E. Pfetsch, M. Rakowitsch, and S. Ulbrich. Identification of model uncertainty via optimal design of experiments applied to a mechanical press. *Optimization and Engineering*, pages 1–28, 2021.


**Project: Exploiting structure in compressed sensing using side constraints – From analysis to system design (EXPRESS II)**

The key objective in EXPRESS II is to design, configure, and dimension hybrid analog/digital data acquisition systems for sparse signal recovery under structure. We consider exploiting prior knowledge of particular structure in the array geometry (e.g., uniform-linear arrays, shift-invariant arrays, etc.), the source signals (e.g., signal constellations, constant modulus, etc.), and the temporal signature of the signals (e.g., block-, row-, or rank-sparsity) in the hybrid system. This requires theoretical results regarding sparse signal recoverability exploiting the available structure as well as formulating and solving the corresponding optimization criteria. As a particularly interesting structure we have considered recovery of integral source signals with and without additional bounds. This structure can be exploited by using $\ell_1$-minimization with an additional integrality constraint and possibly variable bounds. In this case, characterizations of uniform and non-uniform recovery can be formulated using appropriate null space properties (NSP) [2]. To obtain analogous theoretical recovery results for a variety of possible structures in the source signals, we furthermore formulated a general framework for recovery under side constraints. Under some mild assumptions, uniform recovery of structured source signals using a generalization of $\ell_1$-minimization is then characterized by a general NSP [1]. This framework allows to study the impact of various side constraints on the measurement process and the corresponding recovery guarantee. We plan to further investigate this point by considering random matrices and by finding bounds for the minimal number of measurements needed to guarantee uniform recovery for various structured source signals. Moreover, we plan to explore the potential to improve recoverability using methods from mixed-integer nonlinear programming.

**Partner:** DFG Priority Programme (SPP) 1798: "Compressed Sensing in Information Processing"; speakers Prof. Dr. Gitta Kutyniok (LMU München) and Prof. Dr. Holger Rauhut (RWTH Aachen)

**Support:** DFG

**Contact:** F. Matter, M. E. Pfetsch

### References


[1] J. Heuer, F. Matter, M. E. Pfetsch, and T. Theobald. Block-sparse recovery of semidefinite systems and generalized null space conditions. *Linear Algebra and its Applications*, 603:470–495, 2020.

[2] J.-H. Lange, M. E. Pfetsch, B. M. Seib, and A. M. Tillmann. Sparse recovery with integrality constraints. *Discrete Applied Mathematics*, 283:346–366, 2020.


### Project: Strategic booking decisions in the Entry-Exit-System

We are investigating a multi-leader-multi-follower Nash game, which models competition between several firms on the gas market. The competition is modeled in the so called Entry-Exit-System, in which we consider a star shaped graph with a single customer on the middle node and the considered firms (suppliers) on the outer nodes. Gas suppliers first have to book a certain capacity of gas for a longer time period (month/year) and after that can nominate varying amounts of gas in each of several subsequent shorter time periods (hours/days). The booking decisions of the firms are an upper bound for the nomination decisions. Thus each firm needs to anticipate the result of the nomination phase, which leads to a hierarchical structure. The lower level is a constrained Cournot-Nash game, which admits a unique equilibrium, but the upper level is – given this equilibrium – a nonconvex Nash equilibrium problem.

**Partner:** Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks"; speaker Prof. Dr. Alexander Martin (Department of Mathematics, FAU Erlangen-Nürnberg)

**Support:** DFG

**Contact:** D. Nowak, A. Schwartz

**Project: `polymake`**

The mathematical software system `polymake` provides a wide range of functions for convex polytopes, simplicial complexes, polyhedral cones and fans, lattice polytopes, toric geometry and tropical geometry. While the system exists for more than 20 years, it was continuously developed and expanded. The focus of the development in the last years was on interaction with other software systems that complement methods and computations offered by `polymake`, among them `GAP` and `Singular`, and their application to extend the capabilities of `polymake`. `polymake` offers an interface similar to many computer algebra systems. However, on the technical level polymake differs from most mathematical software systems: rule based computations, a flexible object hierarchy and an extendible dual Perl/C++ interface are the most important characteristics. Recent development also allows access to `polymake` via Jupyter notebooks and via a common Julia based interactive shell with `GAP` and `Singular`.
polymake is an open source software project. The current version 3.2 can be downloaded freely from www.polymake.org.

**Partner:** Michael Joswig (TU Berlin); Ewgenij Gawrilow (TomTom N.V.), The `polymake` team

**Contact:** A. Paffenholz

**References**


[1] B. Assarf, E. Gawrilow, K. Herr, M. Joswig, B. Lorenz, A. Paffenholz, and T. Rehn. Computing convex hulls and counting integer points with `polymake`. *Mathematical Programming Computation*, 9(1):1–38, 2017.

[2] A. Paffenholz. `polyDB`: a database for polytopes and related objects. In *Algorithmic and experimental methods in algebra, geometry, and number theory*, pages 533–547. Springer, Cham, 2017.


**Project: Optimization and control (Subproject AP C of PASIROM)**

This project is a subproject of PASIROM, which builds upon the achievements of SIMUROM, its predecessing project. As in SIMUROM, the modeling, simulation and optimization of electromechanical energy converters is investigated. In the subproject we particularly focus on the robust optimization of an electrical machine, which can be modeled by a coupled system of partial differential algebraic equations. In our robust optimization approach we treat uncertainties due to imperfect manufacturing and therefore geometric imprecision. We use the worst case approach and approximate the robust counterpart by Taylor expansions of different degrees to get a numerically convenient problem. To reduce computational effort we apply a model order reduction technique in the form of proper orthogonal decomposition.

**Partner:** Sebastian Schöps (TU Darmstadt); Stephanie Friedhoff (Universität Wuppertal); Michael Hinze (Universität Koblenz-Landau); Stefan Kurz, Oliver Rain (Robert Bosch GmbH); Enno Lange, Stefan Reitzinger (CST - Computer Simulation Technology AG)

**Support:** Federal Ministry of Education and Research (BMBF)

**Contact:** B. Polenz, S. Ulbrich

#### References

[1] P. Kolvenbach, O. Lass, and S. Ulbrich. An approach for robust PDE-constrained optimization with application to shape optimization of electrical engines and of dynamic elastic structures under uncertainty. *Optimization and Engineering*, 19(3):697–731, 2018.

[2] O. Lass and S. Ulbrich. Model order reduction techniques with a posteriori error control for nonlinear robust optimization governed by partial differential equations. *SIAM Journal on Scientific Computing*, 39(5):S112–S139, 2017.

### Project: Optimization methods for mathematical programs with equilibrium constraints in function spaces based on adaptive error control and reduced order or low rank tensor approximations (Project P23 in Phase 1 of SPP 1962)

This project investigates optimization methods for mathematical programs with equilibrium constraints (MPECs) in function space that adaptively control the accuracy of the underlying discretization and of inexact subproblem solves in such a way that convergence is ensured. This enables the use of adaptive discretizations, reduced order models, and low rank tensor methods, thus making the solution of MPECs with high dimensional equilibrium constraints tractable and efficient. Two prototype classes of MPECs in function space are considered in the project: One with a family of parametric variational inequalities as constraints and the other constrained by a parabolic variational inequality. Based on a rigorous analytical foundation in function space, the project will develop and analyze inexact bundle methods combined with an implicit programming approach. In addition, inexact all-at-once methods will be considered. In both cases, the evaluation of cost function, constraints, and derivatives is carried out on discretizations which are adaptively refined during optimization and can further be approximated by reduced order models or low rank tensor methods. We will develop implementable control mechanisms for the inexactness, which are tailored to the needs of the optimization methods and can be based on a posteriori error estimators. The algorithms will be implemented and tested for the considered prototype classes of MPECs.

**Partner:** Michael Ulbrich (TU München), Lukas Hertlein (TU München), DFG Priority Programme (SPP) 1962: "Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization"; speaker Prof. Dr. Michael Hintermüller (HU Berlin / WIAS Berlin)

**Support:** DFG

**Contact:** A.-T. Rauls, S. Ulbrich

#### References

[1] L. Hertlein, A.-T. Rauls, M. Ulbrich, and S. Ulbrich. *An inexact bundle method and subgradient computations for optimal control of deterministic and stochastic obstacle problems*. M. Hintermüller et al. (eds.), SPP1962 Special Issue. ISNM, Birkhäuser, 2020. To appear.

[2] L. Hertlein and M. Ulbrich. An inexact bundle algorithm for nonconvex nonsmooth minimization in Hilbert space. *SIAM Journal on Control and Optimization*, 57(5):3137–3165, 2019.

[3] A.-T. Rauls and S. Ulbrich. Computation of a Bouligand generalized derivative for the solution operator of the obstacle problem. *SIAM Journal on Control and Optimization*, 57(5):3223–3248, 2019.

[4] A.-T. Rauls and S. Ulbrich. On the characterization of generalized derivatives for the solution operator of the bilateral obstacle problem. Preprint, SPP 1962, 2020.

[5] A.-T. Rauls and G. Wachsmuth. Generalized derivatives for the solution operator of the obstacle problem. *Set-Valued and Variational Analysis*, 28(2):259–285, 2020.

**Project: Mathematical optimization of heating networks (Subproject of EnEff:Wärme – MeFlexWärme)**

The decarbonization of heat generation plays a major role for limiting climate change. The project EnEff:Wärme – MeFlexWärme: "Methods for flexible heating networks of the future" is concerned with the flexibility of heating networks to enable decarbonization of heat generation. The heat generation from electrical energy (power-to-heat) can provide a major contribution to maintaining low-$CO_2$ heat and offer an alternative for electricity storing. To enable a flexible balance between heat generators, storage tanks and consumers, appropriate network expansions are significant. The project is executed together with an interdisciplinary group of TU Darmstadt as well as industrial partners and is focused on research in the areas of network transparency, flexibility and mathematical optimization of heating networks.

As part of the project we consider the modeling and globally optimal solving of heating networks to make heating networks flexible. The globally optimal solution determines the control of pumps and heatings in the network to regulate the state variables massflow, pressure and temperature. Boundary conditions are the consumed heat power as well as network related variable bounds. The development of the state variables over the network is determined by nonlinear equations with discrete decisions. The goal is to create good solvability of the Mixed-Integer Nonlinear Problem (MINLP) with the high accuracy. To achieve this, we consider convex relaxations and approximations of the model equations as well as network specific properties. The research is validated with real network data and the results are integrated in the other research areas.

**Partner:** Entega AG; Siemens AG; speaker Prof. Dr. Florian Steinke (TU Darmstadt)

**Support:** BMWi

**Contact:** L. Rehlich, M. E. Pfetsch, S. Ulbrich

**Project: Resilient design (Subproject A9 of Collaborative Research Centre (SFB) 805)**

In this subproject, optimization methods for the optimal design of technical systems under uncertainty are developed. The goal is to find an optimal combination of different components constituting a resilient system structure, i.e., a structure which can tolerate failing components. To evaluate and optimize resilience, we use the concept of $k$-reliability. If a system is $k$-reliable, $k$ of its components can fail and it still fulfills a previously defined minimum function. If one takes this property into account, the corresponding mathematical optimization model has multiple levels, since an emergency function must be guaranteed for each combination of a previously specified maximum number $k$ of failed components. To understand this complex structure, in [1] we have analyzed a model to design a cost-optimal $k$-reliable water supply system for a high-rise building. Furthermore, we have developed a solution approach that repeatedly solves a relaxation of the problem and checks solution candidates for the existence of unbearable pump failures. Suitable inequalities for these worst-case scenarios are then dynamically added to the relaxation in order to cut off non-resilient solution candidates. Convincing computational results motivate a generalization of this framework that checks worst-case failures for given solutions and adds suitable inequalities to prevent non-reliable solutions. The subproblems are mixed-integer nonlinear optimization programs, since they, for instance, include the nonlinear operation of pumps. The convexity properties of the characteristic diagrams of pumps is investigated in [2].

**Partner:** Collaborative Research Centre (SFB) 805: "Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering"; speaker Prof. Dr.-Ing. Peter Pelz (Department of Mechanical Engineering, TU Darmstadt); Lena C. Altherr (Faculty of Energy, Buildings, Environment, Münster University of Applied Sciences), Philipp Leise (Department of Mechanical Engineering, TU Darmstadt)

**Support:** DFG

**Contact:** A. Schmitt, M. E. Pfetsch

### References


[1] L. C. Altherr, P. Leise, M. E. Pfetsch, and A. Schmitt. Resilient layout, design and operation of energy-efficient water distribution networks for high-rise buildings using MINLP. *Optimization and Engineering*, 20(2):605–645, 2019.

[2] M. E. Pfetsch and A. Schmitt. Exploiting partial convexity of pump characteristics in water network design. In J. S. Neufeld, U. Buscher, R. Lasch, D. Möst, and J. Schönberger, editors, *Operations Research Proceedings*. Springer International Publishing, 2020.


**Project: Adaptive multilevel methods for the optimal control of hyperbolic equations in gas networks (Subproject A02 of Transregio/SFB 154)**

This project is part of the Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks". We want to analyze the optimal control of hyperbolic PDE systems with state constraints on the example of gas networks. Through the time-dependent control of compressors and valves, the pressure and velocity distribution of the transported gas in the network has to be optimized under constraints, e.g., such that the pressure lies within a specified tolerance range. The constraints of the resulting optimal control problem (P) consist of coupled systems of one-dimensional isothermal Euler equations describing the gas flow, node conditions and state constraints. We plan to use Moreau-Yosida regularizations to approximate (P) in order to derive optimality conditions. The main goal of this project is to provide an optimization theory, which will form the basis of adaptive multilevel methods.

**Partner:** Transregio/SFB 154: "Mathematical Modelling, Simulation and Optimization on the Example of Gas Networks"; speaker Prof. Dr. Alexander Martin (Department of Mathematics, FAU Erlangen-Nürnberg)

**Support:** DFG

**Contact:** J. M. Schmitt, S. Ulbrich

### References


[1] S. Pfaff and S. Ulbrich. Optimal boundary control of nonlinear hyperbolic conservation laws with switched boundary data. *SIAM Journal on Control and Optimization*, 53(3):1250–1277, 2015.

[2] S. Pfaff and S. Ulbrich. Optimal control of scalar conservation laws by on/off-switching. *Optimization Methods and Software*, 32(4):904–939, 2017.

[3] J. M. Schmitt and S. Ulbrich. Optimal boundary control of hyperbolic balance laws with state constraints. Preprint, TRR 154, 2017. `https://opus4.kobv.de/opus4-trr154/frontdoor/index/index/docId/219`.

[4] J. M. Schmitt and S. Ulbrich. Optimal boundary control of hyperbolic balance laws with state constraints. *SIAM Journal on Control and Optimization*, 2020. To appear.

**Project: Optimal control of Navier-Stokes with combustion**

Based on the work of the SFB 568 subproject D5 we continue to develop efficient methods for the optimization of combustion chambers containing turbulent fluid flow and combustion processes, which are modeled by partial differential equations.
The employed optimization methods rely on adjoints and derivative information, calculated by automatic differentiation [1]. The implementation uses the parallel multi-grid flow solver "Fastest", which incorporates recent simplified combustion models such as the flamelet-generated-manifold (FGM) method.

**Partner:** Darmstadt Graduate School of Excellence Energy Science and Engineering (GSC 1070); speakers Prof. Dr. Wolfram Jaegermann and Prof. Dr. Johannes Janicka (TU Darmstadt)

**Support:** DFG

**Contact:** C. Sehrt, S. Ulbrich

**References**

[1] R. Roth and S. Ulbrich. A discrete adjoint approach for the optimization of unsteady turbulent flows. *Flow, Turbulence and Combustion*, 90(4), 2013.

**Project: Theory and solution methods for generalized Nash equilibrium problems governed by networks of nonlinear hyperbolic conservation laws (Project P21 in Phase 2 of SPP 1962)**

The aim of this project is the analysis of (Generalized) Nash Equilibrium Problems ((G)NEPs) that are governed by networks of nonlinear hyperbolic conservation or balance laws as well as the development and analysis of efficient solution methods for these problems. Networks of conservation laws are an active research field and have led to innovative models of flow or transport problems, e.g., for traffic networks, supply chains, data networks and water or gas networks. In all of these applications, (G)NEPs provide powerful models for the interaction of multiple non-cooperative agents who optimize their strategies. Since solutions of conservation laws may develop discontinuities, they exhibit additional nonsmooth phenomena, e.g., it causes the control-to-state mapping to not be differentiable in the usual sense. Based on recent results concerning the existence and stability of solutions of networks of conservation laws as well as the optimal control of conservation laws we will develop an analytical setting that yields stability and differentiability properties of players' cost functionals. Moreover, we will derive an adjoint-based derivative representation. This will be used to study the existence of quasi-Nash equilibria (QNE) for nonconvex NEPs as well as QNE and quasi-variational equilibria (QVE) for nonconvex

GNEPs of this type. For games with convex feasible sets the analysis of global minima of merit functions based on regularized Nikaido-Isoda functions shall yield existence of QNE. Differentiability results shall be established for the merit functions to develop globally convergent descent methods for convexly constrained (G)NEPs. For (G)NEPs with nonconvex constraints augmented Lagrangian methods shall extend the applicability of the descent methods.

**Partner:** Michael Ulbrich (TU München), Julia Wachter (TU München), DFG Priority Programme (SPP) 1962: "Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization"; speaker Prof. Dr. Michael Hintermüller (HU Berlin / WIAS Berlin)

**Support:** DFG

**Contact:** M. Steinhardt, S. Ulbrich

**Project: Competitive analysis for incremental maximization**

Incremental Maximization deals with the problem of incrementally building a solution set without the knowing the maximum feasible size of the set. Thus, the solution has to be competitive for every size while it is built. Problems like this arise when incrementally developing communication, production, storage, and other infrastructures. In [1], under very mild assumptions, a lower bound of $\sim 2.18$ and an upper bound of $1+\varphi$, where $\varphi \approx 1.618$ is the golden ratio, was proven for the competitive ratio. Furthermore, in this paper, the property of $\alpha$-augmentability was introduced. It was proven that, for $\alpha$-augmentable, monotone objectives, the solution produced by the greedy algorithm is $\alpha\frac{e^\alpha}{e^\alpha-1}$-competitive and that this competitive ratio is tight for $\alpha \in \{1,2\}$ and for $\alpha \to \infty$.
As a first contribution, we introduced $\gamma$-$\alpha$-augmentability as a relaxation of $\alpha$-augmentability [2]. We proved a tight bound of $\frac{\alpha}{\gamma}\frac{e^\alpha}{e^\alpha-1}$ on the competitive ratio of the greedy algorithm for $\gamma$-$\alpha$-augmentable, monotone objective functions, and we were able to extend our lower bound construction to $\alpha$-augmentable objectives to show that the known upper bound of $\alpha\frac{e^\alpha}{e^\alpha-1}$ is tight for all $\alpha > 0$.

**Support:** DFG

**Contact:** D. Weckbecker, Y. Disser

### References


[1] A. Bernstein, Y. Disser, M. Groß, and S. Himburg. General bounds for incremental maximization. *Mathematical Programming*, 2020.

[2] Y. Disser and D. Weckbecker. Unified greedy approximability beyond submodular maximization. arXiv:2011.00962, 2020.


**Project: Optimizing fracture propagation using a phase-field approach (Project P17 in Phase 1 of SPP 1962)**

We consider the numerical approximation and solution of control problems governed by a quasi-static brittle fracture propagation model. As a central modeling component, a phase-field formulation for the fracture formation and propagation is considered.
The fracture propagation problem itself can be formulated as a minimization problem with inequality constraints, imposed by multiple relevant side conditions, such as irreversibility of the fracture-growth or non-selfpenetration of the material across the fracture surface.

These lead to variational inequalities as first order necessary conditions. Consequently, optimization problems for the control of the fracture process give rise to a mathematical program with complementarity constraints (MPCC) in function spaces.

Within this project, we intend to analyze the resulting MPCC with respect to its necessary and sufficient optimality conditions by means of a regularization of the lower-level problem and passage to the limit with respect to the regularization parameter. Moreover, we will consider SQP-type algorithms for the solution of this MPCC in function space and investigate its properties. Additionally, we will consider the discretization by finite elements and show the convergence of the discrete approximations to the continuous limit.

The simultaneous consideration of the inexactness due to discretization and regularization error will allow us to construct and analyze an efficient inexact SQP-type solver for the MPCC under consideration.

**Partner:** Ira Neitzel (Universität Bonn), Thomas Wick (Universität Hannover), Christoph Ortner (University of Warwick), DFG Priority Programme (SPP) 1962: "Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization"; speaker Prof. Dr. Michael Hintermüller (HU Berlin / WIAS Berlin)

**Support:** DFG

**Contact:** M. Mohammadi, W. Wollner

### References


[1] B. Endtmayer, U. Langer, I. Neitzel, T. Wick, and W. Wollner. Multigoal-oriented optimal control problems with nonlinear PDE constraints. *Computers & Mathematics with Applications*, 79(10):3001–3026, 2020.

[2] R. Haller-Dintelmann, H. Meinlschmidt, and W. Wollner. Higher regularity for solutions to elliptic systems in divergence form subject to mixed boundary conditions. *Annali di Matematica Pura ed Applicata*, 198(4):1227–1241, 2019.

[3] M. Mohammadi and W. Wollner. A priori error estimates for a linearized fracture control problem. *Optimization and Engineering*, 2020.

[4] I. Neitzel, T. Wick, and W. Wollner. An optimal control problem governed by a regularized phase-field fracture propagation model. Part II: The regularization limit. *SIAM Journal on Control and Optimization*, 3(57):1672–1690, 2019.


### Project: Optimizing fracture propagation using a phase-field approach (Project P15 in Phase 2 of SPP 1962)

We consider the numerical approximation and solution of control problems governed by a quasi-static brittle fracture propagation model. As a central modeling component, a phase-field formulation for the fracture formation and propagation is considered.

The fracture propagation problem itself can be formulated as a minimization problem with inequality constraints, imposed by multiple relevant side conditions, such as irreversibility of the fracture-growth or non-selfpenetration of the material across the fracture surface. These lead to variational inequalities as first order necessary conditions. Consequently, optimization problems for the control of the fracture process give rise to a mathematical program with complementarity constraints (MPCC) in function spaces.

Within this project, we intend to focus on mathematical challenges, that are also motivated by applications, such as control of the coefficients of the variational inequality, or nonsmooth and/or nonconvex cost functionals in the outer optimization, such as, e.g., maximizing the released energy of the fracture. We will develop first and second order optimality conditions for the resulting MPCC as well as other obstacle-like formulations. Additionally, we will consider the discretization by finite elements and show the convergence of the discrete approximations to the continuous limit. These findings will be substantiated with prototype numerical tests.

**Partner:** Ira Neitzel (Universität Bonn), Thomas Wick (Universität Hannover), DFG Priority Programme (SPP) 1962: "Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization"; speaker Prof. Dr. Michael Hintermüller (HU Berlin / WIAS Berlin)

**Support:** DFG

**Contact:** N. Simon, W. Wollner

### References


[1] A. Hirn and W. Wollner. An optimal control problem for equations with $p$-structure and its finite element discretization. Preprint SPP1962-137, SPP1962, 2020.


## 1.8 Stochastics

Research in the stochastics group is split into a probability theory part (Aurzada, Betz) and a part on mathematical statistics (Kohler, Wichelhaus).

In the mathematical statistics part, we work on curve estimation. The particular focus here is on the derivation of a statistical theory for deep learning. Furthermore, we study non-parametric estimation problems for stochastic networks. The major research topics studied by the probability group are statistical mechanics, interacting particle systems, stochastic processes, and problems from applied probability. The particular problems considered are from the following areas: spacial random permutations, probabilistic methods in quantum theory, the theory of Bose-Einstein condensation, exit problems for stochastic processes and their relation to funcational analysis, fractional processes, insurance mathematics, and limit theorems for spatial models.

The members of the research group stochastics are involved in joint projects with colleagues working in probability and statistics as well as colleagues in sciences where probability and statistics are applied to, such as econometrics, engineering, telecommunication, physics, and psychology. Furthermore, we carry out research projects in applied stochastics with industrial partners.

**Members of the research group**

**Professors and Permament Staff**

Frank Aurzada, Volker Betz, Michael Kohler, Cornelia Wichelhaus

**Postdoc**

Sophie Langer

**PhD Students**

Alina Braun, Johannes Ehlert, Sebastian Kersting, Martin Kilian, Marvin Kettner, Lukas Roth, Dominic T. Schickentanz

**Secretary**

Alexandra Frohn

**Project: Persistence probabilities of fractional processes**

Persistence probabilities concern the question that a stochastic process remains below a fixed boundary for a long time. This is a classical question in probability that was studied extensively for random walks and Lévy processes. It has various connections to other fields, most notably to statistical physics and insurance. In physics, the rate of decay of the persistence probability is perceived as a measure for the return of a complicated physical system to an equilibrium state. In insurance, one asks for the probability of (non)ruin of an asset, which is clearly the probability that a stochastic process remains above a fixed boundary. In this project, we study persistence probabilities of fractional processes [2]. Further, we make a first step in defining fractional Brownian motion conditioned to be positive [1]. Finally, we give an application of persistence probability estimates for a more complicated exit problem [3].

**Support:** German Research Association (DFG), AU370/5.

**Partner:** Mikhail Lifshits (St. Petersburg)

**Contact:** Frank Aurzada

#### References

[1] F. Aurzada, M. Buck, and M. Kilian. Penalizing fractional Brownian motion for being negative. *Stochastic Process. Appl.*, 130(11):6625–6637, 2020.

[2] F. Aurzada and M. Kilian. Asymptotics of the persistence exponent of integrated FBM and Riemann-Liouville process. Preprint, arXiv:2007.01254, 2020.

[3] F. Aurzada and M. A. Lifshits. The first exit time of fractional Brownian motion from a parabolic domain. *Teor. Veroyatn. Primen.*, 64(3):610–620, 2019.

**Project: Persistence probabilities and large deviations**

Persistence probabilities concern the question that a stochastic process remains above/below a fixed boundary for a long time. It is a particular instance of non-exit probabilities. In this project, we study these quantities with the help of large deviation theory and functional analytic tools. The first step – which can be pursued via large deviation techniques or via direct arguments – is to relate the mentioned probabilistic quantities to eigenvalue problems for a related operator [4]. Secondly, we developed a perturbation argument that allows to obtain a series representation of the eigenvalue in the parameter of the underlying stochastic process; this was done for autoregressive processes [2] and is ongoing work for moving average processes. In [3], we study a persistence problem for a generalization of moving average processes. We finally mention [1], where a large deviation problem for another type of exit problem is treated.

**Support:** German Research Association (DFG), AU370/4.

**Partner:** Sumit Mukherjee (Columbia University), Ofer Zeitouni (Weizmann Institute)

**Contact:** Frank Aurzada

#### References

[1] F. Aurzada. Large deviations for infinite weighted sums of stretched exponential random variables. *J. Math. Anal. Appl.*, 485(2):123814, 9, 2020.

[2] F. Aurzada and M. Kettner. Persistence exponents via perturbation theory: AR(1)-processes. *J. Stat. Phys.*, 177(4):651–665, 2019.

[3] F. Aurzada and S. Mukherjee. Persistence probabilities of weighted sums of stationary Gaussian sequences. Preprint, arXiv:2003.01192, 2020.

[4] F. Aurzada, S. Mukherjee, and O. Zeitouni. Persistence exponents in markov chains. Preprint, Annales de l'Institut Henri Poincaré – Probabilités et Statistiques, to appear, 2019.

### Project: Chains of interacting Brownian particles

We investigate the behaviour of a finite chain of Brownian particles, interacting through a pairwise potential, with one end of the chain fixed and the other end pulled away at slow speed, in the limit of slow speed and small Brownian noise. We study the instant when the chain "breaks," that is, the distance between two neighboring particles becomes larger than a certain limit. There are three different regimes depending on the relation between the speed of pulling and the Brownian noise. We prove weak limit theorems for the break time and the break position for each regime.

**Support:** German Research Association (DFG), AU370/7.

**Partner:** Mikhail Lifshits (St. Petersburg)

**Contact:** Frank Aurzada, Volker Betz

#### References

[1] F. Aurzada, V. Betz, and M. Lifshits. Breaking a chain of interacting Brownian particles. Preprint, Annals of Applied Probability, to appear, 2020.

[2] F. Aurzada, V. Betz, and M. Lifshits. Breaking a chain of interacting Brownian particles: a Gumbel limit theorem. Preprint, Theory of Probability and its Applications, to appear, 2020.

[3] F. Aurzada, V. Betz, and M. Lifshits. Universal break law for chains of Brownian particles with nearest neighbour interaction. Preprint, arXiv:2010.07706, 2020.

### Project: Applied probability problems

We investigate several problems related to applied probability models. For examle, we study a variant of the classical Cramér-Lundberg model from insurance mathematics where the insurance company can have temporarily negative capital in the considered asset [1]. Another publication concerns a limit theorem for a random boxes model, which is motivated by analyzing the performance parameters of telecommunication systems [3]. Finally, having applications in information theory in mind, we quantify a certain notion of "amount of information" contained in Boolean models ("random pictures") [2].

**Support:** German Research Association (DFG), GO420/6.

**Contact:** Frank Aurzada

#### References

[1] F. Aurzada and M. Buck. Ruin probabilities in the Cramér-Lundberg model with temporarily negative capital. *European Actuarial Journal*, (10):261–269, 2020.

[2] F. Aurzada and M. Lifshits. How complex is a random picture? *J. Complexity*, 53:133–161, 2019.

[3] F. Aurzada and S. Schwinn. Scaling limits for a random boxes model. *Adv. in Appl. Probab.*, 51(3):773–801, 2019.

**Project: Spatial random permutations and Bose-Einstein condensation**

The theoretical understanding of the quantum phenomenon of Bose-Einstein condensation is one of the great unsolved problems of theoretical physics. It is well known that the quantum mechanical problem can be translated into a probabilistic one by using the Feynman-Kac formula. The result is a system of interacting spatial permutations, and the question to be answered is about a phase transition in the typical length of cycles, with the order parameter being the typical distance of two spatial points that will be mapped into each other by the permutation. Even though an understanding of the full probabilistic model is currently out of reach, there are various simplifications that should exhibit typical properties of the full model and are interesting in their own right. Moreover, these simpler models touch on many other current topics of statistical mechanics, such as motion by mean curvature, percolation or Schramm-Löwner evolution. The work in the research group is focused on understanding various of these aspects in simple cases, using both analytical and numerical methods.

**Partner:** D. Ueltschi (University of Warwick); Lorenzo Taggi (WIAS Berlin); Peter Mörters (Universität Köln); Steffen Dereich (Universität Münster)

**Support:** DFG

**Contact:** V. Betz

**References**


[1] V. Betz, S. Dereich, and P. Mörters". The shape of the emerging condensate in effective models of condensation. *Annales Henri Poincare*, pages 1869–1889, 2018.

[2] V. Betz and H. Schäfer. The number of cycles in random permutations without long cycles is asymptotically gaussian. *ALEA*, 14:427–444, 2017.

[3] V. Betz and L. Taggi. Scaling limit of ballistic self-avoiding walk interacting with spatial random permutations. *Electron. J. Probab.*, 24:paper No. 74, 2019.

[4] V. Betz and D. Ueltschi. Spatial random permutations and poisson-dirichlet law of cycle lengths. *Electronic Journal of Probability*, 16:41, 2011.

[5] V. Betz and D. Ueltschi. Spatial random permutations with small cycle weights. *Probab. Th. Rel. Fields*, 149:191–222, 2011.

[6] V. Betz, D. Ueltschi, and Y. Velenik. Random permutations with cycle weights. *Ann. Appl. Probab.*, 21:312–331, 2011.

[7] H. S. Volker Betz and L. Taggi. Interacting self-avoiding polygons. *Ann. Inst. H. Poincaré Probab. Statist.*, 56:1321–1335, 2020.

[8] H. S. Volker Betz and D. Zeindler. Random permutations without macroscopic cycles. *Ann. Appl. Probab.*, 30:1484–1505, 2020.

[9] H. S. Volker Betz, Julian Mühlbauer and D. Zeindler. Precise asymptotics of longest cycles in random permutations without macroscopic cycles. *accepted in Bernoulli*, 2020.


**Project: Superadiabatic transitions in modecules**

An important problem in quantum chemistry are the so-called non-adiabatic transitions. These enable molecules to change their electronic eigenstates without emitting a photon, and are thus important in chemical processes such as the reception of light in the retina. These transitions are very challenging to predict numerically due to their seemingly highly oscillatory behaviour. In the 2000s, an approach has been developed by Volker Betz that allows to change the frame of reference in a way that eliminates those oscillations. Thus, it is possible to predict non-adiabatic transitions with higher accuracy than previously possible. The ongoing work in this area focusses on extending the range of utility of this approach, especially to higher dimensions.

**Partner:** B. Goddard (University of Edinburgh), U. Manthe (Universität Bielefeld)

**Contact:** V. Betz

### References


[1] V. Betz and B. Goddard. Accurate prediciton of non-adiabatic transitions through avoided crossings. *Phys Rev Letters*, 103:213001, 2009.

[2] B. G. Volker Betz and T. Hurst. Non-adiabatic transitions in multiple dimensions. *SIAM J. Sci. Comput.*, 41:B1011–B1033, 2019.

[3] B. G. Volker Betz and U. Manthe. Wave packet dynamics in the optimal superadiabatic approximation. *Journal of Chemical Physics 144(22)*, 144:224109, 2016.


### Project: Loop models and quantum systems

Quantum many body systems can be described by so-called loop models. These are percolation type models that, however, have much stronger correlations than usual and are thus very hard to analyse. On certain graphs (like trees) there has been some progress. We investigate different types of loop models using probabilistic techniques.

**Partner:** Benjamin Lees (Bristol), Daneil Ueltschi (Warwick)

**Contact:** V. Betz, J. Ehlert

### References


[1] V. Betz, J. Ehlert, and B. Lees. Phase transition for loop representations of quantum spin systems on trees. *Journal of Mathematical Physics*, 59:113302, 2018.

[2] B. L. Volker Betz, Johannes Ehlert and L. Roth. Sharp phase transition for random loop models on trees. *preprint*, 2020.


### Project: Uncertainty propagation with estimated input distributions

In this project we study the problem of quantifying the uncertainty in an experiment with a technical system. We propose new density estimates which combine observed data of the technical system and simulated data from an (imperfect) simulation model based on estimated input distributions. We analyze the rate of convergence of these estimates. The finite sample size performance of the estimates is illustrated by applying them to simulated data. The practical usefulness of the newly proposed estimates is demonstrated by using them to predict the uncertainty of a lateral vibration attenuation system with piezo-elastic supports.

**Partner:** SFB 805 (TU Darmstadt)

**Support:** DFG

**Contact:** S. Kersting, M. Kohler

### References


[1] B. Götz, S. Kersting, and M. Kohler. Estimation of an improved surrogate model in uncertainty quantification by neural networks. *Annals of the Institute of Statistical Mathematics*, 2021.

[2] M. Kohler and S. Kersting. Uncertainty quantification based on (imperfect) simulation models with estimated input distributions. Preprint, TU Darmstadt, 2019.

**Project: Image classification based on convolutional neural networks**

Image classifiers based on convolutional neural networks are defined, and the rate of convergence of the misclassification risk of the estimates towards the optimal misclassification risk is analyzed. Under suitable assumptions on the smoothness and structure of the aposteriori probability, the rate of convergence is shown which is independent of the dimension of the image. This proves that in image classification, it is possible to circumvent the curse of dimensionality by convolutional neural networks. Our classifiers are compared with various other classification methods using simulated data. Furthermore, the performance of our estimates is also tested on real images.

**Partner:** A. Krzyżak (Concordia University, Montreal)

**Support:** DFG

**Contact:** M. Kohler.

**References**


[1] M. Kohler, A. Krzyżak, and B. Walter. On the rate of convergence of image classifiers based on convolutional neural networks. Preprint, TU Darmstadt, 2020.

[2] M. Kohler and S. Langer. Statistical theory for image classification using deep convolutional neural networks with cross-entropy loss. Preprint, TU Darmstadt, 2020.


**Project: Analysis of the rate of convergence of neural network regression estimates which are easy to implement**

Recent results in nonparametric regression show that for deep learning, i.e., for neural network estimates with many hidden layers, we are able to achieve good rates of convergence even in case of high-dimensional predictor variables, provided suitable assumptions on the structure of the regression function are imposed. The estimates are defined by minimizing the empirical $L_2$ risk over a class of neural networks. In practice it is not clear how this can be done exactly. In this project we analyze the rate of convergence of neural network regression estimates which are easy to implement. We introduce various such estimates and show that they are able to achieve the one-dimensional rate of convergence (up to some logarithmic factor) in case that the regression function satisfies the assumptions of projection pursuit. The results are illustrated by applying the estimates to simulated data.

**Partner:** A. Krzyżak (Concordia University, Montreal), H. Walk (Universität Stuttgart)

**Contact:** A. Braun, M. Kohler.

**References**


[1] A. Braun, M. Kohler, and A. Krzyżak. Analysis of the rate of convergence of neural network regression estimates which are easy to implement. Preprint, TU Darmstadt, 2019.

[2] A. Braun, M. Kohler, and H. Walk. On the rate of convergence of a neural network regression estimate learned by gradient descent. Preprint, TU Darmstadt, 2019.


**Project: Analysis of over-parametrized deep neural networks**

Recently it was shown in several papers that backpropagation is able to find the global minimum of the empirical risk on the training data using over-parametrized deep neural networks. In this project a similar result is shown for deep neural networks with the sigmoidal squasher activation function in a regression setting, and a lower bound is presented which proves that these networks do not generalize well on a new data in the sense that networks which minimize the empirical risk do not achieve the optimal minimax rate of convergence in estimation of smooth regression functions.

**Partner:** A. Krzyżak (Concordia University, Montreal)

**Contact:** M. Kohler.

### References


[1] M. Kohler and A. Krzyżak. Over-parametrized deep neural networks minimizing the empirical risk do not generalize well. *Bernoulli*, 2021.


### Project: Analysis of the rate of convergence of deep recurrent neural network estimate

In this project we study the rate of convergence of deep recurrent neural network estimates. In a first step we consider a regression problem with dependent data. Regularity assumptions on the dependency of the data are introduced, and it is shown that under suitable structural assumptions on the regression function a deep recurrent neural network least squares estimate is able to circumvent the curse of dimensionality.

**Partner:** A. Krzyżak (Concordia University, Montreal)

**Contact:** M. Kohler.

### References


[1] M. Kohler and A. Krzyżak. On the rate of convergence of a deep recurrent neural network estimate in a regression problem with dependent data. Preprint, TU Darmstadt, 2020.


## 2 Collaborative Research Projects and Cooperations

The department is involved in a number of interdisciplinary research projects including excellence projects, collaborative research centres and priority programs. This section gives a brief overview of these activities.

## 2.1 Collaborative Research Centre SFB 805

The Collaborative Research Centre SFB 805 “Control of Uncertainty in Load-Carrying Structures in Mechanical Engineering” was established in January 2009. The third funding period started in January 2017 and runs through 2020. The main objective is the development of methods and techniques to control uncertainties in the development, production and usage of load-carrying structures to significantly enhance their safety, reliability and economic efficiency. While uncertainty cannot be avoided or eliminated, its influence during the product lifecycle – from material properties to production and usage – can be controlled and hence minimized. Especially in the area of light-weight construction, the trade-off between low weight and low production cost on one hand and adequate load-bearing capacity on the other hand makes the influence of uncertainties critical. Hence, the control of uncertainty is of significant importance and is therefore a focus of the research to be conducted by the SFB 805.

The control of uncertainty through the entire process chain of development, production and usage necessitates a close interdisciplinary cooperation of engineers, mathematicians

and legal experts. The mathematical research assesses the influence and effects of uncertainty and its interdependencies. It then derives optimal solution strategies for processes with minimal uncertainty and optimal design concepts for load-carrying systems from this. The Department of Mathematics is involved in four projects of the SFB 805 (with P.I.s Kohler, Pfetsch, Ulbrich). To deal with uncertainty, the tool of robust optimization is applied, where complex products are optimized while controlling inherent uncertainty already in the product development phase. Uncertainty may occur because of uncertain loadings, uncertain material properties or unknown user behavior. A further source of uncertainty are models that do not adequately describe reality. To detect such model uncertainty, mathematical methods like optimal design of experiments and parameter identification are applied. Furthermore, the SFB 805 examines the use of active elements to react on uncertainty in a load-carrying system. The question of optimal placement of active elements in the structure is a challenging nonlinear mixed-integer optimization problem. Another focus lies in the optimal design of resilient technical systems, which are able to tolerate component failures. Additionally an attempt is made to control stochastic uncertainty at the planning stage of a product. Therefore knowledge of the effects of unavoidable occurring (random) fluctuations in the production or usage are required. Based on suitable models of the underlying process, methods of nonparametric regression were and will be developed to do this in an efficient way.
The homepage of the SFB 805 is reachable at `www.sfb805.tu-darmstadt.de`.

## 2.2 Collaborative Research Centre SFB 1194

The Collaborative Research Centre SFB 1194 “Interaction between Transport and Wetting Processes”, established in 2016 and prolonged in 2020, involves researchers from the TU Darmstadt, the Max Planck Institute for Polymer Research Mainz and the Leibniz Institute for Polymer Research Dresden. Their common goal is the fundamental analysis of the interaction between transport and wetting processes. The SFB focuses particularly on the interactions between wetting and transport processes when – simultaneously to momentum transport – also heat and mass transport phenomena occur, complex fluids are involved or complex surfaces are examined. Although the physical phenomena take place only in a range of nanometres or micrometres, they often determine the efficiency of the overall process and the resulting product quality. Therefore, fundamental processes and phenomena are investigated over a wide range of length scales (nano-micro-macro) and the transfer of basic research to applications is an integral part of the research program.
The SFB comprises 20 projects in the current second funding period, grouped into three research areas: A – Generic Experiments, B – Modeling and Simulation and C – New and Improved Applications. The Department of Mathematics is involved in four projects of the SFB 1194 (PIs: Bothe, Gründing, Marschall, Ulbrich), which are allocated to research area B, and in the research data management project.
Research area B includes developments of mathematical models and numerical simulation techniques that describe the interaction of wetting processes with momentum, heat and mass transport, using physics-based approaches. These models and simulations are closely linked and validated with the generic experiments performed in research area A. Once validated, these models and simulations are not subjected to the same constraints as the generic experiments, e.g. with respect to resolution or parameter space, and allow for detailed analysis of local data some of which are not accessible by experiments; hence they

contribute essential information to the overall understanding of the phenomena. Based on sensitivity as well as adjoint-based derivative computations, parameter identification, derivative-based optimization, and optimal experimental design are performed. This leads to suggestions for improved designs and process control for specific applications, such as in printing or heat transfer devices (project area C). Throughout the future funding periods of the SFB, the complexity of the fluids and surfaces being examined will be further increased.

## 2.3 Collaborative Research Centre Transregio TRR 146

Multiscale modeling is a central topic in theoretical condensed matter physics and materials science. One prominent class of materials, whose properties can rarely be understood on one length scale and one time scale alone, is soft matter. The properties of soft materials are determined by an intricate interplay of energy and entropy, and minute changes of molecular interactions may lead to massive changes of macroscopic system properties.
In a joint effort of physicists, chemists, applied mathematicians, and computer scientists, the Collaborative Research Center TRR 146 investigates some of the most pressing problems in multiscale modeling, viz.

- Dynamics: In the past, multiscale, coarse-graining approaches have to a large extent focused on static equilibrium properties. However, a thorough understanding of the coarse-grained dynamical system properties is necessary if one wants to apply multiscale concepts to the study of transport and nonequilibrium processes.
- Coarse-graining and mixed resolution: In many applications, selected small (e.g., functional) regions of a material must be treated in great detail, whereas the large bulk can be modeled at a coarse-grained level. Simulation schemes are desirable, where fine-grained and coarse-grained regions can dynamically be assigned to the current state of the system. In this context, we will also have to re-analyze fundamental aspects of coarse-graining from a mathematical point of view.
- Bridging the particle-continuum gap: So far, only few successful attempts have been made to combine particle models of soft matter with continuum models in a nontrivial fashion. Multiscale schemes for particle models have mostly been developed in the soft matter community, whereas schemes for treating continuum models with variable resolution are developed in the applied mathematics community. In the CRC-TR, we will bring these two communities together to advance the field as a whole.

Problems addressed in the TRR 146 require a massive interdisciplinary effort at the level of fundamental science and algorithmic development. The TRR 146 brings together scientists with a complementary expertise in a wide range of modeling methods. Also one professor of the Department of Mathematics (Egger) is under the group of principal investigators.

## 2.4 Collaborative Research Centre Transregio TRR 154

The Collaborative Research Centre Transregio TRR 154 “Mathematical Modelling, Simulation and Optimization Using the Example of Gas Networks” was established in 2014 and after successful evaluation is now in its second funding period. The energy transition (“Energiewende”) in Germany and its success are currently in the focus of public interest.

This transition is of central significance to society, politics, and science, since Germany, like many other industrial nations, finds itself in a situation of dramatically increased dependence on a reliable, secure, and affordable energy supply. At the same time, the request for clean, environment and climate-friendly energy generation is as large as never before. In order to achieve this and, in parallel, to master the nuclear power phase-out, natural gas as an energy source will play a pivotal role in the coming decades. Within this time span, a sufficient amount of natural gas will be available; it will be readily accessible, tradable, and storable. Nevertheless, the focus on an efficient natural gas supply implies a multiplicity of problems concerning gas transport and network technology as well as the consideration of market-regulatory conditions, and also the coupling with other energy sources. As an example, we mention that gas carriers must provide evidence that, within given technical capacities, all contracts which come into existence on the market are physically and technically satisfiable.

The aim of the TRR 154 is to offer answers to these challenges by using methods of mathematical modelling, simulation, and optimization and, in turn, to provide solutions of increased quality. Novel mathematical findings are required in different areas such as mathematical modelling, numerical analysis, simulation and integer, continuous, and stochastic optimization as well as equilibrium problems in order to achieve this aim. As examples, we mention the modelling and analysis of complex networks of hyperbolic balance equations including switches and the development of a mixed-integer optimization theory together with its algorithmic realisation for such networks including the handling of data uncertainty. Furthermore, efficient hierarchical numerical approximation techniques for the resulting algebraically coupled PDEs need to be developed and a sophisticated error control, taking the interaction with the mixed-integer optimization algorithms into account, is required.

The Department of Mathematics at TU Darmstadt has been involved in the collaborative research centre Transregio TRR 154 with Dr. Domschke and Professors Giesselmann, Egger, Lang, Pfetsch, Schwartz and Ulbrich. Furthermore, groups at Universität Erlangen-Nürnberg (speaker), HU Berlin, TU Berlin, Universität Duisburg-Essen, and Weierstraß-Institut für Angewandte Analysis und Stochastik (WIAS) are part of TRR 154.

The homepage of TRR 154 is reachable at `trr154.fau.de`.

## 2.5 Graduate School of Computational Engineering

Computational Engineering (CE) denotes computer based modeling, analysis, simulation, and optimization. It is a cost-effective, efficient and complementary approach to study engineering applications and to engineer new technical solutions when experimental investigations are too complex, risky, or costly. CE enables the creation of scalable models to support research, development, design, construction, evaluation, production, and operation of engineering applications which address key issues in future technology developments for the economy and society in areas such as energy, health, safety, and mobility. However, such engineering applications are becoming increasingly complex. Consequently, the theory and methodologies required to investigate corresponding systems become challenging.

