Book of Abstracts - 5th European Conference on Computational Optimization

Trier, 10-12th of September 2018

Sponsors

We gratefully acknowledge the support of

ALGORITHMIC
OPTIMIZATION

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Universität Trier

Foreword

It is a privilege to carry on the successful series of European Conferences on Computational Optimization (EUCCO) with this 5th edition taking place in Trier, Germany. The series started in Dresden in 2004 and alternated from then on within Germany and outside of Germany. Thus, it took place in Montpellier, France, in 2007, in Chemnitz in 2013, and in Leuven, Belgium, in 2016. The 2018 edition in Trier is organized by the Mathematics department of Trier University and by the DFG Research Training Group on Algorithmic Optimization (ALOP).

The scope of the conference series is quite broad as it aims to bring together scientists from a diversity of subdisciplines from the fields of computational optimization, algorithms and applications. The current edition will have special emphasis on certain aspects of optimization found in the focus sessions while still keeping its more traditional focus on large scale optimization, optimization with partial differential equations and numerical optimization algorithms and software.

Focus Sessions

Computational inverse problems
Discretization and adaptivity
Feedback control for large-scale systems
Infinite dimensional nonsmooth optimization
Linear algebra in computational optimization
Machine learning and PDEs
Mathematical imaging
Mixed-integer PDE-constrained optimization
Model order reduction and low-rank approximation for nonlinear problems
Optimization under uncertainties
Shape and topology optimization

Plenary Speakers

Christina Brandt, *Universität Hamburg*
Tobias Breiten, *University of Graz*
Simon Funke, *Simula Oslo*
Paul Goulart, *University of Oxford*
Serge Gratton, *CERACS Toulouse*
Ira Neitzel, *Universität Bonn*
Stephan Schmidt, *Universität Würzburg*

Sunday, Sept. 9

17.00-20.00	Registration

Welcome reception in front of HS3: light refreshments will be served.

Monday, Sept. 10

8.00-8.45	Registration		
8.40-8.45	Welcome Remarks by Volker Schulz		**HS3**
8.45-9.30	IP1: **Serge Gratton**: A space transformation framework for nonlinear optimization (→p. 47) Chair: Stefan Vandevalle		**HS3**
9.30-10.15	IP2: **Christina Brandt**: Fast regularized reconstructions for dynamic tomographic applications (→p. 33) Chair: Michael Hinze		**HS3**
10.15-10.45	Coffee break		
‖ **Session:**	***Shape and topology optimization***	Chair: Kathrin Welker	**HS9**
10.45-11.10	Roland Herzog	Intrinsic KKT conditions on smooth manifolds	→ p. 53
11.10-11.35	K. E. Loayza-Romero	A new approach for the num. sol. of shape optimization problems	→ p. 65
11.35-12.00	Martin Siebenborn	Optimum experimental design for interface identification problems	→ p. 84
‖ **Session:**	***Discretization and adaptivity***	Chair: Johannes Pfefferer	**HS10**
10