With the Graduate School of Computational Engineering, TU Darmstadt was able to further strengthen its role in CE. The school enables highly talented PhD students to develop their scientific skills in a focused way, and to cooperate under optimal conditions in a highly stimulating interdisciplinary environment based on the interaction of Computer Science, Mathematics, and Engineering Sciences. Partnerships with well established research organizations as well as cooperation with industry increase the impact of the Graduate School. Building on the well established interdepartmental expertise at TU Darmstadt, the Graduate School focusses on the following key research areas: modeling and simulation of coupled multi-physics problems, simulation based optimization, and hierarchical multi-scale modeling and simulation. The research efforts in the above fields are accompanied by corresponding developments of methods of visualization, simulated reality, high-performance computing, verification and validation, as well as software engineering and lifecycle research. The PhD students work together within research foci comprising one or more of the above topics. The joint research on specially defined use cases will further strengthen the interdisciplinary skills and cooperation.

Eight professors of the Department of Mathematics are Principal Investigators within the Graduate School Computational Engineering (Aurzada, Bothe, Egger, Giesselmann, Lang, Pfetsch, Ulbrich, Wollner) with expertise in Probability Theory and Stochastic Analysis, Mathematical Modeling and Analysis, Numerical Analysis and Scientific Computing, Numerics of Partial Differential Equations, Discrete Optimization, and Nonlinear Optimization and Optimal Control. Four more members of the department are Research Group Leaders (Disser, Erath, Marschall, Schwartz) with scientific focus on Online Optimization, Numerical Analysis, Two-Phase and Interfacial Flows, and Discrete-Nonlinear Optimization. Together they supervise more than 14 interdisciplinary PhD projects within the Graduate School in close cooperation with a co-supervisor from Engineering or Computer Science. The field of Computational Electromagnetics is represented by one research assistant (Dölz), who is also a member of the Darmstadt Mathematical School.

## 2.6 Graduate School of Energy Science and Engineering

The mission of the Darmstadt Graduate School of Energy Science and Engineering is to educate tomorrow's leading Energy Engineers in a multidisciplinary field of expertise needed to identify and master the most demanding scientific, engineering, economic and social challenges in an interdisciplinary approach. The main challenge is viewed to be a continuous transition from the carbon-based, non-renewable primary energy sources of today to renewable and environmentally friendly energy resources of tomorrow.

The optimal strategy to meet this challenge is on the one hand to improve conventional energy technologies and render them progressively more efficient, to meet the ever more stringent demands on pollutant emissions, and on the other hand to simultaneously develop innovative, advanced renewable energy technologies, which must be brought to a competitive technological readiness level and provide safe, reliable and cost-effective solutions.

Two professors of the Department of Mathematics are Principal Investigators within the Graduate School Energy Science and Engineering (Lang, Ulbrich) with expertise in Numerical Analysis, Nonlinear Optimization and Optimal Control.

## 2.7 Priority Programme SPP 1748

Numerical simulation techniques are an essential component for the construction, design and optimization of cutting-edge technologies as for example innovative products, new materials as well as medical-technical applications and production processes. These important developments pose great demands on quality, reliability and capability of numerical methods, which are used for the simulation of these complex problems. Challenges are for example capture of incompressibility, anisotropy and discontinuities. Existing computer-based solution methods often provide approximations which cannot guarantee substantial, absolutely necessary stability criteria respectively fulfill them. Especially in the field of geometrical and material non-linearity such uncertainties appear. Typical problems are insufficient or even pathological stress approximations due to unsuitable approximation spaces as well as weak convergence behavior because of stiffening effects or mesh distortion. Similar problems arise in the framework of crack and contact problems. Here the resolution of the local discontinuities as well as their evolution plays a key role. The scientists of the DFG Priority Programme 1748 "Reliable Simulation Techniques in Solid Mechanics. Development of Non-standard Discretization Methods, Mechanical and Mathematical Analysis" have set themselves the goal to establish a new quality in the area of non-conventional discretization methods. Herein the work program of the SPP is founded:

1. The evolution of modern non-conventional discretization methods,
2. their mathematical analysis and
3. the exploration of their application limits on the basis of suitable benchmark problems

The SPP1748 is coordinated by Prof. Dr.-Ing. habil. Jörg Schröder (Universität Duisburg-Essen). The current second funding period started in 2018, comprising 11 scientific projects.
The Department of Mathematics participates with two PIs (Walloth, Wollner) during the second funding period.

## 2.8 Priority Programme SPP 1962

Many of the most challenging problems in the applied sciences involve non-differentiable structures as well as partial differential operators, thus leading to non-smooth distributed parameter systems. Those systems are investigated by the DFG Priority Programme 1962 "Non-smooth and Complementarity-based Distributed Parameter Systems: Simulation and Hierarchical Optimization". The non-smoothness considered in this DFG-Priority Programme typically arises (i) directly in the problem formulation, (ii) through inequality constraints, nonlinear complementarity or switching systems, or (iii) as a result of competition and hierarchy.
In fact, very challenging applications for (i) come from frictional contact problems, or non-smooth constitutive laws associated with physical processes such as Bean's critical state model for the magnetization of superconductors, which leads to a quasi-variational inequality (QVI) problem; for (ii) are related to non-penetration conditions in contact problems, variational inequality problems, or inequality constraints in optimization problems which, upon proper re-formulation lead to complementarity problems and further, by means of non-linear complementarity problem (NCP) functions, to non-smooth systems similar to (i); and for (iii) come from multi-objective control systems or leader-follower principles, as they can be found in optimal system design in robotics and biomechanics. Modeling "competition" often leads to generalized Nash equilibrium problems (GNEPs)

or partial differential games. Moreover, modeling "hierarchy" results in mathematical programs with equilibrium constraints (MPECs), a class of optimization problems with degenerate, non-smooth constraints. All of these problems are highly nonlinear, lead to QVIs, and represent rather novel mathematical structures in applications based on partial differential operators. In these and related applications, the transition from smoothing or simulation-based approaches to genuinely non-smooth techniques or to multi-objective respectively hierarchical optimization is crucial.
The SPP1962 is coordinated by Michael Hintermüller (HU Berlin/WIAS Berlin). The first funding period started in 2016 and ran until 2019, comprising 23 scientific projects. The current second funding period started in 2019, comprising 22 scientific projects.
The Department of Mathematics participated in the SPP1962 with three projects (Schwartz, Ulbrich, Wollner) during the first funding period and now participates with two projects (Ulbrich, Wollner) during the second funding period.

## 2.9 Priority Programme SPP 2026

The DFG-priority programme 2026 "Geometry at infinity" combines research in differential geometry, geometric topology, and global analysis. Crossing and transcending the frontiers of these disciplines it is concerned with convergence and limits in geometric-topological settings and with asymptotic properties of objects of infinite size. The overall theme can roughly be divided into the three cross-sectional topics convergence, compactifications, and rigidity.
Examples of convergence arise in Gromov-Hausdorff limits and geometric evolution equations. The behaviour of geometric, topological and analytic invariants under limits is of fundamental interest. Often limit spaces are non-smooth so that it is desirable to generalize notions like curvature or spectral invariants appropriately. Limits can also be used to construct asymptotic invariants in geometry and topology such as simplicial volume or $L^2$-invariants. Compactifications reflect asymptotic properties of geometric objects under suitable curvature conditions.
Methods from topology, differential geometry, operator algebras and probability play a role in this study. Important issues are boundary value problems for Laplace or Dirac type operators, both in the Riemannian and Lorentzian setting, as well as spectral geometry and Brownian motion on non-compact manifolds. Besides continuous deformations rigidity is essential for many classification problems in geometry and topology. It appears in geometric contexts, typically in the presence of negative curvature, and in topological and even algebraic settings. Rigidity also underlies isomorphism conjectures relating analytic, geometric and homological invariants of infinite groups and more general coarse spaces. The priority programme supports individual research projects and coordinated research activities. These activities will ensure a coherence of research directions, identify promising lines of interdisciplinary research, encourage the establishment of new research cooperations, and realize gender equality measures.
The SPP 2026 has two funding periods, 2017-2020 (33 funded projects) and 2020-2023 (46 funded projects).
The coordinator of the SPP 2026 is Prof. Dr. Bernhard Hanke from the Universität Augsburg.
At the TU Darmstadt, Elena Mäder-Baumdicker participates in the SPP 2026 with projects in both funding periods.

## 2.10 Research Unit Symmetry, Geometry, and Arithmetic

The DFG Research Unit 1920 "Symmetry, Geometry and Arithmetic" examines current issues in modern arithmetic. An important and key theme is the investigation of absolute Galois groups and their generalizations. These elegantly code arithmetic information which can be extracted through the study of these groups and their representations. The researchers, who are based in Heidelberg and Darmstadt, are hoping that by dovetailing motivic homotopy theory, deformation theory, Iwasawa theory, the theory of automorphic forms and $L$-functions, they will be able to draw interesting conclusions from new insight into one of these areas which they can apply to the others, in a contemporary vision and modern understanding of basic mathematical research.

As a principal investigator Jan Bruinier is part of this research unit with a project centered around special cycles on the moduli space of abelian surfaces and their connections with $L$-functions. The spokesperson is Alexander Schmidt from the Universität Heidelberg.

## 2.11 LOEWE Research Unit USAG: Uniformized Structures in Arithmetic and Geometry

The LOEWE research unit Uniformized Structures in Arithmetic and Geometry (USAG) aims at joining the broad expertise of TU Darmstadt and GU Frankfurt in the fields of number theory and arithmetic/algebraic geometry. The spokesperson is Jan H. Bruinier.

The concept of uniformization, which goes back to famous works by Riemann and Klein from the 19th century, allows to replace a complicated geometric space with a much simpler one without changing the local structure. The complexity is then described with inner symmetries of the simpler space. This basic idea has proven to be very effective. The aim of the LOEWE research unit is to gain new insights into current arithmetic and geometric classification problems by combining different techniques of uniformization.

Our research program focusses on the following three research areas: A Special Subvarieties, B Automorphic Forms, and C Variation of Geometry.

In research area A we explore Orthogonal Shimura Varieties and the Kudla Conjecture, in research area B we investigate Borcherds-Products as well as Vertex Algebras, and in research area C we study the Uniformization of Spherical Varieties, the Anabelian Section Conjecture, as well as Tropical Moduli Spaces. The research areas A, B, and C are mutually interconnected and techniques of uniformization are crucial in our research approaches.

## 2.12 Scientific and Industrial Cooperations

In the following we list all scientific and industrial projects by names of the researcher of our department in alphabetic order, by names of partners in universities and industry, and the title of the project.

**Frank Aurzada**

- Mikhail Lifshits (St. Petersburg): research cooperation.
- Sumit Mukherjee (Columbia): research cooperation.
- Ofer Zeitouni (Technion): research cooperation.

**Volker Betz**

- Dr. Daniel Ueltschi (University of Warwick): Spatial random permutations and Bose-Einstein condensation.
- Prof. Erwin Bolthausen (University of Zürich): Enhanced binding via path integrals.
- Dr. Benjamin Goddard (University of Edinburgh): Nonadiabatic Transition through Born-Oppenheimer surfaces.
- Dr. Dirk Zeindler (University of Lancaster): Cycle counts in random permutations.
- Prof. Lorenzo Taggi (La Sapienza, Roma): Spatial Random Permutations.
- Dr. Benjamin Lees (University of Bristol): Loop models.

**Dieter Bothe**

- Freudenberg New Technologies SE & Co. KG: Simulation of viscoelastic flows with OpenFOAM.
- Prof. Dr. Günter Brenn (TU Graz): Numerical and experimental analysis of bubbles rising in viscoelastic liquids.
- Prof. Dr. Wolfgang Dreyer (WIAS Berlin): Continuum thermodynamics of fluid mixtures.
- Prof. Dr. Pierre-Étienne Druet (WIAS Berlin): Modeling and analysis of fluid mixtures.
- Dr. Matthias Köhne (Universität Düsseldorf): Analysis of dynamic contact lines.
- Prof. Dr. Michel Pierre (ENS Cachan, Antenne de Bretagne): Modeling and analysis of reaction-diffusion systems.
- Prof. Dr. Michael Schlüter (Institut für Mehrphasenströmung, TU Hamburg-Harburg): Numerical and experimental analysis of reactive mass transfer at bubbles.
- Dr. Kathrin Schulte (Universität Stuttgart): Direct Numerical Simulation of binary droplet collisions.
- Prof. Dr. Akio Tomiyama (Kobe University): Mass transfer under surfactant influence.

**Regina Bruder**

- Ministry of Education Hesse and Lower Saxony: Development of concepts for further teacher training, project MAKOS (Hesse; projects), ELMA (Lower Saxony).
- Prof. Dr. Wolfram Koepf (Universät Kassel) and Prof. Dr. Rolf Biehler (Universät Paderborn) and Prof. Dr. Reinhard Hochmuth (Universät Hannover): Project VEMINT, Development of bridge courses in mathematics.
- Dr. Eva Sattlberger and Dr. Jan Steinfeld (Ministry of Education Vienna, Austria), Prof. Dr. Tina Hascher (Universät Bern, Switzerland, Dr. Torsten Linnemann (Universät Basel, Switzerland), Prof. Dr. Stefan Siller (Universät Würzburg): O-M-A: project for modelling competencies for the examination MATURA in Austria.

- Prof. Dr. Vincent Geiger, ACU Brisbane, Australia: DAAD-project about the development of challenging learning tasks in digital learning environments.
- Prof. Dr. Olaf Koeller (IPN Kiel) and expert group: Scientific company of mathematics lessons in Hamburg.

**Jan H. Bruinier**

- Prof. Dr. B. Howard (Boston College) and Prof. Dr. T. Yang (University of Wisconsin at Madison): Arithmetic intersection theory on Shimura varieties.
- Prof. Dr. J. Funke (University of Durham) and Prof. Dr. O. Imamoglu (ETH Zürich): Regularized theta liftings and periods of modular functions.
- Dr. Markus Schwagenscheidt (Universität zu Köln): Automorphic products.
- Prof. Dr. S. Kudla (University of Toronto) and Siddarth Sankaran (University of Manitoba): Green currents and Whittaker functions.
- Prof. Dr. T. Yang (University of Wisconsin) and Stephan Ehlen (Universität zu Köln): Higher automorphic Green functions.
- Prof. Dr. M. Möller (Goethe-Universität Frankfurt): Cones of effective divisors.

**Yann Disser**

- Andreas Bärtschi (Los Alamos Natural Laboratory): Collaborative delivery.
- Prof. Dr. Aaron Bernstein (Rutgers University): Incremental maximization.
- Dr. Jérémie Chalopin (Aix-Marseille University): Graph exploration and delivery.
- Prof. Dr. Andreas Feldmann (Charles University): Highway dimension, online optimization.
- Dr. Oliver Friedmann (Ziggeo, New York): Simplex algorithm.
- Dr. Martin Groß (RWTH Aachen): Incremental maximization.
- Dr. Danny Hermelin (Ben Gurion University): Dynamic parameterized algorithms.
- Dr. Wasiur R. KhudaBukhsh (Ohio State University): Approximate lumpability.
- Prof. Dr. Max Klimm (TU Berlin): Graph exploration, secretary leasing.
- Prof. Dr. Jochen Könemann (University of Waterloo, Canada): Highway dimension.
- Prof. Dr. Adrian Kosowski (Paris Diderot University): Collaborative exploration.
- Prof. Dr. Jannik Matuschke (KU Leuven): Robust flows.
- Prof. Dr. Matúš Mihalák (Maastricht University): Graph exploration and delivery.
- Prof. Dr. Michał Pilipczuk (University of Warsaw): Dynamic parameterized algorithms.

- Dr. Kevin Schewior (Universität zu Köln): Online Dial-a-Ride.
- Prof. Dr. Martin Skutella (TU Berlin): Simplex algorithm, network flows.
- Dr. Manuel Sorge (TU Wien): Dynamic parameterized algorithms.
- Prof. Dr. Angelika Steger (ETH Zürich): Collaborative exploration.
- Prof. Dr. Leen Stougie (CWI Amsterdam): Online Dial-a-Ride.
- Dr. Przemysław Uznański (University of Wrocław): Collaborative exploration.
- Dr. Anna Zych-Pawlewicz (University of Warsaw): Interval coloring.

**Pia Domschke**

- Prof. Dr. Mark A.J. Chaplain (University of St. Andrews, UK), Dr. Dumitru Trucu (University of Dundee, UK), Dr. Alf Gerisch (TU Darmstadt): Mathematical Modelling of Cancer Invasion.
- Jun.-Prof. Dr. Oliver Kolb (Universität Mannheim): Simulation and optimization of gas and water supply networks.

**Herbert Egger**

- Prof. Dr. Jürgen Dölz (Universität Bonn): Fast and oblivious convolution quadrature.
- Prof. Dr. Maria Lukacova, Dr. Burkhard Dünweg (JGU Mainz): Modeling and Simulation of spinodal decomposition.
- Prof. Dr. Matthias Schlottbom (University of Twente, The Netherlands): Model order reduction for inverse problems.
- Prof. Dr. Sebastian Schöps (TU Darmstadt): Electromagnetic interface problems.
- Prof. Dr. Cameron Tropea (TU Darmstadt), Prof. Dr. Jürgen Hennig (UK Freiburg): Estimation of wall-shear stress in human arteries.
- Prof. Dr. Bai-Xiang Xu (TU Darmstadt): Phasefield modeling of additive manufaturing processes.
- Dr. Liljegren-Sailer (Universität Trier): Numerical approximation of gas transport models.

**Thomas Eiter**

- Prof. Dr. G. P. Galdi (University of Pittsburgh): Existence and asymptotic structure of fluid flow past an obstacle.
- Prof. Dr. M. Kyed (Hochschule Flensburg): Time-periodic solutions to the Navier–Stokes equations.
- Prof. Dr. Y. Shibata (Waseda University, Tokyo): Free-boundary problems for the Navier–Stokes equations.

**Christoph Erath**

- Prof. Dr. Jens Markus Melenk (TU Wien) and Lorenzo Mascotto, PhD (University of Vienna) and Dr. Alexander Rieder (University of Vienna) and Prof. Ilaria Perugia, PhD (University of Vienna): dGFEM-BEM for Helmholtz problems.
- Prof. Dr. Stefan Kurz (TU Darmstadt) and Mehdi Elasmi (TU Darmstadt): Isogeometric FEM-BEM couplings.
- Prof. Dr. Herbert Egger (TU Darmstadt): Mixed FEM for parabolic problems.

**Anton Freund**

- Dr. J. Aguilera (TU Wien and Ghent University): Generalized Goodstein principles.
- Dr. F. Pakhomov (Steklov Mathematical Institute Moscow and Ghent University): Slow consistency.
- Prof. Dr. M. Rathjen (University of Leeds): Normal functions in reverse mathematics, Uniform Kruskal theorem, Generalized Goodstein principles.
- Prof. Dr. A. Weiermann (Ghent University): Uniform Kruskal theorem, Generalized Goodstein principles.

**Alf Gerisch**

- Prof. Dr. Mark A. J. Chaplain (University of St. Andrews, UK), Dr. Dumitru Trucu (University of Dundee, UK), Dr. Pia Domschke (Frankfurt School of Finance & Management), Prof. Dr. Kevin J. Painter (Heriot-Watt University, Edinburgh, UK), Prof. Dr. Thomas Hillen (University of Alberta, Canada), Dr. Andreas Buttenschön (UBC Vancouver, Canada): Mathematical Modelling of Cancer Invasion.
- Prof. Dr. Jens Lang (TU Darmstadt), Prof. Dr. Rüdiger Weiner, Dr. Helmut Podhaisky (Universität Halle-Wittenberg): Peer methods and their application in the Finite Element system KARDOS.
- Prof. Dr. Jonathan Sherratt (Heriot-Watt University, Edinburgh, UK): Mathematical modelling of wound healing.

**Jan Giesselmann**

- SFB Transregio 154: Mathematische Modellierung, Simulation und Optimierung am Beispiel von Gasnetzwerken, Speaker: Prof. Dr. Alexander Martin (Universität Erlangen-Nürnberg).
- Group of Prof. Dr. Christian Rohde (Universität Stuttgart): Uncertainty quantification in hyperbolic conservation laws.
- Prof. Dr. Martin Gugat (Universität Erlangen-Nürnberg): Boundary observers for hyperbolic balance laws.
- Dr. Sam Krupa (MPI Leipzig): A posteriori error estimates for discontinuous solutions to hyperbolic conservation laws.

- Prof. Dr. Siegfried Müller (RWTH Aachen): Model adaptive schemes for hyperbolic problems.
- Prof. Dr. Martin Frank (KIT), Dr. Graham Kaland: relaxation in moment methods for kinetic equations.
- Dr. Neeraj Sarna (MPI Magdeburg): Reduced models for hyperbolic equations.

**Karsten Große-Brauckmann**

- Prof. Dr. John Sullivan (TU Berlin): Networks and lattices.
- Prof. Dr. Robert Kusner (University of Massachusetts at Amherst): Constant mean curvature surfaces.
- Prof. Dr. Steffen Fröhlich (Universität Mainz): Minimal surfaces.

**Ulrich Kohlenbach**

- Prof. Dr. G. López-Acedo (University of Seville) and Prof. Dr. A. Nicolae (Babeş-Bolyai University) : A quantitative analysis of the 'Lion-Man' game.

**Michael Kohler**

- Prof. Dr. Adam Krzyżak (Concordia University, Montreal): Statistical theory for deep neural networks.
- Prof. Dr. Harro Walk (Universität Stuttgart): Rate of convergence of neural network regression estimates learned by gradient descent.
- SFB 805 (TU Darmstadt): Efficient estimation of uncertainty of technical systems.

**Katja Krüger**

- DZLM (Deutsches Zentrum für Lehrerbildung Mathematik): Online teachertraining courses for teachers in service.
- Dr. Gerda Werth (Universität Paderborn): History of mathematics eduction at the beginning of the 20th century.
- Prof. Hans Dieter Rinkens (Universität Paderborn): Understanding of Euler's identity on the basis of elementary mathematical knowledge .
- Prof. Anselm Lambert (Universität des Saarlandes) and Prof. Jürgen Roth (Universität Koblenz Landau) and Dr. Philipp Ullmann (Goethe Universität Frankfurt) and Prof. Markus Vogel (PH Heidelberg) and Prof. Ysette Weiss-Pidstrygach (Gutenburg Universität Mainz): Oberseminar Südwest.

**Burkhard Kümmerer**

- Prof. Dr. G. Alber (Fachbereich Physik, TU Darmstadt): Quantum Markov Processes.

- Prof. Dr. R. Gohm (Aberystwyth): Quantum System Theory, Quantum Markov Processes.
- Prof. Dr. H. Maassen (Nijmegen): Quantum Probability.

**Jens Lang**

- Prof. Dr. Weiner (Universität Halle-Wittenberg): IMEX-Peer methods.
- Prof. Dr. David Silvester (University of Manchester): Uncertainty quantification.
- Prof. Dr. Robert Scheichl (Universität Heidelberg): Uncertainty quantification.
- Prof. Dr. Martin Gugat (Universität Erlangen-Nürnberg): Probabilistic constrained optimization on flow networks.
- Dr. Rainald Ehrig (ZIB): Kardos programming.
- Dr. Annemarie Lang (Charite Berlin): Modeling of osteoarthritis.
- Prof. Dr. Bernhard A. Schmitt (Universität Marburg): Discrete adjoint implicit Peer methods.
- Prof. Dr. Michael Hinze (Universität Koblenz-Landau): Model order reduction for flow problems.
- Prof. Dr. Weizhang Huang (University of Kansas), Lennard Kamenski (WIAS Berlin): Anisotropic mesh methods.

**Yingkun Li**

- Prof. Tonghai Yang (UW Madison, USA): Research on modular forms.

**Elena Mäder-Baumdicker**

- Prof. Dr. Jonas Hirsch (Universität Leipzig): Analysis of Willmore surfaces.
- Prof. Dr. Rob Kusner (University of Massachusetts at Amherst): Morse theory of Willmore surfaces.
- Dr. Casey Kelleher (Princeton University): Fourth order geometric flows.
- Prof. Dr. Andrea Malchiodi (Scuola Normale Superiore Pisa): Entropies of geometric flows.
- Dr. Ben Lambert (University of Derby): Globally constraint flows.
- Prof. Dr. Jan Giesselmann (TU Darmstadt): Analysis and numerics of parabolic and hyperbolic geometric problems.
- Prof. Dr. Karsten Große-Brauckmann (TU Darmstadt): Minimal surfaces.

**Tomislav Marić**

– Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur 101 (LIMSI), Centre National de la Recherche Scientifique (CNRS), Orsay cedex, France: Hybrid Level Set / Front Tracking methods for numerical simulations of multiphase flows in geometrically complex solution domains.

– Mechancial and System Design Engineering, Hongik University 72-1, Sangsu-dong, Mapo-gu Seoul, 127-791, Korea: Hybrid Level Set / Front Tracking methods for numerical simulations of multiphase flows in geometrically complex solution domains.

**Holger Marschall**

– Freudenberg New Technologies SE & Co. KG: Simulation of viscoelastic flows with OpenFOAM.

– Institute of Catalysis Research and Technology (IKFT), Karlsruhe Institute of Technology (KIT), Germany: Diffuse-Interface Phase-Field methods.

– Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, UK: Diffuse-Interface Phase-Field methods.

– Institute of Energy and Climate Research, Forschungszentrum Jülich, Germany: Coupled simulation approaches for fuel-cells.

– BOSCH GmbH, Campus for Research and Advance Engineering, Renningen, Germany: Diffuse-Interface Phase-Field methods.

– ENGYS Ltd., Corporate Research, London, UK: Generalized Internal Boundaries for interface-tracking.

**Frederic Matter**

– Prof. Dr. Thorsten Theobald (Goethe Universität Frankfurt): Block Semidefinite Programs.

**Marc Pfetsch**

– Prof. Dr. Max Klimm (TU Berlin): Algorithms for Gas Transport Optimization.

– Prof. Dr. Martin Haardt (TU Ilmenau): Compressed Sensing in Signal processing.

– Dr. Christopher Hojny (Eindhoven University of Technology): Symmetry in Integer Programs.

– Dr. Pierre Le Bodic (Monash University, Australia): Estimating the Size of Branch-and-Bound Trees.

– Prof. Dr. Alexander Martin (FAU Erlangen-Nürnberg): Gas Transport Optimization.

– Prof. Dr. Sebastian Pokutta (Zuse Institut Berlin): Methods for Integer Programs.

– Prof. Dr. Marius Pesavento (TU Darmstadt): Mixed-Integer Programs in Signal Processing.

- Prof. Dr. Giovanni Rinaldi (IASI Rome): Separation of Oracle-Based Cutting Planes.
- Prof. Dr. Martin Skutella (TU Berlin): Algorithms for Gas Transport Optimization.
- Prof. Dr. Thorsten Theobald (Goethe Universität Frankfurt): Block Semidefinite Programs.
- Dr. Andreas Tillmann (TU Braunschweig): Recovery of Sparse Solutions.

**Pedro Pinto**

- Dr. Bruno Dinis (University of Lisbon): On variants of the proximal point algorithm.
- Prof. Dr. Laurenţiu Leuştean (University of Bucharest): On variants of the proximal point algorithm.

**Anna-Maria von Pippich**

- Prof. Dr. S. Herrero (Pontificia Universidad Católica de Valparaíso, Chile): Mock modular forms.
- Prof. Dr. Ö. Imamoglu (ETH Zurich): Higher Green's functions.
- Prof. Dr. J. Kramer (HU Berlin): Bounds on Arakelov invariants.
- Dr. G. Freixas i Montplet (CNRS Paris): Arithmetic Riemann–Roch theorems.
- Prof. Dr. Ä. Toth (Eötvös Loránd University, Budapest): Higher Green's functions.

**Ulrich Reif**

- Prof. Dr. Andreas Weinmann (Hochschule Darmstadt): Geometric Hermite Subdivision.
- Dr. Ahmad Lutfi Amri Ramli (Universiti Sains Malaysia): Spline Methods for Road Design.

**Nils Scheithauer**

- Prof. Dr. R. Borcherds (University of California, Berkeley): Automorphic forms and vertex algebras.
- Prof. Dr. J. van Ekeren, (Fluminense Federal University, Rio de Janeiro): Vertex algebras and Lie algebras.
- Prof. Dr. E. Freitag (Universität Heidelberg): Automorphic forms.
- Prof. Dr. V. Gritsenko (University of Lille 1 and National Research University HSE, Moscow): Automorphic forms.
- Prof. Dr. G. Höhn (Kansas State University, Manhattan): Vertex algebras and Lie algebras.
- Prof. Dr. M. Möller (Universität Frankfurt): Automorphic forms.

- Dr. S. Möller (Rutgers University, Piscataway): Automorphic forms and vertex algebras.
- Prof. Dr. R. Salvati Manni (La Sapienza, Rome): Automorphic forms.

**Alexandra Schwartz**

- Prof. Dr. Christian Kanzow (JMU Würzburg): Augmented Lagrangian Method for Cardinality-Constrained Optimization Problems.
- Prof. Dr. Tim Hoheisel (McGill University): Regularization Schemes for Mathematical Programs with Vanishing Constraints.
- Prof. Dr. Gregor Zöttl (FAU Erlangen-Nürnberg): Strategic Booking Decisions in the Entry-Exit-System.
- Prof. Dr. Veronika Grimm (FAU Erlangen-Nürnberg): Nonconvex Nash Games in the Gas Context.
- Prof. Dr. Martin Schmidt (Universität Trier): Nonconvex Nash Games in the Gas Context.
- Dr. Lars Schewe (University of Edingburgh): Nonconvex Nash Games in the Gas Context.
- Prof. Dr. Max Klimm (TU Berlin): Nonconvex Nash Games in the Gas Context.
- Dr. Andreas Tillmann (TU Braunschweig): Survey on Cardinality Optimization Methods.
- Prof. Dr. Daniel Bienstock (Columbia University): Survey on Cardinality Optimization Methods.
- Prof. Dr. Andrea Lodi (Ecole Polytechnique Montreal): Survey on Cardinality Optimization Methods.
- Prof. Dr. Giorgia Oggiono (University of Brescia): Retailer Competition.

**Christian Stinner**

- Prof. Dr. Tomasz Cieślak (Polish Academy of Sciences, Warsaw): Blow-up in Keller-Segel models.
- Dr. Philippe Laurençot (Directeur de Recherches CNRS, University Paul Sabatier of Toulouse): Chemotaxis models.
- Prof. Dr. Mária Lukácová (Universität Mainz): Multiscale models for tumor cell migration.
- Dr. Nikolaos Sfakianakis (University of St. Andrews): Multiscale models for tumor cell migration.
- Prof. Dr. Christina Surulescu (TU Kaiserslautern): Multiscale models for tumor cell migration.

– Prof. Dr. Michael Winkler (Universität Paderborn): Chemotaxis models.

**Stefan Ulbrich**

– Prof. Dr. Herbert de Gersem (TU Darmstadt): Optimization under Uncertainty.

– Prof. Dr. Serge Gratton (INP ENSEEIHT Toulouse): Subspace Decomposition Methods for Optimization.

– Prof. Dr. Peter Groche (TU Darmstadt): Identification of Model Uncertainty.

– Prof. Dr. Martin Gugat (FAU Erlangen-Nürnberg): Optimal Control of Hyperbolic Conservation Laws.

– Prof. Dr. Michael Hintermüller (WIAS Berlin): Optimal Control of Hyperbolic Conservation Laws.

– Prof. Dr. Michael Hinze (Universität Hamburg): Model Order Reduction in Optimization.

– Prof. Dr. Christian Kirches (TU Braunschweig): Mixed-Integer Optimal Control.

– Dr. Paul Manns (TU Braunschweig): Mixed-Integer Optimal Control.

– Prof. Dr. Sebastian Schöps (TU Darmstadt): Optimization under Uncertainty.

– Prof. Dr. Michael Ulbrich (TU München): PDE- and VI-Constrained Optimization.

**Mirjam Walloth**

– Prof. Dr. Thomas Wick (Universität Hannover), Prof. Dr. Winnifried Wollner (TU Darmstadt), Katrin Mang (Universität Hannover): Adaptive numerical simulation of quasi-static fracture phase-field models.

– Prof. Dr. Andreas Veeser (University of Milan, Italy): A posterior error estimators for contact and obstacle problems.

– Dr. Marita Thomas (WIAS Berlin): Convergence of adaptive solution of phase-field models.

**Torsten Wedhorn**

– Dr. Paul Ziegler (TU München): Cycle classes on Shimura varieties.

– Prof. Dr. Eike Lau (Universität Bielefeld): Higher displays.

– Arthur Le Bras (Jussieu, Paris): Structures on prismatic cohomology.

**Cornelia Wichelhaus**

– Dr. Liron Ravner (University of Amsterdam): Inference for fluid systems.

**Winnifried Wollner**

- Prof. Dr. Jörn Behrens (Universität Hamburg): Goal-Oriented Adaptivity for Hyperbolic PDEs.
- Prof. Dr. Sue Brenner (Louisianna State University): Discretization of Gradient Constrained Optimization Problems.
- Dr. Caroline Geiersbach (WIAS Berlin): Stochastic Optimization with PDE Constraints.
- Prof. Dr. Luca Heltai (SISSA, Trieste): Pressure-Robust Stokes Elements.
- Prof. Dr. Adrian Hirn (HS Esslingen): Optimization of Systems with p-Structure.
- Prof. Dr. Christian Kreuzer (TU Dortmund): Finite Element Approximation of PDE Constrained Optimization Problems.
- Prof. Dr. Ulrich Langer (Universität Linz): Numerical Methods for Phase-Field Fracture.
- Dr. Alexander Linke (WIAS, Berlin): Pressure-Robust Stokes Elements.
- Prof. Dr. Matthias Maier (Texas A& M): Eigenvalue Optimization for Maxwell's Equation.
- Dr. Hannes Meinlschmidt (RICAM Linz): Regularity of Elliptic Systems.
- Prof. Dr. Ira Neitzel (Universität Bonn): Optimizing Fracture Propagation Using a Phase-Field Approach.
- Prof. Dr. Thomas Richter (Universität Magdeburg): Numerical Methods for Time Periodic Problems.
- Prof. Dr. Andreas Veeser (University of Milan): Finite Element Approximation of PDE Constrained Optimization Problems.
- Prof. Dr. Thomas Wick (Universität Hannover): Optimizing Fracture Propagation Using a Phase-Field Approach.

## 3 Teaching

Teaching of mathematics in our department can be divided into three categories: teaching in mathematical degree programmes, specific teaching activities for future mathematics teachers (in secondary and vocational education), and teaching mathematics to students in the sciences and engineering subjects (often described as 'service teaching'). Each of these teaching activities has its own characteristics in terms of mathematical content and style as well as in terms of specific regulations of corresponding degree schemes.

### 3.1 Degree Programmes in Mathematics

There are currently five mathematics programmes: the Bachelor's programme,two Master's programmes, taught in German and English, and two teaching programmes, the teaching programme for grammar schools as well as the Master of Education (teaching programme for vocational schools) (Diplom programme is being discontinued). The following table shows the enrolment numbers over the last 8 years:

**Students in Mathematics programmes**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|
| Bachelor | 646 | 581 | 535 | 518 | 480 | 435 | 424 | 440 |
| Master | 224 | 276 | 309 | 292 | 274 | 251 | 235 | 246 |
| Teacher (secondary) | 380 | 351 | 335 | 289 | 270 | 227 | 218 | 240 |
| Teacher (vocational) | 41 | 23 | 18 | 18 | 15 | 12 | 10 | 16 |

In the last few years the enrolment numbers have decreased. The decrease can be explained by the demographic change: although in percentage terms more young people do their A-levels, the number of school graduates in Hesse have decreased, from around 25.000 graduates in 2015 to 23.000 graduates in 2020. Also, the aptitude test ("Eignungsfeststellungsverfahren") does fall into effect. The aptitude test ensures that less eligible students do not apply in the first place or learn that they are not eligible during the test. The aptitude test has been reworked with effect for enrolment in winter semester 2016/17 to simplify the admission criteria.

**New enrolments**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|
| Bachelor | 177 | 150 | 122 | 126 | 120 | 134 | 122 | 118 |
| Master (incl. engl. Master) | 73 | 94 | 96 | 89 | 86 | 79 | 62 | 85 |
| Teacher (secondary) | 54 | 40 | 48 | 45 | 39 | 47 | 49 | 56 |
| Teacher (vocational) | 8 | 2 | 5 | 7 | 5 | 4 | 1 | 10 |

Looking at the number of students who turned up for their courses, it seems that the introduction of the aptitude test has a stronger effect on our Teaching programme than on our Bachelor programmes. We suspect that in both tracks it largely discourages some of the more weakly motivated students from applying, and especially those who might not have the intention to pursue university studies seriously.

With the academic year 2017/18, the study regulations for the Bachelor and Master programmes were modified, and the corresponding accreditations were successfully renewed until September 30, 2026, become effective by October 1, 2018. Due to the interdependencies between our Bachelor programme and our Teaching programme, also the study regulations for the latter had to be revised.

The programmes are studied together with a minor (Bachelor's and Master's programme) or a second subject (teaching programmes), which is typically a subject in which mathematics is applied. The standard choice of a minor can be one of computer science, economics, physics, chemistry and mechanics. Further subjects are available upon application (such as philosophy, psychology or digital philology). If students choose the option “Mathematics with Economics” (available both for Bachelor and Master), their minor is a combination of economics and computer science.

The Bachelor's programme has a duration of 6 semesters and finishes with a Bachelor's thesis on a mathematical topic. A unique feature of our Bachelor's programme are the optional bilingual courses. Both study fields “Mathematics” (with arbitrary minor) and “Mathematics with Economics” can be studied as a bilingual programme.
According to a survey during the orientation week in the winter semester 2019/20, about 26 % among the 118 Bachelor's students interviewed expressed the objective of obtaining the bilingual certificate.

Graduates of the Bachelor's programme have the option of taking up a job or continuing their studies in a Master programme. This can be the Master's programme at our department, at a different university or even a Master's programme in a different area based on their education in mathematics.

Our Master's programme has a duration of 4 semesters. It is centred on two in-depth specializations or focus areas within mathematics or, alternatively, one focus area in mathematics and one in a related subject in which mathematics is applied (such as computer science, economics, physics, chemistry or mechanics). The mathematical specializations (Vertiefungsrichtungen) are offered by the research groups in the department. Beside the two focus areas (at 18 CP each), there is room for additional courses in mathematics, minors and general studies. The topic of the Master thesis is selected in one of the two focus areas; in the case of a combination with an non-mathematical focus area, the topic of the Master thesis may be chosen from that other subject but has to be related to mathematics.

The structure of the English-taught Master's degree programme mathematics is close to the German-taught Master's programme. Deviating from the mandatory minor, the students can choose between taking a minor or additional mathematical courses on the master's level. Since its implementation the application as well as the enrolment numbers in the M.Sc. Mathematics are slowly but continuously increasing. Also, with the academic year 2020/21 our Bachelor's graduates begin to decide to continue their studies in the English-taught Master's programme.

The teaching programme for grammar schools has a duration of 9 semesters and can also be studied as a bilingual programme. Next to the mathematical part, students in this teaching programme study a second subject and take courses in pedagogy and education ("Grundwissenschaften"). The study programme closes with the first state examination ("Erstes Staatsexamen").

The Master of Education, the teaching programme for vocational schools, has a duration for 4 semesters and can only be studied by students who have graduated in a Bachelor of Education, or with a respective professional background or apprenticeship.

**Graduates of the Bachelor programme**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Total | 122 | 90 | 73 | 83 | 78 | 60 |
| Female students | 38 | 30 | 24 | 26 | 32 | 15 |
| Graduation within 3 years | 51 | 31 | 20 | 25 | 26 | 19 |
| Graduation within 4 years | 107 | 68 | 48 | 61 | 55 | 39 |

**Graduates of the Master programme**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Total | 49 | 68 | 89 | 83 | 67 | 79 |
| Female students | 18 | 24 | 25 | 35 | 22 | 29 |
| Graduation within 2 years | 19 | 22 | 32 | 11 | 13 | 18 |
| Graduation within 3 years | 40 | 55 | 72 | 57 | 55 | 62 |

**Graduates in Education for Secondary Schools**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Total | 18 | 18 | 18 | 13 | 19 | 8 |
| Female students | 8 | 9 | 6 | 8 | 11 | 4 |
| Graduation within 9 semesters | 2 | 3 | 1 | 1 | 4 | 0 |
| Graduation within 11 semesters | 5 | 7 | 7 | 4 | 12 | 1 |

**Graduates in Education for Vocational Colleges**
(Source: Data Warehouse (DW), 23.02.2021)

| Programme | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Total | 11 | 6 | 7 | 7 | 1 | 0 |
| Female students | 5 | 2 | 3 | 3 | 0 | 0 |
| Graduation within 4 semesters | 7 | 0 | 1 | 0 | 0 | 0 |
| Graduation within 6 semesters | 10 | 5 | 4 | 3 | 0 | 0 |

**International exchange**

Many students choose to study at a university abroad for one or two semesters, typically in their third year.

The department provides general information (online and through regular information events) as well as individual advice for students who plan a period of time abroad and also maintains contacts with various popular destinations abroad. Upon their return, students are briefly interviewed about their experience. We provide these information for future outgoing students in a list that documents our partner universities and relevant information about them. In addition, students are encouraged to share their experiences in a field report.

Since 2019, incoming students are encouraged to take part in the department's buddy programme. In this programme, students of the department voluntarily help incoming students getting settled in Darmstadt and support them during the exchange period (one semester max.).
Close cooperation between the students and the department facilitates the transfer of their credits from abroad into their study programme in Darmstadt. This helps to avoid negative effects on the overall duration of studies.
The numbers of the academic year 2019/20 represent the students that applied for a semester abroad and accepted their nomination. Due to the Covid-19 pandemic, in summer semester 2020 almost all students cancelled their stay or had to cancel it due to cancellation by the partner universities.

| Academic year | 12/13 | 13/14 | 14/15 | 15/16 | 16/17 | 17/18 | 18/19 | 19/20 |
|---|---|---|---|---|---|---|---|---|
| Erasmus outgoers | 15 | 11 | 8 | 27 | 13 | 12 | 19 | 13 |
| Further outgoers | 9 | 7 | 7 | 12 | 7 | 7 | 3 | 5 |
| Incomers | 8 | 3 | 2 | 5 | 4 | 4 | 8 | 11 |

## 3.2 Teaching for Other Departments

Students in almost all study programmes of this university have to take at least one course in mathematics. The department teaches students in the engineering sciences (mechanical, electrical, civil engineering, material sciences), in computer science, the natural sciences (chemistry, physics, biology, geology), economics, the liberal arts, social sciences, human sciences and in architecture.

Service teaching comprises courses of a variety of different formats. There are large lecture courses providing a solid foundation in mathematics covering subjects such as basic analysis (calculus), differential equations, numerical methods and stochastics. For instance, there is a four semester cycle for students of Electrical Engineering, with 4 hours of lectures and 2 hours of exercise groups per week. There are also smaller courses, concentrating on special areas in mathematics used in particular disciplines, as, for instance, our one-semester statistics courses for students in Biology or the social sciences. In an innovative format (Team Teaching), the course "Mathematik für Chemiker" is taught jointly by a mathematician and a chemist.

**Service courses, no. participants, summer semester 2020**
(Source: TUCaN, 01.03.2021)

| | |
|---|---|
| Lineare Algebra II für Physikstudiernde | 226 |
| Höhere Mathematik II | 55 |
| Mathematik II für Bauwesen | 650 |
| Mathematik II für Elektrotechnik | 608 |
| Mathematik II für Informatik | 837 |
| Mathematik II für Maschinenbau | 850 |
| Mathematik IV für Elektrotechnik, Mathematik III für Informatik | 955 |
| Numerische Mathematik für Maschinenbau | 541 |
| Aussagen- und Prädikatenlogik | 679 |
| Elementare PDGL: Klassische Methoden | 90 |
| Treffpunkt Mathematik (MB II, Inf II) | 1164 |

Unfortunately, the number of attendees in the course Treffpunkt Mathematik I ET cannot be recalled any more.

| **Service courses, no. participants, winter semester 2020/21** (Source: TUCaN, 01.03.2021) | |
|---|---|
| Darstellende Geometrie | 223 |
| Höhere Mathematik I | 103 |
| Mathematik I für Bauwesen | 745 |
| Mathematik I für Elektrotechnik | 727 |
| Mathematik I für Informatik | 1115 |
| Mathematik I für Maschinenbau | 785 |
| Mathematik III für Bauwesen | 400 |
| Mathematik III für Elektrotechnik | 643 |
| Mathematik III für Maschinenbau | 718 |
| Mathematik für Chemiker | 180 |
| Mathematik und Statistik für Biologie | 222 |
| Statistik I für Human- und Sozialwissenschaft | 167 |
| Statistik I für Wirtschaftsingenieurwesen | 752 |
| Statistik I für Cognitive Science | 33 |
| Mathematik als gemeinsame Sprache der Naturwissenschaften | 121 |
| Treffpunkt Mathematik (ET I, MB I, Inf I) | 2010 |

It is one of the principles of this university that the department of mathematics is responsible for the teaching of mathematics across all subjects that require mathematics in their education. The importance of this aspect of our teaching activities was also borne out in the university's KIVA initiative, which among other aspects emphasises the critical role of mathematics education in the early phases of university studies in the sciences and engineering disciplines. Among our efforts to strengthen the basis for this mathematical education, the department has set up optional extra learning platforms under the name of "Treffpunkte Mathematik", which serve to give extra support to students in the large mainstream mathematics lecture courses. We also have established the "Lernzentrum Mathematik", a working space especially for students taking maths courses where more than seven hours a day research assistants (during the term) or advanced students (during the vacations) are available for assistance. One of the guiding ideas in these activities is the attempt to provide individual additional training and to improve the motivation of students from those other subjects through problems that relate mathematics better with themes from the own subjects. Participation and student evaluations for these extras show this approach to be a success.

## 3.3 Characteristics in Teaching

As in previous years, the efforts of the department of mathematics were rewarded in the "CHE-Hochschul Ranking Mathematik" (Bachelor as well as Master). According to the results published in 2018, the department of mathematics again holds one of the top positions among all universities in Germany, with excellent grades especially for "overall study situation" (1.6), "teaching programme" (1.9), "study entry phase" (1.9), "libraries" (1.5) and "IT infrastructure" (1,6). The "study entry phase" achieved the maximum point score. This success also reflects the emphasis on teaching methods at the department of mathematics. Our aim in teaching is to encourage and motivate students to actively pursue the understanding of the taught material. The learning of mathematics is an intellectual activity equally supported by classroom teaching, by individual work and study, and by team work, both with and without direct supervision.

Lectures present mathematical content and methods through personal presentation; the systematic development and exposition of the material in the lectures is intended to stimulate the students' mathematical intuition. Lectures are complemented by exercise groups and self-study, and by additional tutorials during the first year. One course usually contains of about 40% lectures and excercise classes with a time ratio of 2:1, and 60% of self-study.

In exercise classes, students work on problems and topics from the lecture with the support of a tutor and they are encouraged to present and discuss solutions to homework problems. Students are also expected to work on weekly sets of homework problems and to submit their solutions to their tutors for marking in order to obtain feedback. The department has implemented a format for tutorials in the first year, which are provided as an additional learning platform besides exercise groups. Here teaching assistants hold classroom sessions devoted to the review of current material from the lecture classes, current and past problems from the exercises, further examples, basic problems and illustrations, or to filling gaps in students' basic understanding. Regarded as an optional extra rather than as a mandatory part of the course, these tutorials are offered on a weekly alternating basis for the two main first-year courses (Analysis and Linear Algebra). Overall, all these activities are meant to support learning and to give students ample opportunity to improve and to test their knowledge and understanding.
Exercise groups and homework activities also form an integral part of most of the more advanced lecture courses, including those at Master's level. The Master's programme with its rich spectrum of focus areas to choose from, guarantees the concrete choices of specialization areas that would be available to any cohort of Master's students. The department also committed itself to devote any extra teaching capacity that was freed through the termination of freshers' enrolment in the summer semester to a corresponding strengthening of the Master's programme. Among other changes this has enabled us to allow for a larger number of teaching assistants to be employed in exercise classes for Master's level courses. These measures are meant to make our Master's programme even more competitive through its quality of teaching, greater reliability and impressive variety across a considerable breadth of research areas – both to retain our own Bachelor's students and to attract new Master's students from elsewhere. These strengthening of the Master's programme proved to be succesful by the accreditation in 2017/18 and has been continued accordingly.

Moreover, the department supports students in their learning experience by the following measures:

- the organisation or exercises and tutorials typically lies in the hands of experienced teaching assistants
- newly recruited tutors and student demonstrators undergo a dedicated training programme (which serves as an example of good practice in the context of the KIVA project, where similar ideas are being tested in other departments' teaching). In

2020, the Department of Mathematics received the seal of approval "Accredited Qualification Programme" (Gütesiegel "Akkreditiertes Qualifizierungsprogramm") from the Netzwerk Tutorienarbeit for the qualification of tutors.

- exercise groups are limited to a size of 20 students in the first year and 25 students from the second year onwards
- we provide an open learning environment with small learning groups
- all teaching staff offer weekly consultation hours for individual help and support
- the department provides altogether 12 student rooms (open access and reserved) with about 160 places for students to meet in learning groups, to work on their thesis or to prepare for their final exams
- the Mathematics Learning Center (Lernzentrum Mathematik) is staffed during opening hours by an assistant, available to answer questions; in addition textbooks and up-to-date material for the current teaching courses are provided
- there are 32 places for reading and studying in the departmental library (towards the end of 2012, this departmental library was incorporated into the new central university library)
- the department has three open access computer labs (with a total of 43 Linux machines) and two reserved computer labs (with a total of 15 Linux machines)
- since winter semester 2018/19 we annually organize the Analysis I "PowerLernTag" in cooperation with the department of physics. During this event, first-semester students in particular have the opportunity to prepare for the exam alone or with a study group, supported by experienced tutors.

## 3.4 E-Learning/E-Teaching in Academic Training

E-Learning is present in the Department of Mathematics in teaching and research. The Covid-19 pandemic gave our already established concepts in E-Learning and E-Teaching a massive boost. When the pandemic forced us all to work and study from home, lecturers came up with wide range of ideas to realise effective distance learning. Next to the below listed standards, a lot of lecturers are now using a lot more innovative concepts such as Flipped Classrooms and open-book-exams. Due to the efforts of the teaching and administrative staff, all lectures and examinations took place. We will use the experience from the challenges the Covid-19 pandemic provided and will continue to develop the E-Learning and E-Teaching concepts at the Department of Mathematics.

Overall standards and innovation of E-Learning and E-Teaching in the Department of Mathematics are:

- video capturing of almost all lectures during Covid-19
- the learning material and exercises of most of all math-courses are adaptably accessible for the students on the Moodle platform

- support for individual assessment (diagnostic tests, project TELPS)
- two online-lessons (task-diversity (MAVIE) and task-training) for teacher education, available in German as well as in English.
- In some research projects new websites and digital tools as test- or/and learning environments are developed, see projects MAKOS, CODI, BASICS Mathematik, Basics2go
- 4 - 5 half-year-online teacher training courses (in service) are running each semester. The course is taken by 60 - 80 teachers each year. The courses are organised by Prof. Dr. Bruder and Ömer Genc, responsible for the programme is Prof. Dr. Krüger.
- the task-database `www.madaba.de` with more than 1000 interesting math tasks supports teachers to prepare learning environments for math-lessons in school (secondary level I and II)
- Project TU-WAS: Development of a web-based task STACK collection to support tutors in their work and students with individual feedback. The platform STACK was first used in mathematical courses in the engineering study programmes in winter semester 2020/21

## Research and research-based development

In connection with the VEMINT project (cooperation between TU Darmstadt (Reif, Genc), University of Paderborn (Biehler) and University of Kassel (Eichler)) and TU Hannover (Hochmuth), some new E-Learning elements, e.g., for self-regulation in cooperation with psychologists (Dr. Bellhaeuser) and for training of basic school knowledge in mathematics with initial differentiation in a new group formation (Project MOODLE-PEERS), were developed for the preparatory math courses for beginner students. Since 2009, the preparatory course has been presented online via Moodle each winter semester for (as of winter semester 2020/21) almost all departments of TU Darmstadt. In winter semester 2020/21, 1800 students participated in the programme.

`https://www.mathematik.tu-darmstadt.de/studium/orientierungsangebote/mathematikvorkurs_1/index.de.jsp`

VEMINT project homepage:
`http://www.mathematik.uni-kassel.de/~vorkurs/Willkommen1.html`.

## MaViT: Mathematical Video Tutorials for Students of Engineering Sciences

Since the winter semester 2013/14 mathematical video tutorials have been produced to support students of Engineering Sciences to improve their mathematical basic skills singlehandedly.
Especially within the service courses taken by students of other departments a large heterogeneity can be observed regarding previous knowledge as well as learning strategies. The videos are embedded into interactive digital learning environments that give graded hints on how to solve the problem if required and provide a collection of additional exercises with sample solutions. In addition assisted forums offer the possibility to ask and

discuss questions regarding the respective content. Students can access the learning environments via Moodle.
Based on the know how of the project MaViT the presentation of solutions to the given tasks from the data bank is filmed now. More than 50 videos are stored on a central server. In the data bank of tasks weblinks to the videos are integrated. The evaluation shows that students appreciate the offered material for being valuable support of their learning process. An other new feature to support Mathematics I for electrical engineers was a weekly diagnostic test via Moodle. The task format was multiple choice. Indeed, the effort is very high to the construction of such tests. The effort stands with the interest of the students in the tests in no satisfactory relation.

### TU-WAS: Web-based task collection with STACK

As part of the project "Digitally Supported Teaching and Learning in Hesse", the state of Hesse is funding the development of innovative, digitally supported teaching and learning projects at TU Darmstadt. The TU-WAS project is aimed at mathematics courses in first-year engineering study programs. Classroom teaching is to be supplemented by the use of digital tasks in order to provide students with differentiated and individual support by means of a digital task arrangement. As part of the project, a web-based collection of tasks to support teaching is being developed in cooperation with the University Didactics Office (Reif, Celik, Genc, Metzler, Hoppe). The project was launched in 2019 and the platform was used for the first time in the winter semester 2020/21. In the long term, STACK should also be applicable for e-examinations.
`https://www.mathematik.tu-darmstadt.de/geometrie-und-approximation/arbeitsgruppe_geometrie_und_approximation/projekte/digitales_lehren_und_lernen/index.de.jsp`

## 3.5 Career-related Activities

In the series of lectures "Heute Mathe, morgen . . . ?" mathematicians present their current area of work, their vita and their employer. The main purpose is to give students a more personal insight into jobs for mathematicians outside the university than can be given by a job fair. A further intention is to give female students an easy opportunity to ask gender-specific questions and to present role models to the students.

22/01/2019 Alexander Milke (SKS Group),

29/01/2019 Marcel Zeuch (XTP AG),

30/04/2019 Pia Potrikus (Senacor),

21/05/2019 Miriam Hornauer, Clarissa Kreh (RELEX Solutions GmbH),

28/05/2019 Markus Schäfer, Aurora Posta (compertis Beratungs GmbH),

04/06/2019 Sara Tiburtius, Jochen Boy (PROSTEP AG),

11/06/2019 Dr. Debora Clever (ABB and TU Darmstadt),

18/06/2019 Charlotte Assing (LIDL Stiftung), 29/10/2019 Mareike Könen, Markus Schupp (EY),

05/11/2019 Friederike Steglich, Florian Sokoli (R+V Versicherung AG),

12/11/2019 Janine Herzog (Daniel Görich, Thomas Schneider), *DB Systel*

19/11/2019 Jutta Hübner (ESA),

26/11/2019 Daniel Pfeifer, Jan Weldert (INVENSITY),

03/12/2019 Sarah Fatemi, Stefan Walter (Finbridge),

24/11/2020 Maximilian Wei"s (Panda Insight),

01/12/2020 Dr. Thorsten Schindler (ABB AG),

12/12/2020 Dr. Martin Bolkart (Württembergische Versicherung),

In summer semester 2020, the talks in the series of "Heute Mathe, morgen . . . ?" had to be cancelled due to the Covid-19 pandemic. In winter semester 2020/21, the talks took place online.

# 4 Publications

## 4.1 Co-Editors of Publications

### 4.1.1 Editors of Journals

**Regina Bruder**

– *mathematik lehren* (Associate Editor)

**Jan H. Bruinier**

– *Forum Mathematicum* (Managing Editor)
– *Research in Number Theory* (Associate Editor)
– *Journal of Algebra and its Applications* (Associate Editor)
– *Annali dell'Università di Ferrara* (Associate Editor)

**Reinhard Farwig**

– *Annali dell'Università di Ferrara, Sez. VII Sci. Mat.* (Associate Editor)
– *Mathematica Bohemica* (Associate Editor)
– *Analysis (Berlin)* (Associate Editor)
– *Mathematische Nachrichten* (Associate Editor)

**Alf Gerisch**

– *PLOS ONE* (Academic Editor)

**Matthias Hieber**

– *Differential Integral Equations* (Editor-in-Chief)
– *Journal of Mathematical Fluid Dynamics* (Associate Editor)
– *Advances in Differential Equations* (Associate Editor)
– *Evolution Equations and Control Theory* (Associate Editor)
– *Mathematics of Climate and Weather Forecasting* (Associate Editor)
– *Springer Lecture Notes in Mathematical Fluid Dynamics* (Associate Editor)

**Ulrich Kohlenbach**

– *Annals of Pure and Applied Logic* (Coordinating Editor)
– *Computability* (Member of Editorial Board)
– *Journal of Mathematical Logic* (Advisory Editor)
– *Logical Methods in Computer Science* (Member of Editorial Board)

**Michael Kohler**

- *AStA Advances in Statistical Analysis* (Associate Editor)

**Katja Krüger**

- *Stochastik in der Schule* (Associate Editor)

**Jens Lang**

- *Applied Numerical Mathematics* (Editor)

**Martin Otto**

- *ASL Lecture Notes in Logic (book series)* (Editor)

**Marc Pfetsch**

- *Operations Research Letters* (Area Editor)
- *Mathematical Programming Computation* (Associate and Technical Editor)
- *INFORMS Journal on Computing* (Associate Editor)

**Anna-Maria von Pippich**

- *Elemente der Mathematik* (Member of the Editorial Board)

**Ulrich Reif**

- *Journal of Approximation Theory* (Associate Editor)
- *Computer Aided Geometric Design* (Associate Editor)
- *Jahresberichte der DMV* (Associate Editor)

**Werner Schindler**

- *Journal of Cryptographic Engineering* (Associate Editor)

**Thomas Streicher**

- *Applied Categorical Structures* (Associate Editor)
- *Mathematical Structures in Computer Science* (Associate Editor)

**Stefan Ulbrich**

- *Journal of Optimization Theory and Applications* (Associate Editor)
- *Optimization Methods and Software* (Senior Editor)
- *SIAM Journal on Optimization* (Associate Editor)
- *Asymptotic Analysis* (Associate Editor)
- *ESAIM: Control, Optimisation and Calculus of Variations* (Associate Editor)
- *SIAM Book Series: MOS-SIAM Series on Optimization* (Associate Editor)

**Winnifried Wollner**

- *International Journal of Applied and Computational Mathematics* (Associate Editor)

### 4.1.2 Editors of Proceedings

**Ulrich Reif**

- *Dagstuhl Reports, Volume 9, Issue 12* (jointly with Thomas A. Grandine and Jörg Peters)

## 4.2 Monographs and Books


[1] J. Biehl. *Adaptive Multilevel Optimization of Fluid-Structure Interaction Problems*. Dr. Hut Verlag, 2019.

[2] A. Birx. *Competitive analysis of the online dial-a-ride problem*. TU Prints, 2020.

[3] R. Bruder. *Traditions and Changes in the Teaching and Learning of Mathematics in Germanys*. Springer, Cham., 2020.

[4] R. Bruder, E. Brunner, and H.-S. Siller. *Teaching research under subject-specific perspectives - Mathematics*. Wiesbaden: Springer – https://doi.org/10.1007/978-3-658-24734-8_49-1 , 2020.

[5] K. Eickmeyer. *Logics with Invariantly Used Relations (Habilitationsschrift)*. TU Darmstadt tuprints, 2020.

[6] T. Gally. *Computational Mixed-Integer Semidefinite Programming*. sierke Verlag, 2019.

[7] O. Genc, F. Johlke, M. Schaub, N. Feldt-Caesar, R. Fournier, U. Roder, and R. Bruder. *Mathematics didactic research approaches and development work on digital diagnostic and support services at the TU-Darmstadt*. Waxmann Münster, 2020.

[8] O. Habeck. *Mixed-Integer Optimization with Ordinary Differential Equations for Gas Networks*. Dr. Hut Verlag, 2019.

[9] W. Herfort, K. H. Hofmann, and F. G. Russo. *Periodic Locally Compact Groups*. Walter de Gruyter GmbH, Berlin/Boston, 2019.

[10] K. H. Hofmann and S. A. Morris. *The Structure of Compact Groups*. Walter de Gruyter GmbH, Berlin/Boston, 2020.

[11] A. V. Hopp. *The Complexity of Zadeh's Pivot Rule*. Logos Verlag, 2020.

[12] B. M. Horn. *Shape Optimization for Frictional Contact Problems by a Bundle Trust-Region Method for Constrained Nonsmooth Problems*. sierke Verlag, 2019.

[13] F. H. József Lörinczi and V. Betz. *Feynman-Kac-Type Formulae and Gibbs Measures on Path Space, Volume 1*. de Gruyter, 2020.

[14] P. Kolvenbach. *Robust optimization of PDE-constrained problems using second-order models and nonsmooth approaches*. Dr. Hut Verlag, 2019.

[15] G. Pinkernell and R. Bruder. *Results from lesson protocols in the Lower Saxony CALiMERO project on CAS use in lower secondary education*. Springer Spektrum Wiesbaden – DOI: 10.1007/978-3-658-24292-3_11, 2019.

[16] H.-D. Rinkens and K. Krüger. *Die schönste Gleichung aller Zeiten. Von mathematischen Grundkenntnissen zur eulerschen Identität*. Springer Spektrum, 2020.

[17] J. M. Schmitt. *Optimal control of initial-boundary value problems for hyperbolic balance laws with switching controls and state constraints*. Dr. Hut Verlag, 2019.

[18] H.-S. Siller, R. Bruder, J. Steinfeld, E. Sattlberger, T. Linnemann, and T. Hascher. *Mathematical modelling in the context of a competency level modelling for a final examination*. Springer Spektrum, Berlin, Heidelberg – https://doi.org/10.1007/978-3-662-60815-9_7 , 2020.

[19] C. Wichelhaus. *Nonparametric estimation in stochastic networks*. TU Darmstadt, 2020.

## 4.3 Publications in Journals and Proceedings

### 4.3.1 Journals

[1] F. Abed, L. Chen, Y. Disser, M. Groß, N. Megow, J. Meißner, A. T. Richter, and R. Rischke. Scheduling maintenance jobs in networks. *Theoretical Computer Science*, 754:107–121, 2019.

[2] A. Alla, M. Hinze, P. Kolvenbach, O. Lass, and S. Ulbrich. A certified model reduction approach for robust parameter optimization with PDE constraints. *Advances in Computational Mathematics*, 45(3):1221–1250, 2019.

[3] L. C. Altherr, P. Leise, M. E. Pfetsch, and A. Schmitt. Resilient layout, design and operation of energy-efficient water distribution networks for high-rise buildings using MINLP. *Optimization and Engineering*, 20(2):605–645, 2019.

[4] B. Augner. Well-posedness and stability of infinite-dimensional linear port-Hamiltonian systems with nonlinear boundary feedback. *SIAM J. Control Optim.*, 57(3):1818–1844, 2019.

[5] B. Augner. Uniform exponential stabilisation of serially connected inhomogeneous Euler-Bernoulli beams. *ESAIM: Control, Optimisation and Calculus of Variations*, 26:Art. No. 110, 2020.

[6] B. Augner and D. Bothe. The fast-sorption-fast-surface-reaction limit of a heterogeneous catalysis model. *Discrete and Continuous Dynamical Systems: Series S*, 14(2):533–574, 2021.

[7] B. Augner and H. Laasri. Exponential stability for infinite-dimensional non-autonomous port-Hamiltonian systems. *Systems & Control Letters*, 144:Art. No. 104757, 2020.

[8] F. Aurzada. Large deviations for infinite weighted sums of stretched exponential random variables. *J. Math. Anal. Appl.*, 485(2):123814, 9, 2020.

[9] F. Aurzada, V. Betz, and M. Lifshits. Breaking a chain of interacting Brownian particles. Preprint, *A*nnals of Applied Probability, to appear, 2020.

[10] F. Aurzada, V. Betz, and M. Lifshits. Breaking a chain of interacting brownian particles: a gumbel limit theorem. Preprint, *T*eor. Veroyatn. Primen., to appear, 2020.

[11] F. Aurzada and M. Buck. Ruin probabilities in the Cramér-Lundberg model with temporarily negative capital. *European Actuarial Journal*, (10):261–269, 2020.

[12] F. Aurzada, M. Buck, and M. Kilian. Penalizing fractional Brownian motion for being negative. *Stochastic Process. Appl.*, 130(11):6625–6637, 2020.

[13] F. Aurzada and M. Kettner. Persistence exponents via perturbation theory: AR(1)-processes. *J. Stat. Phys.*, 177(4):651–665, 2019.

[14] F. Aurzada and M. Lifshits. How complex is a random picture? *J. Complexity*, 53:133–161, 2019.

[15] F. Aurzada and M. A. Lifshits. The first exit time of fractional Brownian motion from a parabolic domain. *Teor. Veroyatn. Primen.*, 64(3):610–620, 2019.

[16] F. Aurzada, S. Mukherjee, and O. Zeitouni. Persistence exponents in Markov chains. Preprint, Annales de l'Institut Henri Poincaré - Probabilités et Statistiques, to appear, 2019.

[17] F. Aurzada and S. Schwinn. Scaling limits for a random boxes model. *Adv. in Appl. Probab.*, 51(3):773–801, 2019.

[18] A. Bärtschi, J. Chalopin, S. Das, Y. Disser, B. Geissmann, D. Graf, A. Labourel, and M. Mihalák. Collaborative delivery with energy-constrained mobile robots. *Theoretical Computer Science*, 810:2–14, 2020.

[19] A. Bauer, S. Wegt, M. Bopp, S. Jakirlic, C. Tropea, A. Krafft, N. Shokina, J. Hennig, G. Teschner, and H. Egger. Comparison of wall shear stress estimates obtained by laser Doppler velocimetry, magnetic resonance imaging and numerical simulations. *Experiments in Fluids*, 60:112, 2019.

[20] B. Bauer, F. Heimrich, M. Kohler, and A. Krzyżak. On estimation of surrogate models for high-dimensional computer experiments. *Annals of the Institute of Statistical Mathematics*, 71:107–136, 2019.

[21] B. Bauer and M. Kohler. On deep learning as a remedy for the curse of dimensionality in nonparametric regression. *Annals of Statistics*, 47:2261–2285, 2019.

[22] S. Bechtel and M. Egert. Interpolation theory for sobolev functions with partially vanishing trace on irregular open sets. *J. Fourier Anal. Appl.*, 25:2733–2781, 2019.

[23] S. Bechtel, M. Egert, and R. Haller-Dintelmann. The kato square root problem on locally uniform domains. *Adv. Math.*, 375, 2020.

[24] S. Beckers, J. Behrens, and W. Wollner. Duality based error estimation in the presence of discontinuities. *Applied Numerical Mathematics*, 144:83–99, 2019.

[25] A. Bernstein, K. Däubel, Y. Disser, M. Klimm, T. Mütze, and F. Smolny. Distance-preserving graph contractions. *SIAM Journal on Discrete Mathematics*, 33(3):1607–1636, 2019.

[26] A. Bernstein, Y. Disser, M. Groß, and S. Himburg. General bounds for incremental maximization. *Mathematical Programming*, 2020.

[27] V. Betz and L. Taggi. Scaling limit of ballistic self-avoiding walk interacting with spatial random permutations. *Electron. J. Probab.*, 24:paper No. 74, 2019.

[28] A. Birx and Y. Disser. Tight analysis of the smartstart algorithm for online dial-a-ride on the line. *SIAM Journal on Discrete Mathematics*, 34(2):1409–1443, 2020.

[29] A. Bjelde, Y. Disser, J. Hackfeld, C. Hansknecht, M. Lipmann, J. Meißner, K. Schewior, M. Schlöter, and L. Stougie. Tight bounds for online TSP on the line. *ACM Transactions on Algorithms*, 17(1), 2020.

[30] A. Böttcher and H. Egger. Structure preserving discretization of Allen-Cahn type problems modeling the motion of phase boundaries. *Vietnam J. Math.*, 48:847–863, 2020.

[31] O. Braun, K. H. Hofmann, and L. Kramer. Automatic Continuity of Abstract Homomorphisms between Locally Compact and Polish Groups. *Transformation Groups*, 25:1–32, 2020.

[32] S. C. Brenner, L.-Y. Sung, and W. Wollner. Finite element methods for one dimensional elliptic distributed optimal control problems with pointwise constraints on the derivative of the state. *Optimization and Engineering*, 2020.

[33] S. C. Brenner, L.-Y. Sung, and W. Wollner. A one dimensional elliptic distributed optimal control problem with pointwise derivative constraints. *Numerical Functional Analysis and Optimization*, 41(13):1549–1563, 2020.

[34] K. Bringmann, B. Kane, and A.-M. von Pippich. Regularized inner products of meromorphic modular forms and higher Green's functions. *Commun. Contemp. Math.*, 21(5):1–35, 2019.

[35] R. Bruder. Stay tuned to Homeschooling. Basic needs in view. *mathematik lehren*, 221:42–43, 2020.

[36] R. Bruder and T. Hascher. Motivation to learn. *mathematik lehren*, 221:2–6, 2020.

[37] R. Bruder and T. Hascher. Scope for design. *mathematik lehren*, 221:7–11, 2020.

[38] R. Bruder and B. Krauth. (Again) puzzling from time to time. *mathematik lehren*, 221:38–41, 2020.

[39] R. Bruder and B. Kümmerer. Mathematik verbindet. ein neuer ansatz für das gymnasiale lehramt im darmstädter projekt mintplus in der qualitätsoffensive lehrerbildung. *GDM-Mitteilungen*, 107:27 – 32, 2019.

[40] J. H. Bruinier, B. Howard, S. Kudla, M. Rapoport, and T. Yang. Modularity of generating series of divisors on unitary Shimura varieties. *Astérisque*, 421:7–125, 2020.

[41] J. H. Bruinier, B. Howard, S. Kudla, M. Rapoport, and T. Yang. Modularity of generating series of divisors on unitary Shimura varieties II: arithmetic applications. *Astérisque*, 421:127–186, 2020.

[42] J. H. Bruinier and M. Möller. Cones of heegner divisors. *Journal of Algebraic Geometry*, 28:497–517, 2019.

[43] J. H. Bruinier and M. Schwagenscheidt. A converse theorem for Borcherds products on $X_0(N)$. *Nagoya Mathematical Journal*, 240:237–256, 2020.

[44] J. H. Bruinier and M. Schwagenscheidt. Theta lifts for Lorentzian lattices and coefficients of mock theta functions. *Mathematische Zeitschrift*, to appear.

[45] J. H. Bruinier and T. Yang. Arithmetic degrees of special cycles and derivatives of Siegel Eisenstein series. *Journal of the European Mathematical Society*, to appear.

[46] T. Burggraf, M. Joswig, M. E. Pfetsch, M. Radons, and S. Ulbrich. Semiautomatically optimized calibration of internal combustion engines. *Optimization and Engineering*, 21(1):73–106, 2020.

[47] R. Burlacu, H. Egger, A. M. Martin Groß, M. E. Pfetsch, L. Schewe, M. Sirvent, and M. Skutella. Maximizing the storage capacity of gas networks: a global MINLP approach. *Optimization and Engineering*, 20:543–573, 2019.

[48] P. Caserman, K. Hoffmann, P. Müller, M. Schaub, K. Straßburg, J. Wiemeyer, R. Bruder, and S. Göbel. Quality Criteria for Serious Games: Serious Part, Game Part, and Balance. *JMIR serious games*, 8(3):e19037, 2020.

[49] P. Charollois and Y. Li. Harmonic Maass forms associated to real quadratic fields. *J. Eur. Math. Soc. (JEMS)*, 22(4):1115–1148, 2020.

[50] N. Chatterjee and U. S. Fjordholm. Convergence of second-order, entropy stable methods for multi-dimensional conservation laws. *ESAIM Math. Model. Numer. Anal.*, 54(4):1415–1428, 2020.

[51] I. Ciardelli and M. Otto. Inquisitive bisimulation. *Journal of Symbolic Logic*, 2020. To appear.

[52] R. Dahmen and K. H. Hofmann. On the Component Factor Group $G/G_0$ of of a Pro-Lie Group. *Journal of Lie Theory*, 29:221–225, 2019.

[53] R. Dahmen and K. H. Hofmann. The Pro-Lie Group Aspect of Weakly Complete Algebras and Weakly Complete Group Hopf Algebras. *Journal of Lie Theory*, 29:413–455, 2019.

[54] B. Dinis and P. Pinto. Metastability of the multi-parameters proximal point algorithm. *Portugaliae Mathematica*, 77(3):345–381, 2020.

[55] B. Dinis and P. Pinto. On the convergence of algorithms with Tikhonov regularization terms. *Optimization Letters*, 15(3):1263–1276, 2021.

[56] B. Dinis and P. Pinto. Quantitative results on the multi-parameters proximal point algorithm. *Journal of Convex Analysis*, 28(3), 2021.

[57] Y. Disser, J. Fearnley, M. Gairing, O. Göbel, M. Klimm, D. Schmand, A. Skopalik, and A. Tönnis. Hiring secretaries over time: The benefit of concurrent employment. *Mathematics of Operations Research*, 45(1):323–352, 2020.

[58] Y. Disser, A. E. Feldmann, M. Klimm, and J. Könemann. Travelling on graphs with small highway dimension. *Algorithmica*, 2020. To appear.

[59] Y. Disser, J. Hackfeld, and M. Klimm. Tight bounds for undirected graph exploration with pebbles and multiple agents. *Journal of the ACM*, 66(6):1–41, 2019.

[60] Y. Disser and J. Matuschke. The complexity of computing a robust flow. *Operations Research Letters*, 48(1):18–23, 2020.

[61] Y. Disser, F. Mousset, A. Noever, N. Škorić, and A. Steger. A general lower bound for collaborative tree exploration. *Theoretical Computer Science*, 811:70–78, 2020.

[62] M. Dittmann. Reflective automorphic forms on lattices of squarefree level. *Trans. Amer. Math. Soc.*, 372(2):1333–1362, 2019.

[63] M. Dittmann, R. Salvati Manni, and N. Scheithauer. Harmonic theta series and the Kodaira dimension of $A_6$. *Algebra Number Theory*, 15(1):271–285, 2021.

[64] J. Dölz. A higher order perturbation approach for electromagnetic scattering problems on random domains. *SIAM/ASA Journal on Uncertainty Quantification*, 8:748–774, 2020.

[65] J. Dölz, H. Harbrecht, S. Kurz, M. D. Multerer, S. Schöps, and F. Wolf. Bembel: The fast isogeometric boundary element c++ library for Laplace, Helmholtz, and electric wave equation. *SoftwareX*, 11:100476, 2020.

[66] H. Egger. Structure preserving approximation of dissipative evolution problems. *Numer. Math.*, 143:85–106, 2019.

[67] H. Egger, O. Habrich, and V. Shashkov. On the Energy stable Galerkin approximation of Hamiltonian and gradient systems. *Comput. Meth. Appl. Math.*, 2020. in press.

[68] H. Egger and N. Philippi. On the transport limit of singularly perturbed convection-diffusion problems on networks. *Math. Meth. Appl. Sci.*, 44:5005–5020, 2020.

[69] H. Egger and B. Radu. A mass-lumped mixed finite element method for acoustic wave propagation. *Numer. Math.*, 145:239–269, 2020.

[70] H. Egger and B. Radu. A second order finite element method with mass lumping for Maxwell's equations on tetrahedra. *SIAM J. Numer. Analysis*, 2020. accepted.

[71] H. Egger and B. Radu. A second order multipoint flux mixed finite element method on hybrid meshes. *SIAM J. Numer. Anal.*, 58:1822–1844, 2020.

[72] H. Egger and M. Sabouri. On the structure preserving high-order approximation of quasistatic poroelasticity. arXiv:1912.13086, 2019. Accepted.

[73] H. Egger and M. Schlottbom. A perfectly matched layer approach for radiative transfer in highly scattering regimes. *SIAM. J. Numer. Anal.*, 57:2166–2188, 2019.

[74] H. Egger, K. Schmidt, and V. Shashkov. Multistep and Runge-Kutta convolution quadrature methods for coupled dynamical systems. *Comput. Appl. Math.*, 2019.

[75] H. Egger and L. Schöbel-Kröhn. Chemotaxis on networks: analysis and numerical approximation. *ESAIM: M2AN*, 54:1339–1372, 2020.

[76] H. Egger and G. Teschner. On the stable estimation of flow geometry and wall shear stress from magnetic resonance images. *Inverse Problem*, 35:095001, 2019.

[77] K. Eickmeyer, J. van den Heuvel, K. ichi Kawarabayashi, S. Kreutzer, P. O. de Mendez, M. Pilipczuk, D. A. Quiroz, R. Rabinovich, and S. Siebertz. Model-checking on ordered structures. *ACM Transactions on Computational Logic*, 21(2), 2020.

[78] T. Eiter and M. Kyed. Viscous Flow Around a Rigid Body Performing a Time-periodic Motion. *J. Math. Fluid Mech.*, 23(1), 2021.

[79] T. Eiter, M. Kyed, and Y. Shibata. On periodic solutions for one-phase and two-phase problems of the Navier–Stokes equations. *J. Evol. Equ.*, 2020.

[80] B. Endtmayer, U. Langer, I. Neitzel, T. Wick, and W. Wollner. Multigoal-oriented optimal control problems with nonlinear PDE constraints. *Computers & Mathematics with Applications*, 79(10):3001–3026, 2020.

[81] C. Erath, G. Gantner, and D. Praetorius. Optimal convergence behavior of adaptive FEM driven by simple $(h-h/2)$-type error estimators. *Comput. Math. Appl.*, 79(3):623–642, 2020.

[82] C. Erath and D. Praetorius. Adaptive vertex-centered finite volume methods for general second-order linear elliptic partial differential equations. *IMA J. Numer. Anal.*, 39(2):983–1008, 2019.

[83] C. Erath and D. Praetorius. Optimal adaptivity for the SUPG finite element method. *Comput. Methods Appl. Mech. Engrg.*, 353:308–327, 2019.

[84] C. Erath and R. Schorr. Stable non-symmetric coupling of the finite volume method and the boundary element method for convection-dominated parabolic-elliptic interface problems. *Comput. Methods Appl. Math.*, 20(2):251–272, 2020.

[85] R. Farwig. Das Millenniumsproblem der Navier-Stokes-Gleichungen. *Mitt. Dtsch. Math.-Ver.*, 28(1):18–25, 2020.

[86] R. Farwig, Y. Giga, and P.-Y. Hsu. On the continuity of the solutions to the Navier-Stokes equations with initial data in critical Besov spaces. *Ann. Mat. Pura Appl. (4)*, 198(5):1495–1511, 2019.

[87] R. Farwig, H. Kozono, and D. Wegmann. Maximal regularity of the Stokes operator in an exterior domain with moving boundary and application to the Navier-Stokes equations. *Math. Ann.*, 375(3-4):949–972, 2019.

[88] R. Farwig and C. Qian. Asymptotic behavior for the quasi-geostrophic equations with fractional dissipation in $\mathbb{R}^2$. *J. Differential Equations*, 266(10):6525–6579, 2019.

[89] R. Farwig and C. Qian. The global existence and attractor for $p$-Laplace equations in unbounded domains. *J. Elliptic Parabol. Equ.*, 6(1):311–342, 2020.

[90] R. Farwig, C. Qian, and P. Zhang. Incompressible inhomogeneous fluids in bounded domains of $\mathbb{R}^3$ with bounded density. *J. Funct. Anal.*, 278(5):108394, 2020.

[91] R. Farwig and V. Rosteck. Maximal regularity of the Stokes system with Navier boundary condition in general unbounded domains. *J. Math. Soc. Japan*, 71(4):1293–1319, 2019.

[92] T. Fischer and M. E. Pfetsch. On the structure of linear programs with overlapping cardinality constraints. *Discrete Applied Mathematics*, pages 42–68, 2020.

[93] G. Freixas i Montplet and A.-M. von Pippich. Riemann–Roch isometries in the non-compact orbifold setting. *J. Eur. Math. Soc. (JEMS)*, 22(11):3491–3564, 2020.

[94] A. Freund. A categorical construction of Bachmann-Howard fixed points. *Bulletin of the London Mathematical Society*, 51(5):801–814, 2019.

[95] A. Freund. A note on iterated consistency and infinite proofs. *Archive for Mathematical Logic*, 58(3):339–346, 2019.

[96] A. Freund. $\Pi^1_1$-comprehension as a well-ordering principle. *Advances in Mathematics*, 355, 2019. Article no. 106767, 65 pp.

[97] A. Freund. Computable aspects of the Bachmann-Howard principle. *Journal of Mathematical Logic*, 20(2), 2020. Article no. 2050006, 26 pp.

[98] A. Freund. From Kruskal's theorem to Friedman's gap condition. *Mathematical Structures in Computer Science*, 30(8):952–975, 2020.

[99] A. Freund. How strong are single fixed points of normal functions? *The Journal of Symbolic Logic*, 85(2):709–732, 2020.

[100] A. Freund. A note on ordinal exponentiation and derivatives of normal functions. *Mathematical Logic Quarterly*, 66(3):326–335, 2020.

[101] A. Freund. Predicative collapsing principles. *The Journal of Symbolic Logic*, 85(1):511–530, 2020.

[102] A. Freund. Set-theoretic reflection is equivalent to induction over well-founded classes. *Proceedings of the American Mathematical Society*, 148:4503–4515, 2020.

[103] A. Freund. What is effective transfinite recursion in reverse mathematics? *Mathematical Logic Quarterly*, 66(4):479–483, 2020.

[104] A. Freund. Well ordering principles and $\Pi^1_4$-statements: a pilot study. *The Journal of Symbolic Logic*, 2021. To appear (doi:10.1017/jsl.2021.22), 35 pp.

[105] A. Freund and F. Pakhomov. Short proofs for slow consistency. *Notre Dame Journal of Formal Logic*, 61(1):31–49, 2020.

[106] A. Freund and M. Rathjen. Derivatives of normal functions in reverse mathematics. *Annals of Pure and Applied Logic*, 172(2), 2021. Article no. 102890, 49 pp.

[107] M. Fricke and D. Bothe. Boundary conditions for dynamic wetting - A mathematical analysis. *The European Physical Journal Special Topics*, 229:1849–1865, 2020.

[108] M. Fricke, M. Köhne, and D. Bothe. A kinematic evolution equation for the dynamic contact angle and some consequences. *Physica D: Nonlinear Phenomena*, 394:26–43, 2019.

[109] M. Fricke, T. Marić, and D. Bothe. Contact Line Advection using the geometrical Volume of Fluid Method. *Journal of Computational Physics*, 407, 2020.

[110] K. Furukawa, Y. Giga, M. Hieber, A. Hussein, T. Kashiwabara, and M. Wrona. Rigorous justification of the hydrostatic approximation for the primitive equations by scaled Navier-Stokes equations. *Nonlinearity*, 33(12):6502–6516, 2020.

[111] F. Gaspoz, C. Kreuzer, A. Veeser, and W. Wollner. Quasi-best approximation in optimization with PDE constraints. *Inverse Problems*, 36(1), 2019.

[112] C. Geiersbach and W. Wollner. A stochastic gradient method with mesh refinement for PDE constrained optimization under uncertainty. *SIAM Journal on Scientific Computing*, 42(5):A2750–A2772, 2020.

[113] J. Giesselmann and P. G. LeFloch. Formulation and convergence of the finite volume method for conservation laws on spacetimes with boundary. *Numer. Math.*, 144(4):751–785, 2020.

[114] J. Giesselmann, F. Meyer, and C. Rohde. A posteriori error analysis and adaptive non-intrusive numerical schemes for systems of random conservation laws. *BIT*, 60(3):619–649, 2020.

[115] Y. Giga, M. Gries, M. Hieber, A. Hussein, and T. Kashiwabara. Analyticity of solutions to the primitive equations. *Math. Nachr.*, 293(2):284–304, 2020.

[116] Y. Giga, M. Gries, M. Hieber, A. Hussein, and T. Kashiwabara. The hydrostatic Stokes semigroup and well-posedness of the primitive equations on spaces of bounded functions. *J. Funct. Anal.*, 279(3):108561, 46, 2020.

[117] Y. Giga, M. Gries, M. Hieber, A. Hussein, and T. Kashiwabara. The primitive equations in the scaling invariant space $l^\infty(l^1)$. *J. Evol. Equ.*, to appear.

[118] A. Gohr, D. Klein, and W. Schindler. Verräterischer Stromverbrauch. *Datenschutz und Datensicherheit*, 44:431–435, 2020.

[119] B. Götz, S. Kersting, and M. Kohler. Estimation of an improved surrogate model in uncertainty quantification by neural networks. *Annals of the Institute of Statistical Mathematics*, 2021.

[120] C. Gräßle, M. Hinze, J. Lang, and S. Ullmann. POD model order reduction with space-adapted snapshots for incompressible flows. *Advances in Computational Mathematics*, 45:2401–2428, 2019.

[121] M. Gross, M. E. Pfetsch, L. Schewe, M. Schmidt, and M. Skutella. Algorithmic results for potential-based flows: Easy and hard cases. *Networks*, 73(3):306–324, 2019.

[122] D. Gründing, M. Smuda, T. Antritter, M. Fricke, D. Rettenmaier, F. Kummer, P. Stephan, H. Marschall, and D. Bothe. A comparative study of transient capillary rise using direct numerical simulations. *Applied Mathematical Modelling*, 86:142–165, 2020.

[123] O. Habeck, M. E. Pfetsch, and S. Ulbrich. Global optimization of mixed-integer ODE constrained network problems using the example of stationary gas transport. *SIAM Journal of Optimization*, 29(4):2949–2985, 2019.

[124] S. Hajian, M. Hintermüller, and S. Ulbrich. Total variation diminishing schemes in optimal control of scalar conservation laws. *IMA Journal of Numerical Analysis*, 39(1):105–140, 2019.

[125] R. Haller-Dintelmann, H. Meinlschmidt, and W. Wollner. Higher regularity for solutions to elliptic systems in divergence form subject to mixed boundary conditions. *Annali di Matematica Pura ed Applicata*, 198(4):1227–1241, 2019.

[126] M. Hansmann and M. Kohler. Estimation of conditional quantiles from data with additional measurement errors. *Journal of Statistical Planning and Inference*, 200:176–195, 2019.

[127] M. Hansmann, M. Kohler, and H. Walk. On the strong universal consistency of local averaging regression estimates. *Annals of the Institute of Statistical Mathematics*, 71:1233–1263, 2019.

[128] M. Hartmann, M. Fricke, L. Weimar, D. Gründing, T. Marić, D. Bothe, and S. Hardt. Breakup dynamics of Capillary Bridges on Hydrophobic Stripes. *International Journal of Multiphase Flow*, 2021.

[129] J. Haubner, M. Ulbrich, and S. Ulbrich. Analysis of shape optimization problems for unsteady fluid-structure interaction. *Inverse Problems*, 36(3):034001, 38, 2020.

[130] F. Heimrich, M. Kohler, and L. Kristl. Nonparametric estimation of time-dependent quantiles in a simulation model. *Statistica Sinica*, 30:135–151, 2020.

[131] W. Herfort, K. H. Hofmann, L. Kramer, and F. G. Russo. The Sylow Structure of Scalar Automorphism Groups. *Topology and Applications*, 263:26–43, 2019.

[132] W. Herfort, K. H. Hofmann, and F. G. Russo. Locally Compact Abelian $p$-Groups. *Topology and Applications*, 259:203–241, 2019.

[133] W. Herfort, K. H. Hofmann, and F. G. Russo. When is the sum of two closed subgroups closed in a locally compct abelian group? *Topology and Applications*, 270:1–30, 2019.

[134] J. C. Hernàndez Arzusa and K. H. Hofmann. A Note on Locally Compact Subsemigroups of Compact Groups. *Semigroup Forum*, 101:4pp, 2021 accepted 2020.

[135] S. Herrero, O. Imamoglu, A.-M. von Pippich, and A. Tóth. A jensen–rohrlich type formula for the hyperbolic 3-space. *Trans. Amer. Math. Soc.*, 371(9):6421–6446, 2019.

[136] S. Herrero and A.-M. von Pippich. Mock modular forms whose shadows are eisenstein series of integral weight. *Math. Res. Lett.*, 27(2):435–463, 2020.

[137] J. Heuer, F. Matter, M. E. Pfetsch, and T. Theobald. Block-sparse recovery of semidefinite systems and generalized null space conditions. *Linear Algebra and its Applications*, 603:470–495, 2020.

[138] M. Hieber. On operator semigroups arising in the study of incompressible viscous fluid flows. *Philos. Trans. Roy. Soc. A*, 378(2185):20190618, 22, 2020.

[139] M. Hieber and A. Hussein. An approach to the primitive equations for ocean and atmospheric dynamics by evolution equations. pages 1–109, 2020.

[140] M. Hieber, N. Kajiwara, K. Kress, and P. Tolksdorf. The periodic version of the Da Prato–Grisvard theorem and applications to the bidomain equations with FitzHugh-Nagumo transport. *Ann. Mat. Pura Appl. (4)*, 199(6):2435–2457, 2020.

[141] M. Hieber, H. Kozono, A. Seyfert, S. Shimizu, and T. Yanagisawa. A characterization of harmonic $L^r$-vector fields in two-dimensional exterior domains. *J. Geom. Anal.*, 30(4):3742–3759, 2020.

[142] M. Hieber, H. Kozono, A. Seyferth, S. Shimizu, and T. Yanagisawa. $l^r$-helmhotz-weyl decomposition for two dimensional exterior domains. *J. Geom. Anal.*, 2020.

[143] M. Hieber, K. Kress, and C. Stinner. The keller-segel system on bounded convex domains on critical spaces. *Partial Differ. Equ. Appl.*, to appear.

[144] M. Hieber, A. Mahalov, and R. Takada. Time periodic and almost time periodic solutions to rotating stratified fluids subject to large forces. *J. Differential Equations*, 266(2-3):977–1002, 2019.

[145] M. Hieber, O. Misiats, and O. Stanzhytskyi. On the bidomain equations driven by stochastic forces. *Discrete Contin. Dyn. Syst.*, 40(11):6159–6177, 2020.

[146] M. Hieber and T. H. Nguyen. Stability and periodicity of solutions to the Oldroyd-B model on exterior domains. *Rend. Istit. Mat. Univ. Trieste*, 52:113–129, 2020.

[147] M. Hieber and J. Prüss. Dynamics of the Ericksen-Leslie equations with general Leslie stress II: The compressible isotropic case. *Arch. Ration. Mech. Anal.*, 233(3):1441–1468, 2019.

[148] M. Hieber and J. Prüss. Bounded $H^\infty$-calculus for a class of nonlocal operators: the bidomain operator in the $L_q$-setting. *Math. Ann.*, 378(3-4):1095–1127, 2020.

[149] M. Hieber and C. Stinner. Strong time periodic solutions to Keller-Segel systems: an approach by the quasilinear Arendt-Bu theorem. *J. Differential Equations*, 269(2):1636–1655, 2020.

[150] M. Hieber and C. Stinner. Strong time periodic solutions to Keller-Segel systems: an approach by the quasilinear Arendt-Bu theorem. *J. Differential Equations*, 269:1636–1655, 2020.

[151] M. Hieber, H. Wen, and R. Zi. Optimal decay rates for solutions to the incompressible Oldroyd-B model in $\mathbb{R}^3$. *Nonlinearity*, 32(3):833–852, 2019.

[152] K. H. Hofmann. Optical Illusions in Rome - a Mathematical Travel Guide by Kirsti Andersen (Bookreview). *Mathematische Semesterberichte*, 67:311–322, 2020.

[153] K. H. Hofmann and L. Kramer. On Weakly Complete Group Algebras and Weakly Complete Group Hopf Algebras. *Journal of Lie Theory*, 30:407–424, 2020.

[154] K. H. Hofmann and J. D. Lawson. Throwing a glance at 100 volumes of a journal and at half a century of its existence. *Semigroup Forum*, 100:2–8, 2019.

[155] T. Hoheisel, B. Pablos, A. Pooladian, A. Schwartz, and L. Steverango. A study of one-parameter regularization methods for mathematical programs with vanishing constraints. *Optimization Methods and Software*, pages 1–43, 2020.

[156] C. Hojny, T. Gally, O. Habeck, H. Lüthen, F. Matter, M. E. Pfetsch, and A. Schmitt. Knapsack polytopes: a survey. *Annals of Operations Research*, 292(1):469–517, 2020.

[157] C. Hojny, H. Lüthen, and M. E. Pfetsch. Sparsity of integer formulations for binary programs. *Operations Research Letters*, 47(5):348–352, 2019.

[158] C. Hojny and M. E. Pfetsch. Polytopes associated with symmetry handling. *Mathematical Programming*, 175(1):197–240, 2019.

[159] Y. Hori, D. Bothe, K. Hayashi, S. Hosokawa, and A. Tomiyama. Mass transfer from single carbon-dioxide bubbles in surfactant-electrolyte mixed aqueous solutions in vertical pipes. *International Journal of Multiphase Flow*, 124:103207, 2020.

[160] W. Huang, L. Kamenski, and J. Lang. Conditioning of implicit Runge-Kutta integration for finite element approximation of linear diffusion equations on anisotropic meshes. *J. Comput. Appl. Math.*, 2019. Available online 1 October 2019, 112497.

[161] K. Kellner, M. E. Pfetsch, and T. Theobald. Irreducible infeasible subsystems of semidefinite systems. *Journal of Optimization Theory and Applications*, 181(3):727–742, 2019.

[162] W. R. KhudaBukhsh, A. Auddy, Y. Disser, and H. Koeppl. Approximate lumpability for markovian agent-based models using local symmetries. *Journal of Applied Probability*, 56(3):647–671, 2019.

[163] C. Kirches, P. Manns, and S. Ulbrich. Compactness and convergence rates in the combinatorial integral approximation decomposition. *Mathematical Programming*, 2020.

[164] D. Klein and J. Kupka. Completions and algebraic formulas for the coefficients of Ramanujan's mock theta functions. *The Ramanujan Journal*, 2020. To appear.

[165] U. Kohlenbach. On the reverse mathematics and Weihrauch complexity of moduli of regularity and uniqueness. *Computability*, 8:377–387, 2019.

[166] U. Kohlenbach. A polynomial rate of asymptotic regularity for compositions of projections in Hilbert space. *Foundations of Computational Mathematics*, 19:83–99, 2019.

[167] U. Kohlenbach. Quantitative analysis of a Halpern-type proximal point algorithm for accretive operators in banach spaces. *Journal of Nonlinear and Convex Analysis*, 21:2125–2138, 2020.

[168] U. Kohlenbach. Proof-theoretic uniform boundedness and bounded collection principles and Heine-Borel compactness. *Archive for Mathematical Logic*, 2021. To appear.

[169] U. Kohlenbach. Quantitative results on the proximal point algorithm in uniformly convex Banach spaces. *Journal of Convex Analysis*, 28:11–18, 2021.

[170] U. Kohlenbach, G. López-Acedo, and A. Nicolae. Moduli of regularity and rates of convergence for Fejér monotone sequences. *Israel Journal of Mathematics*, 232:261–297, 2019.

[171] U. Kohlenbach, G. López-Acedo, and A. Nicolae. A uniform betweenness property in metric spaces and its role in the quantitative analysis of the Lion-Man game. *Pacific Journal of Mathematics*, 319:181–212, 2021.

[172] U. Kohlenbach and T. Powell. Rates of convergence for iterative solutions of equations involving set-valued accretive operators. *Computers & Mathematics with Applications*, 80:490–503, 2020.

[173] U. Kohlenbach and A. Sipoş. The finitary content of sunny nonexpansive retractions. *Communications in Contemporary Mathematics*, 23:63 ppages, 2021.

[174] M. Kohler and A. Krzyżak. Estimation of a density from an imperfect simulation model. *IEEE Transactions on Information Theory*, 65:1535–1546, 2019.

[175] M. Kohler and A. Krzyżak. Estimation of extreme quantiles in a simulation model. *Journal of Nonparametric Statistics*, 31:393–419, 2019.

[176] M. Kohler and A. Krzyżak. Estimating quantiles in imperfect simulation models using conditional density estimation. *Annals of the Institute of Statistical Mathematics*, 72:123–155, 2020.

[177] M. Kohler and A. Krzyżak. Estimation of a density using an improved surrogate model. *Electronic Journal of Statistics*, 15:1–41, 2021.

[178] M. Kohler and S. Langer. Discussion of nonparametric regression using deep neural networks with relu activation function. *Annals of Statistics*, 48:1906–1910, 2020.

[179] M. Kohler and S. Langer. On the rate of convergence of fully connected very deep neural network regression estimates. *Annals of Statistics*, 2021.

[180] M. Kohler and R. Tent. Nonparametric quantile estimation using surrogate models and importance sampling. *Metrika*, 83:141–169, 2020.

[181] N. Kolbe, N. Sfakianakis, C. Stinner, C. Surulescu, and J. Lenz. Modeling multiple taxis: tumor invasion with phenotypic heterogeneity, haptotaxis, and unilateral interspecies repellence. *Discrete Contin. Dyn. Syst. Ser. B*, to appear.

[182] J. Kramer and A.-M. von Pippich. Logarithm and dilogarithm. *Elem. Math.*, 74(1):10–23, 2019.

[183] J. Kromer and D. Bothe. Highly accurate computation of volume fractions using differential geometry. *Journal of Computational Physics*, 396:761–784, 2019.

[184] J. M. Kroos, C. Stinner, C. Surulescu, and N. Surulescu. SDE-driven modeling of phenotypically heterogeneous tumors: the influence of cancer cell stemness. *Discrete Contin. Dyn. Syst. Ser. B*, 24:4629–4663, 2019.

[185] J. Lang, R. Scheichl, and D. Silvester. A fully adaptive multilevel stochastic collocation strategy for solving elliptic pdes with random data. *Journal of Computational Physics*, 419:109692, 2020.

[186] J.-H. Lange, M. E. Pfetsch, B. M. Seib, and A. M. Tillmann. Sparse recovery with integrality constraints. *Discrete Applied Mathematics*, 283:346–366, 2020.

[187] N. Lehmann, L.-B. Maier, S. Odathuparambil, and U. Reif. Ambient approximation on hypersurfaces. *Constructive Approximation*, 49(1):175–190, 2019.

[188] L. Leuştean and P. Pinto. Quantitative results on a Halpern-type proximal point algorithm. *Computational Optimization and Applications*, 79:101–125, 2021.

[189] Y. Li, H. Narita, and A. Pitale. An explicit construction of non-tempered cusp forms on $O(1,8n+1)$. *Ann. Math. Qué.*, 44(2):349–384, 2020.

[190] Y. Li and M. Neururer. A magnetic modular form. *Int. J. Number Theory*, 15(5):907–924, 2019.

[191] Y. Li and T. Yang. On a conjecture of Yui and Zagier. *Algebra Number Theory*, 14(8):2197–2238, 2020.

[192] M. Liu and D. Bothe. Toward the predictive simulation of bouncing versus coalescence in binary droplet collisions. *Acta Mechanica*, 230(2):623–644, 2019.

[193] K. Mang, M. Walloth, T. Wick, and W. Wollner. Mesh adaptivity for quasi-static phase-field fractures based on a residual-type a posteriori error estimator. *GAMM Mitteilungen*, 43(1), 2019.

[194] K. Mang, M. Walloth, T. Wick, and W. Wollner. Mesh adaptivity for quasi-static phase-field fractures based on a residual-type a posteriori error estimator. *GAMM-Mitteilungen*, 43(1), 2020.

[195] K. Mang, T. Wick, and W. Wollner. A phase-field model for fractures in incompressible solids. *Computational Mechanics*, 65(1):61–78, 2020.

[196] T. Marić, D. B. Kothe, and D. Bothe. Unstructured un-split geometrical volume-of-fluid methods–a review. *Journal of Computational Physics*, 420:109695, 2020.

[197] S. Meburger, M. Niethammer, D. Bothe, and M. Schäfer. Numerical simulation of non-isothermal viscoelastic flows at high Weissenberg numbers using a finite volume method on general unstructured meshes. *J. Nonnewton. Fluid Mech.*, 287(November 2020):104451, 2020.

[198] F. Meyer, C. Rohde, and J. Giesselmann. *a posteriori* error analysis for random scalar conservation laws using the stochastic Galerkin method. *IMA J. Numer. Anal.*, 40(2):1094–1121, 2020.

[199] P. Mindt, J. Lang, and P. Domschke. Entropy-preserving coupling of hierarchical gas models. *SIAM Journal on Mathematical Analysis*, 51:4754–4775, 2019.

[200] J. Mittmann and W. Schindler. Timing attacks and local timing attacks against Barrett's modular multiplication algorithm. *Journal of Cryptographic Engineering*, to appear.

[201] S. Modena and G. Sattig. Convex integration solutions to the transport equation with full dimensional concentration. *Annales de l'Institut Henri Poincaré C, Analyse non linéaire*, 37(5):1075–1108, 2020.

[202] S. Modena and L. Székelyhidi. Non-renormalized solutions to the continuity equation. *Calculus of Variations and PDE*, 58:208, 2019.

[203] M. Mohammadi and W. Wollner. A priori error estimates for a linearized fracture control problem. *Optimization and Engineering*, 2020.

[204] C. Müller, S. Ullmann, and J. Lang. A Bramble-Pasciak conjugate gradient method for discrete Stokes equations with random viscosity. *SIAM/ASA J. Uncertainty Quantification*, 7(3):787–805, 2019.

[205] I. Neitzel, T. Wick, and W. Wollner. An optimal control problem governed by a regularized phase-field fracture propagation model. Part II: The regularization limit. *SIAM Journal on Control and Optimization*, 3(57):1672–1690, 2019.

[206] M. Niethammer, G. Brenn, H. Marschall, and D. Bothe. An extended volume of fluid method and its application to single bubbles rising in a viscoelastic liquid. *J. Comput. Phys.*, 387:326–355, 2019.

[207] M. Niethammer, H. Marschall, and D. Bothe. Robust Direct Numerical Simulation of Viscoelastic Flows. *Chemie Ing. Tech.*, 91(4):522–528, 2019.

[208] M. E. Pfetsch and T. Rehn. A computational comparison of symmetry handling methods for mixed integer programs. *Mathematical Programming Computation*, 11(1):37–93, 2019.

[209] P. Pinto. A rate of metastability for the Halpern type Proximal Point Algorithm. *Numerical Functional Analysis and Optmization*, 42(3):320–343, 2021.

[210] I. Ratnayake, M. Thomas, and B. Kensington-Miller. Professional development for digital technology task design by secondary mathematics teachers . *ZDM – International Journal on Mathematics Education*, 52:1423–1437, 2020.

[211] A.-T. Rauls and S. Ulbrich. Computation of a Bouligand generalized derivative for the solution operator of the obstacle problem. *SIAM Journal on Control and Optimization*, 57(5):3223–3248, 2019.

[212] A.-T. Rauls and G. Wachsmuth. Generalized derivatives for the solution operator of the obstacle problem. *Set-Valued and Variational Analysis*, 28(2):259–285, 2020.

[213] U. Reif and M. A. Sabin. Old problems and new challenges in subdivision. *Journal of Computational and Applied Mathematics*, 349:523 – 531, 2019.

[214] D. Rettenmaier, D. Deising, Y. Ouedraogo, E. Gjonaj, H. De Gersem, D. Bothe, C. Tropea, and H. Marschall. Load balanced 2d and 3d adaptive mesh refinement in openfoam. *SoftwareX*, 10:100317, 2019.

[215] S. Roch. Compact sequences in quasifractal algebras. *Operator Theory: Advances and Applications*, 282, 2020 (accepted).

[216] M. Rohde and W. Schindler. Künstliche Intelligenz in Evaluierung und Zulassung. *Datenschutz und Datensicherheit*, 43:627–630, 2019.

[217] N. Sarna, J. Giesselmann, and M. Torrilhon. Convergence analysis of Grad's Hermite expansion for linear kinetic equations. *SIAM J. Numer. Anal.*, 58(2):1164–1194, 2020.

[218] P. Schäfer Aguilar, J. M. Schmitt, S. Ulbrich, and M. Moos. On the numerical discretization of optimal control problems for conservation laws. *Control and Cybernetics*, 48(2):345–376, 2019.

[219] M. Schmidt, M. Sirvent, and W. Wollner. A decomposition method for MINLPs with Lipschitz continuous nonlinearities. *Mathematical Programming*, 178(1-2):449–483, 2019.

[220] J. M. Schmitt and S. Ulbrich. Optimal boundary control of hyperbolic balance laws with state constraints. *SIAM Journal on Control and Optimization*, 2020. To appear.

[221] M. Schneider, J. Lang, and R. Weiner. Super-convergent implicit-explicit peer methods with variable step sizes. *J. Comput. Appl. Math.*, 2019. Available online 26 September 2019, 112501.

[222] L. Schöbel-Kröhn. *Analysis and numerical approximation of nonlinear evolution equations on network structures*. PhD thesis, 2020.

[223] J. Schröder, T. Wick, S. Reese, P. Wriggers, R. Müller, S. Kollmannsberger, M. Kästner, A. Schwarz, M. Igelbüscher, N. Viebahn, H. R. Bayat, S. Wulfinghoff, K. Mang, E. Rand, T. Bog, D. d'Nagella, M. Elhaddad, P. Hennig, A. Düster, W. Garhuom, S. Hubrich, M. Walloth, W. Wollner, C. Kuhn, and T. Heister. A selection of benchmark problems in solid mechanics and applied mathematics. *Archives of Computational Methods in Engineering*, 28:713–751, 2020.

[224] S. Schweer and C. Wichelhaus. Nonparametric estimation of the service time distribution in discrete-time queueing networks. *Stochastic Processes and their Applications*, 130:4643–4666, 2020.

[225] N. Shokina, A. Bauer, G. Teschner, W. B. Buchenberg, C. Tropea, H. Egger, J. Hennig, and A. J. Krafft. MR-based wall shear stress measurements in fully developed turbulent flow using the Clauser plot method. *J. Magn. Res.*, 305:16–21, 2019.

[226] N. Shokina, G. Teschner, A. Bauer, C. Tropea, H. Egger, J. Hennig, and A. Krafft. Parametric sequential method for mri-based wall shear stress quantification. *IEEE Transactions on Medical Imaging*, 2020.

[227] N. Shokina, G. Teschner, A. Bauer, C. Tropea, H. Egger, J. Hennig, and A. J. Krafft. Quantification of wall shear stress in large blood vessels using magnetic resonance imaging. *J. Comput. Techn.*, 24:4–27, 2019.

[228] O. Souček, V. Orava, J. Málek, and D. Bothe. A continuum model of heterogeneous catalysis: Thermodynamic framework for multicomponent bulk and surface phenomena coupled by sorption. *International Journal of Engineering Science*, 138:82–117, 2019.

[229] Z. Sun, M. Braack, and J. Lang. An adaptive moving finite element method for steady low Mach number compressible combustion problems. *International Journal for Numerical Methods in Fluids*, 92:1081–1095, 2020.

[230] T. Tolle, D. Bothe, and T. Marić. Saample: A segregated accuracy-driven algorithm for multiphase pressure-linked equations. *Computers & Fluids*, 200:104450, 2020.

[231] J. van Ekeren, S. Möller, and N. R. Scheithauer. Construction and classification of holomorphic vertex operator algebras. *J. Reine Angew. Math.*, 759:61–99, 2020.

[232] J. van Ekeren, S. Möller, and N. R. Scheithauer. Dimension formulae in genus zero and uniqueness of vertex operator algebras. *Int. Math. Res. Not. IMRN*, (7):2145–2204, 2020.

[233] B. G. Volker Betz and T. Hurst. Non-adiabatic transitions in multiple dimensions. *SIAM J. Sci. Comput.*, 41:B1011–B1033, 2019.

[234] H. S. Volker Betz and L. Taggi. Interacting self-avoiding polygons. *Ann. Inst. H. Poincaré Probab. Statist.*, 56:1321–1335, 2020.

[235] H. S. Volker Betz and D. Zeindler. Random permutations without macroscopic cycles. *Ann. Appl. Probab.*, 30:1484–1505, 2020.

[236] H. S. Volker Betz, Julian Mühlbauer and D. Zeindler. Precise asymptotics of longest cycles in random permutations without macroscopic cycles. *accepted in Bernoulli*, 2020.

[237] A.-M. von Pippich, M. Schwagenscheidt, and F. Völz. Kronecker limit formulas for parabolic, hyperbolic, and elliptic Eisenstein series via Borcherds products. *J. Number Theory*, 225:18–58, 2021.

[238] M. Walloth. A reliable, efficient and localized error estimator for a discontinuous galerkin method for the Signorini problem. *Applied Numerical Mathematics*, 135:276–296, 2019.

[239] M. Walloth. Residual-type a posteriori error estimator for a quasi-static Signorini contact problem. *IMA Journal of Numerical Analysis*, 40(3):1937–1971, 2019.

[240] M.-C. Weber, L. Fischer, A. Damerau, I. Ponomarev, M. Pfeiffenberger, T. Gaber, S. Götschel, J. Lang, S. Röblitz, F. Buttgereit, R. Ehrig, and A. Lang. Macroscale mesenchymal condensation to study cytokine-driven cellular and matrix-related changes during cartilage degradation. *Biofabrication*, 12:045016, 2020.

[241] T. Wedhorn. On the Work of Peter Scholze. *Jahresbericht der Deutschen Mathematiker-Vereinigung*, 121:245–289, 2019.

[242] A. Weiner, D. Hillenbrand, H. Marschall, and D. Bothe. Data-driven subgrid-scale modeling for convection-dominated concentration boundary layers. *Chemical Engineering & Technology*, 42(7):1349–1356, 2019.

[243] A. Weiner, J. Timmermann, C. Pesci, J. Grewe, M. Hoffmann, M. Schlüter, and D. Bothe. Experimental and numerical investigation of reactive species transport around a small rising bubble. *Chemical Engineering Science: X*, 1:100007, 2019.

[244] T. Wick and W. Wollner. On the differentiability of stationary fluid-structure interaction problems with respect to the problem data. *Journal of Mathematical Fluid Mechanics*, 21(3), 2019.

[245] T. Wick and W. Wollner. Optimization with nonstationary, nonlinear monolithic fluid-structure interaction. *International Journal for Numerical Methods in Engineering*, 2020.

[246] M. Winkler and C. Stinner. Refined regularity and stabilization properties in a degenerate haptotaxis system. *Discrete Contin. Dyn. Syst.*, 40:4039–4058, 2020.

[247] Y. Yang, P. Kühn, M. Yi, H. Egger, and B.-X. Xu. Non-isothermal phase-field modeling of heat-melt-microstructure-coupled processes during powder bed fusion. *JOM*, 72:1719–1733, 2020.

### 4.3.2 Proceedings and Chapters in Collections

[1] I. Apel. Results of a survey with first-year mathematics students about the phenomena at the transition to university. In M. Graven, H. Venkat, A. Essien, and P. Vale, editors, *Proceedings of the 43rd Conference of the International Group for the Psychology of Mathematics Education*, page 31, 2019.

[2] I. Apel. Tätigkeitstheoretische Betrachtung von Kenntnisqualitäten für mathematische Beweisprozesse. In Andreas Frank and Stefan Krauss and Karin Binder, editor, *Beiträge zum Mathematikunterricht 2019*, pages 57–60. WTM Verlag, 2019.

[3] I. Apel. Zum Einfluss von Kenntnisqualitäten auf Beweisprozesse am Beispiel der $\epsilon$-$\delta$-Stetigkeit. In Hans-Stefan Siller, Wolfgang Weigel and Jan Franz Wörler, editor, *Beiträge zum Mathematikunterricht 2020*, pages 69–72. WTM Verlag, 2020.

[4] B. Augner. Well-posedness and stability for interconnection structures of port-Hamiltonian type. In J. Kerner, H. Laasri, and D. Mugnolo, editors, *Control Theory of Infinite-dimensional Systems.*, volume 277 of *Operator Theory: Advances and Applications. Linear Operators and Linear Systems.*, pages 1–52. Birkhäuser/Springer, 2020.

[5] A. Bärtschi, E. Bampas, J. Chalopin, S. Das, C. Karousatou, and M. Mihalák. Near-gathering of energy-constrained mobile agents. In *Proceedings of the 26th International Colloquium on Structural Information and Communication Complexity (SIROCCO)*, pages 52–65, 2019.

[6] A. Birx and Y. Disser. Tight analysis of the smartstart algorithm for online dial-a-ride on the line. In *Proceedings of the 36th International Symposium on Theoretical Aspects of Computer Science (STACS)*, pages 15:1–15:17, 2019.

[7] A. Birx, Y. Disser, and K. Schewior. Improved bounds for open online dial-a-ride on the line. In *Proceedings of the 22nd International Workshop on Approximation Algorithms for Combinatorial Optimization Problems (APPROX)*, volume 145, pages 21:1–21:22, 2019.

[8] T. Bitsch, J. Schäfer, E. Diehl, H. M. Sauer, E. Dörsam, and S. Ulbrich. An experimental and numerical cooperative research concept for doctor blading. In *Advances in Printing and Media Technology*, volume 46, pages 68–74, 2019.

[9] B. Bosek, Y. Disser, A. E. Feldmann, J. Pawlewicz, and A. Zych-Pawlewicz. Recoloring interval graphs with limited recourse budget. In *Proceedings of the 17th Scandinavian Symposium and Workshops on Algorithm Theory (SWAT)*, pages 17:1–17:23, 2020.

[10] J. Chalopin, S. Das, Y. Disser, A. Labourel, and M. Mihalák. Collaborative delivery on a fixed path with homogeneous energy-constrained robots. In *Proceedings of the 26th International Colloquium on Structural Information and Communication Complexity (SIROCCO)*, pages 139–153, 2019.

[11] J. Chen, W. Czerwinski, Y. Disser, A. E. Feldmann, D. Hermelin, W. Nadara, M. Pilipczuk, M. Pilipczuk, M. Sorge, B. Wróblewski, and A. Zych-Pawlewicz. Efficient fully dynamic elimination forests with applications to detecting long paths

and cycles. In *Proceedings of the 32nd Annual ACM-SIAM Symposium on Discrete Algorithms (SODA)*, 2020. To appear.

[12] Y. Disser, A. E. Feldmann, M. Klimm, and J. Könemann. Travelling on graphs with small highway dimension. In *Proceedings of the 45th International Workshop on Graph-Theoretic Concepts in Computer Science (WG)*, pages 175–189, 2019.

[13] Y. Disser and A. V. Hopp. On Friedmann's subexponential lower bound for Zadeh's pivot rule. In *Proceedings of the 20th Conference on Integer Programming and Combinatorial Optimization (IPCO)*, pages 168–180, 2019.

[14] Y. Disser and S. Schmitt. Evacuating two robots from a disk: A second cut. In *Proceedings of the 26th International Colloquium on Structural Information and Communication Complexity (SIROCCO)*, pages 200–214, 2019.

[15] J. Dölz, S. Kurz, S. Schöps, and F. Wolf. Recent advances of isogeometric boundary element methods for electromagnetic scattering problems. *Oberwolfach Reports*, 17, 2020.

[16] H. Egger, J. Dölz, and V. Shashkov. A convolution quadrature method for Maxwell's equations in dispersive media. In *Proceedings SCEE 2020*. Springer, 2020.

[17] H. Egger, M. Harutyunyan, M. Merkel, and S. Schöps. On the stability of harmonic mortar methods with application to electric machines. In *Proceedings SCEE 2020*. Springer, 2020. in press.

[18] H. Egger and T. Kugler. Uniform exponential stability of Galerkin approximations for damped wave systems. In *Advanced Finite Element Methods with Applications, Selected papers from the 30th Chemnitz Finite Element Symposium*. Springer, 2019.

[19] H. Egger, T. Kugler, and B.-L. Sailer. Stability preserving approximations of a semilinear hyperbolic gas transport model. Springer, 2019. in press.

[20] H. Egger, T. Kugler, and V. Shashkov. An inexact Petrov-Galerkin approximation for gas transport in pipeline networks. In *Proceedings of ICOSAHOM 2018*. Springer.

[21] H. Egger and N. Philippi. A hybrid discontinuous galerkin method for transport equations on networks. In *International Conference on Finite Volumes for Complex Applications*, pages 487–495. Springer, 2020.

[22] H. Egger and B. Radu. Comparison of the hybrid and multipoint-flux method. *PAMM*, 19(1):e201900280, 2019.

[23] H. Egger and B. Radu. A mass-lumped mixed finite element method for Maxwell's equations. In *Proceedings of SCEE 2018*. Springer, 2020. in press.

[24] H. Egger and V. Shashkov. On energy preserving high-order discretizations for nonlinear acoustics. In *Proceedings ENUMATH 2019*. Springer, 2019. in press.

[25] T. Eiter and G. P. Galdi. New results for the Oseen problem with applications to the Navier-Stokes equations in exterior domains. In *Mathematical Analysis of Viscous Incompressible Fluid*, number 2171 in RIMS Kôkyûroku, pages 1–15. Res. Inst. Math. Sci. (RIMS), Kyoto, 2020.

[26] B. Endtmayer, U. Langer, I. Neitzel, T. Wick, and W. Wollner. Mesh adaptivity and error estimates applied to a regularized $p$-Laplacian constrainted optimal control problem for multiple quantities of interest. In *PAMM*, volume 19. WILEY-VCH Verlag, 2019.

[27] C. Erath and R. Schorr. A simple boundary approximation for the non-symmetric coupling of the finite element method and the boundary element method for parabolic-elliptic interface problems. In *Numerical Mathematics and Advanced Applications ENUMATH 2017*, pages 993–1001. Springer, 2019.

[28] R. Feldmann, C. M. Gehb, M. Schäffner, A. Matei, J. Lenz, S. Kersting, and M. Weber. A detailed assessment of model form uncertainty in a load-carrying truss structure. In Z. Mao, editor, *Model Validation and Uncertainty Quantification*, volume 3, pages 303–314, Cham, 2020. Springer International Publishing.

[29] J. Fielding-Wells, V. Geiger, J. Miller, R. Bruder, U. Roder, and I. Ratnayake. Designing challenging online mathematical tasks for initial teacher education: Motivational considerations. In M. Graven, H. Venkat, A. Essien, and P. Vale, editors, *Proceedings of the 43rd Conference of the International Group for the Psychology of Mathematics Education*, pages 240–247. PME, Pretorie, South Africa, 2019.

[30] M. Fricke, T. Marić, and D. Bothe. Contact Line Advection using the Level Set Method. *PAMM*, 19(1):e201900476, 2019.

[31] B. Geißler, A. Martin, A. Morsi, M. Walther, O. Kolb, J. Lang, and L. Wagner. Optimization. In A. Pirsing and A. Morsi, editors, *Decision Support Systems for Water Supply Systems, Smart Water System to Improve the Operation of Water Supply Systems by Using Applied Mathematics*, volume 2 of *EMS Series in Industrial and Applied Mathematics*, pages 73–104, doi:10.4171/207, 2020. European Mathematical Society.

[32] O. Genc. Projekt TUWAS: Einsatzszenarien und mögliche Effekte STACK-basierter Mathematikaufgaben im Ingenieursstudium. In *Beiträge zum Mathematikunterricht 2020*. WTM-Verlag, 2020.

[33] O. Genc. STACK for mathematics in engineering - concepts and effects for teachers and students. In *Contributions to the 3rd International STACK Conference 2020*. TTK University of Applied Science: Tallinn, 2020.

[34] O. Genc, H. Bellhäuser, J. Konert, M. Schaub, and R. Bruder. Das Online-Vorkursangebot der TU Darmstadt – Algorithmus zur Gruppenbildung und adaptive Diagnosetests. In *Unterstützungsmaßnahmen in mathematikbezogenen Studiengängen. Eine anwendungsorientierte Darstellung verschiedener Konzepte, Praxisbeispiele und Untersuchungsergebnisse (zu Vorkursen, Brückenvorlesungen und Lernzentren). Konzepte und Studien zur Hochschuldidaktik und Lehrerbildung Mathematik*. Springer Verlag, 2021.

[35] O. Genc, F. Johlke, N. Feldt-Caesar, R. Fournier, U. Roder, and R. Bruder. Mathematikdidaktische Forschungsansätze und Entwicklungsarbeiten zu digitalen Diagnose- und Förderangeboten an der TU-Darmstadt. In *Bildung, Schule, Digitalisierung*. Waxmann, 2020.

[36] O. Genc, F. Johlke, M. Schaub, N. Feldt-Caesa, R. Fournier, U. Roder, and R. Bruder. Mathematikdidaktische Forschungsansätze und Entwicklungsarbeiten zu digitalen Diagnose und Förderangeboten an der TU-Darmstadt. In Kai Kaspar and Michael Becker-Mrotzek, Ssandra Hofhues and Johannes König and Daniela Schmeinck, editor, *Bildung, Schule, Digitalisierung*. Waxmann Münster, 2020.

[37] J. Giesselmann and H. Joshi. Model adaptation of balance laws based on a posteriori error estimates and surrogate fluxes. In *Finite volumes for complex applications IX –*

*methods, theoretical aspects, examples. FVCA 9, Bergen, Norway, June 15–19, 2020. In 2 volumes. Volume I and II*, pages 375–383. Cham: Springer, 2020.

[38] J. Giesselmann and H. Joshi. Model adaptation of chemically reacting flows based on a posteriori error estimates. In *Hyperbolic problems: theory, numerics, applications. Proceedings of the 17th international conference, HYP2018, Pennsylvania State University, University Park, PA, USA, June 25–29, 2018*, pages 442–448. Springfield, MO: American Institute of Mathematical Sciences (AIMS), 2020.

[39] J. Giesselmann, F. Meyer, and C. Rohde. An a posteriori error analysis based on non-intrusive spectral projections for systems of random conservation laws. In *Hyperbolic problems: theory, numerics, applications. Proceedings of the 17th international conference, HYP2018, Pennsylvania State University, University Park, PA, USA, June 25–29, 2018*, pages 449–456. Springfield, MO: American Institute of Mathematical Sciences (AIMS), 2020.

[40] J. Giesselmann and D. Zacharenakis. A posteriori analysis for the Navier-Stokes-Korteweg model. In *Hyperbolic problems: theory, numerics, applications. Proceedings of the 17th international conference, HYP2018, Pennsylvania State University, University Park, PA, USA, June 25–29, 2018*, pages 682–690. Springfield, MO: American Institute of Mathematical Sciences (AIMS), 2020.

[41] A. Gohr, S. Jacob, and W. Schindler. Subsampling and knowledge distillation on adversarial examples: New techniques for deep learning based side channel evaluations. In M. J. Jacobson, O. Dunkelman, and C. O'Flynn, editors, *Selected Areas in Cryptography - SAC 2020*. Springer, to appear.

[42] E. Grädel and M. Otto. Guarded teams: the horizontally guarded case. In M. Fernández and A. Muscholl, editors, *28th EACSL Annual Conference on Computer Science Logic (CSL 2020)*, volume 152 of *Leibniz International Proceedings in Informatics (LIPIcs)*, pages 22:1–22:17. Schloss Dagstuhl–Leibniz-Zentrum f ur Informatik, 2020.

[43] C. Gräßle, M. Hinze, J. Lang, S. Ullmann, and J. Lang. Model order reduction for space-adaptive simulations of Navier-Stokes. volume 19 of *Proceedings of Applied Mathematrics and Mechanics*, doi:10.1002/pamm.201900435, 2019. Wiley-VCH Verlag GmbH & Co. KGaA Weinheim.

[44] D. Gründing, M. Fricke, and D. Bothe. Capillary Rise - Jurin's Height vs Spherical Cap. *Proceedings in Applied Mathematics and Mechanics*, 19(1), 2019.

[45] J. Guillot, G. Koenig, H. Minbashian, E. Frenod, H. Fluorescent, and J. Brajard. Partial differential equations for oceanic artificial intelligence. In *CEMRACS 2019 Proceedings (Geophysical Fluids, Gravity Flows), Marseille*, 2019.

[46] L. Hertlein, A.-T. Rauls, M. Ulbrich, and S. Ulbrich. *An inexact bundle method and subgradient computations for optimal control of deterministic and stochastic obstacle problems*. M. Hintermüller et al. (eds.), SPP1962 Special Issue. ISNM, Birkhäuser, 2020. To appear.

[47] Y. Hori, Y. Hirota, K. Hayashi, S. Hosokawa, and A. Tomiyama. Combined effects of alcohol and electrolyte on mass transfer from single carbon-dioxide bubbles in vertical pipes. *International Journal of Heat and Mass Transfer*, 136:521–530, 2019.

[48] F. Johlke. E-Feedback to overcome Misconceptions. In Mellony Graven and Hamsa Venkat and Anthony Essien and Pamela Vale, editor, *Proceedings of the 43rd Confer-*

*ence of the International Group for the Psychology of Mathematics Education*, page 52. PME Pretoria, South Africa, 2019.

[49] F. Johlke. E-Feedback - Zur Relevanz individueller Fehler und Lernpräferenzen. In Hans-Stefan Siller and Wolfgang Weigel and Jan Franz Wörler, editor, *Beiträge zum Mathematikunterricht 2020*, pages 473–476. WTM Münster, 2020.

[50] F. Johlke, U. Roder, and R. Bruder. Project elma - an investigation of factors influencing achievement in the realschulabschluss mathematics with the help of the analysis of class tests of the final years. In W.-V. Münster, editor, *Beiträge zum Mathematikunterricht*, pages 1069–1072, 2019.

[51] M. Klimm, M. E. Pfetsch, R. Raber, and M. Skutella. Packing under convex quadratic constraints. In D. Bienstock and G. Zambelli, editors, *Integer Programming and Combinatorial Optimization*, Lecture Notes in Computer Science, pages 266–279. Springer International Publishing, 2020.

[52] U. Kohlenbach. Proof-theoretic methods in nonlinear analysis. In *Proc. of the International Congress for Mathematicians 2018 (ICM 2018) Vol.2*, pages 61–82. World Scientitic, 2019.

[53] U. Kohlenbach. Local formalizations in nonlinear analysis and related areas and proof-theoretic tameness. In *Kreisel's Interests. On the Foundations of Logic and Mathematics*, pages 45–61. College Publications. Tributes vol. 41, 2020.

[54] U. Kohlenbach. Kreisel's 'shift of emphasis' and contemporary proof mining. In *Intuitionism, Computation, and Proof: Selected themes from the research of G. Kreisel*, 2021.

[55] K. Krüger. Functional thinking: The history of a didactical principle. In Hans Georg Weigand and William McCallum and Marta Menghini and Michael Neubrand and Gert Schubring, editor, *The Legacy of Felix Klein – ICME 13 Monographs*. Springer International Publishing, 2019.

[56] K. Mang, M. Walloth, T. Wick, and W. Wollner. Adaptive numerical simulation of a phase-field fracture model in mixed form tested on an l-shaped specimen with high poisson ratios. *Numerical Mathematics and Advanced Applications - ENUMATH 2019*, 2020.

[57] H. Minbashian and J. Giesselmann. Deep learning for hyperbolic conservation laws with non-convex flux. In *Proceedings in Applied Mathematics & Mechanics*, pages 1–6. Wiley-VCH GmbH, 2020.

[58] S. Modena. On some recent results concerning non-uniqueness for the transport equation. In A. Bressan, M. Lewicka, D. Wang, and Y. Zheng, editors, *Hyperbolic problems: theory, numerics, applications. Proceedings of the 17th international conference on Hyperbolic Problems*, pages 562–568. AIMS, 2020.

[59] M. E. Pfetsch and A. Schmitt. Exploiting partial convexity of pump characteristics in water network design. In J. S. Neufeld, U. Buscher, R. Lasch, D. Möst, and J. Schönberger, editors, *Operations Research Proceedings*. Springer International Publishing, 2020.

[60] S. Pokutta and M. E. Pfetsch. IPBoost–non-convex boosting via integer programming. In *Proceedings of Machine Learning and Systems 2020*, pages 8932–8941. PMLR, 2020.

[61] I. Ratnayake. Teaching algebra with digital technology: Factors influencing secondary mathematics teachers' task development and implementation. In *Bulletin of the Australian Mathematical Society*, volume 101, pages 350–352. doi: https://doi.org/10.1017/S0004972719001436, 2020.

[62] I. Ratnayake, R. Bruder, F. Johlke, and N. Feldt-Caesar. Quality criteria for teachers to choose video tutorials for different learning situations. In *Proceedings of EDULEARN19 Conferencs*, pages 3669–3674. doi. 10.21125/edulearn.2019.0957, 2019.

[63] I. Ratnayake, R. Bruder, M. F. Mammana, and E. Taranto. Supporting teachers in choosing mathematics learning videos. In *Proceedings of EDULEARN20 Conference*, pages 3022–3031, 2020.

[64] F. J. Regina Bruder, Insa Apel. Basics2go und Basics2play – Digitale Tools zum Wachhalten von Grundwissen und Grundkönnen. In Hans-Stefan Siller, Wolfgang Weigel and Jan Franz Wörler, editor, *Beiträge zum Mathematikunterricht 2020*, page 1503. WTM Verlag, 2020.

[65] M. Schaub, K. Straßburg, R. Bruder, P. Casermann, S. Göbel, K. Hoffmann, P. Müller, and E. Staub. Quality criteria for serious games shown on mathematical education games. In *EDULEARN 20 Proceedings*, pages 5882–5888, 2020.

[66] M. Schneider and J. Lang. Well-Balanced and Asymptotic Preserving IMEX-Peer Methods. Numerical Mathematics and Advanced Applications ENUMATH 2019, doi:10.1007/978-3-030-55874-1, 2021. Springer International Publishing.

[67] Y. Shinano, D. Rehfeldt, and T. Gally. An easy way to build parallel state-of-the-art combinatorial optimization problem solvers: A computational study on solving Steiner tree problems and mixed integer semidefinite programs by using ug[SCIP-*,*]-libraries. In *2019 IEEE International Parallel and Distributed Processing Symposium Workshops (IPDPSW)*, pages 530–541, 2019.

[68] A.-C. Söhling, J. Dick, L. Baumanns, R. Bruder, T. Fritzlar, D. Aßmuss, G. Ambrus, J. Joklitschke, A. Möller, I. Gebel, and B. Rott. Qualitative analyses and interpretations of a problem solving process – a comparison of different approaches. In L. Baumanns, J. Dick, A.-C. Söhling, N. Sturm, and B. Rott, editors, *Wat jitt dat, wenn et fädich es? Tagungsband der Herbsttagung des GDM-Arbeitskreises Problemlösen in Köln*, pages 187–213. WTM-Verlag Münster, 2019.

[69] F. J. Ulrike Roder, Insa Apel. Förderung von Grundwissen und Grundkönnen. In Andreas Frank and Stefan Krauss and Karin Binder, editor, *Beiträge zum Mathematikunterricht 2019*, pages 645–648. WTM Verlag, 2019.

[70] A. Voss-Böhme and A. Gerisch. Multi-scale analysis of contact-dependent interaction in tissue aggregation and invasion. In O. Wolkenhauer, editor, *Systems Medicine*, pages 156–168. Academic Press, Oxford, 2021, published online August 2020.

## 4.4 Preprints

[1] J. P. Aguilera, A. Freund, M. Rathjen, and A. Weiermann. Ackermann and Goodstein go functorial, 2020. Preprint (arXiv:2011.03439), 37 pp.

[2] J. Alex and K. Grosse-Brauckmann. Periodic networks of fixed degree minimizing length. eprint, arXiv:1911.01792, 2019.

[3] B. Augner and D. Bothe. Analysis of some heterogeneous catalysis models with fast sorption and fast surface chemistry. *https://arxiv.org/abs/2006.12098*, 2020.

[4] F. Aurzada, V. Betz, and M. Lifshits. Universal break law for chains of Brownian particles with nearest neighbour interaction. Preprint, arxiv:2010.07706, 2020.

[5] F. Aurzada and M. Kilian. Asymptotics of the persistence exponent of integrated FBM and Riemann-Liouville process. Preprint, arxiv:2007.01254, 2020.

[6] F. Aurzada and S. Mukherjee. Persistence probabilities of weighted sums of stationary Gaussian sequences. Preprint, arxiv:2003.01192, 2020.

[7] S. Basava, K. Mang, M. Walloth, T. Wick, and W. Wollner. Adaptive and pressure-robust discretization of incompressible pressure-driven phase-field fracture. arXiv:2006.16566, Fachbereich Mathematik, TU Darmstadt, 2020.

[8] S. Bechtel. The extension problem for fractional sobolev spaces with a partial vanishing trace condition. Preprint, TU Darmstadt, 2020.

[9] S. Bechtel, R. Brown, R. Haller-Dintelmann, and P. Tolksdorf. Extendability of functions with partially vanishing trace. Preprint, TU Darmstadt, 2020.

[10] A. Birx, Y. Disser, A. V. Hopp, and C. Karousatou. Improved lower bound for competitive graph exploration. Preprint, arXiv:2002.10958, 2020.

[11] D. Bothe. Sharp-interface continuum thermodynamics of multicomponent fluid systems with interfacial mass, 2020.

[12] D. Bothe and P.-É. Druet. Mass transport in multicomponent compressible fluids: Local and global well-posedness in classes of strong solutions for general class-one models, 2019.

[13] D. Bothe and P.-É. Druet. On the structure of continuum thermodynamical diffusion fluxes – a novel closure scheme and its relation to the maxwell-stefan and the fick-onsager approach, 2020.

[14] D. Bothe and P.-É. Druet. Well-posedness analysis of multicomponent incompressible flow models, 2020.

[15] A. Braun, M. Kohler, and A. Krzyżak. Analysis of the rate of convergence of neural network regression estimates which are easy to implement. Preprint, TU Darmstadt, 2019.

[16] A. Braun, M. Kohler, and H. Walk. On the rate of convergence of a neural network regression estimate learned by gradient descent. Preprint, TU Darmstadt, 2019.

[17] J. H. Bruinier, S. Ehlen, and T. Yang. CM values of higher automorphic Green functions for orthogonal groups. Preprint, 2019.

[18] J. H. Bruinier and S. Zemel. Special cycles on toroidal compactifications of orthogonal Shimura varieties. Preprint, 2020.

[19] A. Brunk, B. Dünweg, H. Egger, O. Habrich, M. Lukacova-Medvidova, and D. Spiller. Analysis of a viscoelastic phase separation model. arXiv:2012.04234, 2020.

[20] J. Burczak, S. Modena, and L. Székelyhidi. Non Uniqueness of power-law flows. Preprint, 2020.

[21] F. Canavoi and M. Otto. Cayley structures and common knowledge. Preprint, revised, under review, TU Darmstadt, 2020. arXiv:1909.11521.

[22] R. Danchin, M. Hieber, M. P., and P. Tolksdorf. Free boundary value problems via Da Prato-Grisvard theory. Preprint, 2020.

[23] A. Dedner, J. Giesselmann, T. Pryer, and J. K. Ryan. Residual estimates for post-processors in elliptic problems. arXiv:1906.04658, 2019.

[24] E. Diehl, J. Haubner, M. Ulbrich, and S. Ulbrich. Differentiability results and sensitivity calculation for optimal control of incompressible two-phase Navier-Stokes equations with surface tension. Preprint, arXiv:2003.04971, 2020.

[25] B. Dinis and P. Pinto. Effective metastability for a method of alternating resolvents. Preprint, TU Darmstadt, 2021.

[26] Y. Disser, O. Friedmann, and A. V. Hopp. An exponential lower bound for Zadeh's pivot rule. Preprint, arXiv:1911.01074, 2019.

[27] Y. Disser and D. Weckbecker. Unified greedy approximability beyond submodular maximization. Preprint, arXiv:2011.00962, 2020.

[28] M. Dittmann and H. Wang. Theta blocks related to root systems. 2020.

[29] J. Dölz, H. Egger, and M. Schlottbom. A model reduction approach for inverse problems with operator valued data. arXiv:2004.11827, 2020.

[30] J. Dölz, H. Egger, and V. Shashkov. A convolution quadrature method for maxwell's equations in dispersive media. arXiv:2004.00359, 2020.

[31] J. Dölz, H. Harbrecht, C. Jerez-Hanckes, and M. Multerer. Isogeometric multilevel quadrature for forward and inverse random acoustic scattering. arXiv:2010.14613, 2020.

[32] P. Domschke, O. Kolb, and J. Lang. Fast and reliable transient simulation and continuous optimization of large-scale gas networks. arXiv:2012.02737, 2020.

[33] H. Egger and J. Giesselmann. Stability and asymptotic analysis for instationary gas transport via relative energy estimates. arXiv:2012.14135, 2020.

[34] H. Egger and B. Radu. A second order finite element method with mass lumping for wave equations in H(div). arXiv:1912.07057, 2019.

[35] H. Egger and B. Radu. A second order finite element method with mass lumping for Maxwell's equations on tetrahedra. arXiv:2002.05575, 2020.

[36] H. Egger and M. Sabouri. On the structure preserving high-order approximation of quasistatic poroelasticity. arXiv:1912.13086, 2019.

[37] H. Egger and V. Shashkov. On energy preserving high-order discretizations for nonlinear acoustics. arXiv:1912.07037, 2019.

[38] T. Eiter, M. Kyed, and Y. Shibata. Falling drop in an unbounded liquid reservoir: Steady-state solutions. Preprint, 2019.

[39] M. Elasmi, C. Erath, and S. Kurz. Non-symmetric isogeometric fem-bem couplings. arXiv:2007.09057, 2020.

[40] R. Farwig. Optimal and almost optimal initial values for weak solutions to the Navier-Stokes equations. Survey, Morningside Lecture in Mathematics, 2019.

[41] R. Farwig and R. Kanamaru. Optimality of Serrin type extension criteria to the Navier-Stokes equations. Preprint, 2020.

[42] R. Farwig, H. Kozono, K. Tsuda, and D. Wegmann. Periodic solutions of Navier-Stokes flow in bounded domains with moving boundary. Preprint, 2020.

[43] R. Farwig and C. Qian. The uniform global attractor for non-autonomous quasi-geostrophic equations with fractional dissipation in $\mathbb{R}^2$. Manuscript, 2020.

[44] R. Farwig and M. H. Ri. Maximal $L^1$-regularity of sectorial operators in $(\theta, 1)$-type real interpolation spaces. Preprint, arXiv:2004.12620, 2020.

[45] D. Frenzel and J. Lang. A third-order weighted essentially non-oscillatory scheme in optimal control problems governed by nonlinear hyperbolic conservation laws. arXiv:2009.12392, 2020.

[46] A. Freund. A mathematical commitment without computational strength, 2020. Preprint (arXiv:2004.06915), 25 pp.

[47] A. Freund. Patterns of resemblance and Bachmann-Howard fixed points, 2020. Preprint (arXiv:2012.10292), 24 pp.

[48] A. Freund, M. Rathjen, and A. Weiermann. Minimal bad sequences are necessary for a uniform Kruskal theorem, 2020. Preprint (arXiv:2001.06380), 31 pp.

[49] J. Frey and T. Streicher. Triposes as a generalization of localic geometric morphisms. Preprint, TU Darmstadt, 2020.

[50] M. Fricke, B. Fickel, M. Hartmann, D. Gründing, M. Biesalski, and D. Bothe. A geometry-based model for spreading drops applied to drops on a silicon wafer and a swellable polymer brush film. 2020.

[51] G. Gamrath, D. Anderson, K. Bestuzheva, W.-K. Chen, L. Eifler, M. Gasse, P. Gemander, A. Gleixner, L. Gottwald, K. Halbig, G. Hendel, C. Hojny, T. Koch, P. Le Bodic, S. J. Maher, F. Matter, M. Miltenberger, E. Mühmer, B. Müller, M. E. Pfetsch, F. Schlösser, F. Serrano, Y. Shinano, C. Tawfik, S. Vigerske, F. Wegscheider, D. Weninger, and J. Witzig. The SCIP Optimization Suite 7.0. ZIB-Report 20-10, Zuse Institute Berlin, 2020.

[52] C. Geiersbach and W. Wollner. Optimality conditions for convex stochastic optimization problems in Banach spaces with almost sure state constraint. Preprint 2755, WIAS, 2020.

[53] J. Giesselmann and E. Mäder-Baumdicker. A posteriori error estimates for wave maps into spheres. arXiv:2010.07552, 2020.

[54] J. Giesselmann and E. Mäder-Baumdicker. A posteriori error estimates for wave maps into spheres. Preprint, arXiv:2010.07552, 2020.

[55] J. Giesselmann, F. Meyer, and C. Rohde. Error control for statistical solutions. arXiv:1912.04323, 2019.

[56] A. Gohr, S. Jacob, and W. Schindler. CHES 2018 Side Channel Contest CTF – Solution of the AES Challenges. Eprint, IACR Cryptol. ePrint Arch., Report 2019/094, 2019.

[57] A. Gohr, S. Jacob, and W. Schindler. Efficient solutions of the CHES 2018 AES challenge using deep residual neural networks and knowledge distillation on adversarial examples. Eprint, IACR Cryptol. ePrint Arch., Report 2020/165, 2020.

[58] V. Grimm, D. Nowak, L. Schewe, M. Schmidt, A. Schwartz, and G. Zöttl. A tractable multi-leader multi-follower peak-load-pricing model with strategic interaction. Preprint, TRR 154, 2020.

[59] M. Gugat and J. Giesselmann. Boundary feedback stabilization of a semilinear model for the flow in star-shaped gas networks. submitted to ESAIM: Control, Optimisation and Calculus of Variations, 2020.

[60] O. Habeck and M. E. Pfetsch. Combinatorial acyclicity models for potential-based flows. Technical report, Optimization Online, 2020. http://www.optimization-online.org/DB_HTML/2020/04/7761.html, to appear in Networks.

[61] M. Hartmann, M. Fricke, L. Weimar, D. Gründing, T. Marić, D. Bothe, and S. Hardt. Breakup dynamics of capillary bridges on hydrophobic stripes. Preprint, TU Darmstadt, 2020.

[62] A. Hehl, M. Mohammadi, I. Neitzel, and W. Wollner. Optimizing fracture propagation using a phase-field approach. Preprint, TU Darmstadt, 2019.

[63] G. Hendel, D. Anderson, P. L. Bodic, and M. E. Pfetsch. Estimating the size of branch-and-bound trees. Technical report, Optimization Online, 2020. http://www.optimization-online.org/DB_HTML/2020/04/7722.html.

[64] W. Herfort, K. H. Hofmann, and F. G. Russo. Locally Compact Groups with Permutable Closed Subgroups. Preprint, TU Wien, 2020.

[65] M. Hieber, A. Hussein, and M. Saal. Global strong well-posedness of thre stochastic bidomain equations with FitzHugh-Nagumo transport. Preprint, 2020.

[66] M. Hieber, A. Hussein, and M. Saal. The primitive equations with stochastic wind driven boundary conditions: global strong well-posedness in critical spaces . Preprint, 2020.

[67] M. Hieber, H. Kozono, A. Seyferth, S. S., and T. Yanagisawa. $L^r$-Helmhotz-Weyl decomposition for three dimensional exterior domains. Preprint, 2019.

[68] M. Hieber, K. Kress, and C. Stinner. The Keller-Segel system on bounded convex domains in critical spaces. Preprint, 2020.

[69] A. Hirn and W. Wollner. An optimal control problem for equations with $p$-structure and its finite element discretization. Preprint SPP1962-137, SPP1962, 2020.

[70] J. Hirsch and E. Mäder-Baumdicker. On the Morse Index of Willmore Spheres. Preprint, arXiv:1905.04185, 2019.

[71] K. H. Hofmann and L. Kramer. On Weakly Complete Universal Enveloping Algebras of Pro-Finite-Dimensional Lie Algebras. Preprint, Mathematisches Forschungsinstitut Oberwolfach, 2020.

[72] Y. Hu, Y. Zheng, P. Feng, L. Liu, C. Zhang, A. Gohr, S. Jacob, W. Schindler, I. Buhan, and K. Tobich. Machine learning and side channel analysis in a CTF competition. Eprint, IACR Cryptol. ePrint Arch., Report 2019/860, 2019.

[73] C. Kanzow, A. B. Raharja, and A. Schwartz. An augmented Lagrangian method for cardinality-constrained optimization problems. Preprint, TU Darmstadt, 2020.

[74] U. Kohlenbach and P. Pinto. Quantitative translations for viscosity approximation methods in hyperbolic spaces. Preprint, arXiv:2102.03981, 2021.

[75] U. Kohlenbach and N. Pischke. Quantitative analysis of a subgradient-type method for equilibrium problems. Preprint, arXiv:2008.06900, 2020.

[76] M. Kohler and S. Kersting. Uncertainty quantification based on (imperfect) simulation models with estimated input distributions. Preprint, TU Darmstadt, 2019.

[77] M. Kohler and A. Krzyżak. On the rate of convergence of a deep recurrent neural network estimate in a regression problem with dependent data. Preprint, TU Darmstadt, 2020.

[78] M. Kohler, A. Krzyżak, and S. Langer. Estimation of a function of low local dimensionality by deep neural networks. Preprint, TU Darmstadt, 2019.

[79] M. Kohler, A. Krzyżak, and B. Walter. On the rate of convergence of image classifiers based on convolutional neural networks. Preprint, TU Darmstadt, 2020.

[80] M. Kohler and S. Langer. Statistical theory for image classification using deep convolutional neural networks with cross-entropy loss. Preprint, TU Darmstadt, 2020.

[81] J. Lang. Rosenbrock-Wanner methods: Construction and mission. arXiv:2002.12028, 2020.

[82] J. Lang, P. Domschke, and E. Strauch. Adaptive single- and multilevel stochastic collocation methods for uncertain gas transport in large-scale networks. arXiv:2012.03565, 2020.

[83] J. Lang and B. A. Schmitt. Discrete adjoint implicit peer methods in optimal control. arXiv:2002.12081, 2020.

[84] P. Laurençot and C. Stinner. Mass threshold for infinite-time blowup in a chemotaxis model with splitted population. Preprint, arXiv:2009.09655, 2020.

[85] Y. Li and S. Zemel. Shintani lifts of nearly holomorphic modular forms. 2020.

[86] M. Ljulj, K. Schmidt, A. Semin, and J. Tambača. Homogenization of the time-dependent heat equation on planar one-dimensional periodic structures. arXiv:1912.12989, 2019.

[87] K. Mang, M. Walloth, T. Wick, and W. Wollner. Adaptive numerical simulation of a phase-field fracture model in mixed form tested on an L-shaped specimen with high poisson ratios. Preprint, arXiv:2003.09459, 2020.

[88] Y. Mao, A. Gerisch, J. Lang, M. Böhm, and F. Müller-Plathe. Uncertainty quantification guided parameter selection in a fully coupled molecular dynamics-finite element model of the mechanical behaviour of polymers. submitted to Journal of Chemical Theory and Computation, 2020.

[89] T. Maric. Iterative volume-of-fluid interface positioning in general polyhedrons with consecutive cubic spline interpolation. Preprint, TU Darmstadt, 2020.

[90] S. Meißner and M. Otto. A first-order framework for inquisitive modal logic. Preprint, extended, under review, TU Darmstadt, 2020. arxiv:1906.04981.

[91] J. Mittmann and W. Schindler. Timing attacks and local timing attacks against Barrett's modular multiplication algorithm. Eprint, IACR Cryptol. ePrint Arch., Report 2020/946, 2020.

[92] S. Möller and N. R. Scheithauer. Dimension formulae and generalised deep holes of the Leech lattice vertex operator algebra. arxiv:1910.04947, submitted, 2019.

[93] M. Otto. Acyclicity in finite groups and groupoids. Preprint, corrected and extended, TU Darmstadt, 2020. arXiv:1806.08664.

[94] M. Otto. Graded modal logic and counting bisimulation. Preprint, TU Darmstadt, 2020. arXiv:1910.00039.

[95] A.-T. Rauls and S. Ulbrich. On the characterization of generalized derivatives for the solution operator of the bilateral obstacle problem. Preprint, SPP 1962, 2020.

[96] S. Roch. Ideals of band-dominated operators. Preprint, TU Darmstadt, 2020.

[97] N. Sarna, J. Giesselmann, and P. Benner. Data-driven snapshot calibration via monotonic feature matching. arXiv:2009.08414, 2020.

[98] K. Schmidt and A. Semin. Surface homogenization of an array of Helmholtz resonators for a viscoacoustic model using two-scale convergence. arXiv:2003.11965, 2020.

[99] M. Schuster, E. Strauch, M. Gugat, and J. Lang. Probabilistic constrained optimization on flow networks. arXiv:2009.00352, 2020.

[100] N. Shokina, G. Teschner, A. Bauer, C. Tropea, H. Egger, J. Hennig, and A. J. Krafft. Parametric sequential method for MRI-based wall shear stress quantification. arXiv:2004.11827, 2020.

[101] P. Steinbach, D. O. Schulte, B. Welsch, I. Sass, and J. Lang. Quantification of bore path uncertainty in borehole heat exchanger arrays. arXiv:2103.00271, 2021.

[102] T. Streicher and J. Weinberger. Simplicial sets inside cubical sets. Preprint, TU Darmstadt, 2019.

[103] S. Ullmann, C. Müller, and J. Lang. Stochastic Galerkin reduced basis methods for parametrized linear elliptic partial differential equations. arXiv:1812.08519, 2020.

[104] B. L. Volker Betz, Johannes Ehlert and L. Roth. Sharp phase transition for random loop models on trees. *preprint*, 2020.

## 4.5 Reviewing and Refereeing

**Björn Augner:** Mathematical Reviews; IEEE Conference on Decision and Control (CDC), IFAC World Congress, IEEE Control Systems Letters, SIAM Journal on Control and Optimization

**Frank Aurzada:** Mathematical Reviews; ALEA: Latin American Journal of Probability, Bernoulli, Electronic Communications in Probability, Journal of Applied Probability, Journal of Theoretical Probability, Journal of Statistical Physics, Mathematical Reviews, Probability Theory and Mathematical Statistics

**Dieter Bothe:** Reviews; Chemical Engineering Science, Communications in Partial Differential Equations, European Physical Journal Special Topics, Journal of Fluid Mechanics, Journal of Mathematical Analysis and Applications, International Journal of Heat and Mass Transfer, Physical Review Letters

**Regina Bruder:** Journal für Didaktik der Mathematik, Journal mathematik lehren, Journal Zentralblatt für Didaktik der Mathemtatik

**Jan H. Bruinier:** Invent. Math., Ann. of Math., Acta Math., Journal of the AMS, Math. Ann., Duke Math. Journal, Crelle, Advances in Mathematics, Compositio Mathematica, etc.

**Yann Disser:** Mathematical Reviews ; APPROX 2020, Discrete Applied Mathematics, Discrete Mathematics & Theoretical Computer Science, ESA 2019, ESA 2020, IPCO 2021, ISAAC 2019, Journal of Computer and System Sciences, Journal of Scheduling, MFCS 2019, MFCS 2020, Operations Research Letters, OPODIS 2019, SODA 2019, SODA 2020, SPAA 2019, STACS 2019, Theoretical Computer Science

**Jürgen Dölz:** Applied Mathematical Modelling, MathSciNet, Numerische Mathematik, SIAM Journal on Matrix Analysis and Applications

**Pia Domschke:** Mathematical Methods of Operations Research

**Herbert Egger:** Mathematical Reviews, ERC, DFG; Applied Mathematics and Computation, Applied Numerical Mathematics, BIT Numerical Mathematics, Computers and Mathematics with Applications, ESAIM: Mathematical Modelling and Numerical Analysis, European Transactions on Numerical Analysis, Inverse Problems, Journal of Computational Physics, Mathematical Methods in the Applied Sciences, Mathematics and Computers in Simulation, Numerical Functional Analysis and Optimization, Numerische Mathematik, SIAM Journal on Control and Optimization, SIAM Journal on Numerical Analysis, SIAM Journal on Scientific Computing, SMAI Journal of Computational Mathematics

**Kord Eickmeyer:** Logical Methods in Computer Science, Journal of Symbolic Logic, ACM Transactions on Computational Logic, Fundamenta Informaticae, Theoretical Computer Science

**Christoph Erath:** Mathematical Reviews, Zentralblatt; Applied Numerical Mathematics, Computers and Mathematics with Applications, Science China Mathematics

**Reinhard Farwig:** Mathematical Reviews; Advances in Nonlinear Analysis (2x), Annali dell'Università di Ferrara Sez. VII Sci. Mat., Applied Mathematics Letters, Calculus of Variations and Partial Differential Equations, Communications on Pure and Applied Analysis, Communications in Mathematical Physics, Contemporary Mathematics, ESAIM: Control, Optimisation and Calculus of Variations, J. Differential Equations (3x), J. Dynamics and Differential Equations, J. Evolution Equations, J. Mathematical Analysis and Applications, J. Functional Analysis, J. Mathematical Fluid Mechanics, J. Mathématiques Pures et Appliquées, Mathematica Bohemica (2x) Mathematical Methods in the Applied Sciences (2x), Mathematische Nachrichten, Nonlinear Analysis (3x), Nonlinearity (3x), Quarterly J. Mechanics Applied Mathematics, SN Partial Differential Equations and Applications, Studia Mathematica, Zeitschrift für Angewandte Mathematik und Physik, Book project of Springer Verlag (2x), Book project of Elsevier

**Anton Freund:** Mathematical Reviews, Zentralblatt; Annals of Pure and Applied Logic, The Journal of Symbolic Logic, Archive for Mathematical Logic, Mathematical Structures in Computer Science

**Mathis Fricke:** Reviews; European Physical Journal Special Topics

**Alf Gerisch:** Journal of Computational and Applied Mathematics, Journal of Mathematical Biology, Royal Society Open Science, Philosophical Transactions B, Journal of Theoretical Biology, The Fund for Scientific Research (FNRS, Belgium), Institute Research Fellowships Program (IIT Roorkee, India), LE STUDIUM – Loire Valley Institute for Advanced Studies (France)

**Jan Giesselmann:** Mathematical Reviews; Applied Numerical Mathematics, Networks Heterogeneous Media, Computational Methods in Applied Mathematics, Discrete & Continuous Dynamical Systems-B, Journal on Scientific Computing, Journal of Computational and Applied Mathematics, ESAIM: Mathematical Modelling and Numerical Analysis, Mathematics of Computation, Mathematical Methods in Applied

Sciences, SIAM Journal on Applied Mathematics, SIAM Journal on Mathematical Analysis, SIAM Journal on Numerical Analysis, SIAM Journal on Scientific Computing

**Ulrich Kohlenbach:** Advances in Mathematics, Annals of Pure and Applied Logic, Foundations of Computational Mathematics, Journal of Symbolic Logic, Mathematical Logic Quarterly, Proceedings of the American Mathematical Society

**Michael Kohler:** Annals of Statistics, British Journal of Mathematical and Statistical Psychology, IEEE Transcations on Information Theory, Journal of Nonparametric Statistics, New Zeeland Journal of Statistics, SIAM Journal of Numerical Analysis

**Katja Krüger:** Stochastik in der Schule; mathematica didactica

**Burkhard Kümmerer:** Journal of Functional Analysis, Communications in Mathematical Physics, Journal of Operator Theory, Journal of Statistical Physics, Journal of Mathematical Analysis and Applications, Journal of Mathematical Physics

**Jens Lang:** Applied Numerical Mathematics, Combustion Theory and Modelling, Journal of Physics A: Mathematical and General, Inverse Problems, Computing and Visualization in Science, International Journal of Hyperthermia, International Journal for Numerical Methods in Fluids, Transactions on Mathematical Software, Journal of Computational Physics, Computational and Applied Mathematics, IMA Journal of Numerical Analysis, Mathematics of Computation, SIAM Journal Numerical Analysis, SIAM Journal Scientific Computing

**Yingkun Li:** Forum Math., IMRN, Math. Nach., Open Math, SIGMA, Transaction of AMS, International Journal of Number Theory, Journal of Number Theory

**Elena Mäder-Baumdicker:** Advances in Differential Equations, Communications in Analysis and Geometry

**Tomislav Marić:** Computational Physics Reviews; Journal of Computational Physics, Computers & Fluids, Chemical Engineering Science

**Holger Marschall:** Reviews; Applied Mathematical Modelling, Chemical Engineering Science, Computers & Fluids, Computer Physics Communications, Journal of Computational Physics, Journal of Computational Science, Transport in Porous Media

**Stefano Modena:** Inventiones Mathematicae, Annals of PDE, Communications in Mathematical Physics, Calculus of Variations and Partial Differential Equations, Mathematische Annalen, SIAM Journal on Mathematical Analysis, Communications in Partial differential equations

**Martin Otto:** Studia Logica, Bulletin of Symbolic Logic (BSL), Review of Symbolic Logic (JSL), Archive for Mathematical Logic, Mathematical Logic Quarterly (MLQ), Journal of Philosophical Logic, Journal of Logic and Computation (JLC), ACM/IEEE Symposium on Logic in Computer Science (LICS), Symposium on Theoretical Aspects of Computer Science (STACS), ACM Transactions on Computational Logic (TOCL), Information and Computation, Theoretical Computer Science (TCS), Logical Methods in Computer Science (LMCS)

**Andreas Paffenholz:** American Mathematical Monthly, Algebraic Combinatorics, Electronic Journal of Combinatorics, Discrete & Computational Geometry, Discrete Mathematics, Journal of Combinatorial Theory Series A

**Marc Pfetsch:** Acta Informatica, Algorithmica, Annals of Operations Research, Control & Cybernetics, Computers & Operations Research, Discrete & Computational Geometry, Discrete Optimization, Engineering Optimization, IEEE Transactions on Information Theory, IEEE Transactions on Signal Processing, INFORMS Journal on Computing, INFORMS Journal on Optimization, IPCO 2019, Journal of Engineering Mathematics, Journal of Optimization Theory and Applications, Mathematics of Operations Research, Naval Research Logistics Editorial Office, Networks, Operations Research, Optimization and Engineering, Set-Valued and Variational Analysis, SIAM Journal on Scientific Computing

**Pedro Pinto:** Optimization

**Anna-Maria von Pippich:** Compos. Math., Elem. Math., Int. J. Number Theory, Math. Ann., Res. Number Theory

**Anne-Therese Rauls:** Optimization Methods and Software

**Ulrich Reif:** Journal of Approximation Theory, Computer Aided Geometric Design, Graphical Models, NUMA, Advances in Computational Mathematics, Constructive Approximation, Linear Algebra and Applications

**Steffen Roch:** Mathematical Reviews; Advances in Mathematics, Applied Numerical and Harmonic Analysis, Complex Analysis and Operator Theory, Complex Variables and Elliptic Equations, Operator Theory: Advances and Applications, Operators and Matrices, Proceedings A of the Royal Society of Edinburgh

**Nils Scheithauer:** Advances in Mathematics, Algebra and Number Theory, Annales scientifiques de l'Ecole normale superieure, Communications in Contemporary Mathematics, Communications in Mathematical Physics, Communications in Number Theory and Physics, Compositio Mathematica, International Mathematics Research Notices, Journal of the EMS, Journal für die reine und angewandte Mathematik

**Werner Schindler:** Journal of Cryptology, Transactions on Information Forensics & Security

**Kersten Schmidt:** Applied Numerical Mathematics, Journal of Computational and Applied Mathematics, ESAIM: Mathematical Modelling and Numerical Analysis, Nonlinearity

**Andreas Schmitt:** Journal of Optimization Theory and Applications, Optimization and Engineering

**Johann Michael Schmitt:** Optimization Methods and Software

**Alexandra Schwartz:** Journal of Global Optimization, Mathematical Methods of Operations Research, SIAM Journal on Optimization, Optimization Methods and Software

**Christian Stinner:** Mathematical Reviews, Zentralblatt; Advances in Differential Equations, European Journal of Applied Mathematics, Journal of Evolution Equations, Mathematical Methods in the Applied Sciences, Nonlinear Analysis: Real World Applications, Zeitschrift für Angewandte Mathematik und Mechanik, Zeitschrift für angewandte Mathematik und Physik

**Thomas Streicher:** Mathematical Reviews; Annals of Pure and Applied Logic, Journal of Pure and Applied Algebra, Logic and Analysis, Logical Methods in Computer Sciencel, Mathematical Structures in Computer Science

**Stefan Ulbrich:** Computers & Mathematics with Applications, Computational Optimization and Applications, ESAIM: Control, Optimisation and Calculus of Variations, IMA Journal on Numerical Analysis, Interfaces and Free Boundaries, Optimization Methods and Software, SIAM Journal on Control and Optimization, SIAM Journal on Optimization

**Mirjam Walloth:** ESAIM: Mathematical Modelling and Numerical Analysis, International Journal of Applied and Computational Engineering, IMA Journal of Numerical Analysis

**Torsten Wedhorn:** Inventiones Math., Math. Ann., Journal of Algebraic Geometry, Canadian Journal of Math., Documenta Math., Compositio Math., Pacific Journal of Math., Math. Zeitschrift, IMRN, CMB

**Jonathan Weinberger:** 4th International Conference on Formal Structures for Computation and Deduction

**Winnifried Wollner:** Mathematical Reviews, Zentralblatt MATH ; Applied Mathematics and Computation, Applicable Analysis, Calcolo, Journal of Computational and Applied Mathematics, Computers and Mathematics with Applications, Computational Optimization and Applications, CUBO, A Mathematical Journal, Journal of Mathematical Fluid Mechanics, Journal of Optimization Theory and Applications, ESAIM: Mathematical Modelling and Numerical Analysis, Mathematics of Computation, Numerical Mathematics: Theory, Methods and Applications, Numerical Methods for Partial Differential Equations, Results in Applied Mathematics, Results in Mathematics, SIAM Journal on Scientific Computing

## 4.6 Software

**BEMBEL:** *Boundary Element Method Based Engineering Library*

BEMBEL is an open source library for isogeometric boundary element methods for Laplace, Helmholtz and Maxwell problems. Available on Github and on `www.bembel.eu`

Contributor at TU Darmstadt: J. Dölz, H. Harbrecht, S. Kurz, M. Multerer, S. Schöps, and F. Wolf

**ANACONDA:** *Solving Hyperbolic Partial Differential Algebraic Equations on Networks*
ANACONDA is a software package to solve hyperbolic partial differential algebraicequations on networks. Particularly, it is designed to solve simulation and optimal control tasks for gas and water supply networks.

Contributor at TU Darmstadt: Pia Domschke, Jens Lang, Elisa Strauch, and formerly Oliver Kolb

**FastCOIN:** *Fast adaptive stochastic COllocation INfrastructure*
FastCOIN is a software package that implements an adaptive, anisotropic stochastic collocation approach on sparse grids for the quantification of uncertainty in PDEs or other models with random parameters described by finitely many random variables. This includes, in particular, finite-dimensional parametrizations of correlated random fields. Similar to a Monte Carlo simulation, this approach decouples and, hence, parallelizes the stochastic problem into a set of deterministic problems. FastCOIN is able to resolve a stochastic parameter space of dimensions up to $20-50$.

Contributor at TU Darmstadt: Jens Lang, Alf Gerisch, Sebastian Ullmann, and formerly Bettina Schieche (now at COMSOL)

**KARDOS:** *Solving Time-Dependent Partial Differential Equations*
KARDOS is a software package to solve partial differential equations in one, two and three space dimension adaptively in space and time. Linearly implicit one-step methods of Rosenbrock type or two-step PEER-methods are coupled with standard Finite Elements of various orders. Extensions that we are working on include: incorporation of uncertainty quantification and optimisation.

Contributor at TU Darmstadt: Jens Lang, Alf Gerisch, Philipp Steinbach

**geophase:** *A C++ template library for geometrical operations on non-convex polyhedra with non-planar faces*
`https://git.rwth-aachen.de/leia/geophase`

Contributor at TU Darmstadt: Tomislav Marić

**SCIP-SDP:** *A mixed integer semidefinite programming plugin for SCIP*
SCIP-SDP is a plugin for SCIP to solve mixed integer semidefinite programs (MISDPs). It combines the branch-and-bound framework of SCIP with interior-point SDP-solvers to solve MISDPs using either a nonlinear branch-and-bound approach or an LP-based cutting-plane approach. It extends SCIP by several heuristics, propagators, file readers and the handling of SDP-constraints.
For more information, see `http://www.opt.tu-darmstadt.de/scipsdp/`

Contributor at TU Darmstadt: Tristan Gally, Frederic Matter, Marc E. Pfetsch

**SCIP:** *Software for Solving Constraint Integer Programs*
SCIP is a framework for solving constraint integer programs and performing branch-cut-and-price. It allows total control of the solution process and the access of detailed information. SCIP is also currently one of the fastest non-commercial mixed integer programming (MIP) solvers. It is developed together with the Zuse-Institut Berlin and FAU Erlangen-Nürnberg.

For more information, see https://scip.zib.de

Contributor at TU Darmstadt: Tristan Gally, Christopher Hojny, Marc E. Pfetsch

**CONCEPTS:** *High-order and generalized finite element library*
The numerical C++ library provides finite element methods of higher order, generalized finite element methods and boundary element methods in common object-oriented structures. We developed hp-adaptive finite element methods on curved quadrilateral and hexadredal meshes with locally varying and anisotropic polynomial orders for Poisson and Helmholtz problems, problems in elektromagnetics, quantum physics, viscous acoustics (based on Navier-Stokes equations), elasticity and coupling of those models. The matrices can be assembled and linear systems solved in parallel where we also give access to external direct solvers. There is is a number of time integration schemes for dynamical modelling. CONCEPTS has got a large class documentation and various tutorials are available.
For more information, see https://dowiki.mathematik.tu-darmstadt.de/numa/Concepts

Contributor at TU Darmstadt: Kersten Schmidt, Adrien Semin, Vsevolod Shashkov

**donlp2:** *Solving general smooth nonlinear optimization problems, last revision January 2015*
donlp2 is a software for the solution of general nonlinear programming problems. A first version has been distributed in 1994. Different versions exist now concerning the programming language (strict f77, f90, C99), the user interface and some options (for example elimination of redundant linear equality constraints and an interfacing known as “reverse communication”). donlp2 is free for research, whereas commercial use requires licensing by TU Darmstadt. During the report period 8 academic (free) licenses were given. There were 4 commercial requests, but due to misconceptions concerning the royalty fee from the partners side 3 of these were not satisfied, whereas one given. For more information, see www.mathematik.tu-darmstadt.de/fbereiche/numerik/staff/spellucci/DONLP2/

Contributor at TU Darmstadt: Peter Spellucci

**numawww:** *Interactive computing exercises for numerical methods and continuous optimization*
Numawww is a cgi/html-based computing device for general numerical methods and methods of continuous optimization. In operation since 1996 it has been continuously further developed. It may be used for exercises during a numerical methods course, as a self teaching aid or even as a small scale computing device, requiring minimal knowledge of programming which is presented inside the system itself. It is accessible from anywhere in the world. Many visits were very minimalistic, may be due to problems with long range connections, but during 2019 there were 18868 visits, larger ones from 49 countries, viewing 135482 pages and in 2020 9071 such visits from 12 countries viewing 112667 pages. Any application comes with predefined test cases which can be used without programming knowledge at all. Presently only the English version receives further development, but the German version will be maintained. In the current report period some minor improvements only were

done. For more information, see `numawww.mathematik.tu-darmstadt.de`

Contributor at TU Darmstadt: Peter Spellucci

**DOpElib:** *Differential Equations and Optimization Environment*
DOpElib is a software library for the solution of optimization problems subject to partial differential equations.
For more information, see `www.dopelib.net`

Contributor at TU Darmstadt: Mirjam Walloth, Winnifried Wollner

# 5 Theses

## 5.1 Habilitations

**2019**

Eickmeyer, Kord, *Logics with Invariantly Used Relations* (Martin Otto)

**2020**

Wichelhaus, Cornelia, *Nonparametric Estimation in Stochastic Networks* (Michael Kohler)

## 5.2 PhD Dissertations

**2019**

Bitterlich, Julian, *Investigations into the Universal Algebra of Hypergraph Coverings and Applications* (Martin Otto)

Dalinger, Alexander, *On the hydrodynamic behaviour of a particle system with nearest neighbour interactions* (Volker Betz)

Deising, Daniel, *Modelling and Numerical Simulation of Species Transfer in Bubbly Flows using OpenFOAM* (Dieter Bothe)

Gally, Tristan, *Computational Mixed-Integer Semidefinite Programming* (Marc Pfetsch)

Gründing, Dirk, *An Arbitrary Lagrangian-Eulerian Method for the Direct Numerical Simulation of Wetting Processes* (Dieter Bothe)

Horn, Benjamin, *Shape Optimization for Frictional Contact Problems by a Bundle Trust-Region Method for Constrained Nonsmooth Problems* (Stefan Ulbrich)

Huang, Wei, *Optimal Operation of Water Supply Networks by Mixed Integer Nonlinear Programming and Algebraic Methods* (Marc Pfetsch)

Kromer, Johannes, *Towards a Computer-Assisted Global Linear Stability Analysis of Fluid Particles* (Dieter Bothe)

Kugler, Thomas, *Galerkin methods for simulation of wave propagation on a network of pipes* (Herbert Egger)

Niethammer, Matthias, *A Finite Volume Framework for Viscoelastic Flows at High Weissenberg Number* (Dieter Bothe)

Pesci, Chiara, *Computational Analysis of Fluid Interfaces Influenced by Soluble Surfactant* (Dieter Bothe)

Roder, Ulrike, *Ein Förderkonzept zu mathematischem Grundwissen und Grundkönnen am Übergang in die Sekundarstufe II* (Regina Bruder)

Schorr, Robert, *Numerical Methods for Parabolic-Elliptic Interface Problems* (Christoph Erath)

**2020**

Biehl, Johanna, *Adaptive Multilevel Optimization of Fluid-Structure Interaction Problems* (Stefan Ulbrich)

Birx, Alexander, *Competitive analysis of the online dial-a-ride problem* (Yann Disser)

Buck, Micha, *Exit problems for fractional processes, random walks and an insurance model* (Frank Aurzada)

Celik, Aday, *Non-resonant Solutions in Hyperbolic-Parabolic Systems with Periodic Forcing* (Reinhard Farwig)

Eiter, Thomas, *Existence and Spatial Decay of Periodic Navier-Stokes Flows in Exterior Domains* (Reinhard Farwig)

Ewald, Tobias, *Analyse geometrischer univariater Subdivisionsalgorithmen* (Ulrich Reif)

Frenzel, David, *Weighted Essentially Non-Oscillatory Schemes in Optimal Control Problems Governed by Nonlinear Hyperbolic Conservation Laws* (Jens Lang)

Fricke, Mathis, *Mathematical modeling and Volume-of-Fluid based simulation of dynamic wetting* (Dieter Bothe)

Habeck, Oliver, *Mixed-Integer Optimization* (Marc Pfetsch)

Henkel, Timo, *Classification of BTn-groups over perfectoid rings* (Torsten Wedhorn)

Hesse, Jens, *Central leaves and EKOR strata on Shimura varieties with parahoric reduction* (Torsten Wedhorn)

Hopp, Alexander, *The Complexity of Zadeh's Pivot Rule* (Prof. Dr Yann Disser)

Kersting, Sebastian, *Quantifizierung von Unsicherheit mit tiefen neuronalen Netzen* (Michael Kohler)

Kreß, Klaus, *Time-Periodic Solutions to Bidomain, Chemotaxis-Fluid, and Q-Tensor Models* (Matthias Hieber)

Langer, Sophie, *Ein Beitrag zur statistischen Theorie des Deep Learnings* (Michael Kohler)

Möller, Jens-Henning, *Time-Periodic Solutions to the Equations of Magnetohydrodynamics with Background Magnetic Field* (Reinhard Farwig)

Schöbel-Kröhn, Lucas, *Analysis and Numerical Approximation of Nonlinear Evolution Equations on Network Structures* (Herbert Egger)

Weiner, Andre, *Modeling and Simulation of Convection-dominated Species Transfer at Rising Bubbles* (Dieter Bothe)

Windemuth, Arthur, *Surfaces in Homogeneous Manifolds generated by Schwarz Reflection* (Karsten Große-Brauckmann)

Wrona , Marc, *Liquid Crystals and the Primitive Equations: An Approach by Maximal Regularity* (Matthias Hieber)

## 5.3 Master Theses

**2019**

Accorsini, Lisamarie, *Masslumping Verfahren höherer Ordnung für die effiziente Berechnung der linearen Wellengleichung mittels FEM* (Herbert Egger)

Aegerter, Arvid Stefan, *Zufällige räumliche Permutationen und Cardys Formel* (Volker Betz)

Ahmadi, Sajia, *Robust wachstumsoptimale Portfolios* (Stefan Ulbrich)

Ayar, Özlem, *Periodische Lösungen für bidomain Gleichungen mit FitzHugh-Nagumo Nichtlinearitäten* (Matthias Hieber)

Baden, Manuel, *Ruin models with dependence between claim sizes and claim intervals* (Cornelia Wichelhaus)

Ball, Johannes, *Deep versus deeper learning in der nichtparametrischen Regression* (Michael Kohler)

Bauer, Stephanie Katrin, *Quantilschätzung in einem Simulationsmodell: Monte-Carlo versus numerische Integration* (Michael Kohler)

Behrmann, Nadine, *Learning Step Size Control in Runge-Kutta Methods* (Kristian Kersting)

Benzing, Jan, *Eine Orakel-Ungleichung für deep learning* (Michael Kohler)

Bieker, Patrick, *Modular Units for Orthogonal Groups of Signature (2,2)* (Jan Hendrik Bruinier)

Bielmeier, Silvan Laurin, *On the rate of convergence of a two hidden layer neural network estimator for Hölder continuous regression functions* (Michael Kohler)

Blum, Hendrik Jan Reiner, *Mathematische Programme mit Vanishing Constraints - Epsilon Stationäre Punkte für die Butterfly Relaxierung* (Winnifried Wollner)

Bochenko, Timo, *Scholtes Regularization Method for Truss Design Problems with Semicontinuous and Vanishing Constraints* (Alexandra Schwartz)

Bouaraba, Kai Vincent, *Blended Spline Graphs: A new Paradigm for Curve and Surface Modeling* (Ulrich Reif)

Brockschmidt, Clara Maria, *Maximum Workload of FBM Queues* (Frank Aurzada)

Dautenheimer, Lukas, *Zur Konvergenzrate eines durch Gradientenabstieg gelernten neuronale Netze Regressionsschätzers* (Michael Kohler)

Detzel, Andreas, *Gradientenverfahren in Banachräumen* (Winnifried Wollner)

Diehl, Katharina, *Optimierungsprobleme mit Komplementaritätsnebenbedingungen mit Anwendung auf inverse optimale Steuerungsprobleme* (Stefan Ulbrich)

Diehl, Marie Cathrine, *Verfahren zur Trendschätzung mit geringer Revision* (Jens Krüger)

Flindt, Konrad, *Evacuation on m Rays with k Searchers* (Yann Disser)

Georgi, Philipp Ulrich, *Persistence of Markov Chains* (Frank Aurzada)

Günter, Anna, *Decentralized Collaborative Learning of Personalized Models over Networks and Convergence Analysis* (Stefan Ulbrich)

Groß, Vera, *Zur optimalen Konvergenzgeschwindigkeit bei der Schätzung von Interaktionsmodellen* (Michael Kohler)

Hainz, Claudia, *Stochastische Quasi-Newton-Verfahren für Optimierungsprobleme des maschinellen Lernens und Vergleich mit Verfahren erster Ordnung* (Stefan Ulbrich)

Hamann, Philipp, *Vergleich von Branch-and-Bound Algorithmen für das stabile Mengen Problem* (Marc Pfetsch)

Heil, Caroline Esther, *Panel Data Analysis with Mixed-Effects Models* (Jens Krüger)

Himburg, Sandra Michaela, *Incremental Maximization: Competitive Solutions and improved Lower Bounds* (Yann Disser)

Hintner, Clara, *Analyse des Gradientenabstiegs in der Regressionsschätzung mit neuronalen Netzen* (Michael Kohler)

Ivanov, Vladimir, *Evaluation of Reingold's Algorithm for st-Connectivity in log-Space* (Yann Disser)

Jacob, Isabel, *A robust optimization approach for nonconvex machine learning problems* (Stefan Ulbrich)

Jäger, Maike Elisa, *Kollaborative Auslieferung auf festem Pfad* (Yann Disser)

Kaiser, Kim Doreen, *Estimation of a regression function in a projection pursuit model by neural networks* (Michael Kohler)

Karadeniz, Kasim, *Ein stochastisches semiglattes Newton-Verfahren für nichtglatte nichtkonvexe Optimierung* (Stefan Ulbrich)

Khalil, Suleman Ahmed, *Vector Valued Modular Forms for the Weil Representation of Simple Lattices* (Jan Hendrik Bruinier)

Kilian, Martin Alexander Dennis, *Persistence-Wahrscheinlichkeiten für Summen korrelierter Zufallsvariablen* (Frank Aurzada)

Kirpicev, Denis, *A deep structured learning approach for system identification* (Stefan Ulbrich)

Klein, Simon, *Das Graphexplorationsproblem: Ein kompetive Analyse verschiedener Algorithmen* (Yann Disser)

Klingenberg, Florian Tim, *Ziehen an einer Kette wechselwirkender Brown´scher Teilchen* (Volker Betz)

Knof, Isburg Käthe, *The Geometric Argyris Element* (Ulrich Reif)

Kosara, Thomas, *Modellierung und Simulation akustischer Wellenausbreitung unter Beachtung nichtlinearer Effekte* (Herbert Egger)

Kuete Tiayo, Perpetue, *Estimation of Multivariate Regression Functions by Multilayer Neural Networks* (Michael Kohler)

Lauber, Felix, *Comparison of different Proofs of Goodman´s Theorem and their arithmetic Complexity* (Ulrich Kohlenbach)

Lenz, Jonas Christopher, *Global existence for a tumor invasion model with repellent taxis and therapy* (Christian Stinner)

Mesfun, Yonas, *Stability results for chemotaxis systems with logistic growth* (Christian Stinner)

Metzler, Ingmar, *Coefficients of Eisenstein series on SL2 and related Whittaker functions* (Jan Hendrik Bruinier)

Mohring, Sarah, *Iran Sanctions and Crude Oil Prices - an Empirical Exploration* (Jens Krüger)

Moos, Michael Werner, *Convergent Approximation of Adjoints for Derivative Calculations in Optimal Control of Hyperbolic Laws* (Stefan Ulbrich)

Mugler, Philipp, *Topologie-Optimierung von Gasnetzen* (Marc Pfetsch)

Ott, Claire Tabea, *All Set-based triposes are induced by implicative algebras* (Thomas Streicher)

Philippi, Nora Marie, *Analysis and Numerical Approximation of Transport Processes on Networks* (Herbert Egger)

Plitzko, Sebastian, *Die Dynamik und Stabilität von räumlichen Nahrungsnetzen* (anerkannt)

Polat, Tolga, *Schätzung einer Regressionsfunktion in einem Projection-Pursuit-Modell durch stückweise Polynome* (Michael Kohler)

Rasch, Janes, *Konvergenz von Teletraffic-Modellen* (Frank Aurzada)

Rentschler, Johannes Bernhard, *Entwicklung und Bewertung von Lösungsverfahren für das Stochastic Service Design Problem* (Ralf Elbert)

Sancar, Kenan Philipp, *Continuity of spectra and pseudospectra in continuous fields of C*-Algebras* (Steffen Roch)

Scheuermann, Nadine Edith Ottilie, *Stationäre Verteilungen für stochastische Netzwerke mit Blockierungen* (Cornelia Wichelhaus)

Schmalz, Tobias, *Parametrisierung von Gittern durch Steiner-Netzwerke* (Karsten Große-Brauckmann)

Schmidt, Carsten, *Solvability of chemotaxis models with semigroup theory* (Christian Stinner)

Schmidt, Fabian, *Schätzung einer Dichte unter Verwendung eines fehlerbehafteten Simulationsmodels* (Michael Kohler)

Schmitt, Jannik, *A Robust Optimization Approach for Training Artificial Neural Networks* (Stefan Ulbrich)

Schneiter, Clément Denis Raymond, *Lp Estimates for Time-Periodic Boundary Value Problems* (Robert Haller-Dintelmann)

Seipp, Sebastian, *Schätzung einer Regressionsfunktion durch tiefe neuronale Netze: Theorie und Praxis* (Michael Kohler)

Skryagin, Arseny, *Deep versus deeper learning in nonparametric regression* (Michael Kohler)

Storzer, Matthias, *A dimension formula for symmetric modular forms and equivariant Gauss sums* (Nils Scheithauer)

Strelow, Erik Laurin, *Relaxierung von diskreten Steuervariablen mittels äußerer Konvexifizierung* (Jens Lang)

Tran, Theresa Thanh Mai, *A Game Theoretical Approach to Explainable Machine Learning* (Alexandra Schwartz)

Trapp, Franziska, *Das Service Network Design Problem - Ein systemathischer Literaturüberblick zum aktuellen Stand der Forschung* (Ralf Elbert)

Vock, Christian Willy, *The Weakly Complete Group Algebra of a Topological Group* (Karl Heinrich Hofmann)

Walter, Benjamin, *Schätzung einer Regressionsfunktion durch einen linearen kleinsten-Quadrate-Schätzer basierend auf neuronalen Netzen* (Michael Kohler)

Weber, Julia Ute, *Schätzung einer hochdimensionalen Regressionsfunktion durch mehrschichtige neuronale Netze* (Michael Kohler)

Weckbecker, David Michael, *Preservation of Graph Properties under Color Refinement* (Yann Disser)

Werner, Philipp, *Optimierung von Stromnetzen mit erneuerbaren Energien* (Stefan Ulbrich)

Wilfert, Florian Maximilian, *Optimal reinsurance in risk models* (Cornelia Wichelhaus)

Wolfenstetter, Andreas Klaus-Dieter, *Regressionsschätzung mit tiefen Neuronalen Netzen mit ReLU Aktivierungsfunktion* (Michael Kohler)

Woznik, Saskia Sophia, *Siegel Eisenstein series* (Jan Hendrik Bruinier)

Yaylali, Can, *Equivariant Chow theory over general base schemes* (Torsten Wedhorn)

Zedler, Nora Anna Barbara, *Exakte und inexakte Subsampled-Newton-Verfahren für Optimierungsprobleme im Maschinellen Lernen* (Stefan Ulbrich)

Zender, Sebastian, *Zur Konvergenzgeschwindigkeit bei der Schätzung einer multivariaten Regressionsfunktion durch neuronale Netze* (Michael Kohler)

Zierau, Darja-Maria, *Cross-Ratios of Torsion Points on Elliptic Curves and Uniformisation of Punctered Spheres* (Brice Loustau)

**2020**

Altin, Hakki, *Approximation von glatten Funktionen durch sehr breite tiefe neuronale Netze* (Michael Kohler)

Andiryous, Dawood, *A theoretical and computational analysis of the Lemke-Howson method for bimatrix games* (Alexandra Schwartz)

Beckmann, Markus, *Zur Konvergenzgeschwindigkeit von sehr tiefen vollständig verbundenen neuronalen Netzen in der nichtparametrischen Regression* (Michael Kohler)

Beck, Tobias, *Truss design using multi-dimensional vanishing constraints: Theoretical analysis and numerics* (Alexandra Schwartz)

Buchholz, Johannes Christian, *Robuste Optimierung durch quadratische Approximierung im Kontext des maschinellen Lernens in der Bildklassifikation* (Stefan Ulbrich)

Dick, Fabian, *Schätzung einer Regressionsfunktion durch überparametrisierte tiefe neuronale Netze* (Michael Kohler)

Forstner, Philipp, *Regularity Structures for SQG driven by Space-Time White Noise* (Volker Betz)

Gabel, Adrian Salahaddin, *Analyse der Konvergenzgeschwindigkeit eines einfach berechenbaren Neuronale-Netze-Regressionsschätzers* (Michael Kohler)

Gerlach, Isabelle, *MARS and Deep Learning: A Connection* (Michael Kohler)

Grobe, Philip, *Analyse der Konvergenzgeschwindigkeit eines durch Gradientenabstiegs gelernten Neuronale-Netze Regressionsschätzers* (Michael Kohler)

Gutermann, Jannis, *Energie-effiziente Wasserversorgung im Hochhaus* (Marc Pfetsch)

Junker, Markus Peter, *Ein einfach berechenbarer Neuronale-Netze-Regressionschätzer in einem Projection-Pursuit-Modell* (Michael Kohler)

Klein, Johanna, *Konvergenzrate von sehr tiefen Neuronale-Netze-Regressionschätzern mit ReLU-Aktivierungsfunktion* (Michael Kohler)

Kober, Kyrill Benedikt, *Eine semiglatte Newton Methode mit mehrdimensionaler Filterglobalisierung für l1-Optimierung* (Stefan Ulbrich)

Komkowski, Luisa, *Estimation of a regression function by deep over-parametrized neural networks* (Michael Kohler)

Kovacevic, Jovan, *Fourierkoeffizienten von Jacobi-Formen* (Jan Hendrik Bruinier)

Kreh, Melissa, *Zur Konvergenzrate von tiefen und sehr breiten neuronalen Netzen* (Michael Kohler)

Käse, Philipp, *Warped Products and Hypersurface Theory in General Relativity* (Karsten Große-Brauckmann)

Kunkel, Teresa, *Estimation of interface motion by velocity identification in a level-set method* (Herbert Egger)

Latocha, David Peter, *The Expressive Power of Modal Team Logic* (Martin Otto)

Lioutikov, Michelle, *Toeplitzalgebren mit symmetrischen Erzeugern* (Steffen Roch)

Luckas, Michelle Melanie, *Regularity Properties of Divergence Form Operators in the H-1 Setting* (Robert Haller-Dintelmann)

Mantel, Franziska Gabriele, *Wachhalten mathematischer Grundlagen in der beruflichen Schule - Metalltechnik* (Regina Bruder)

Marakis, Vassilios, *Adiabatic pertubation theory for multiple bands* (Volker Betz)

Möll, Michelle Christin, *Optimale Entscheidungsbäume für binäre Daten* (Marc Pfetsch)

Neumann, Nils, *Orbifolds, groupoids and fundamental groups* (Karsten Große-Brauckmann)

Pellmann, Oliver, *Approximation von glatten Funktionen mit sehr tiefen neuronalen Netzen* (Michael Kohler)

Pilz, Maximilian Robert Urs Leonard, *Quantifizierung von Unsicherheit bei geschätzter Verteilung der Eingangsparameter* (Michael Kohler)

Polzer, Steffen Robert, *Limit theorems for Polaron-like measures by a point process representation* (Volker Betz)

Proschmann, Dominik, *Identifiability results for service time distributions in stochastic networks* (Cornelia Wichelhaus)

Rehlich, Lea Charlotte, *Robuste Optimierung von Stromnetzen unter Unsicherheit* (Stefan Ulbrich)

Schadt, Stefan, *Aktuariell-ökonomische Bewertung von Versicherungsbeständen in der Lebensversicherung* (Michael Kohler)

Schipp von Branitz, Johannes Philipp Manuel, *Higher Groups via Displayed Univalent Reflexive Graphs in Cubical Type Theory* (Thomas Streicher)

Schmitt, Miriam, *Global existence for a tumor invasion model with general taxis terms* (Christian Stinner)

Schoch, Viktor, *Multi-Curve Gaussian Quadratic Short Rate Modelling* (Volker Betz)

Schröder, Jan Philipp, *Minimale Regelflächen in homogenen Räumen* (Karsten Große-Brauckmann)

Seiche, Timo, *On the rate of convergence of fully connected very deep neural network regression estimates* (Michael Kohler)

Simon, Nicolai, *The Stochastic Gradient Method and its Application on PDE Constrained Optimization* (Winnifried Wollner)

Sitnikov, Konstantin, *The Dirichlet-to-Neumann operator on rough domains* (Robert Haller-Dintelmann)

Spahn, Christopher Daniel, *Zwei Resultate zur Approximation glatter Funktionen durch sehr tiefe neuronale Netze* (Michael Kohler)

Tekam Feudjo, Stephane, *A Gaussian Mixture Model Approach to Off-Policy Policy Gradient Estimation* (Jan Peters)

Tritschler, Marius Fabian, *Context Guarded Team Logics* (Martin Otto)

Tsiouris, Alexandros, *Poisson's Equation: Influence of Small Deviations of the Domain on the Solution* (Volker Betz)

Uihlein, Andrian Gerhard, *Sequential quadratic programming for degenerate optimization problems in function spaces* (Winnifried Wollner)

Wejwoda, Dominik, *Zu Einflussfaktoren auf die technische Rechenkompetenz im Fachbereich Metalltechnik der beruflichen Schule* (Regina Bruder)

Wrba, Philipp Fritz, *A Column Generation Approach for Logistic Networks with Tree Constraints* (Marc Pfetsch)

Zhao, Wenjia, *Density estimation based on improved surrogate model* (Michael Kohler)

Zheng, Anny Ning, *Zur Schätzung von Regressionsfunktionen mit niedriger lokaler Dimension durch tiefe neuronale Netze* (Michael Kohler)

## 5.4 Staatsexamen Theses

**2019**

Bettac, Lea, *Erstellung von Lernvideos zum Hypothesentesten für den Stochastikunterricht in der Sek II – Erprobung eines Zugangs über die P-Wert Methode* (Katja Krüger)

Darmstädter, Vera, *Entwicklung eines Unterrichtskonzeptes zum Themengebiet Stöchiometrie auf der Grundlage einer mathematikdidaktischen Analyse* (Katja Krüger)

Herzog, Jan, *Teilnehmendencharakteristik und Ergebnisanalyse eines Mathematik-Abiturvorbereitungskurses* (Regina Bruder)

Mentz, Anna Katharina, *Wachhalten von mathematischem Grundwissen und Grundkönnen aus Klasse 5 mit digitalen Lernangeboten* (Regina Bruder)

Schaper, Lena, *Quizzbasierte mathematische Grundlagensicherung ab Jahrgangsstufe 8* (Regina Bruder)

von Gehlen, Paula, *Problemlösenlernen im Stochastikunterricht - Eine Analyse ausgewählter Aufgaben im Hinblick auf Heurismen* (Katja Krüger)

Wollbeck, Vanessa, *Quizzbasierte mathematische Grundlagensicherung ab Jahrgangsstufe 7* (Regina Bruder)

Steffler, Marvin, *Entwicklung einer digitalen Selbstlernumgebung als Zugang zur Taylorapproximation* (Katja Krüger)

**2020**

Jung, Jenny, *Grundvorstellungen zu Termen wachhalten* (Regina Bruder)

Küppers, Sebastian, *Konzept für eine Schüler-App zum Üben von mathematischem Grundwissen und Grundkönnen* (Regina Bruder)

Rose, Luisa, *Digitale Kopfübungsaufgaben zum Umgang mit Größen am Übergang Primarstufe - Sekundarstufe I* (Regina Bruder)

Thomas, Esther, *Geometrische Denkaufgaben – Eine Untersuchung gemeinsamer Lösungsprozesse von Schüler*innen* (Katja Krüger)

Wolff, Robin, *Pilotierung des Kopfübungsangebots im Projekt Basics2go für Klasse 5/6* (Regina Bruder)

## 5.5 Bachelor Theses

**2019**

Borkowski, Markus, *Theorem of Malgrange-Ehrenpreis* (Mads Kyed)

Brandt, Felix Christopher Helmut Ludwig, *Calderòn-Zygmund Decomposition and Singular Integral Operators* (Robert Haller-Dintelmann)

Cakaj, Rinor, *Portfolio Optimization* (Frank Aurzada)

Daknou, Ahmed, *Ein Optimierungsansatz zur Berechnung der impliziten Volatilität amerikanischer Optionen* (Stefan Ulbrich)

Dieringer, Nicolette Ada Sabrina, *Introduction in Insurance Mathematics* (Michael Kohler)

Doat, Joel Andre, *Modal Logic in Coalgebraic Context* (Martin Otto)

Drews, Selina Katharina, *Eine Einführung in die Lebensversicherungsmathematik* (Michael Kohler)

Forstner, Philipp, *The Divergence Problem due to O. Ladyzhenskaya* (Reinhard Farwig)

Franck, Sascha Josef, *A functional calculus approach to the Dore-Venni Theorem* (Robert Haller-Dintelmann)

Gajewski, Marvin, *Asymptotic properties of quantum dynamical semigroups* (Burkhard Kümmerer)

Galkin, Wladislaw, *Minimum Equivalent Precedence Relation Systems* (Marc Pfetsch)

Göbel, Tim Mathias, *Introduction to Distribution Theory* (Christian Stinner)

Gegelia, Nutsa, *Elliptische Kurven und das arithmetisch-geometrische Mittel* (Jan Hendrik Bruinier)

Gehlhaar, Rebekka Doris, *Equivalence in Provenance Semantics* (Kord Eickmeyer)

Göksu, Yasemin, *Eine Testumgebung für online Dial-A-Ride on the line* (Yann Disser)

Grimm, Lorenz Walter Heinz, *Fast optimization algorithms for sparse reconstruction* (Stefan Ulbrich)

Güthge, Anton Basil Kato, *Mustafin Degenerations of Projective Spaces* (Torsten Wedhorn)

Harder, Christian Lennart, *Ein Stochastisches Quasi-Newton-Verfahren für das Machine Learning* (Stefan Ulbrich)

Helmer, Max Peter, *The Preferential Attachment Model* (Frank Aurzada)

Helm, Falko Frederik Herbert Martin, *Die Klassifikation von Niemeier-Gittern mit Hilfe von Jacobi-Formen* (Nils Scheithauer)

Herbert, Eric Louis, *Gleichgradige Integrierbarkeit und der Satz von de Finetti* (Frank Aurzada)

Höfling, Benedikt Otto, *Ein relativ verteilungs-robuster Optimierungsansatz für die Portfolioauswahl* (Stefan Ulbrich)

Ihrig, Anna-Lisa, *Numerische Zeitintegration für Neuronale Netzwerke* (Jens Lang)

Jegatheeswaran, Prabashan, *Eigenschaften der Riesz-Transformation und der Satz von Mihlin-Hörmander* (Matthias Hieber)

Karg, Jonas, *Einführung in die Interpolationstheorie und eine Anwendung* (Matthias Hieber)

Karner, Stephanie, *Rankin-Cohen Operatoren und L-Funktionen* (Jan Hendrik Bruinier)

Kuhr, Christopher, *Die Dimensionsformel für Modulformen zur Weildarstellung von II1,1(N)* (Nils Scheithauer)

Langhammer, Carmen Tamina Anna, *Optimization of T-Period Supply-Chain Problems: Decomposition, Algorithms, Sensitivity Analysis and Computational Example* (Winnifried Wollner)

Lind, Ludwig Paul, *Das Malgrange-Ehrenpreis-Theorem* (Robert Haller-Dintelmann)

Maas, Florian, *Classifying Toposes for Finitely Presented, Geometric Theories* (Thomas Streicher)

Mahncke, Swantje, *Analysis of a human category learning algorithm* (Frank Jäkel)

Mäder, Jan Philipp, *Anchored rectangle and square packings in the plane* (Marc Pfetsch)

Müller, Manuel Karl-Heinz, *Modular polynomials and their computations* (Ph.D. Yingkun Li)

Müller, Sven-Andre, *An Open Mapping Theorem for Analytic Rings* (Torsten Wedhorn)

Möll, Ricardo, *On Maximum Principles to Linear Second-Order Elliptic Equations* (Matthias Hieber)

Moneke, Jasmina Cosima, *Single-machine scheduling with supporting tasks* (Marc Pfetsch)

Moral Garcia del Cerro, Maria, *A combinatorial approach to the max k-vertex cover problem for bipartite graphs* (Marc Pfetsch)

Morasch, Jakob Mathias, *Machine Learning for Fraud Detection in E-Commerce* (Marc Pfetsch)

Niehof, Christian, *Fundamentallösungen linearer Differentialgleichungen* (Matthias Hieber)

Olbert, Yannik, *Ein Genetischer Algorithmus zum Lösen des Dial-a-Ride Problems* (Yann Disser)

Pfeiffer, Isabell, *Eine ILP-Formulierung für das Dial-a-Ride Problem* (Yann Disser)

Rampe, Till, *Construction of a model structure on the category of cochain complexes* (Torsten Wedhorn)

Scherf, Fabian William, *Fractional Order Derivatives and Fractional Sobolev Spaces* (Robert Haller-Dintelmann)

Scherf, Robert Ralf, *Gaußsche Maße auf unendlichdimensionalen Räumen* (Volker Betz)

Schierholz, Jan Luca, *Robuste Optimierung mehrstufiger Portfolios* (Stefan Ulbrich)

Schmidt, Jakob, *Monetary measures of risk* (Frank Aurzada)

Schuchter, Jan, *The k-Server Problem* (Yann Disser)

Seidel, Jona Luis, *Connectedness in Hyperspaces* (René Bartsch)

Shala, Blendi, *Introduction to Cooperative Game Theory and Solution Concepts* (Alexandra Schwartz)

Solms, Felix Mathias, *Incrementally Solving the Region Choosing Problem* (Yann Disser)

Sombre, Wanja Leon, *The Configuration Model* (Frank Aurzada)

Strobel-Hofmann, Christina, *A Survey on Mathematical Models for a Smart Autonomous Public Transportation System* (Yann Disser)

Tewolde, Emanuel, *Component-based Wind Turbine Health Monitoring using Support Vector Machines on Operational and Event Data* (Stefan Ulbrich)

Tümmler, Marcel Marc Kevin, *Kreditrisiko Optimierung bezüglich des Conditional Value-at-Risk* (Stefan Ulbrich)

Tobiasch, Tim Nelson, *Compositionality in Provenance Semantics* (Kord Eickmeyer)

Volk, Laura, *Ein relativ robuster CVaR Ansatz zur Portfoliooptimierung unter Verteilungsunsicherheit* (Stefan Ulbrich)

Wienk-Borgert, Teresa, *Cost-Minimal Supplier Selection and Order Allocation of Multiple Products Considering Discounts* (Marc Pfetsch)

Wigandt, Arthur, *Performance analysis of depth-first search* (Yann Disser)

Wilka, Hendrik, *Superconvergent Explicit Peer Methods with Step Size Control: Theory and Applications* (Jens Lang)

Winkel, Noah Dominic, *Optimales Anordnen von statistisch abhängigen Tests* (Marc Pfetsch)

**2020**

Agamia, Josef, *Percolation: How do the clusters behave below the critical value?* (Frank Aurzada)

Altenbockum, Christian, *Pricing of American Options and Optimal Stopping* (Michael Kohler)

Anthes, Christopher, *Eingebettete explizite Runge-Kutta-Verfahren höherer Ordnung* (Jens Lang)

Antunes Vieira, Marilia, *Exponentielle Runge-Kutta-Verfahren* (Jens Lang)

Baligacs, Julia, *Projection-Based Algorithms for the k-Server Problem* (Yann Disser)

Breitkopf, Jannik, *Die Porous-Medium-Equation im Ganzraum* (Robert Haller-Dintelmann)

Calo, Luca Domenico Mirko, *A relation between the Sobolev and the isoperimetric inequality* (Robert Haller-Dintelmann)

Demke, Melanie, *Beweis einer kompetitiven $O(\log^2 k)$ Schranke für das K-Server Problem auf HST's* (Yann Disser)

Dorschner, Timon, *Komplexität der Burning-Zahl eines Graphen* (Marc Pfetsch)

Dyson, Isabel Dorita, *On the approximation of continuous functions by neural networks* (Michael Kohler)

Edenhofer, Roman Hanno, *Abort-Strategies for Preemptive Online Dial-a-Ride* (Yann Disser)

Englert, Johannes Andreas, *Analysis and Discretization of an elastic model on graphs* (PD Kersten Schmidt)

Falkenberg, Peer, *A model of mutation and selection* (Frank Aurzada)

Füg, Leonie, *Variationsrechnung: Schwache Lösungen der Euler-Lagrange-Gleichung* (Robert Haller-Dintelmann)

Folger, Lea, *Eine Einführung in die Schadenversicherungsmathematik* (Michael Kohler)

Fries, Marco Dorian, *Linearly Implicit Two-Step Peer Methods: Theory and Application* (Jens Lang)

Fuhrer, Sebastian, *Die Modellierung von Rendite/Risikokennziffern von verschiedenen Anlageklassen mit Hilfe von Zeitreihenanalyse und Monte-Carlo-Simulation* (Volker Betz)

Funke, Clara, *Preistheorie für amerikanische Optionen in vollständigen Märkten* (Frank Aurzada)

Göbel, Michelle, *The Picard-Lindelöf theorem in a Hilbert space setting* (Robert Haller-Dintelmann)

Görlich, Kai Jasper, *Semidefinite Programs: A Minimum Function-based Newton-type Method with Quadratic Convergence without Strict Complementarity* (Stefan Ulbrich)

Gunkel, Jonas, *Regressionsbasierte Monte-Carlo-Verfahren zur Bewertung von Amerikanischen Optionen* (Michael Kohler)

Halbey, Jannis, *Optimization of Top-K Support Vector Machines by Semismooth Newton Methods* (Stefan Ulbrich)

Hammett, Antonia Julia, *On Submodular Search and Machine Scheduling* (Marc Pfetsch)

Jany, Jeremy Anton, *Real Forms of Complex Simple Lie Algebras* (Nils Scheithauer)

Jiang Vicente, Daniel, *On Robust Optimization With Recourse* (Winnifried Wollner)

Kastner, Anton, *Foundations of Markov chains on a general state space* (Frank Aurzada)

Keil, Niels Heinrich, *Finite Volumen Verfahren für Euler Gleichungen zur Wettervorhersage auf Arakawa C-Gittern* (Jens Lang)

Kühnel, Bianca Margit, *Sensorplatzierung und 2-Zusammenhang* (Martin Kiehl)

Klarner, Lukas Paul, *Algorithmen für nichtlineare und stochastische ressourcen-beschränkte kürzeste Wege* (Marc Pfetsch)

Klippel, Andreas, *Lace-expansion* (Benjamin Lees)

Knötzele, Hannes, *Introduction to W-algebras* (Nils Scheithauer)

Kontohow-Beckers, Konstantin Pentscho, *Schätzung einer multivariaten Regressionsfunktion durch tiefe neuronale Netze* (Michael Kohler)

Kopp, Maximilian Bernd, *The invariants of the Weil representation associated with II (N)* (Nils Scheithauer)

Koynov, Radoslav, *Stochastic Methods in Local Timing Attack against RSA with Montgomery Multiplication* (Werner Schindler)

Kozymka, Olena, *Zwei Anwendungen des Satzes von Stokes: Der Satz von Radò und der Satz vom gekämmten Igel* (Elena Mäder-Baumdicker)

Kunz, Daniel, *Conformal Maps and Applications to the Theory of Minimal Surfaces* (Elena Mäder-Baumdicker)

Lang, Christopher Matthias, *Das Satz von Gearhart und Greiner* (Robert Haller-Dintelmann)

Martin, Julian Lucas, *Schätzung der Verteilung des Gesamtschadens in der Versicherungsmathematik* (Michael Kohler)

Martin, Tatjana, *Implizit-Explizite Runge-Kutta Methoden mit optimierten Speicher* (Jens Lang)

Mittenbühler, Pascal, *Der sektorielle Funktionalkalkül* (Robert Haller-Dintelmann)

Moritz, Jan, *Charakterisierungssätze für Operatorhalbgruppen* (Matthias Hieber)

Muncke, Helge Jan, *Mathematical Modeling of Solar Power Forecasting* (Frank Aurzada)

Nowak, Patrick, *Schätzung einer Regressionsfunktion mit Kernen* (Michael Kohler)

Olt, Markus Andreas, *Interpolation of Operators on LP Spaces* (Matthias Hieber)

Pelzer, Alexander Jan, *Damage reservation with long lasting settlement* (Michael Kohler)

Pfaff, Sven, *Numerische Simulation von Mehrkörpersystemen* (Herbert Egger)

Raßmann, Simon Vincent, *On Prefix Fragments of Various New First-Order Team Logics* (Martin Otto)

Ritter, Nadine Marlise, *Zur Berechnung der Prämie in der Schadenversicherungsmathematik* (Michael Kohler)

Rodrigues Nunez, Yoel Amandio, *Schätzung einer Regressionsfunktion durch stückweise konstante Funktionen* (Michael Kohler)

Sänger, Alisha Jessica Lilli, *Gradient Methods for Machine Learning* (Stefan Ulbrich)

Stappert, Mirko, *Stone Duality* (Torsten Wedhorn)

Stonner, David Jakob, *Permutation Automorphisms* (Nils Scheithauer)

Thümmel, Annette Elisabeth, *Optimal Charging Station Placement for Balanced Electric Car Sharing* (Stefan Ulbrich)

Tibke, Elena Christine, *Die Enneper-Weierstraß Darstellung von Minimalflächen und der Uniformisierungssatz* (Elena Mäder-Baumdicker)

Trieb, Mirjam, *The Dunford-Pettis Property* (Steffen Roch)

Törner, Nils, *Planung der Aufteilung von Prozessoren mit linearer Verlangsamung* (Marc Pfetsch)

Urban, Mira, *Modellierung und Numerische Simulation von Nervenzellen mittels Neuronenmodelle* (Jens Lang)

Volkert, Nathalie, *Distribution of the Surplus at and prior to Ruin in the Cramér-Lundberg Model* (Frank Aurzada)

Walker, Harry Richard Havelock, *The Krein-Milman Theorem and Applications* (Robert Haller-Dintelmann)

Wenzel, Johanna, *Modular forms an the number of representation of integers as sums of squares* (Anna-Maria von Pippich)

Williamson, Len Cewa, *The Dunford-Riesz Calculus* (Matthias Hieber)

Windt, Anna, *Relaxation Runge-Kutta Methods: Theory and Application* (Jens Lang)

Özalp, Elise, *Sympletic Runge-Kutta Methods for Hamiltonian Systems* (Alf Gerisch)

Zöchling, Tarek Manuel, *Eindeutigkeit schwacher Lösungen von Wellengleichungen* (Matthias Hieber)

# 6 Presentations

## 6.1 Talks and Visits

### 6.1.1 Invited Talks and Addresses

**Frank Aurzada**

14/06/2019 *How complex is a random picture?*
Seminar talk, Universität Innsbruck

26/08/2019 *Persistence probabilities of autoregressive processes*
Workshop “Dynamics, random media and universality of complex physical systems”, Münster

24/10/2019 *Persistence probabilities of autoregressive processes*
Seminar talk, Universität Köln

**Sebastian Bechtel**

08/05/2019 *The Kato square root problem on irregular open sets*
Parabolic Equations, Harmonic Analysis and Spectral Theory, Bad Herrenalb

29/10/2019 *The Kato square root problem on locally uniform domains*
Evolution Equations: Applied and Abstract Perspectives, CIRM 2071, Luminy

17/01/2020 *Interpolation theory for Sobolev functions with partially vanishing trace on irregular open sets*
Function spaces seminar, Jena

07/07/2020 *Function spaces and interpolation theory under minimal geometric assumptions and with mixed boundary conditions*
Analysis seminar, Delft (Zoom)

**Volker Betz**

14/01/2019 *Scaling limit of a self-avoiding walk interacting with spatial random permutatinos*
Seminar, München

08/04/2019 *The phase transition for random loop models on trees*
Conference, Yerevan

21/08/2019 *The phase transition for random loop models on trees*
Workshop, Venice

27/08/2019 *The phase transition for random loop models on trees*
Workshop, Münster

23/01/2020 *Random permutations and loops*
Kolloquium, Universität Innsbruck

16/09/2020 *Hydrodynamic limit for variants of the simple symmetric exclusion process*
DMV-Tagung, online, Universität Chemnitz

**Alexander Birx**

16/03/2019 *Tight analysis of the Smartstart algorithm for online Dial-a-Ride on the line*
International Symposium on Theoretical Aspects of Computer Science (STACS), Berlin

21/09/2019 *Improved Bounds for Open Online Dial-a-Ride on the Line*
International Conference on Approximation Algorithms for Combinatorial Optimization Problems (APPROX), Cambridge, USA

**Dieter Bothe**

21/02/2019 *Mass transfer processes at fluid interfaces*
GAMM Jahrestagung, Vienna, Austria

27/03/2019 *Modeling and analysis of bulk-surface systems with sorption and surfacy chemistry, PDE: From Theory to applications*
International Workshop for the 70th birthday of Michel Pierre, Nancy

18/10/2019 *Reaction-Diffusion systems revisited: a kaleidoscope of classical & emerging topics*
IGKD Workshop Mathematics in Industry, Graz

06/12/2019 *Modeling and simulation of convection-dominated species transfer at rising bubbles*
$10^{th}$ Anniversary of the Institute of Multiphase Flows, TU Hamburg-Harburg

09/12/2019 *Sharp-Interface Continuum Thermodynamics for Multicomponent Fluid Systems*
16th Annual German-Japanese Colloquium Process Engineering, TU Hamburg-Harburg

30/10/2020 *Sharp-interface modeling and simulation of mass trasfer influenced by adsorbed surfactant*
Kick-off conference of the Thematic Einstein Semester, Berlin

**Regina Bruder**

21/02/2019 *'Target perspectives of mathematics teaching'*
Talk and workshop - Symposium on mathematics as part of the scientific support for mathematics lessons in Hamburg

06/03/2019 *'Assessing and Evaluating in the Teaching and Learning of Mathematics'*
Chairing the mini-symposium - Annual Conference of the Society for Didactics of Mathematics (GDM), Universität Regensburg

17/06/2019 *'Potentials and limitations of discovery learning from a theoretical and empirical perspective - a contribution to the discussion of instructional designs for mathematics education'*
Didactic Colloquium Universität Essen

20/06/2019 *'Become fundamentally competent in math - what is meant by that and how can it be done?'*
Luckenwalde symposium

04/09/2019 *'Become fundamentally competent in math - but how?'*
MNU state conference Kassel

19/10/2019 *'Activity-theoretical analysis of task processing using the example: Axel and the 7-goal task'*
Working Group Problem Solving of the GDM, Satellite Conference Universität Köln

08/11/2019 *'Long-term competence development in the area of conflict between knowledge, will and ability'*
Curriculum Commission Bern

20/11/2019 *'Mental agility in problem solving in mathematics'*
Problem Solving Seminar at the TU Braunschweig

06/02/2020 *'(Mathematical) Argumentation can be learned - but how?'*
Mathematics Day at the Universität Graz

29/02/2020 *'Differences can be expected...'*
Conference: Mathematics with a difference at the Universität Köln

05/12/2020 *'Method modules and materials for dealing with heterogeneity in mathematics education'*
MINT-webinar (Westermann)

**Jan H. Bruinier**

29/01/2019 *Arithmetic degrees of special cycles and derivatives of Siegel Eisenstein series*
Forschungsseminar Arithmetische Geometrie, HU Berlin

02/06/2019 *Borcherds products, Green functions, and their CM values*
PMI advanced lecture series (3 lectures), Postech, Korea, 02.06.19–03.06.19

17/07/2019 *Special values of regularized theta lifts*
Bethe Forum on Number Theoretic Methods in Quantum Physics, Bonn

11/09/2019 *CM values of higher automorphic Green functions*
ABKLS Seminar on Automorphic Forms, Universität Köln

26/09/2019 *Theta series in geometry and arithmetic*
Mathematics Colloquium, University of Virginia

25/11/2019 *Theta series in geometry and arithmetic*
Mathematisches Kolloquium, Universität Paderborn

**Yann Disser**

29/08/2019 *Collaborative Graph Exploration*
Group Seminar, University of Warsaw

**Moritz Dittmann**

10/12/2019 *Harmonic theta series and the Kodaira dimension of $A_6$*
Oberseminar Zahlentheorie, Universität zu Köln

**Jürgen Dölz**

15/03/2019 *On the Intersection of Non-local Operators and Uncertainty Quantification*
Seminar on Numerical Analysis, TU Delft (The Netherlands)

03/07/2019 *On the Intersection of Non-local Operators and Uncertainty Quantification*
Seminar on Numerical Analysis, Universität Bonn

05/10/2019 *Electromagnetic Scattering on Random Domains*
Seminar on Mathematical Theory of Uncertainty Quantification, University of Twente, Enschede (The Netherlands)

**Pia Domschke**

19/03/2019 *Error-controlled adaptive simulation of gas transmission networks*
Women in Optimization 2019, Bonn

**Herbert Egger**

08/01/2019 *Systematic approximation of evolution problems with dissipation, Hamiltonian, or gradient structure*
Kolloquium AG Modellierung-Numerik-Differentialgleichungen, TU Berlin

15/05/2019 *Structure preserving approximation of nonlinear evolution problems*
Mathematics Colloquium, Universität Duisburg/Essen

09/09/2019 *Systematic discretization of some nonlinear evolution problems*
Conference on Reliable Methods of Mathematical Modeling, TU Wien

19/09/2019 *Structure preserving approximation of quasistatic poroelasticty*
Modelling 2019, Olomouc

02/10/2019 *Energy stable approximation of nonlinear wave propagation problems*
ENUMATH Conference, Egmond an Zee

22/06/2020 *On model order reduction for inverse problems in tomographic imaging applications*
SSD Seminar, RWTH Aachen

15/09/2020 *Structure preserving discretization of dissipative Hamiltonian dynamics*
DMV Annual Meeting, TU Chemnitz

28/10/2020 *Stability and asymptotic analysis for instationary gas transport via relative energy estimates*
Thematic Einstein Semester on Energy-based mathematical methods for reactive multiphase flows, Kickoff Conference, Berlin

07/12/2020 *On model order reduction for inverse problems with operator valued data*
Worshop on Computational Inverse Problems for Partial Differential Equations, Oberwolfach

**Christoph Erath**

12/03/2019 *Numerische Mathematik in der Sekundarstufe*
PH Vorarlberg, Austria

**Reinhard Farwig**

29/03/2019 *Incompressible nonhomogeneous fluids in bounded domains of* $\mathbb{R}^3$ *with bounded density*
Conference “Maximal regularity and nonlinear PDE”, RIMS, Kyoto University, Kyoto

03/04/2019 *Incompressible inhomogeneous fluids in bounded domains in* $\mathbb{R}^3$ *with bounded density*
Invited Talk, Chung Ang University, Seoul

05/04/2019 *The Navier-Stokes equations with moving boundaries*
Invited Talk, Yonsei University, Seoul

23/04/2019 *The Navier-Stokes Equations with Moving Boundaries*
“Workshop on Partial Differential Equations”, Czech Academy of Sciences, Prague

15/08/2019 *The Navier-Stokes Equations in Domains with Moving Boundaries*
“Mathematical Aspects of Hydrodynamics”, MFO Oberwolfach

03/12/2019 *Von Jean Leray zum Millenniumsproblem - die Navier-Stokes-Gleichungen*
Colloquium, Universität Erlangen-Nürnberg

10/01/2020 *Von Jean Leray zum Millenniumsproblem - die Navier-Stokes-Gleichungen*
Colloquium, Universität Düsseldorf

11/03/2020 *The Navier-Stokes Equations in Domains with Moving Boundaries*
Conference “Mathflows2020”, Banach Center Bedlewo (Polen)

**Anton Freund**

08/04/2019 *Collapsing large ordinals*
Séminaire Général de Logique, Paris

13/05/2019 *How strong are derivatives of normal functions?*
Steklov Institute Proof Theory Seminar, Moskow

05/11/2019 *Reflection and induction in set theory*
Workshop on Proof Theory, Modal Logic and Reflection Principles, Barcelona

08/01/2020 *A uniform Kruskal theorem*
Logic and Analysis Seminar, Ghent

23/07/2020 *Mathematical independence without extensional invariants*
Inaugural talk of the Ghent-Leeds Virtual Logic Seminar

09/11/2020 *Goodstein's theorem meets reverse mathematics*
Oberwolfach Workshop on Mathematical Logic: Proof Theory, Constructive Mathematics

**Tristan Gally**

14/01/2019 *Parallelizing SCIP-SDP via the UG framework*
Ubiquity Generator (UG) Workshop, Berlin

**Alf Gerisch**

08/05/2019 *What is … Mathematical modeling of cancer invasion in tissue?*
What is? seminar, TU Darmstadt

06/03/2020 *Modelling and Simulation of Collective Cell Migration: Cross-diffusion and Attracting/Repelling Nonlocal Interactions*
Frankfurt Institute for Advanced Studies (FIAS), Frankfurt (Main)

**Jan Giesselmann**

09/01/2019 *A posteriori error estimators for systems of hyperbolic conservation laws*
Oberseminar KIT

21/05/2019 *Relative Entropies for Hyperbolic Problems on Networks*
Workshop on Nonlinear Hyperbolic Problems: modeling, analysis, and numerics, Oberwolfach

19/06/2019 *Model-adaptive discontinuous Galerkin schemes for compressible fluid flows*
MAFELAP 2019, Brunel University London, UK

04/07/2019 *A Posteriori Error Estimates of Numerical Methods for Random Conservation Laws*
Innovative Training Network Workshop on Shocks and Interfaces, Oxford

19/07/2019 *Relative entropy based model-adaptive numerical schemes in fluid mechanics*
ICIAM 2019, Valencia

19/07/2019 *Aposteriori estimates for random systems of hyperbolic conservation laws*
ICIAM 2019, Valencia

09/09/2019 *A Posteriori Error Estimates of Numerical Methods for Random Hyperbolic Conservation Laws*
14th Hirschegg Workshop on Conservation Laws, Hirschegg (Kleinwalstertal)

27/09/2019 *Relative entropy for the Euler-Korteweg system with non-monotone pressure*
SMF Week - Inhomogeneous Flows: Asymptotic Models and Interfaces Evolution, Luminy

15/11/2019 *A posteriori error analysis for nonlinear systems of hyperbolic conservation laws*
CSC Seminar, Max Planck Institut für Dynamik komplexer Technischer Systeme, Magdeburg

09/01/2020 *Relative Entropy for Gas Flows on Networks*
Seminar of Graduate School Energy, Entropy, and Dissipative Dynamics, RWTH Aachen

**Karsten Grosse-Brauckmann**

30/01/2019 *Minimal surfaces in the Lie group Sol*
Seminar Geometrie und Algebra Gießen/Marburg

**Matthias Hieber**

11/02/2019 *Analysis and Modelling of Liquid Crystal Flows I*
Analysis-Seminar, Waseda University, Tokyo, Japan

13/02/2019 *Analysis and Modelling of Liquid Crystal Flows II*
Analysis-Seminar, Waseda University, Tokyo, Japan

19/02/2019 *The primitive equations and phase changes*
Oberwolfach

25/03/2019 *Maximal regularity and PDE*
RIMS, Kyoto, Japan

09/04/2019 *On the work of Reinhard Racke*
Workshop on PDE, Konstanz

07/05/2019 $H^\infty$*-calculus for the bidomain operator*
Conference on Harmonic Analysis, Bad Herrenalb

12/06/2019 *The Ericksen-Leslie model for liquid crystal flows*
Conference on Nonlinear Analysis, Cortona, Italy

22/07/2019 *Analysis of incompressible, viscous fluids III*
Waseda University, Tokyo, Japan

24/07/2019 *Analysis of incompressible, viscous fluids IV*
Waseda University, Tokyo, Japan

26/07/2019 *Analysis of incompressible, viscous fluids V*
Waseda University, Tokyo, Japan

02/09/2019 *The bidomain equations with FitzHugh-Nagumo transport*
Analysis-Seminar, Universiy of Concepcion, Chile

05/09/2019 *On the Ericksen-Leslie model*
Analysis-Seminar, Federal University of Rio de Janeiro, Brasil

10/09/2019 *Analysis of the bidomain equations*
LNCC, Petropolis, Brasil

08/11/2019 *Analysis of the Q-tensor model*
Int. Conference Fluid Mechanics, Guangzhou, China

21/11/2019 *A general approach to periodic evolution equations I*
Winter School, VIASM, Hanoi, Vietnam

22/11/2019 *A general approach to periodic evolution equations II*
Winter School, VIASM, Hanoi, Vietnam

23/11/2019 *A general approach to periodic evolution equations III*
Winter School, VIASM, Hanoi, Vietnam

03/12/2019 *Analysis of incompressible, viscous fluids VI*
Waseda University, Tokyo, Japan

04/12/2019 *Analysis of incompressible, viscous fluids VII*
Waseda University, Tokyo, Japan

05/12/2019 *Analysis of incompressible, viscous fluids VIII*
Waseda University, Tokyo, Japan

06/12/2019 *Analysis of incompressible, viscous fluids IX*
Waseda University, Tokyo, Japan

26/11/2020 *Operator semigroups in Fluid Mechanics*
Online-Conference on Evolution Equations, Tübingen

**Karl H. Hofmann**

07/03/2019 *In Search of Dualities: Vector Spaces–Groups*
Algebra Seminar, Tulane University, New Orleans

02/10/2019 *Weakly complete real group algebras revisited*
Algebra Seminar, Tulane University, New Orleans

23/06/2020 *Group Algebras of Compact Groups and Tannaka-Hochschild Duality*
International zoom Seminar on Topological Groups, University of Hawaii, Honolulu

**Christopher Hojny**

27/03/2019 *Strong IP Formulations Need Large Coefficients*
Networks and Optimization (N&O) Seminar, CWI Amsterdam, Netherlands

01/07/2019 *Symmetry Handling in Binary Programs: Combining Symretopes and Orbital Fixing*
Algorithmic Optimization (ALOP) Colloquium, Universität Trier

**Alexander V. Hopp**

22/05/2019 *On Friedmann's subexponential Lower Bound for Zadeh's pivot rule*
Integer Programming and Combinatorial Optimization (IPCO), Ann Arbor, USA

14/09/2020 *An exponential Lower Bound for Zadeh's pivot rule*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Martin Kiehl**

23/02/2019 *Gier – Nicht immer ein Weg zum Erfolg*
Mathematikolympiade Hessen, Darmstadt

16/03/2019 *Mathematische Modellierung mit Funktionen*
Tag der Mathematik, Bensheim

25/09/2019 *Mit Mathematik Probleme spielerisch lösen*
Schülernachmittag, TU Darmstadt

22/02/2020 *Spieltheorie – Was ist der beste Zug*
Mathematikolympiade Hessen, Darmstadt

**Ulrich Kohlenbach**

06/05/2019 *Truth and Proof: from Paradoxes in Logic to Science*
General public talk at Wuhan University, School of Philosophy, Wuhan, China

07/05/2019 *Finitism and Constructivism in Mathematics Revisited*
Colloquium Lecture, School of Philosophy, Wuhan University, Wuhan, China

10/05/2019 *Proof-theoretic Methods in Nonlinear Analysis*
Colloquium Lecture, School of Mathematics, Wuhan University, Wuhan, China

11/06/2019 *The Lion-Man Game quantitatively*
Seminario IMUS, Universidad de Seville, Spain

10/07/2019 *The Lion and Man Game Revisited II*
13th International Conference of Fixed Point Theory and Applications, Xinxiang City, Henan Normal University, China

16/07/2019 *The Lion and Man Game and Proof Mining*
Institut Mittag-Leffler, Djursholm, Sweden

15/08/2019 *Local proof-theoretic foundations and proof-theoretic tameness in ordinary mathematics*
Retiring Presidential Address, ASL Logic Colloquium 2019, Prague

27/02/2020 *A quantitative analysis of the Lion and Man Game*
Logic Seminar Talk, University of Bucharest, Romania

06/03/2020 *The role of intuitionistic reasoning in the development of the proof mining methodology*
Anne Troelstra Memorial Event, U Amsterdam, The Netherlands

25/08/2020 *Effective Logical Methods in Nonlinear Analysis*
IECMSA-2020, Skopje, held online

02/12/2020 *Proof Mining and the 'Lion-Man' Game*
Talk in Virtual Proof Theory Seminar

07/12/2020 *Some Recent Developments in Proof Mining*
Seminário de Lógica Matemática, CMAFcIO, U Lisbon, held online

10/12/2020 *Proof Theory: From the Foundations of Mathematics to Applications in Core Mathematics*
Colloquium Lecture, Institute of Mathematics, U Halle

**Michael Kohler**

17/01/2019 *Statistical Theory for Deep Neural Networks*
Statistical Seminar, Universität Heidelberg

30/07/2019 *On deep learning as a remedy against the curse of dimensionality in nonparameteric regression*
Joint Statistical Meeting, Denver

28/10/2019 *Statistical aspects of (deep) neural networks*
Mathematical Colloquium, Universität Stuttgart

**Philip Kolvenbach**

25/02/2019 *Robust optimization of PDE-constrained problems using second-order models*
SIAM Conference on Computational Science and Engineering, Spokane, USA

**Burkhard Kümmerer**

09/05/2019 *Scattering Theory for Markov Processes. An Interplay between Classical and Quantum Probability*
Mathematics of Quantum Information Theory, Lorentz Center Leiden

13/05/2019 *Der Vernetzungsbereich*
Kick-Off Meeting MINTplus2, TU Darmstadt

29/06/2019 *Magnete, Luft und Kosmos. Die Anfänge der wissenschaftlichen Beobachtung und der Aufbruch zu neuen Ufern der Physik*
Opening of the exhibition of the same name, Ehemals Reichsstädtische Bibliothek, Lindau

01/07/2019 *Magnets, Air, and the Universe. The Beginnings of Scientific Observation and New Horizons in Physics*
Curator guided tour on the occasion of the 69th Lindau Nobel Laureate Meeting, Ehemals Reichsstädtische Bibliothek, Lindau

02/07/2019 *Magnets, Air, and the Universe. The Beginnings of Scientific Observation and New Horizons in Physics*
Curator guided tour on the occasion of the 69th Lindau Nobel Laureate Meeting, Ehemals Reichsstädtische Bibliothek, Lindau

25/09/2019 *Magnete, Luft und Kosmos. Die Anfänge der wissenschaftlichen Beobachtung und der Aufbruch zu neuen Ufern der Physik*
Curator guided tour, Ehemals Reichsstädtische Bibliothek, Lindau

10/02/2020 *Mathematik verbindet. Mathematik als gemeinsame Sprache der Naturwissenschaften*
Zentrum für Lehrerbildung, TU Darmstadt

18/02/2020 *Verknotete Mathematik. Why Knot?*
Lecture for pupils of the Ricarda Huch School, Dreieich

**Jens Lang**

26/04/2019 *Adaptive Moving Meshes in Large Eddy Simulation for Turbulent Flows*
Towards Computable Flows Workshop honoring the 68th birthday of Gert Lube, Göttingen

27/05/2019 *An Adaptive Multilevel Stochastic Collocation Method for Elliptic PDEs with Uncertain Data*
ADMOS, Alicante

23/07/2019 *Super-Convergent IMEX-Peer Methods with Variable Time Steps*
SCICADE, Innsbruck

**Yingkun Li**

22/07/2019 *Higher Green's function and arithmetic application*
Workshop on Arithmetic and Geometric Aspects of Modular Forms, Oxford University, UK

04/09/2019 *CM values of modular functions and factorization*
Number theory seminar, MPIM, Germany

12/09/2019 *CM values of modular functions and factorization*
Number theory seminar, UW Madison, USA

14/09/2019 *Higher Green's function and arithmetic application*
AMS sectional meeting, UW Madison, USA

08/10/2019 *CM values of modular functions and factorization*
Number theory seminar, Universität Köln, Germany

16/12/2019 *Some old and new results on singular moduli*
Workshop on modular forms, MFO, Germany

30/12/2019 *Some old and new results on singular moduli*
Number theory seminar, Tsinghua University, Beijing, China

06/01/2020 *Some old and new results on singular moduli*
Number theory seminar, Zhejiang University, Hangzhou, China

**Elena Mäder-Baumdicker**

04/04/2019 *The free boundary setting of the area preserving curve shortening flow*
SPP2026-Geometry at infinity conference, Münster

09/07/2019 *Willmore spheres are unstable*
RTG-day of the RTG 2229, Karlsruhe

20/09/2019 *Willmore spheres are unstable*
Brussels-London Geometry Seminar, Brüssel

24/09/2019 *Introducing the work of Karen Uhlenbeck, Abel Prize 2019*
7th Heidelberger Laureate Forum, Heidelberg

21/10/2019 *Willmore spheres are unstable*
Seminar, Münster

28/11/2019 *Willmore spheres are unstable*
Geometry Seminar, Granada

20/01/2020 *The Morse index of Willmore spheres and its relation to the geometry of minimal surfaces*
Partial Differential Equations Seminar, Oxford

24/01/2020 *Willmore spheres are unstable*
2. FHST meeting on Geometric Analysis, Freiburg

05/05/2020 *The Morse index of Willmore spheres and its relation to the geometry of minimal surfaces*
Online Seminar "Geometric Analysis", online

**Holger Marschall**

05/11/2019 *Scale-bridging interface-resolving simulation of reactive bubble flow*
Joint workshop on "Recent advances in bubble columns" of the EFCE Working Party "Multiphase Fluid Flow" and the SFGP (Societe française de Génie des Procédés, France) Working Group "Reactor and Reactor Intensification", Paris, France.

08/06/2020 *Multiphase Flows*
International PhD Course on Computational Fluid Dynamics with Open-source Software, Energy and Nuclear Science and Technology, Politecnico di Milano, Italy.

12/10/2020 *Simulation of Droplet Impact at High Dynamics using a Diffuse Interface Phase-Field Method in OpenFOAM*
International Conference on Advances in Differential Equations and Numerical Analysis, IIT Guwahati, India.

**Frederic Matter**

13/07/2019 *Detection of Ambiguities in Linear Arrays in Signal Processing*
SIAM Conference on Applied Algebraic Geometry (SIAMAG), Bern, Switzerland

**Stefano Modena**

12/12/2019 *Non-uniqueness for the transport equation with Sobolev vector fields*
China-Italy Conference on Partial Differential Equations and Their Applications, Shanghai, China

23/01/2020 *Non-uniqueness for the transport equation with Sobolev vector fields*
Universität Mainz

**Andreas Paffenholz**

17/04/2019 *Ehrhart Negativity*
Discrete Geometry Seminar, TU Berlin

13/07/2020 *polyDB: A Database for Polytopes and Related Objects*
International Congress on Mathematical Software (ICMS), Braunschweig

14/07/2020 *polyDB: A database for geometric objects based on MongoDB*
International Congress on Mathematical Software (ICMS), Braunschweig

**Marc Pfetsch**

28/05/2019 *Robust Mixed-Integer Nonlinear Optimization for Engineering Applications*
BCAI Distinguished Lecture Series, Bosch, Renningen

18/07/2019 *Polyhedral Symmetry Handling for Integer Programs*
MIP-Workshop, MIT, Cambdridge, USA

19/09/2019 *Resilient and Efficient Layout of Water Distribution Networks*
French-German-Swiss Conference on Optimization (FGS), Nice, France

17/09/2020 *Solving Mixed-Integer SDPs*
CO@Work, Zuse Institute Berlin

**Nora Philippi**

23/11/2020 *On the transport limit of singularly perturbed convection-diffusion problems on networks*
Mini-workshop on Robots Learning, Optimization and Control, FAU

**Pedro Pinto**

03/02/2020 *Commentaries on the application of the bounded functional interpretation*
Seminário de Lógica Matemática, Faculty of Science, University of Lisbon

26/10/2020 *Quantitative translations for viscosity approximation methods*
Seminário de Lógica Matemática, Faculty of Science, University of Lisbon

11/11/2020 *Quantitative translations for viscosity approximation methods*
MFO Workshop on Mathematical Logic: Proof Theory, Constructive Mathematics, Oberwolfach

04/03/2021 *Unwinding of proofs*
FMI/IMAR Logic Seminar, Faculty of Mathematics and Computer Science, University of Bucharest

**Anna-Maria von Pippich**

10/01/2019 *Special values of Selberg's zeta function*
Oberseminar "Algebra", Eberhard Karls Universität Tübingen

22/05/2019 *The special value $Z'(1)$ of the Selberg zeta function*
Oberseminar "Zahlentheorie", Universität Paderborn

07/01/2020 *An arithmetic application of Arakelov geometry*
SFB-Kolloquium, Universität Regensburg

22/07/2020 *An analytic class number type formula for the Selberg zeta function*
International Seminar on Automorphic Forms, ETH Zurich

27/08/2020 *An analytic class number type formula for the Selberg zeta function*
3rd Chennai–Tirupati Number Theory Conference

**Anne-Therese Rauls**

20/09/2019 *Computing a Bouligand Generalized Derivative for the Solution Operator of the Obstacle Problem*
French-German-Swiss Conference on Optimization (FGS), Nice, France

15/10/2019 *Generalized derivatives for the solution operator of obstacle problems*
RICAM Special Semester on Optimization, Linz, Austria

15/09/2020 *Generalized derivatives for the solution operator of the bilateral obstacle problem*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Ulrich Reif**

05/03/2019 *Geometric Hermite Subdivision*
Workshop on Applied Approximation, Signals and Images, Bernried

09/07/2019 *ABS Surfaces*
Seminar, ETH Zürich

28/08/2019 *Watertight Trimmed NURBS Surfaces*
MAIA conference, Wien

02/10/2019 *Watertight Trimmed NURBS Surfaces*
NFN Workshop, Strobl

21/11/2019 *Geometric Hermite Subdivivsion*
Conference SAT 2019, Rennes

18/12/2019 *A Few Thoughts about Design and Simulation*
Dagstuhl Seminar on Interactive Design and Simulation, Dagstuhl

29/01/2020 *Spline Methods in Simulation*
INdAM Workshop on Geometric Challenges in Isogeometric Analysis, Rom

**Steffen Roch**

25/07/2019 *On quasifractal algebras*
IWOTA 2019, IST Lisbon

**Nils Scheithauer**

25/06/2019 *Generalised deep holes in the vertex algebra associated with the Leech lattice*
Representation theory XVI, IUC, Dubrovnik, Croatia

13/12/2019 *Eisenstein series, dimension formulas and orbifolds*
Beyond rationality $\infty$: Exploring the many roads to postrational conformal field theory, Woudschoten, Zeist, The Netherlands

19/12/2019 *Eisensteinreihen, Dimensionsformeln und Orbifolds*
Oberseminar Topologie, Universität Bochum

**Werner Schindler**

16/04/2019 *Security Evaluation of Physical RNGs*
Workshop on Randomness and Arithmetics for Cryptography on Hardware, Roscoff

20/11/2019 *Künstliche Intelligenz in der Kryptographie*
AFCEA Zukunfts- und Technologieforum 2019, Wachtberg

22/01/2020 *Anwendungen der künstlichen Intelligenz in der Kryptographie*
OMNISECURE 2020, Berlin

23/01/2020 *The AIS 31 (and the AIS 20) – Fundamental concepts, experiences and perspectives*
Workshop on Quantum Random Number Generation, Jena

21/09/2020 *BSI approach: RNG evaluation methodology*
ICMC 2020, Washington (virtual)

**Johann Michael Schmitt**

20/09/2019 *Optimal boundary control of entropy solutions for conservation laws with state constraints*
French-German-Swiss Conference on Optimization (FGS), Nice, France

**Alexandra Schwartz**

21/02/2019 *A complementarity-based approach to cardinality-constrained optimization*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

19/03/2019 *Strategische Buchungsentscheidungen im Gasmarkt: Ein spieltheoretisches Modell*
Invited Speaker at Workshop Women in Optimization, Bonn

**Christian Stinner**

22/02/2019 *Time-periodic solutions for Keller-Segel systems*
The 4th International Workshop on Mathematical Analysis of Chemotaxis, Tokyo University of Science

**Elisa Strauch**

09/05/2019 *Stochastic Collocation Method for Partial Differential Equations with Random Input Data*
CAA Seminar, Universität Erlangen-Nürnberg

23/11/2020 *Probabilistic Constraints in Optimization Problems on Flow Networks*
Mini-workshop on Robots Learning, Optimization and Control, Universität Erlangen-Nürnberg

**Thomas Streicher**

20/08/2019 *Neutral Models of Constructive Mathematics*
University of Stcokholm

06/09/2019 *An Effective Spectral Theorem for Bounded Self Adjoint Operators within Computable Analysis (TTE)*
CCA 2019 University of Ljubljana

15/12/2020 *A Geometric View of Triposes*
University of Leicester

**Stefan Ulbrich**

12/02/2019 *Robust Optimization Techniques for PDE-Constrained Problems under Uncertainty*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

28/02/2019 *Subgradient Computation for the Solution Operator of the Obstacle Problem and Numerical Realization*
Workshop Numerical Algorithms in Nonsmooth Optimization, ESI, University of Vienna, Austria

26/03/2019 *Optimal Boundary Control of Hyperbolic Conservation Laws with State Constraints*
Workshop on Calculus of Variation and Nonlinear Partial Differential Equations, Regensburg

07/06/2019 *Recent Developments in Mixed-Integer PDE- and ODE-Constrained Optimal Control*
Oberwolfach Workshop Mixed-integer Nonlinear Optimization, Oberwolfach

19/07/2019 *A Robust Optimization Approach for PDE-Constrained Problems under Uncertainty*
International Council for Industrial and Applied Mathematics (ICIAM), Valencia, Spain

07/08/2019 *Time-Domain Decomposition for PDE-Constrained Optimization*
International Conference on Continuous Optimization (ICCOPT), Berlin

18/10/2019 *Optimal Control of Hyperbolic Conservation Laws with State Constraints and Convergent Numerical Schemes for Adjoints*
RICAM Workshop on New Trends in PDE Constrained Optimization, RICAM, Linz, Austria

13/11/2019 *Robust Optimization Approaches for PDE-Constrained Problems under Uncertainty*
RICAM Workshop on Optimization and Inversion under Uncertainty, RICAM, Linz, Austria

29/01/2020 *Robust Optimization Techniques for PDE-Constrained Problems under Uncertainty*
Workshop PDE Constrained Optimization under Uncertainty and Mean Field Games, WIAS, Berlin

11/02/2020 *Analysis of Shape Optimization Problems for Unsteady Fluid-Structure Interaction*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

**Mirjam Walloth**

19/02/2019 *A posteriori estimator for the adaptive solution of a quasi-static fracture phase-field model*
90th Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Wien

14/05/2019 *Reliable, efficient and robust a posteriori estimators for the variational inequality in fracture phase-field models*
WIAS Berlin

20/06/2019 *Residual-type a posteriori estimators for the singularly perturbed variational inequality in quasi-static fracture phase-field models*
The Mathematics of Finite Elements and Applications (MAFELAP) 2019, Brunel University London, UK

28/08/2019 *A residual-type a posteriori estimator for the adaptive discretization in space and time of a viscoelastic contact problem*
8th GACM Colloquium on Computational Mechanics (GACM), Kassel

30/09/2019 *Adaptive discretization methods for the numerical simulation of static and time-dependent contact problems*
European Conference on Numerical Mathematics and Advanced Applications (ENUMATH 2019), Egmond aan Zee

16/01/2020 *Residual-type a posteriori estimator for a quasi-static contact problem*
Fachbereich Mathematik und Informatik, Universität Münster

03/02/2020 *Residual-type a posteriori estimators for the adaptive solution of quasi-static fracture phase-field models*
Fakultät Mathematik, KIT

**David Weckbecker**

17/09/2020 *The Greedy Algorithm for Cardinality-Constrained Maximization*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Jonathan Weinberger**

10/10/2019 *Modalities and fibrations for synthetic* $(\infty, 1)$*-categories*
The New York City Category Theory Seminar, The Graduate Center of The City University of New York, New York, NY

25/09/2020 *Cocartesian fibrations in simplicial type theory*
Homotopy Type Theory Seminar, Carnegie Mellon University, Pittsburgh, PA

**Cornelia Wichelhaus**

21/03/2019 *Nonparametric estimation in stochastic networks*
University of Amsterdam

**Winnifried Wollner**

23/01/2019 *Optimization of phase-field damage and fracture – and its discretization*
Guest lecture, Universität Duisburg-Essen

09/04/2019 *PDE constrained optimization with pointwise constraints on the derivative of the state*
Guest lecture, Louisiana State University, Baton Rouge, USA

19/04/2019 *Optimization of phase-field damage*
Guest lecture, Courant Institut, New York, USA

06/06/2019 *Optimization of phase-field damage*
Guest lecture, TU Dortmund

22/08/2019 *Optimization of phase-field damage*
Guest lecture, EPN Quito, Ecuador

11/09/2019 *Optimization of phase-field damage*
Guest lecture, Texas A&M, College Station, USA

26/09/2019 *PDE constrained optimization with pointwise constraints on the derivative of the state*
BI.discrete Numerical Analysis, Bielefeld

14/10/2019 *Optimization of phase-field damage*
RICAM Special Semester on Optimization, Linz, Austria

02/12/2019 *Results and Questions in the Optimization of Phase-Field Damage Evolution*
Workshop on Optimal Control, Konstanz

31/01/2020 *Optimization of phase-field damage*
Guest lecture in GRK 2339, Erlangen

### 6.1.2 Contributed Talks

**Paloma Schäfer Aguilar**

01/02/2019 *Numerical approximation for optimal control problems of hyperbolic conservation laws*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

20/02/2019 *Numerical approximation for optimal control problems of hyperbolic conservation laws*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

07/08/2019 *Numerical approximation for optimal control problems of hyperbolic conservation laws*
International Conference on Continuous Optimization (ICCOPT), Berlin

10/02/2020 *Convergence of numerical adjoint schemes arising from optimal boundary control problems of hyperbolic conservation laws*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

29/05/2020 *Numerical approximation for optimal control problems of hyperbolic conservation laws*
Optimization Seminar, TU Darmstadt

**Björn Augner**

19/02/2019 *Thermodynamically consistent modelling and analysis of bulk-surface systems with sorption and surface chemistry.*
90th GAMM Annual Meeting, Vienna (Austria)

17/07/2019 *Fast Limit Models of Bulk-Surface Reaction-Diffusion-Sorption Systems.*
Oberseminar Partielle Differentialgleichungen, Konstanz

**Seshadri Basava**

02/09/2019 *Pressure Robust Techniques for Stationary Stokes Equation*
Graduate School CE Research Colloquium, TU Darmstadt

14/02/2020 *Pressure Robust Techniques for FEM in Incompressible materials*
Optimization Seminar, TU Darmstadt

21/09/2020 *Divergence Free Reconstruction Operators for Stokes Problem and Implementation in deal.II*
Graduate School CE Research Colloquium, TU Darmstadt

**Jan Becker**

25/01/2019 *Multi-Leader-Follower Games in Function Spaces*
Optimization Seminar, TU Darmstadt

25/02/2019 *Multi-Leader-Follower Games in Function Space with Unique Lower Level Solution*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

05/08/2019 *Linear-Quadratic Multi-Leader-Follower Games in Hilbert Spaces*
International Conference on Continuous Optimization (ICCOPT), Berlin

04/11/2019 *Linear-Quadratic Multi-Leader-Follower Games in Hilbert Spaces*
Graduate School CE Research Colloquium, TU Darmstadt

**Johanna Biehl**

06/02/2019 *Adaptive Optimization of FSI problems with Reduced Order Models*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

06/08/2019 *Adaptive Multilevel Optimization with Application to Fluid-Structure Interaction*
International Conference on Continuous Optimization (ICCOPT), Berlin

29/08/2019 *Adaptive Multilevel Optimization of Fluid-Structure Interaction Problems*
German Association for Computational Mechanics (GACM), Kassel

**Alexander Birx**

09/09/2019 *Improved Bounds for Online Dial-a-Ride on the Line*
Graduate School CE Research Colloquium, TU Darmstadt

24/01/2020 *Improved Bounds for Online Dial-a-Ride on the Line*
Optimization Seminar, TU Darmstadt

**Dieter Bothe**

27/08/2019 *On the kinematics of moving contact lines*
Challenges in Nanoscale Physics of Wetting Phenomena, Dresden

29/09/2020 *Kinematics of wetting – impact on continuum modelling and simulation*
Wetting Dynamics Conference, Gustav-Stresemann-Institute Bonn

**Neelabja Chatterjee**

29/10/2019 *Convergence analysis of a numerical scheme for a general class of Mean field Equation*
Seminar der AG Numerik, TU Darmstadt

23/11/2020 *Convergence of second-order, entropy stable scheme in multi-dimension*
Seminar der AG Numerik, TU Darmstadt

**Elisabeth Diehl**

19/09/2019 *Mathematical Model of Multiphase Flow with a Dynamic Contact Line for the Simulation and Optimization of Wetting Phenomena*
French-German-Swiss Conference on Optimization (FGS), Nice, France

19/06/2020 *Mathematical Model of Multiphase Flow for Simulation based Optimization of Wetting Phenomena*
Optimization Seminar, TU Darmstadt

16/09/2020 *Optimal Control of Multiphase Flow in the context of Wetting Phenomena*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

30/09/2020 *Optimization of Doctor Blading*
Wetting Dynamics, Bonn

**Jürgen Dölz**

22/01/2019 *A higher order perturbation approach for electromagnetic scattering problems on random domains*
WONAPDE 2019, Concepcion (Chile)

20/02/2019 *A higher order perturbation approach for electromagnetic scattering problems on random domains*
90th GAMM Annual Meeting (GAMM 2019), Vienna, Austria

27/02/2019 *On the best approximation of the hierarchical matrix product*
SIAM CSE 2019, Spokane (Washington, USA)

13/06/2019 *H-matrix accelerated second moment analysis for potentials with rough correlation*
PASC 2019, Zürich

06/02/2020 *Recent advances of isogeometric boundary element methods for electromagnetic scattering problems*
Mini-workshop on Boundary Element Methods, Oberwolfach

**Herbert Egger**

31/05/2019 *Variationally consistent modeling and simulation of laser-based additive manufactering*
SPP 2256 Information Event, DFG Bonn

27/06/2019 *Some notes on high-order methods*
Workshop on High-order and spectral methods, TU Darmstadt

10/07/2019 *Nonlocal diffusion, poroelastodynamics, and network vibrations*
3rd Darmstadt/Graz Workshop, TU Darmstadt

19/11/2019 *Spinodal decomposition of polymer-solvent systems*
TRR 146 Retreat, Nierstein

24/02/2020 *Energy-based modeling and numerical approximation of coupled dynamical systems*
4th Darmstadt/Graz Workshop, TU Graz

03/06/2020 *On the inf-sup stability of harmoncic coupling for the simulation of electric machines*
AG Seminar Numerik, TU Darmstadt

30/09/2020 *On relative energy estimates for macroscopic models describing phase separating systems*
CECAM Conference on Multiscale Simulation Methods in Soft Matter Systems III, Nierstein

19/10/2020 *Quantitative variational phase-field modeling and simulation of PBF additive manufacturing*
SPP 2256 Kickoff Meeting

**Christoph Erath**

12/09/2019 *On the nonsymmetric coupling method for parabolic-elliptic interface problems*
Reliable Methods of Mathematical Modeling, TU Wien, Austria

16/09/2019 *Efficient solving of a time-dependent interface problem*
OeMG-Conference (Austrian Mathematical Society), Dornbirn, Austria

04/10/2019 *Parabolic-elliptic interface problem on an unbounded domain: full discretization with the method of lines*
Fast BEM 2019, Hirschegg (Kleinwalsertal)

**Anton Freund**

17/05/2019 *How to single out the $\Pi^0_1$-theorems of a theory*
Logic Postgraduate Seminar, TU Darmstadt

04/12/2019 *The Infinite in Graph Theory*
“What is ...?"-seminar, TU Darmstadt

04/09/2020 *Kruskal’s tree theorem and continuous transformations of partial orders*
Continuity, Computability, Constructivity – From Logic to Algorithms, Faro

14/09/2020 *Mathematical incompleteness without extensional invariants*
DMV annual meeting, Minisymposium on Proof and Computation in Mathematics, Chemnitz

17/09/2020 *A uniform Kruskal theorem*
DMV annual meeting, Section on Mathematical Logic, Chemnitz

18/12/2020 *Friedman’s gap condition as an iteration of Kruskal’s theorem*
Logic Postgraduate Seminar, TU Darmstadt

**Mathis Fricke**

21/02/2019 *The contact line advection problem*
GAMM Jahrestagung, Vienna, Austria

12/04/2019 *A Kinematic Evolution Equation for the Dynamic Contact Angle and some Consequences*
Heraeus Seminar on Wetting on soft or microstructured surfaces, Bad Honnef

28/05/2019 *Breakup Behavior of a Capillary Bridge on a Hydrophobic Stripe Separating two Hydrophilic Stripes*
Annual Meeting on Reaction Engineering in Cooperation with the Working Group Multiphase Flows, Würzburg

27/08/2019 *On the numerical transport of the dynamic contact angle*
Challenges in Nanoscale Physics of Wetting Phenomena, Dresden

29/09/2020 *Breakup dynamics of capillary bridges on hydrophobic stripes*
Wetting Dynamics Conference, Gustav-Stresemann-Institute Bonn

**Oliver Habeck**

25/06/2019 *Global Optimization of ODE Constrained Network Problems*
European Conference on Operational Research (EURO), Dublin, Ireland

**Christine Herter**

09/11/2020 *Eigenvalue optimization with respect to shape-variations in electro-magnetic systems*
Graduate School CE Research Colloquium, TU Darmstadt

**Dennis Hillenbrand**

28/09/2019 *Entwicklung und Anwendung einer Methode zur Direkten Numerischen Simulation reaktiver Transportprozesse in Blasensystemen*
Annual Meeting of the SPP 1740, Hamburg.

**Christopher Hojny**

09/01/2019 *Strong IP Formulations Need Large Coefficients*
Combinatorial Optimization Workshop, Aussois, France

05/09/2019 *Strong IP Formulations Need Large Coefficients*
Operations Research, TU Dresden

**Alexander V. Hopp**

08/07/2019 *On Friedmann's subexponential lower bound for Zadeh's pivot rule*
Graduate School CE Research Colloquium, TU Darmstadt

31/01/2020 *An exponential Lower Bound for Zadeh's pivot rule*
Optimization Seminar, TU Darmstadt

**Benjamin Horn**

07/08/2019 *A Bundle Trust-Region Method for Constrained Nonsmooth Problems applied to a Shape Optimization for Frictional Contact Problems*
International Conference on Continuous Optimization (ICCOPT), Berlin

17/09/2019 *A Constrained Bundle Trust-Region Method in the Context of Shape Optimization governed by Frictional Contact Problems*
French-German-Swiss Conference on Optimization (FGS), Nice, France

**Isabel Jacob**

18/12/2020 *Machine learning algorithms motivated by differential equations*
Optimization Seminar, TU Darmstadt

**Kristina Janzen**

07/08/2019 *Cost-optimal design of decentralized energy networks with coupling of electricity, gas and heat networks including renewable energies*
International Conference on Continuous Optimization (ICCOPT), Berlin

17/09/2019 *Cost-Optimal Design and Operation of Decentralized Energy Networks Including Renewable Energies*
French-German-Swiss Conference on Optimization (FGS), Nice, France

27/09/2019 *Cost-Optimal Design and Operation of Decentralized Energy Networks*
Energy Science and Engineering PhD Platform Conference, TU Darmstadt

16/09/2020 *Cost-Optimal Design and Operation of Decentralized Energy Networks including Partial Differential Equations*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Hrishikesh Joshi**

19/06/2019 *Model adaptation for chemically reacting flows: an a posteriori estimator based approach*
Numerical Methods for Hyperbolic Problems (NumHyp 2019), Malaga, Spain

09/09/2019 *Model adaptation for hyperbolic balance laws*
14th Hirschegg Workshop on Conservation Laws, Hirschegg (Kleinwalsertal)

15/06/2020 *Model adaptation of balance laws based on a posteriori error estimates and surrogate fluxes*
Finite Volumes for Complex Applications (FVCA9), Bergen, Norway (virtual)

**Christina Karousatou**

07/06/2019 *Exploring Trees with Energy-Constrained Mobile Agents*
Optimization Seminar, TU Darmstadt

**David Klein**

19/06/2019 *What is an absolute Galois group?*
"What is...?" Seminar, TU Darmstadt

**Tomislav Marić**

09/09/2019 *Distance-gradient normal reconstruction*
9$^{th}$ International conference on numerical methods for multi-material fluid flow MULTIMAT, Trento, Italy

**Holger Marschall**

27/02/2019 *Direct Numerical Simulation of Interfacial Transport Processes*
Retreat of the SFB/TRR 150, Seeheim, Germany

15/10/2019 *Enhancing multiphase flow simulation capabilities in OpenFOAM*
OpenFOAM User Conference, Berlin, Germany.

25/06/2020 *Development and Deployment of Diffuse Interface Phase-Field Methods in OpenFOAM*
15$^{th}$ OpenFOAM Workshop, Arlington, VA, USA.

**Alexander Matei**

08/08/2019 *Detecting model uncertainty via parameter estimation and optimal design of experiments*
International Conference on Continuous Optimization (ICCOPT), Berlin

26/06/2020 *Optimum experimental design with PDE-constraints and its application to the detection of model uncertainty*
Optimization Seminar, TU Darmstadt

16/09/2020 *Identification of Model Uncertainty via Optimal Design of Experiments Applied to a Mechanical Press*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Frederic Matter**

19/07/2019 *Detection of Ambiguities in Linear Arrays in Signal Processing*
Workshop on Future Research in Combinatorial Optimization (FRICO), Kaiserslautern

20/11/2020 *Block-sparse recovery of semidefinite systems and generalized null space conditions*
Optimization Seminar, TU Darmstadt

**Ingmar Metzler**

23/01/2019 *A short introduction to classical modular forms via elliptic curves*
weekly research seminar, TU Darmstadt

10/07/2020 *Zagier duality and Borcherd's products*
Modular forms seminar, TU Darmstadt

12/11/2020 *The condensed world*
DaFra seminar, TU Darmstadt

**Hadi Minbashian**

02/08/2019 *A dual-weighted residual error estimate for hyperbolic problems*
CEMRACS 2019, Marseille

**Masoumeh Mohammadi**

20/02/2019 *A priori error estimates for fracture control problem*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

20/06/2019 *A priori error estimates for fracture control problems*
Mathematics of Finite Elements and Applications (MAFELAP), Uxbridge, UK

05/08/2019 *A priori estimates for optimal control of a phase-field fracture model*
International Conference on Continuous Optimization (ICCOPT), Berlin

**Christopher Müller**

09/07/2019 *A stochastic Galerkin reduced basis method with adaptive snapshots*
Seminar der AG Numerik, TU Darmstadt

11/09/2019 *A stochastic Galerkin reduced basis (SGRB) method for convection-diffusion-reaction equations based on adaptive snapshots*
Workshop on Frontiers of Uncertainty Quantification in Fluid Dynamics (FRONTUQ 2019), Pisa, Italy

30/09/2019 *A stochastic Galerkin reduced basis (SGRB) method for parametrized elliptic PDEs based on adaptive snapshots*
European Numerical Mathematics and Advanced Applications Conference (ENUMATH 2019), Egmond aan Zee, The Netherlands

**Daniel Nowak**

21/02/2019 *A Multi-Leader-Multi-Follower Game with Application in Gas Markets*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

11/11/2019 *A Hierarchical Cournot-Nash Game with Application in Gas Markets*
Graduate School CE Research Colloquium, TU Darmstadt

**Marc Pfetsch**

17/01/2020 *SCIP and LP Solvers*
SCIP & Google Meeting, Berlin

12/06/2020 *Estimating the Size of Branch-and-Bound Trees*
Oberseminar, Braunschweig

14/07/2020 *IPBoost – Non-Convex Boosting via Integer Programming*
International Conference on Machine Learning (ICML), Vienna, Austria

**Nora Philippi**

06/05/2020 *On the transport limit of singularly perturbed convection-diffusion problems on networks*
Seminar der AG Numerik, TU Darmstadt

18/06/2020 *A hybrid discontinuous Galerkin method for transport equations on networks*
Finite Volumes for Complex Applications IX (FVCA9), Bergen, Norway (virtual)

**Pedro Pinto**

31/01/2020 *Proof mining of a discussion by cases*
Days in Logic 2020, Faculty of Science, University of Lisbon

**Anna-Maria von Pippich**

12/02/2020 *Lauschen zwecklos!*
Schülerinnentag, TU Darmstadt

**Bjoern Polenz**

14/06/2019 *Modeling of an induction machine and approaches towards its robust shape optimization*
Optimization Seminar, TU Darmstadt

14/09/2020 *Robust geometry optimization of asynchronous electrical motors*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Bogdan Radu**

21/02/2019 *A second order multipoint flux mixed finite element method on hybrid meshes*
90th GAMM Annual Meeting (GAMM 2019), Vienna, Austria

01/07/2019 *A second order multipoint flux mixed finite element method on hybrid meshes*
12th Workshop on Analysis and Advanced Numerical Methods for Partial Differential Equations, Strobl, Austria

27/07/2019 *High-order mass lumping for wave propagation*
Workshop on higher order methods, Darmstadt, Germany

12/09/2019 *A Mixed FEM with mass lumping for acoustic wave propagation*
GAMM Workshop Numerische Analysis 2019, 11.-12. September 2019, Uni Essen

04/10/2019 *A second order multipoint flux mixed finite element method on hybrid meshes*
European Conference on Numerical Mathematics and Advanced Applications (ENUMATH 2019), Egmond aan Zee, The Netherlands

05/08/2020 *What is poroelasticity?*
"What is" presentation, Darmstadt, Germany

**Anne-Therese Rauls**

11/02/2019 *Subgradient Computation for the Solution Operator of the Obstacle Problem*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

19/02/2019 *Structure of Subgradients for the Obstacle Problem and Numerical Realization*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

07/08/2019 *Subgradient Calculus for the Obstacle Problem*
International Conference on Continuous Optimization (ICCOPT), Berlin

13/02/2020 *Bouligand generalized derivatives for the solution operator of the obstacle problem: theory, applications and challenges in numerics*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

**Mania Sabouri**

27/06/2019 *Introduction to spectral element methods*
Workshop on High-order and Spectral Methods, TU Darmstadt

27/06/2019 *Mortar spectral element method for the p-Laplacian equation*
Workshop on High-order and Spectral Methods, TU Darmstadt

**Kersten Schmidt**

27/06/2019 *High-order FEM and generalized FEM for resolving singular solutions*
Workshop on High-order and Spectral Methods, Darmstadt

27/08/2019 *Asymptotic analysis of the visco-acoustic equations for absorbing walls of arrays of Helmholtz resonators*
14th International Conference on Mathematical and Numerical Aspects of Wave Propagation, Vienna, Austria

17/09/2019 *Asymptotic analysis of the visco-acoustic equations for absorbing perforated walls*
Singular Days 2019, Kassel

**Andreas Schmitt**

21/01/2019 *An Interdiction Approach for the Design of Resilient High-Rise Water Supply Systems*
Optimization Seminar, TU Darmstadt

05/09/2019 *Exploiting Partial Convexity of Pump Characteristics in Water Network Design*
Operations Research, TU Dresden

20/09/2019 *An Interdiction Approach for the Design of Robust High-Rise Water Supply Systems*
Workshop on Robust Optimization, Universität Siegen

07/01/2020 *Lifted Perspective Cuts for the Operation of Pumps in Tree-shaped Water Network Design Problems*
Combinatorial Optimization Workshop, Aussois, France

**Johann Michael Schmitt**

02/02/2019 *Optimalsteuerung von hyperbolischen Bilanzgleichungen mit Zustandsschranken*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

22/02/2019 *Numerical approximation for optimal control problems of hyperbolic conservation laws*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

07/08/2019 *Optimal Boundary Control of Hyperbolic Balance Laws with State Constraints*
International Conference on Continuous Optimization (ICCOPT), Berlin

10/02/2020 *Optimal control of hyperbolic balance laws and extensions to networks*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

**Moritz Schneider**

15/07/2019 *Superconvergent IMEX Peer methods with variable step sizes*
International Congress on Industrial and Applied Mathematics (ICIAM 2019), Valencia, Spain

04/10/2019 *Superconvergent IMEX Peer methods with variable step sizes*
European Conference on Numerical Mathematics and Advanced Applications (ENUMATH 2019), Egmond aan Zee, The Netherlands

08/07/2020 *Superconvergent IMEX Peer methods with variable step sizes*
SIAM Annual Meeting (AN20), Toronto, Canada (virtual)

**Alexandra Schwartz**

05/08/2019 *A generalized Nash game for computation offloading*
International Conference on Continuous Optimization (ICCOPT), Berlin

**Vsevolod Shashkov**

22/02/2019 *Convolution quadrature methods for coupled nonlinear-linear dynamical systems*
90th GAMM Anual Meeting (GAMM 2019), Vienna, Austria

20/05/2020 *On convolution quadrature for Maxwell's equations in dispersive media*
Seminar der AG Numerik, TU Darmstadt

**Philipp Steinbach**

06/05/2020 *Uncertainty Quantification of Borehole Thermal Energy Storage Facilities*
EGU General Assembly 2020, online

24/06/2020 *Uncertainty Quantification of Borehole Thermal Energy Storage Facilities*
Seminar der AG Numerik, TU Darmstadt

**Elisa Strauch**

15/07/2019 *Stochastic Collocation Method for Hyperbolic PDEs with Random Initial Data*
The XV International Conference on Stochastic Programming (ICSP XV), Trondheim, Norway

**Gabriel Teschner**

02/10/2019 *A framework for estimation of flow geometry and wall shear stress from MRV*
Chemnitz Symposium on Inverse Problems 2019, Frankfurt

12/11/2019 *A framework for estimation of flow geometry and wall shear stress from MRV*
Seminar der AG Numerik, TU Darmstadt

**Mirjam Walloth**

22/01/2019 *A posteriori estimator for the singularly perturbed variational inequality for a fracture phase-field model*
Seminar der AG Numerik, TU Darmstadt

02/07/2019 *A posteriori estimators for the adaptive solution of quasi-static fracture phase-field models*
Modern Finite Element Technologies Mathematical and Mechanical Aspects (MFET 2019), Bad Honnef

**Anna Walter**

07/08/2019 *Numerical Solution Strategies for the Elastoplasticity Problem with Finite Deformations*
International Conference on Continuous Optimization (ICCOPT), Berlin

17/09/2019 *Numerical Solution Strategies for Finite Plasticity in the Context of Optimal Control*
French-German-Swiss Conference on Optimization (FGS), Nice, France

09/02/2020 *Optimization of finite elastoplasticity problems using reduced order models*
Chemnitzer Seminar zur Optimalsteuerung, Haus im Ennstal, Austria

16/09/2020 *Optimization of Finite Elastoplasticity Problems using Reduced Order Models*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, TU Chemnitz

**Jonathan Weinberger**

06/06/2019 *Fibrations, modalities, and universes for synthetic* $(\infty, 1)$*-categories*
HoTT-UF Project Seminar, Centre of Advanced Study, Oslo

11/06/2019 *Type-theoretic modalities for synthetic* $(\infty, 1)$*-categories*
TYPES 2019/HoTT-UF, Oslo

14/08/2019 *Type-theoretic modalities for synthetic* $(\infty, 1)$*-categories*
Homotopy Type Theory 2019, Carnegie Mellon University, Pittsburgh, PA

26/09/2019 *Modalities and fibrations for synthetic* $(\infty, 1)$*-categories*
Category Theory Seminar, Johns Hopkins University, Baltimore, MD

04/10/2019 *Modalities and fibrations for synthetic* $(\infty, 1)$*-categories*
Homotopy Type Theory Seminar, Carnegie Mellon University, Pittsburgh, PA

**Winnifried Wollner**

19/02/2019 *Optimizing Fracture Propagation Using a Phase-Field Approach*
Annual Meeting of the International Association of Applied Mathematics and Mechanics (GAMM), Vienna, Austria

20/06/2019 *Finite element error in the control of damage processes*
Mathematics of Finite Elements and Applications (MAFELAP), Uxbridge, UK

17/07/2019 *Optimization of phase-field damage*
International Council for Industrial and Applied Mathematics (ICIAM), Valencia, Spain

24/09/2019 *Optimization of phase-field damage*
Deutsche Mathematiker-Vereinigung (DMV) Jahrestagung, Karlsruhe

**Dimitrios Zacharenakis**

13/09/2019 *Asymptotic preserving schemes for gas flows on large networks*
14th Hirschegg Workshop on Conservation Laws, Hirschegg (Kleinwalsertal)

04/10/2019 *Asymptotic analysis on large-scale gas networks*
European Conference on Numerical Mathematics and Advanced Applications (ENUMATH 2019), Egmond aan Zee, The Netherlands

### 6.1.3 Visits

Björn Augner, Universität Konstanz, July 2019

Björn Augner, KIT, Karlsruhe, July 2019

Björn Augner, Universität Wuppertal, January 2020

Sebastian Bechtel, University of Paris-Sud, March 2019

Yann Disser, University of Warsaw, Poland, August 2019

Yann Disser, TU Berlin, August 2020

Thomas Eiter, University of Pittsburgh, February 2019

Thomas Eiter, University of Pittsburgh, July–August 2019

Reinhard Farwig, RIMS, Kyoto University, Kyoto, March 2019

Reinhard Farwig, Chung Ang University, Seoul, March-April 2019

Reinhard Farwig, Ajou University, Suwon, South Korea, April 2019

Reinhard Farwig, Yonsei University, Seoul, April 2019

Reinhard Farwig, Czech Academy of Sciences, Prague, April 2019

Reinhard Farwig, Scuola Normale Superiore, Cortona, Italy, June 2019

Reinhard Farwig, MFO Oberwolfach, August 2019

Reinhard Farwig, Universität Erlangen-Nürnberg, Dezember 2019

Reinhard Farwig, Universität Düsseldorf, Januar 2020

Reinhard Farwig, Banach Center Bedlewo, Poland, March 2020

Anton Freund, Paris Diderot University, April 2019

Anton Freund, University of Leeds, June 2019

Anton Freund, Ghent University, January 2020

Jan Giesselmann, King Abdullah Universiy of Science and Technology, Thuwal, Saudi-Arabia, April 2019

Jan Giesselmann, Foundation for Research and Technology - Hellas, Crete, Greece, March 2020

Matthias Hieber, Hausdorff Center, Bonn, February 2019

Matthias Hieber, Waseda University, Tokyo, Japan, February 2019

Matthias Hieber, University of Tokyo, Japan, February 2019

Matthias Hieber, MFO, Oberwolfach, February 2019

Matthias Hieber, RIMS, Kyoto, March 2019

Matthias Hieber, Universität Konstanz, April 2019

Matthias Hieber, KIT, Karlsruhe, May 2019

Matthias Hieber, Waseda University, Tokyo, Japan, June 2019

Matthias Hieber, University of Tokyo, Tokyo, Japan, June 2019

Matthias Hieber, Scoula Normale Superiore, Pisa, Italy, June 2019

Matthias Hieber, MFO, Oberwolfach, August 2019

Matthias Hieber, University of Concepcion, Chile, August 2019

Matthias Hieber, Federal University of Rio de Janeiro, Brasil, September 2019

Matthias Hieber, LNCC, Petropolis, Brasil, September 2019

Matthias Hieber, CIRM, Luminy, France, October 2019

Matthias Hieber, South China Research Center, Guangzhou, China, November 2019

Matthias Hieber, VIASM, Hanoi, Vietnam, November 2019

Matthias Hieber, Waseda University, Tokyo, Japan, December 2019

Matthias Hieber, MPI, Hamburg, February 2020

Matthias Hieber, MFO, Oberwolfach, June 2020

Ulrich Kohlenbach, MFO Oberwolfach, Research in Pairs with G. López-Acedo (U Seville), A. Niculae (Babeş-Bolyai U), March 10-23, 2019

Ulrich Kohlenbach, University of Seville, June 2019

Burkhard Kümmerer, Lorentz Center Leiden, May 2019

Elena Mäder-Baumdicker, KIT, Karlsruhe, May 2019

Tomislav Marić, Computer Science Laboratory for Mechanics and Engineering Sciences 101 (LIMSI), French National Centre for Scientific Research (CNRS), Orsay cedex, France, September – October 2019

Holger Marschall, Visiting Professor, Institut de Mécanique des Fluides de Toulouse (IMFT), France, February 2019

Andreas Paffenholz, TU Berlin, April to July 2019

Anna-Maria von Pippich, Fachbereich Mathematik, Universität Tübingen, October 2018 – March 2019

Anna-Maria von Pippich, Mathematisches Institut, Universität Göttingen, April 2019 – September 2019

Nils Scheithauer, IUC, Dubrovnik, Croatia, June 2019

Nils Scheithauer, Universität Freiburg, July 2019

Nils Scheithauer, Woudschoten, Zeist, The Netherlands, December 2019

Nils Scheithauer, Universität Bochum, December 2019

Tobias Tolle, LIMSI, September 2019

Stefan Ulbrich, RICAM Linz, Austria, November 2019

Stefan Ulbrich, TU Graz, Austria, February 2020

Jonathan Weinberger, Centre of Advanced Study, Oslo, Feb 2019

Jonathan Weinberger, Centre of Advanced Study, Oslo, Jun 2019

Jonathan Weinberger, Johns Hopkins University, Baltimore, MD, Sep 2019

Jonathan Weinberger, Carnegie Mellon University, Pittsburgh, PA, Sep 2019

Cornelia Wichelhaus, University of Amsterdam, March 2019

Winnifried Wollner, Universität Duisburg-Essen, January 2019

Winnifried Wollner, Louisiana State University, Baton Rouge, USA, April 2019

Winnifried Wollner, New York University, USA, April 2019

Winnifried Wollner, WIAS Berlin, May 2019

Winnifried Wollner, Universität Kassel, May 2019

Winnifried Wollner, TU Dortmund, June 2019

Winnifried Wollner, National Polytechnic School, Quito, Ecuador, August 2019

Winnifried Wollner, Texas A&M, College Station, USA, Septemper 2019

Winnifried Wollner, Universität Hannover, January 2020

## 6.2 Organization and Program Commitees of Conferences and Workshops

**Frank Aurzada**

- Oberwolfach Workshop “Stochastic processes under constraints”, 27.09.20–03.10.20, Darmstadt (jointly with Martin Kolb (Paderborn), Françoise Pène (Brest), Vitali Wachtel (Augsburg))

**Volker Betz**

- Spring school on Spin Systems - Discrete and Continuous, Darmstadt, March 2019 (jointly with Matthias Meiners, Frank Aurzada)
- Spring school on Probability in mathematics and physics (jointly with Frank Aurzada and Matthias Meiners), March 2020

**Jan H. Bruinier**

- ABKLS-Seminar on *Automorphic Forms* (jointly with K. Bringmann, V. Gritsenko, A. Krieg, G. Nebe, N.-P. Skoruppa, D. Zagier), 27.02.19 Lille, 11.09.19 Köln, 12.02.20 Aachen

– Workshop *Modular forms* (jointly with A. Ichino, T. Ikeda, Ö. Imamoglu), Mathematisches Forschungsinstitut Oberwolfach, 15.12.19–21.12.19

**Yann Disser**

– Minisymposium on "Online Optimization" at the DMV Annual Meeting, 14.09.20–17.09.20, TU Chemnitz

**Pia Domschke**

– Minisymposium: Numerical methods to advance mathematical biology research (jointly with Alf Gerisch (TU Darmstadt) and Chandrasekhar Venkataraman (Sussex, UK)) at the European Conferences on Numerical Mathematics and Advanced Applications (ENUMATH2019), 30.09.19–04.10.19, Egmond aan Zee, The Netherlands

**Herbert Egger**

– Minisymposium: Recent developments in the numerical approximation of transport equations, Mafelap 2019, 18.06.19–21.06.19, Brunel University London, UK

– Workshop on High-order and Spectral Methods, 27.06.19, TU Darmstadt (jointly with Mania Sabouri)

– Section on Numerical analysis, GAMM Conference 2020, 16.03.20–20.03.20, Kassel

**Kord Eickmeyer**

– International Colloquium on Automata, Languages and Programming (ICALP) 2020, PC member

**Christoph Erath**

– Strategietagung TU Darmstadt und TU Graz, 10.07.19–11.07.19, TU Darmstadt

**Reinhard Farwig**

– "Evolution Equations: Applied and Abstract Perspectives. Equations d'évolution: perspectives appliquées et abstraites", Centre International de Rencontres Mathématiques CIRM in Luminy (Marseille), 28.10.19–01.11.19, jointly with K. Disser (TU Darmstadt) et al.

– International Conference "Vorticity, Rotation and Symmetry (V) - Global Results and Nonlocal Phenomena", Centre International de Rencontres Mathématiques (CIRM) in Luminy (Marseille), 06.04.20–10.04.20, jointly with R. Danchin (Paris), J. Neustupa (Prague) and Š. Nečasová (Prague). Canceled due to corona pandemic

– Hybrid International Conference "Vorticity, Rotation and Symmetry (V) - Global Results and Nonlocal Phenomena", Centre International de Rencontres Mathématiques (CIRM) in Luminy (Marseille), 26.10.20–30.10.20, jointly with R. Danchin (Paris), J. Neustupa (Prague) and Š. Nečasová (Prague)

**Anton Freund**

- Proof Theory Virtual Seminar (co-organizer). Seminar series with up to 100 live participants and videos published on YouTube

**Alf Gerisch**

- Minisymposium: Numerical methods to advance mathematical biology research (jointly with Pia Domschke (TU Darmstadt) and Chandrasekhar Venkataraman (Sussex, UK)) at the European Conferences on Numerical Mathematics and Advanced Applications (ENUMATH2019), 30.09.19–04.10.19, Egmond aan Zee, The Netherlands

**Matthias Hieber**

- Conference on Maximal Regularity and Nonlinear PDE, RIMS, Kyoto, Japan, 25.03.19–29.03.19, (jointly with H. Kozono, S. Shimizu)
- Conference on PDE, Konstanz, 09.04.19–11.04.19, (joinlty with R. Denk)
- Conference on Nonlinear Analysis, Cortona, 11.06.19–14.06.19
- Workshop on Geophysical Flows, Oberwolfach, 15.06.19–19.06.20, (jointly with Y. Giga, P. Korn, E. Titi)

**Ulrich Kohlenbach**

- PC Member, Foundations of Mathematics, 21.03.19–27.03.19, Wuhan, China
- Member of Scientific Committee of '13th International Conference on Fixed Point Theory and its Applications', 09.07.19–13.07.19, XinXiang, HeNan, China
- Organizer Oberwolfach Workshop on 'Mathematical Logic', 08.11.19–14.11.20 (jointly with Sam Buss, Rosalie Iemhoff, Michael Rathjen)

**Burkhard Kümmerer**

- Exhibition: Magnets, Air, and the Universe. The Beginnings of Scientific Observation and New Horizons in Physics, Exhibition on the occasion of the 69th Lindau Nobel Laureate Meeting, Ehemals Reichsstädtische Bibliothek, Lindau

**Elena Mäder-Baumdicker**

- "Geometric Analysis meets Geometric Topology" conference (jointly with Friederike Dittberner, Valentina Disarlo, Federica Fanoni and Beatrice Pozzetti), 25.02.19–28.02.19, Universität Heidelberg

**Ingmar Metzler**

- Research seminar of the local research group Algebra *Winterseminar 2020* (jointly with J.H. Bruinier), Manigod, France, 08.03.20–15.03.20

**Anna-Maria von Pippich**

- Workshop and Conference "Algebraic and analytic aspects of automorphic forms" (jointly with A. Aryasomayajula, D. Prasad, et. al.), International Center for Theoretical Sciences (ICTS), Bangalore, 25.02.19–07.03.19

**Ulrich Reif**

- Dagstuhl Seminar on Interactive Design and Simulation, 15.12.19–20.12.19

**Mania Sabouri**

- Workshop on High-order and Spectral Methods, 27.06.19, TU Darmstadt (jointly with Herbert Egger)

**Nils Scheithauer**

- 12th Seminar on Conformal Field Theory, 05.07.19, Freiburg (organized by Peter Fiebig, Nils Scheithauer and Katrin Wendland)

**Alexandra Schwartz**

- Cluster: Multi-Objective and Vector Optimization at ICCOPT 2019 (jointly with Gabriele Eichfelder), August 05.08.19–08.08.19, Berlin

**Torsten Wedhorn**

- Workshop on Prismatic Cohomology, 27.03.19–29.03.19 (jointly with Ulrich Görtz, Eike Lau and Eva Viehmann)

**Winnifried Wollner**

- Section S19: Optimization of differential equation (jointly with Kathrin Welker) at GAMM, 18.02.19–22.02.19, Vienna, Austria
- Minisymposium: Numerical Methods for Phase Field Fracture Problems at MAFELAP, June 17.06.19–21.06.19, Uxbridge, UK
- Minisymposium: Phase-Field Models in Simulation and Optimization (jointly with Roberto Alessi, Thomas Wick) at ICIAM, 15.07.19–19.07.19, Valencia, Spain
- Minisymposium: Discretization aspects in PDE-constrained optimization at DMV 2020, 14.09.20–17.09.20, Chemnitz (virtual conference)

# 7 Workshops and Visitors at the Department

## 7.1 The Colloquium

**Winter term 2018**

17/10/2018 Celebration colloquium on the occasion of 60th Birthday of Prof. Dr. Steffen Roch: Prof. Dr. Albrecht Böttcher (TU Chemnitz), *Die Duduchava-Roch-Formel*

24/10/2018 Prof. Dr. Patrick Joly (ENSTA ParisTech), *Artificial boundary conditions for wave propagation in complex media*

31/10/2018 Prof. Dr. Guido Sweers (Universität Köln), *Laundry lines, curtain rods, membranes and thin plates*

07/11/2018 Prof. Dr. Johannes Schmidt-Hieber (Universiteit Leiden), *Statistical theory for deep neural networks*

14/11/2018 Prof. Dr. Peter Fiebig (Universität Erlangen-Nürnberg), *Darstellungstheorie in positiver Charakteristik*

21/11/2018 Prof. Dr. Denis-Charles Cisinski (Universität Regensburg), *Higher categories as a basic language for mathematics*

28/11/2018 Prof. Dr. Gianluigi Rozza (International School for Advanced Studies (Sissa), Trieste), *State of the art and perspectives for reduced order methods in computational fluid dynamics*

05/12/2018 Prof. Dr. Roland Herzog (TU Chemnitz), *An Introduction to Optimal Experimental Design with PDEs*

12/12/2018 Prof. Dr. Stefan Krauss (Universität Regensburg), *Die diagnostische Kompetenz von Lehrkräften in der COACTIV-Studie*

19/12/2018 Prof. Dr. Christoph Buchheim (TU Dortmund), *Oracle-based Algorithms for Robust Optimization*

16/01/2019 Prof. Dr. Amin Coja-Oghlan (Universität Frankfurt), *Spin systems on Bethe lattices*

23/01/2019 Prof. Dr. Esther Brunner (PH Thurgau, Kreuzlingen), *Welche Beweistypen setzen Lehrpersonen ein und womit hängt das zusammen?*

30/01/2019 Prof. Dr. Yingkun Li (TU Darmstadt), *Green's function and arithmetic*

06/02/2019 Prof. Dr. Jochen Heinloth (Universität Duisburg-Essen), *Hitchin's fibration: From integrable systems to number theory*

13/02/2019 Celebration colloquium on the occasion of the retirement of Prof. Dr. Burkhard Kümmerer: Prof. Dr. Burkhard Kümmerer (TU Darmstadt), *Mathematik berührt – Keine Abschiedsvorlesung*

**Summer term 2019**

17/04/2019 Prof. Dr. Christian Rohde (Universität Stuttgart), *Modelling Multiphase Flow across Scales*

24/04/2019 Prof. Dr. Jan Giesselmann (TU Darmstadt), *Zum Konzept der Entropie in hyperbolischen Erhaltungsgleichungen und der kompressiblen Strömungsmechanik*

08/05/2019 Prof. Dr. Christina Surulescu (TU Kaiserslautern), *Mathematical modeling of cancer invasion: The influence of the tumor microenvironment*

15/05/2019 Prof. Dr. Leif Döring (Universität Mannheim), *Individualisierung in der Mathematiklehre*

22/05/2019 Prof. Dr. Johannes Kraus (Universität Duisburg-Essen), *Parameter-robust solvers for poroelasticity problems with applications*

24/05/2019 Graduation Ceremony for summer term 2018 and winter term 2018/2019: Prof. Dr. Peter Gritzmann (TU München), *Die diskrete Mathematik der Demokratie: Oder die Qual mit der Wahl*

29/05/2019 Prof. Dr. Irene Bouw (Universität Ulm), *Computing arithmetic invariants via reduction*

05/06/2019 Prof. Dr. Bernd Thaller (Universität Graz), *Was können unsere StudienanfängerInnen in Mathematik?*

19/06/2019 Prof. Dr. Jakob Stix (Universität Frankfurt), *Can loops catch rational points?*

26/06/2019 Prof. Dr. Michael Hinze (Universität Koblenz-Landau), *Global minima in nonconvex PDE constrained optimization*

01/07/2019 Celebration colloquium on the occasion of the retirement of Prof. Dr. Hans Jürgen Prömel: Prof. Dr. Hans Jürgen Prömel (TU Darmstadt), *90 Semester und 5 Universitäten – Facetten einer Zeitreise*

03/07/2019 DAMS PostDoc Event and Poster Presentation (TU Darmstadt),

10/07/2019 Prof. Dr. Elena Mäder-Baumdicker (TU Darmstadt), *Über die schönsten Kleinschen Flaschen*

17/07/2019 Prof. Dr. Lisa Hefendehl-Hebeker (Universität Duisburg-Essen), *Hermann G. Grassmann – Visionär der Linearen Algebra*

**Winter term 2019**

11/10/2019 Celebration colloquium on the occasion of the retirement of Prof. Dr. Regina Bruder: Prof. Dr. Olaf Köller (IPN, Universität Kiel), *Ohne Daten keine Taten: Der Beitrag der empirischen Forschung zur Schul- und Unterrichtsentwicklung*

16/10/2019 Prof. Dr. Patrick Guidotti (University of California, Irvine), *Nonlinear Parabolic Equations with Expected and Surprising Dynamical Behavior*

23/10/2019 Prof. Dr. Herold Dehling (Universität Bochum), *Dependence in Probability, Statistics, and Analysis*

30/10/2019 Prof. Dr. Günter Last (KIT, Karlsruhe), *Hyperuniform point processes*

06/11/2019 Celebration colloquium on the occasion of 70th Birthday of Prof. Dr. Dr. h. c. Hans-Dieter Alber: Prof. Dr. Dr. h. c. Hans-Dieter Alber (TU Darmstadt), *Mein akademisches Leben, geleitet durch meine Faszination für partielle Differentialgleichungen*

13/11/2019 Prof. Dr. Norbert Henze (KIT, Karlsruhe), *Verständnisorientierter Stochastikunterricht am Gymnasium: Anforderungen an die Lehrerbildung*

20/11/2019 Prof. Dr. Martin Ulirsch (Universität Frankfurt), *From Riemann surface to tropical curves (and back again)*

27/11/2019 Prof. Dr. Ansgar Jüngel (TU Wien), *Diffusion in multi-component systems: Maxwell-Stefan and compressible fluid models*

04/12/2019 Prof. Dr. Michael Rathjen (University of Leeds), *Graph Theory, Logic, and the Transfinite*

11/12/2019 Prof. Dr. Daniel Peterseim (Universität Augsburg), *Beyond Numerical Homogenization*

18/12/2019 Prof. Dr. Timo Richarz (TU Darmstadt), *Where do elliptic curves meet modulo p?*

15/01/2020 Prof. Dr. Manuel Torrilhon (RWTH Aachen), *Hierarchical Modeling: Rarefied Gases and Shallow Flow*

22/01/2020 Prof. Dr. Detlef Müller (Universität Kiel), *Über Wellengleichungen und Spektralmultiplikatoren auf Mannigfaltigkeiten mit sub-Riemannscher Geometrie*

29/01/2020 Prof. Dr. Eugen Hellmann (Universität Münster), *Zeta-Functions of varieties and Galois representations, and their meromorphic continuation*

05/02/2020 Prof. Dr. Stefano Modena (TU Darmstadt), *Convex integration and the equations of fluid dynamics*

12/02/2020 Prof. Dr. Carla Cederbaum (Universität Tübingen), *Über CMC-Blätterungen asymptotisch Euklidischer Mannigfaltigkeiten*

**Summer term 2020**

All talks cancelled due to corona pandemic

**Winter term 2020**

13/01/2021 Prof. Dr. Lorenzo Taggi (University of Rome – La Sapienza), *Bose-Einstein Condensation and Random Loops* (Online event)

20/01/2021 Prof. Dr. Jose Iovino (University of Texas at San Antonio), *Self-improving convergence theorems* (Online event)

27/01/2021 Prof. Dr. Thomas Surowiec (Universität Marburg), *Risk-Averse Optimization of Random Elliptic Partial Differential Equations: Modeling, Theory and Numerical Solution* (Online event)

03/02/2021 Prof. Dr. Serge Prudhomme (Polytechnique Montréal), *Goal-oriented formulations for finite element approximations and reduced-order models* (Online event)

10/02/2021 Prof. Dr. Gerd Laures (Universität Bochum), *Codes, lattice algebras and string groups from the topological viewpoint* (Online event)

## 7.2 Guest Talks at the Department

11/01/2019 Prof. Dr. Eyal Goren (McGill University Montreal, Canada), *P-adic dynamics of Hecke operators* (Torsten Wedhorn)

14/01/2019 Dr. Mané Harytyunyan (TU Kaiserslautern), *Modellierung, Analyse und Diskretisierung von magnetorestriktiven Materialien* (Herbert Egger)

17/01/2019 Dr. Tobias Barker (Université Paris-Diderot, École normale supérieure), *Relationship between failure of a Liouville type theorem and Type I singularities of the Navier-Stokes equations* (Reinhard Farwig)

24/01/2019 Dr. Jonas Sauer (Max-Planck-Institut, Leipzig), *Space-Time Sobolev Regularity for the Porous Medium Equations* (Reinhard Farwig)

24/01/2019 Helmut Pitters (Universität Mannheim), *The number of cycles in a random permutation and the number of segregating sites jointly converge to the Brownian sheet* (Volker Betz)

31/01/2019 Prof. Dr. Hideo Kozono (Waseda University, Tokyo), *$L^r$ Harmonic vector fields in 2 D exterior domains* (Reinhard Farwig)

05/02/2019 Prof. Dr. Jennifer K. Ryan (Universität Düsseldorf and University of East Anglia, UK), *Constructing Accurate Post-Processing Convolution Kernels* (Jan Giesselmann)

07/02/2019 Chiranjib Mukherjee (Universität Münster), *The solution of the Polaron problem* (Volker Betz)

20/02/2019 Marcel Klinge (Universität Halle-Wittenberg), *A comparison of one-step and two-step AMF methods* (Jens Lang)

18/03/2019 Prof. Dr. Bruno F. Lourenço (ISM, Tachikawa, Japan), *Squared slack variables in nonlinear semidefinite programming: optimality conditions and algorithms* (Tristan Gally)

17/04/2019 Dr. Marcel Braukhoff (TU Wien), *The importance of the boundary conditions for a chemotaxis-consumption model* (Reinhard Farwig)

17/04/2019 Prof. Dr. Christian Rohde (Universität Stuttgart), *Modelling Multiphase Flow across Scales* (Reinhard Farwig)

23/04/2019 Prof. Dr. Robert Osburn (University College Dublin, Ireland), *Generalized Kontsevich-Zagier series via knots* (Yingkun Li)

03/05/2019 Herbert Spohn (TU München and Universität Bonn), *Gibbs measures of the Toda chain and random matrix theory* (Volker Betz)

03/05/2019 Lisa Hartung (Universität Mainz), *The Ginibre charactzeristic polynomial and Gaussian Multiplicative Chaos* (Volker Betz)

03/05/2019 Prof. Dr. Adrian Mathias (University of Reunion), *Using generic extensions of ill-founded omega-models to build standard ones* (Anton Freund)

14/05/2019 Prof. Dr. Dimitri Wyss (Sorbonne University, Paris, France), *Non-Archimedean integrals on the Hitchin fibration* (Timo Richarz)

21/05/2019 Mark Feldmann (Universität Münster), *p-adic Weil group representations* (Torsten Wedhorn)

04/06/2019 Kishore Nori (RWTH Aachen), *Viscous extension of Moment models for Shallow flows: Theory and Numeric* (Jan Giesselmann)

06/06/2019 Dr. Kazuyuki Tsuda (Osaka University, Osaka), *Global existence and time decay estimate of solutions to the compressible Navier-Stokes-Korteweg system under critical condition* (Reinhard Farwig)

11/06/2019 Dr. Neeraj Sarna (MPI Dynamik komplexer technischer Systeme, Magdeburg), *Entropy stable schemes for linear kinetic equations* (Jan Giesselmann)

12/06/2019 Dr. Reinhald Ehrig (Zuse Institute Berlin), *Model development and FE calculations for the characterization of human osteoarthritis* (Jens Lang)

25/06/2019 Dr. Andrew Corbett (University of Exeter, UK), *Fourier coefficients of automorphic forms: p-adic analysis and arithmetic at the cusps* (Jan H. Bruinier)

27/06/2019 Ass. Prof. Dr. Frankziska Weber (Carnegie Mellon University, USA), *Numerical approximation of statistical solutions for systems of hyperbolic conservation laws* (Jan Giesselmann)

02/07/2019 Dr. Kęstutis Česnavičius (University Paris-Sud, Orsay), *Purity for the Brauer group of singular schemes* (Jan H. Bruinier)

02/08/2019 Jan-Hendrik Lange (MPI Saarbrücken), *Combinatorial persistency criteria for multicut* (Marc Pfetsch)

28/08/2019 Dr. Alexander Linke (WIAS, Berlin), *On high Reynolds number flows, pressure-robustness and high-order methods* (Winnifried Wollner)

17/09/2019 Prof. Dr. Nils-Peter Skoruppa (Universität Siegen), *The Macdonald identities and Jacobi forms of lattice index* (Jan H. Bruinier)

17/09/2019 Prof. Dr. Siegfried Böcherer (Universität Mannheim), *On paramodular forms of arbitrary degree* (Jan H. Bruinier)

17/09/2019 Prof. Dr. Soumya Das (Indian Institute of Science Bangalore, India), *Fundamental Fourier coefficients of Siegel modular forms* (Jan H. Bruinier)

18/09/2019 Dr. Athanasios Bouganis (University of Durham, UK), *Quaternionic modular forms and the Rankin-Selberg method* (Jan H. Bruinier)

18/09/2019 Dr. Olivier Taïbi (ENS Lyon, France), *Discrete series multiplicities for classical groups over Z and level 1 algebraic cusp forms* (Jan H. Bruinier)

18/09/2019 Prof. Dr. Masaaki Furusawa (Osaka City University, Japan), *OnBöcherer's conjecture* (Jan H. Bruinier)

19/09/2019 Dr. Abhishek Saha (Queen Mary University of London, UK), *Critical L-values and congruences for Siegel modular forms, II* (Jan H. Bruinier)

19/09/2019 Dr. David Yuen (University of Hawaii, USA), *Finding all paramodular Borcherds products and applications* (Jan H. Bruinier)

19/09/2019 Dr. Shaul Zemel (Hebrew University of Jerusalem, Israel), *Heegner divisors on toroidal compactifications of orthogonal Shimura varieties* (Jan H. Bruinier)

19/09/2019 Prof. Dr. Ameya Pitale (University of Oklahoma, USA), *Critical L-values and congruences for Siegel modular forms, I* (Jan H. Bruinier)

20/09/2019 Prof. Dr. Aaron Pollack (Duke University, USA), *Modular forms on exceptional groups* (Jan H. Bruinier)

20/09/2019 Prof. Dr. Jens Funke (University of Durham, UK), *The construction of Green currents and singular theta lifts for unitary groups* (Jan H. Bruinier)

20/09/2019 Prof. Dr. John Millson (University of Maryland, USA), *Holomorphic forms on quotients of hermitian locally symmetric spaces and generalized special cycles* (Jan H. Bruinier)

22/10/2019 Rahel Brügger (Universität Basel), *On the Solution of a Time-dependent Inverse Shape Identification Problem of Heat Equation* (Herbert Egger)

05/11/2019 Dipl. Math. Daniel Sebastian (TU Wien), *How functional error estimates could unite adaptivity and error control for boundary element methods* (Christoph Erath)

13/11/2019 Dr. Xin Liu (FU Berlin), *Bounded entropy and moving boundary in compressible Navier-Stokes system* (Reinhard Farwig)

21/11/2019 Dr. Philipp Öffner (Universität Zürich), *About the stability of numerical schemes for hyperbolic conservation laws* (Jan Giesselmann)

26/11/2019 Prof. Dr. Anilatmaja Aryasomayajula (IISER Tirupati, India), *Estimates of holomorphic cusp forms associated to co-compact arithmetic subgroup* (Anna von Pippich)

03/12/2019 Camile Kunz (FIAS Frankfurt), *An overview of numerical approaches for a coupled chemotaxis-reaction-diffusion system* (Alf Gerisch)

05/12/2019 Lorenzo Taggi (WIAS Berlin), *Phase transition in lattice permutations and uniformly positive correlations in the dimer model via reflection positivity* (Volker Betz)

10/12/2019 Dr. Alexander Konschin (Universität Bremen), *Streuung an lokal gestörten periodischen Medien und die Bloch-Floquet-Transformation* (Herbert Egger)

17/12/2019 Dr. Johan Commelin (Universität Freiburg), *Formalising perfectoid spaces* (Torsten Wedhorn)

18/12/2019 Dr. Ryo Kanamaru (Waseda University, Tokyo), *Optimality of logarithmic interpolation inequalities and extension criteria to the Navier-Stokes and Euler equations in Vishik spaces* (Reinhard Farwig)

14/01/2020 Dr. Edgar Assing (Universität Bonn), *Wilton estimates and the fine structure of Fourier coefficients* (Jan H. Bruinier)

17/01/2020 Fabian Kertels (Universität Freiburg), *BPS algebras for heterotic theories on tori* (Nils Scheithauer)

17/01/2020 Prof. Dr. Drazen Adamovic (University of Zagreb, Croatia), *On logarithmic and Whittaker modules for affine vertex operator algebras and beyond* (Nils Scheithauer)

17/01/2020 Prof. Dr. Giovanna Carnovale (University of Padua, Italy), *Jordan classes in Lie algebras and algebraic groups* (Nils Scheithauer)

21/01/2020 Dr. Daniel Kohen (Universität Duisburg-Essen), *A Gross-Kohnen-Zagier theorem for non-split Cartan curves* (Torsten Wedhorn)

22/01/2020 Prof. Dr. Detlef Müller (Universität Kiel), *Wave equation and spectral multipliers on manifolds with sub-Riemannian geometry* (Reinhard Farwig)

22/01/2020 Prof. Dr. Maria Deijfen (Stockholm University), *Competing frogs on $\mathbb{Z}^d$* (Frank Aurzada)

22/01/2020 Prof. Dr. Siva Athreya (Indian Statistical Institute, Bengaluru), *Graphon dynamics from population genetics* (Frank Aurzada)

28/01/2020 Prof. Dr. Eugen Hellmann (Universität Münster), *On the derived category of the Iwahori-Hecke Algebra* (Torsten Wedhorn)

30/01/2020 Dimitrios Tsagkarogiannis (University of L'Aquila), *Cluster expansions and coarse-graining* (Volker Betz)

30/01/2020 Dr. Julian Köllermeier (KU Leuven, Belgium), *Moment Models for Kinetic Equations — On Efficient Numerical Methods* (Jan Giesselmann)

31/01/2020 Prof. Dr. Steffen Dereich (Universität Münster), *Quasi-processes for branching Markov chains* (Frank Aurzada)

31/01/2020 Sabine Jansen (LMU München), *Cluster expansions for Gibbs point processes: probabilistic aspects* (Volker Betz)

04/02/2020 Dr. Maria Lymbery (Universität Duisburg-Essen), *On the numerical solution of the fully dynamic MPET system* (Herbert Egger)

06/02/2020 Prof. Dr. Markus Bause (Helmut-Schmidt-Universität Hamburg), *On Generalized Space-Time Finite Element Methods for Flow and Waves* (Herbert Egger)

07/02/2020 Dr. Kevin Schewior (Universität zu Köln), *Sample-Based Prophet Inequalities* (Yann Disser)

11/02/2020 Dr. Ehsan Shakeri (Shahid Beheshti University, Tehran, Iran), *Fokker-Planck-based Nonlinear Model Predictive Control: Shaping the Probability Density Function* (Winnifried Wollner)

11/02/2020 Dr. Hongbo Yin (Max-Planck-Institut für Mathematik Bonn), *Cubic sum problem and singular moduli* (Yingkun Li)

21/02/2020 Matías Villagra (Pontifical Catholic University of Chile), *On a canonical symmetry breaking technique for polytopes* (Marc Pfetsch)

08/04/2020 Dr. Danylo Radchenko (ETH Zurich, Switzerland), *Universal optimality of the* $E_8$ *and Leech lattice* (Jan H. Bruinier)

15/04/2020 Dr. Paloma Bengoechea (ETH Zurich, Switzerland), *Periods of modular functions and Diophantine approximation* (Jan H. Bruinier)

22/04/2020 Prof. Dr. Jan Vonk (Institute for Advanced Study Princeton, USA), *Singular moduli for real quadratic fields* (Jan H. Bruinier)

27/04/2020 Prof. Dr. Eugen Hellmann (Universität Münster), *On the derived category of the Iwahori-Hecke algebra, I* (Timo Richarz)

29/04/2020 Prof. Dr. Nick Andersen (Brigham Young University, Utah, USA), *Zeros of* $GL_2$ *L-functions on the critical line* (Jan H. Bruinier)

04/05/2020 Prof. Dr. Eugen Hellmann (Universität Münster), *On the derived category of the Iwahori-Hecke algebra, II* (Timo Richarz)

06/05/2020 Prof. Dr. Soma Purkait (Tokyo Institute of Technology, Japan), *Local Hecke algebras and new forms* (Jan H. Bruinier)

11/05/2020 Dr. Ben Heuer (Universität Bonn), *Perfectoid universal covers of abelian varieties, I* (Torsten Wedhorn)

13/05/2020 Dr. Matthias Schlottbom (University of Twente, The Netherlands), *A model reduction approach for inverse problems with operator valued data* (Herbert Egger)

13/05/2020 Prof. Dr. Peter Humphries (University College London, UK), *Sparse equidistribution of hyperbolic orbifolds* (Jan H. Bruinier)

18/05/2020 Prof. Dr. Ben Heuer (Universität Bonn), *Perfectoid universal covers of abelian varieties, II* (Torsten Wedhorn)

20/05/2020 Prof. Dr. Larry Rolen (Vanderbilt University, Nashville, USA), *Periodicities for Taylor coefficients of half-integral weight modular forms* (Jan H. Bruinier)

25/05/2020 Dr. Andreas Mihatsch (MIT Cambridge, USA), *Currents on Lubin-Tate spaces, I* (Torsten Wedhorn)

27/05/2020 Melvin Liebsch (TU Darmstadt and CERN), *Bayesian Inference in Magnetic Measurement of Accelerator Magnets* (Herbert Egger)

27/05/2020 Prof. Dr. Olivia Beckwith (University of Illinois, USA), *Polyharmonic Maass forms and Hecke L-series* (Jan H. Bruinier)

03/06/2020 Dr. Dan Fretwell (University of Bristol, UK), *(Real quadratic) Arthurian tales* (Jan H. Bruinier)

08/06/2020 Dr. Andreas Mihatsch (MIT Cambridge, USA), *Currents on Lubin-Tate spaces, II* (Timo Richarz)

10/06/2020 Laura D'Angelo (TU Darmstadt), *Quasi-3D Quench Simulation of Superconducting Magnets* (Herbert Egger)

10/06/2020 Prof. Dr. Martin Raum (Chalmers Technical University, Gothenburg, Sweden), *Divisibilities of Hurwitz class numbers* (Jan H. Bruinier)

15/06/2020 Dr. Alexander Ivanov (Universität Bonn), *On p-adic Deligne-Lusztig spaces, I* (Torsten Wedhorn)

17/06/2020 Iryna Kultchytsa (TU Darmstadt), *Parallel-in-time calculation of the periodic steady-state solution with application in electrical engineering* (Herbert Egger)

22/06/2020 Dr. Alexander Ivanov (Universität Bonn), *On p-adic Deligne-Lusztig spaces, II* (Torsten Wedhorn)

24/06/2020 Dr. Sven Möller (Rutgers University, New Brunswick, USA), *Eisenstein Series, Dimension Formulae and Generalised Deep Holes of the Leech Lattice Vertex Operator Algebra* (Nils Scheithauer)

29/06/2020 Dr. Johannes Anschütz (Universität Bonn), *Averaging functors in Fargues' program for* $GL_n$ (Timo Richarz)

01/07/2020 Dr. Hao Zhang (Sorbonne University, Paris, France), *Elliptic cocycle for* $GL_n(Z)$ *and Hecke operators* (Jan H. Bruinier)

06/07/2020 Prof. Dr. Eva Viehmann (TU München), *Harder-Narasimhan and Newton polygons for modifications of G-bundles, I* (Torsten Wedhorn)

08/07/2020 Dr. Shaul Zemel (Hebrew University of Jerusalem, Israel), *Shintani lifts of nearly holomorphic modular forms* (Jan H. Bruinier)

13/07/2020 Prof. Dr. Eva Viehmann (TU München), *Harder-Narasimhan and Newton polygons for modifications of G-bundles, II* (Torsten Wedhorn)

15/07/2020 Prof. Dr. Nikos Diamantis (University of Nottingham, UK), *Twisted L-functions and a conjecture by Mazur, Rubin, and Stein* (Jan H. Bruinier)

17/07/2020 Richard Löscher (TU Graz), *A space-time finite element method for the wave equation using a modified Hilbert transformation* (Herbert Egger)

04/09/2020 Prof. Dr. Adam Krzyżak (Concordia University (Montreal)), *Deep Learning and MARS: A connection* (Michael Kohler)

14/10/2020 Dr. Haowu Wang (Max-Planck-Institut für Mathematik Bonn), *Root systems and free algebras of modular forms* (Jan H. Bruinier)

16/10/2020 Dr. Kathrin Smetana (University of Twente, The Netherlands), *Stable Petrov-Galerkin methods for (kinetic) transport equations* (Herbert Egger)

21/10/2020 Dr. Yunqing Tang (University Paris-Sud, Orsay), *Reductions of K3 surfaces via intersections on GSpin Shimura varieties* (Yingkun Li)

28/10/2020 Alessandro Lägeler (ETH Zurich, Switzerland), *Continued fractions and Hardy sums* (Jan H. Bruinier)

04/11/2020 Prof. Dr. Michael Griffin (Brigham Young University, Utah, USA), *Class pairings and elliptic curves* (Yingkun Li)

11/11/2020 Christina Röhrig (Universität Köln), *Siegel theta series for indefinite quadratic forms* (Jan H. Bruinier)

18/11/2020 Dr. Toshiki Matsusaka (University of Nagoya, Japan), *Two analogues of the Rademacher symbol* (Yingkun Li)

25/11/2020 Dr. Kathrin Maurischat (RWTH Aachen), *Explicit construction of Ramanujan bigraphs* (Jan H. Bruinier)

07/12/2020 Jun.-Prof. Dr. Sandra May (TU Dortmund), *Time-dependent conservation laws on cut cell meshes and the small cell problem* (Herbert Egger)

09/12/2020 Prof. Dr. Ariel Pacetti (University of Cordoba, Spain), *$\mathbb{Q}$-curves, Hecke characters and some Diophantine equations* (Yingkun Li)

16/12/2020 Ass. Prof. Dr. Elena Rossi (University Modena and Reggio Emilia, Italy), *Traffic flows at road junctions: a macroscopic multilane approach* (Jan Giesselmann)

16/12/2020 Dr. Eugenia Rosu (Universität Regensburg), *Twists of elliptic curves with CM* (Jan H. Bruinier)

23/12/2020 Prof. Dr. Martin Gugat (Universität Erlangen-Nürnberg), *On problems of dynamic optimal nodal control for gas networks* (Jan Giesselmann)

## 7.3 Visitors at the Department

Prof. Dr. Mikhail Lifshits (St. Petersburg State University), August 2019.

Prof. Dr. Mikhail Lifshits (St. Petersburg State University), Janaur – February 2020.

Dr. Benjamin Lees (Humboldt Fellow), January 2019 – August 2020.

Prof. Dr. Hans-Joachim Schmid (Universität Paderborn ), March 2019.

Prof. An-Bang Wang (National Taiwan University), May 2019.

Dr. Alex Rattner (MTFE, Penn State University), May 2019.

Prof. Serafim Kalliadasis (Imperial College London), July 2019.

Prof. Dr. Kohei Soga (Keio University, Japan), August 2019.

Dr. Matthias Köhne (Universität Düsseldorf), September 2019.

Dr. Pierre-Etienne Druet (WIAS, Berlin), September 2019.

Prof. Dr. Patrick Guidotti (University of California), October 2019.

Prof. Dr. Ansgar Jüngel (TU Wien), November 2019.

Dr. Dirk Peschka (WIAS, Berlin), January 2020.

Dr. Pierre-Etienne Druet (WIAS, Berlin), January 2020.

Dr. Damir Juric (LIMSI, CNRS), January 2020.

Dr. Jalel Chergui (LIMSI, CNRS), January 2020.

Prof. Dr. Shin Juric (Mechancial and System Design Engineering, Hongik University, Korea), January 2020.

Dr. Matthias Köhne (Universität Düsseldorf), September 2020.

Dr. Kevin Schewior (Universität zu Köln), April 2019, February 2020, October 2020.

Prof. Dr. Max Klimm (TU Berlin), October 2020.

Prof. Dr. Olaf Steinbach (TU Graz, Austria), March 2019.

Dr. Ryo Kanamaru (Waseda University, Tokyo), December 2019 – February 2020.

Dr. Kazuyuki Tsuda (Osaka University, Osaka), May – July 2019.

Prof. Dr. Adrian Mathias (University of Reunion), May 2019.

Prof. Dr. Bruno F. Lourenço (ISM, Tachikawa, Japan), March 2019.

Dr. Sam G. Krupa (Max Planck Institute Leipzig), July - August 2020.

Dr. Evangelos Bampas (University of Paris-Saclay), July 2019.

Prof. Dr. Adam Krzyżak (Concordia University, Montreal), November 2019.

Prof. Dr. Hans Maassen (University of Nijmegen), November 2019.

Prof. Dr. Hans Maassen (University of Nijmegen), January 2020.

Prof. Dr. Jonas Hirsch (Universität Leipzig), August 2019.

Prof. Dr. Jonas Hirsch (Universität Leipzig), February 2020.

Dr. Sam Sanders (LMU München, Center for Advanced Studies), August 2018 – August 2019.

Prof. Genaro López Acedo (University of Seville), February – March 2019.

Franziskus Wiesnet (LMU München), February 2019.

Dr. Emmanuele Frittaion, Humboldt Fellow (University of Leeds), September 2020 – August 2022.

Prof. Dr. Eyal Goren (McGill University Montreal, Canada), January 2019.

Prof. Dr. Stephen Kudla (University of Toronta, Canada), April 2019.

Prof. Dr. Jens Funke (University of Durham, UK), April 2019.

Prof. Dr. Robert Osburn (University College Dublin, Ireland), April 2019.

Prof. Dr. Dimitri Wyss (Sorbonne University, Paris, France), May 2019.

Mark Feldmann (Universität Münster), May 2019.

Dr. Andrew Corbett (University of Exeter, UK), June 2019.

Dr. Paul Ziegler (Oxford University, UK), June 2019.

Dr. Kęstutis Česnavičius (University Paris-Sud, Orsay), July 2019.

Dr. Sven Möller (Rutgers University, New Brunswick, USA), July 2019.

Robert Little (University of Durham, UK), July 2019.

Prof. Dr. Siegfried Böcherer (Universität Mannheim), September 2019.

Prof. Dr. Nils-Peter Skoruppa (Universität Siegen), September 2019.

Prof. Dr. Soumya Das (Indian Institute of Science Bangalore, India), September 2019.

Prof. Dr. Masaaki Furusawa (Osaka City University, Japan), September 2019.

Dr. Athanasios Bouganis (University of Durham, UK), September 2019.

Dr. Olivier Taïbi (ENS Lyon, France), September 2019.

Prof. Dr. Ameya Pitale (University of Oklahoma, USA), September 2019.

Dr. Abhishek Saha (Queen Mary University of London, UK), September 2019.

Dr. Shaul Zemel (Hebrew University of Jerusalem, Israel), September 2019.

Dr. David Yuen (University of Hawaii, USA), September 2019.

Prof. Dr. John Millson (University of Maryland, USA), September 2019.

Prof. Dr. Aaron Pollack (Duke University, USA), September 2019.

Prof. Dr. Jens Funke (University of Durham, UK), September 2019.

Dr. Markus Schwagenscheidt (Universität Köln), October 2019.

Prof. Dr. Jürg Kramer (HU Berlin), November 2019.

Prof. Dr. Anilatmaja Aryasomayajula (IISER Tirupati, India), November 2019.

Prof. Dr. Tonghai Yang (University of Wisconsin, USA), December 2019.

Dr. Johan Commelin (Universität Freiburg), December 2019.

Dr. Edgar Assing (Universität Bonn), January 2020.

Prof. Dr. Peter Fiebig (Universität Erlangen-Nürnberg), January 2020.

Prof. Dr. Simon Lentner (Universität Hamburg), January 2020.

Prof. Dr. Katrin Wendland (Universität Freiburg), January 2020.

Prof. Dr. Dražen Adamović (University of Zagreb, Croatia), January 2020.

Prof. Dr. Giovanna Carnovale (University of Padua, Italy), January 2020.

Fabian Kertels (Universität Freiburg), January 2020.

Dr. Mara Ungureanu (Universität Freiburg), January 2020.

Yuhang Hou (Universität Freiburg), January 2020.

Veronika Pedić (University of Zagreb, Croatia), January 2020.

Dr. Thomas Gemünden (ETH Zurich, Switzerland), January 2020.

Daniel Brügmann (Max-Planck-Institut für Mathematik Bonn), January 2020.

Ilaria Flandoli (Universität Hamburg), January 2020.

Dr. Daniel Kohen (Universität Duisburg-Essen), January 2020.

Prof. Dr. Jürg Kramer (HU Berlin), January 2020.

Prof. Dr. Eugen Hellmann (Universität Münster), January 2020.

Dr. Hongbo Yin (Max-Planck-Institut für Mathematik Bonn), February 2020.

Prof. Dr. Gerard Freixas (IMJ-PRG Paris, France), February 2020.

Dr. Danylo Radchenko (ETH Zurich, Switzerland), April 2020.

Dr. Paloma Bengoechea (ETH Zurich, Switzerland), April 2020.

Prof. Dr. Jan Vonk (Institute for Advanced Study Princeton, USA), April 2020.

Prof. Dr. Eugen Hellmann (Universität Münster), April 2020.

Prof. Dr. Nick Andersen (Brigham Young University, Utah, USA), April 2020.

Prof. Dr. Eugen Hellmann (Universität Münster), May 2020.

Prof. Dr. Soma Purkait (Tokyo Institute of Technology, Japan), May 2020.

Dr. Ben Heuer (Universität Bonn), May 2020.

Prof. Dr. Peter Humphries (University College London, UK), May 2020.

Prof. Dr. Larry Rolen (Vanderbilt University, Nashville, USA), May 2020.

Dr. Andreas Mihatsch (MIT Cambridge, USA), May 2020.

Prof. Dr. Olivia Beckwith (University of Illinois, USA), May 2020.

Dr. Dan Fretwell (University of Bristol, UK), June 2020.

Dr. Andreas Mihatsch (MIT Cambridge, USA), June 2020.

Prof. Dr. Martin Raum (Chalmers Technical University, Gothenburg, Sweden), June 2020.

Dr. Alexander Ivanov (Universität Bonn), June 2020.

Dr. Sven Möller (Rutgers University, New Brunswick, USA), June 2020.

Dr. Johannes Anschütz (Universität Bonn), June 2020.

Dr. Hao Zhang (Sorbonne University, Paris, France), July 2020.

Prof. Dr. Eva Viehmann (TU München), July 2020.

Dr. Shaul Zemel (Hebrew University of Jerusalem, Israel), July 2020.

Prof. Dr. Nikos Diamantis (University of Nottingham, UK), July 2020.

Dr. Haowu Wang (Max-Planck-Institut für Mathematik Bonn), October 2020.

Dr. Yunqing Tang (University Paris-Sud, Orsay), October 2020.

Alessandro Lägeler (ETH Zurich, Switzerland), October 2020.

Prof. Dr. Michael Griffin (Brigham Young University, Utah, USA), November 2020.

Christina Röhrig (Universität Köln), November 2020.

Dr. Toshiki Matsusaka (University of Nagoya, Japan), November 2020.

Dr. Kathrin Maurischat (RWTH Aachen), November 2020.

Prof. Dr. Ariel Pacetti (University of Cordoba, Spain), December 2020.

Dr. Eugenia Rosu (Universität Regensburg), December 2020.

Prof. Dr. Josip Tambača (University of Zagreb, Croatia), February – March 2020.

Matko Ljulj (University of Zagreb, Croatia), February – March 2020.

Prof. Dr. Luca Heltai (SISSA, Trieste, Italy), May 2019.

Prof. Dr. Ira Neitzel (Universität Bonn), May 2019.

Dr. Alexander Linke (WIAS, Berlin), August 2019.

Dr. Ehsan Shakeri (Shahid Beheshti University, Tehran, Iran), February 2020.

Prof. Dr. Ira Neitzel (Universität Bonn), February 2020.

Prof. Dr. Adrian Hirn (HS Esslingen), February 2020.

Prof. Dr. Christian Kreuzer (TU Dortnund), March 2020.

## 7.4 Workshops and Conferences at the Department

- Spring School "Selected aspects in stochastic geometry", 25.02.19–01.03.19 (organized by Frank Aurzada, Volker Betz, and Matthias Meiners (Innsbruck))
- Spring School "Complex Networks", 02.03.20–06.03.20 (organized by Frank Aurzada, Volker Betz, Heinz Köppl (FB ETIT), and Matthias Meiners (Innsbruck))
- Workshop "Modular forms on higher rank groupsi", 17.09.19–20.09.19 (organized by Jan Bruinier, Yingkun Li, and Michalis Neururer)
- Workshop and Colloquium on Mathematical Methods in Continuum Physics and Engineering: Theory, Models, Simulation, 06.11.19–07.11.19 (organized by Reinhard Farwig jointly with P. Neff (Duisburg-Essen) and Chr. Chełminski (Warsaw University of Technology))
- Conference on Maximal Regularity and Nonlinear PDE, RIMS, Kyoto, Japan, 26.03.19–30.03.19 (organized by Matthias Hieber, Hideo Kozono, Senjo Shimizu, Gieri Simonett)
- Workshop on PDE, Konstanz, 09.04.19–11.04.19 (organized by Robert Denk, Lisa Fischer, Karsten Herth (Universiät Konstanz), Matthias Hieber, Martin Saal (TU Darmstadt))
- Conference on Nonlinear Analysis, Cortona, 11.06.19–14.06.19 (organized by Michel Chipot, Franco Flandoli, Patrick Guidotti, Matthias Hieber, Pablo Koch-Medina, Alessandra Lunardi, Gieri Simonett, Christoph Walker)
- Workshop on Geophysical Flows, Oberwolfach, 15.06.20–19.06.20 (organized by Yoshikazu Giga (Tokyo), Matthias Hieber (Darmstadt), Peter Korn (Hamburg), Edriss S. Titi (Cambridge))
- Mathematische Modellierungswoche, Fuldatal, 06.10.19–11.10.19 (organized by Martin Kiehl, Jan Giesselmann TU Darmstadt and Tobias Braumann, Zentrum für Mathematik, Bensheim)
- Workshop "Asymptotic Completeness, Universal Preparability, and Synchronizability", 02.09.19–05.09.19 (organized by Burkhard Kümmerer)
- Workshop "Vernetzung des Vernetzungsbereichs", 06.03.19–07.03.1x99 (organized by Burkhard Kümmerer)

- A Darmstadt-Frankfurt Afternoon on Optimization, 05.07.19 (organized by Marc E. Pfetsch, Stefan Ulbrich, TU Darmstadt, and by Thorsten Theobald, Universität Frankfurt)
- LOEWE-Vortragsreihe “Mathe für alle – Was Sie schon immer über Mathematik wissen wollten, aber bisher nicht zu fragen wagten”, 25.10.19 (organized by Annette Werner and Anna-Maria von Pippich)
- 13th Seminar on Conformal Field Theory, 17.01.20 (organized by Peter Fiebig, Nils Scheithauer, and Katrin Wendland)
- Workshop on $\infty$-categories, 14.02.19–15.02.19 (organized by Timo Richarz and Torsten Wedhorn)
- Conference “Arithmetic Algebraic Geometry”, canceled due to Corona, 16.03.20–20.03.20 (organized by Ulrich Görtz, Timo Richarz, and Torsten Wedhorn)

# 8 Other scientific and organisational activities

## 8.1 Memberships in Scientific Boards and Committees

**Frank Aurzada**

- Vorstand Fachgruppe Stochastik in der DMV, Treasurer

**Volker Betz**

- Fellow in the EPSRC Peer Review College

**Dieter Bothe**

- Advisory Board of ProccessNet technical committee on Computational Fluid Dynamics
- Advisory Board of ProcessNet technical committee on Multiphase Flows
- Member of GAMM section Partial Differential Equations

**Regina Bruder**

- Member of the international group for PME (Psychology of Mathematics Education)
- Member of the group 'Arbeitskreis Empirische Bildungsforschung' of the GDM (Organization for Didactics of Mathematics)
- Member of the ISTRON – group in Germany
- Member of the group 'Arbeitskreis Problemlösen' of the GDM

**Jan H. Bruinier**

- Associate Member of the Pohang Mathematics Institute (PMI), Postech, Pohang, Korea

**Matthias Hieber**

- Member Scientific Committee 'Minkowski Medal', DMV
- Member Scientific Committee 'Seibold Prize', DFG

**Karl H. Hofmann**

- Fellow of the American Mathematical Society

**Karl H. Hofmann**

- Honorary Editor of Semigroup Forum

**Martin Kiehl**

- Vorsitzender des Aufsichtsrats, Zentrum für Mathematik, Bensheim

**Ulrich Kohlenbach**

- Council of the Association for Symbolic Logic (ASL)
- Advisory Board Member of Springer book series 'Theory and Applications of Computability Theory'
- Member of WoLLIC Steering Committee
- Member of LCC (Logic and Computational Complexity) Steering Committee
- Member of 'Wissenschaftliche Gesellschaft an der Universität Frankfurt'

**Katja Krüger**

- Member of the group 'Arbeitskreis Stochastik in der Schule' of the GDM
- Member of the Center of Teacher Education (ZfL) TU Darmstadt

**Jens Lang**

- Member of Board of Deans of the DFG Graduate School of Excellence Computational Engineering, TU Darmstadt, since 2008
- Member of Scientific Steering Committee of Profile Area Termo-Fluids & Interfaces, TU Darmstadt, since 2017
- Member of Scientific Committee of the Conference on the Numerical Solution of Differential and Differential-Algebraic Equations to be held at the Universität Halle-Wittenberg every three years

**Holger Marschall**

- Assigned Member of the DECHEMA ProcessNet Committee Computational Fluid Dynamics
- Chair of the Multiphase Technical Committee within the ESI OpenFOAM Governance structure
- Member of the OpenFOAM Workshop Committee

**Marc Pfetsch**

- Universitätsversammlung, TU Darmstadt
- HRZ AG, TU Darmstadt
- Forschungsrat der Rhein-Main Universitäten
- Applied Mathematics Committee of the European Mathematical Society

**Steffen Roch**

- Auswahlausschuss Bundeswettbewerb Mathematik

**Stefan Ulbrich**

- Member of the IFIP Technical Committee TC 7, WG 7.2 "Computational Techniques in Distributed Systems"

– Universitätsversammlung, TU Darmstadt

– Senat, TU Darmstadt

– Fachkollegium Mathematik, DFG

**Winnifried Wollner**

– Speaker of GAMM Activity Group on “Optimization with Partial Differential Equations”

– Senatsausschuss Lehre, TU Darmstadt

## 8.2 Awards and Offers

**Awards**

**Mathis Fricke:** Dissertationspreis der Freunde der TU Darmstadt, für die beste Dissertation jedes Fachbereichs der TU Darmstadt aus dem Jahr 2020

**Matthias Hieber:** Vice Director, Mathematisches Forschungsinstitut Oberwolfach (MFO)

**Matthias Hieber:** Jean-Morlet Chair, CIRM, Luminy

**Christopher Hojny:** Preis für hervorragende wissenschaftliche Leistungen (Vereinigung von Freunden der Technischen Universität zu Darmstadt e.V.), May 16, 2019

**Jens Lang:** Berlin Research Award for Alternatives to Animal Experiments, December 12, 2019

**Tomislav Marić:** Athene Young Investigator

**Marc Pfetsch:** Optimization and Engineering Rosenbrock Prize 2019 for Burlacu et al.: *Maximizing the storage capacity of gas networks: a global MINLP approach*, Optimization and Engineering 20, 543–573 (2019)

**Marc Pfetsch:** Best Paper Award of Mathematical Programming Computation 2019 for M. E. Pfetsch and T. Rehn: *A Computational Comparison of Symmetry Handling Methods for Mixed Integer Programs*, Mathematical Programming Computation 11, 37–93 (2019)

**Stefan Ulbrich:** Charles Broyden Prize 2018 for T. Gally, M. E. Pfetsch, S. Ulbrich: *A Framework for Solving Mixed-Integer Semidefinite Programs*, Optimization Methods and Software 33 (2018), no. 3, pp. 594-632.

**Offers of Appointments**

**Jan Bruinier:** Professorship (W3) for Pure Mathematics, University of Bonn

**Jan Giesselmann:** Professorship (W3) for Applied Mathematics, Universität Paderborn

**Jan Giesselmann:** Professorship (W3) for Numerical Mathematics, Ruhr–Universität Bochum

**Stefano Modena:** Assistant Professorship (W1) for Analysis, TU Darmstadt

The department of mathematics is involved in various activities for schools, secondary school students, and public relations. In addition to providing printed information material, the department of mathematics presents itself to the public on its web pages. These were fundamentally revised in 2020 and provide useful information about all aspects of the study as well as an attractive insight into the department. The information is available in German and in English.

**Math on Demand** In April 2015, the mathematics department of TU Darmstadt launched the programme *Math on Demand* for mathematically interested secondary school students and mathematics teachers. The purpose of this programme is to stimulate their interest in mathematics beyond the traditional classroom. On demand, scientists from the mathematics department offer lectures or workshops, which are intended to illustrate the variety and importance of mathematics in everyday life, and to give a first insight in some recent developments in the tremendous opportunities for careers in mathematics and about the mathematics programme at TU Darmstadt.

By now, 10 scientists (F. Aurzada, P. Domschke, R. Haller-Dintelmann, A. Knof, B. Kümmerer, M. Otto, A.-M. von Pippich, U. Reif, A. Schwartz, B. Seyfferth) have offered lectures covering a wide range of topics. In 2019, lectures within the frame of Math on Demand have taken place in the context of school visits at our department (see list below). In 2020, there have been no lectures due to the Covid-19 pandemic. Further information is available on our homepage:
`https://www.mathematik.tu-darmstadt.de/studium/orientierungsangebote/studieninteressierte_1/math_on_demand/index.de.jsp`

The following is a list of further public relations activities.

**Activities for secondary school students and prospective students**

- Presentation of the department with a booth and several talks at the job and study information fair HoBIT, Hochschul- und Berufsinformationstage, three days every January: about 20.000 participants; with a booth staffed by professors, academic staff, and students, as well as scientific talks from the fields of Analysis, Numerical Analysis and Optimisation in 2019 and from the fields of Algebra, Geometry and Numerical Analysis in 2020.
- Presentation of the department and its study programmes at the university information day, TUDay, every May: with talks by the student advisor, sample lectures, tutorial classes, and meetings with students of the department; about 80 participants over the course of the day (two lectures from the field of Logic in 2019 and two lectures from the fields of Algebra and Analysis in 2020). Due to the Covid-19 pandemic, the TUDay in 2020 took place virtually.
- Participation in the university fair "vocatium", a fair for school students who are interested in a university study programme (28.05.19 in Offenbach, Dr. Seeberg; 2020 (online))
- Participation in two university fairs abroad in 2019 in Russia and Poland to recruite international students (October and November 2019, Nathalie Becker).

- Participation in a virtual university fair for international prospective students in Ukraine and Belarus (27.11.20, Nathalie Becker).

- Due to the Covid-19 pandemic, student advisory for prospective students mostly was held online via Zoom by Dr. Seeberg in 2020.

- Annual organisation of an afternoon with several talks about mathematics for secondary school students, “Darmstädter Schülerinnen- und Schülernachmittag zur Mathematik” (organisation: Prof. Kohler; in 2019 with talks from the fields of Algebra, Numerical Analysis and Stochastics). In 2020, the event had to be cancelled due to the Covid-19 pandemic.

- Annual participation at the information days for female students, “Schnuppertage für Schülerinnen”, with participation at the central event for female students with interest in STEM/MINT programmes and an on-site presentation of the department including a talk by the student advisor, a sample lecture, and talks by female mathematicians. About 30 participants in each year (organized by the department’s gender equalitity officers; lectures from the field of Numerical Analysis in 2019 and from the field of Algebra in 2020).

- Support of the annual organization of the Mathematikolympiade Hessen (third level) in cooperation with the Center for Mathematics Bensheim for all grades (about 20 participants per grade each year), by Prof. Kiehl, academic staff and students. In the recent years, the department had the opportunity to host the finals with about 150 participants.
  Mathematical afternoon (lectures were delivered by Prof. Kiehl and Prof. Haller-Dintelmann (2019)) and Prof. Kiehl and Prof. Schwartz (2020).

- Organization of the Mathematical Modeling Week for secondary school students in grade 12 in cooperation with the Center for Mathematics Bensheim each October (40 participants each year) (Prof. Kiehl, Prof. Giesselmann).

- Involvement in the annual German Maths Contest (Bundeswettbewerb Mathematik) (Prof. (em.) Alber, Prof. Roch).

- Lecture titled "Kryptographie" in the context of the "Kinder-Uni" by Prof. Bruder and Insa Apel in 2019.

- In connection with the project course “Teaching in Mathematics: Problem Solving” (Prof. Bruder, StR Krauth, OStR Klein and participating students, winter semester 2016/17), diverse mathematical “Knobelstraßen” for secondary schools were developed and conducted at several schools in Darmstadt and Frankfurt. The ”Knobelstraßen” take place annually shortly before Christmas.

**Other activities**

- In connection with the "Profilwerkstatt" Darmstadt, production of a short video to promote the Master’s programme Mathematics in 2020. Protagonists were Prof. Schwartz and a student enrolled in this study programme.

- Talk titled "Endlos summieren?" at Berufliche Schule Gelnhausen (25.01.19, Prof. Haller-Dintelmann).
- Talk titled "Wie gewinnt man eine Goldmedaille im Skifliegen?" and "Wie löst man die Wettbewerbsaufgaben?" (16.03.19, Prof. Kiehl).
- Talk titled "Mit welcher Wahrscheinlichkeit stirbt ein Familienname aus?", visit from the Max-Planck-Gymnasium Groß-Umstadt (18.06.19, Prof. Aurzada).
- Visit of the lecture "Lineare Algebra II" in the context of the visit of the Gymnasium Michelstadt (26.06.19, Prof. Pfetsch, Dr. Hojny).
- Talk titled "Mit Mathematik Probleme spielerisch lösen", visit from the Georg-August-Zinn-Schule Reichelsheim/Odenwald (25.09.19, Prof. Kiehl).
- Talk titled "Was Sie schon immer über perfektoide Räume wissen wollten und nie zu fragen wagten" (25.10.19, Prof. Wedhorn).
- Talk titled "Verknotete Mathematik: Why Knot?", visit from the Martin-Niemöller-Schule Wiesbaden (18.02.20, Prof. Kümmerer).
- Talk titled "Das Newton-Verfahren: Wie entsteht eigentlich schöne Mathematik?", at the "Landes-Olympiade Mathematik" (22.02.20, Prof. Schwartz).
- Annual Graduation Event: celebration with friends and family of the graduated students (organisation: Prof. Aurzada and staff). Talk titled "Die diskrete Mathematik der Demokratie: Oder die Qual mit der Wahl" by Prof. Gritzmann, TU München (24.05.19).

## 8.4 Student Body (Fachschaft)

Officially, the students at the Department of Mathematics are represented by the five people forming the "Fachschaftsrat". This board is elected once a year during the university elections. However, since there usually is more work to be done than five people can handle, there are many more students participating actively in the Students' Union. Moreover, some of them are members of university-wide committees such as the Senate or the University Assembly.
We, the Students' Union, regard ourselves as representatives inside and outside the mathematics department for all math students. As such, all students are invited to talk to us in order to tell us about problems or suggestions they might have. Furthermore, we organise a lot of orientation events for students and secondary school students throughout the year. Finally, a student's life does not only consist of attending lectures and exercises, so we additionally offer some extra-curricular activities.
As part of our activities we appoint the student representatives in the committees of the department. Some of us are members of the "Fachbereichsrat" (another important board consisting of professors, assistants and students, elected during the university elections) and its committees, like the committee for learning and studying, the library committee, and many more. The evaluation and quality control of teaching done at the department are two of our main objectives. We think it is essential to hear and consider students' opinions

regarding these areas because they are the ones directly affected. We also support the improvement and development of courses and studying in general, a point which every student should be concerned about naturally. We are working on those subjects together with Students' Unions from other departments and with the university administration.

Concerning orientation events, we organise the orientation week for the first semester students, which takes place at the beginning of each semester. During the semester, there is an orientation colloquium for the students in their first two years, which is meant to give them an impression of what the work in the research groups usually is about (meant to support the decision on a thesis subject). After finishing their first two years, students attend another orientation event, the "Introduction to Advanced Studies" (*Einführung ins Hauptstudium*), giving them more information about the research groups, the relevant regulations and much more.

Not all of these events take place in the mathematics department. University-wide orientation events for secondary school students are also part of our work. There, we cooperate with the student counsellors.

However, not all our activities concern purely study-related topics. The organisation of game evenings, music evenings, as well as the traditional Christmas party of the department are examples of what we do to help students socialize among themselves.

We hope that this rather brief introduction helps to give an impression of our work.

# 9 Contact

### Address

Fachbereich Mathematik
Schlossgartenstraße 7
D-64289 Darmstadt

| | |
|---|---|
| Building: | S2\|15 |
| Homepage: | `http://www.mathematik.tu-darmstadt.de` |
| Fax: | +49-(0)6151-16 21439 |
| E-mail: | dekan@mathematik.tu-darmstadt.de |

### Dean (until September 2020)

Prof. Dr. Ulrich Kohlenbach

| | |
|---|---|
| Room: | S2\|15 - 205 |
| Phone: | +49-(0)6151-16 22862 |
| E-mail: | kohlenbach@mathematik.tu-darmstadt.de |

### Dean (from October 2020)

Prof. Dr. Karsten Große-Brauckmann

| | |
|---|---|
| Room: | S2\|15 - 305 |
| Phone: | +49-(0)6151-16 22492 |
| E-mail: | kgb@mathematik.tu-darmstadt.de |

### Dean (Deputy, until September 2020)

Prof. Dr. Marc Pfetsch

| | |
|---|---|
| Room: | S4\|10 - 144 |
| Phone: | +49-(0)6151-16 23440 |
| E-mail: | pfetsch@mathematik.tu-darmstadt.de |

### Dean (Deputy, from October 2020)

Prof. Dr. Dieter Bothe

| | |
|---|---|
| Room: | L2\|06 - 400 |
| Phone: | +49-(0)6151-16 21463 |
| E-mail: | bothe@mma.tu-darmstadt.de |

### Dean (Studies, until September 2019)

Prof. Dr. Volker Betz

| | |
|---|---|
| Room: | S2\|15 - 340 |
| Phone: | +49-(0)6151-16 23370 |
| E-mail: | betz@mathematik.tu-darmstadt.de |

### Dean (Studies, from October 2019)

Prof. Dr. Torsten Wedhorn

| | |
|---|---|
| Room: | S2\|15 - 413 |
| Phone: | +49-(0)6151-16 22463 |
| E-mail: | wedhorn@mathematik.tu-darmstadt.de |

**Department Coordinator**

Dr. Andreas Mars
Room: S2|15 - 240
Phone: +49-(0)6151-16 21431
E-mail: mars@mathematik.tu-darmstadt.de

**Coordinator of Studies**

Dr.-Ing. Cornelia Seeberg
Room: S2|15 - 241
Phone: +49-(0)6151-16 21441
E-mail: seeberg@mathematik.tu-darmstadt.de

**Administration**

Claudia Cramer
Room: S2|15 - 238
Phone: +49-(0)6151-16 21430
E-mail: cramer@mathematik.tu-darmstadt.de

**Administration (Staff)**

Sigrid Hartmann
Room: S2|15 - 237
Phone: +49-(0)6151-16 21433
E-mail: sihartmann@mathematik.tu-darmstadt.de
E-mail: personal@mathematik.tu-darmstadt.de

**Administration (Staff)**

Karin Jacob
Room: S2|15 - 232
Phone: +49-(0)6151-16 21455
E-mail: kjacob@mathematik.tu-darmstadt.de
E-mail: personal@mathematik.tu-darmstadt.de

**Administration (Staff)**

Annette Petters
Room: S2|15 - 237
Phone: +49-(0)6151-16 21084
E-mail: petters@mathematik.tu-darmstadt.de
E-mail: personal@mathematik.tu-darmstadt.de

**Administration (Budget)**

Monika Kammer
Room: S2|15 - 249

Phone: +49-(0)6151-16 21432
E-mail: kammer@mathematik.tu-darmstadt.de

**Equal Opportunity Commissioner**

Claudia Cramer, Isabel Jacob, Alexandra Neutsch, Anne-Therese Rauls
E-mail: gleichstellungsbeauftragte@mathematik.tu-darmstadt.de

**Students Representatives**

Room: S2|15 - 347
Phone: +49-(0)6151-16 4515/-16 21663
E-mail: fachschaft@mathematik.tu-darmstadt.de

Technische Universität Darmstadt
Fachbereich Mathematik
Schlossgartenstraße 7
D-64289 Darmstadt

www.mathematik.tu-darmstadt.de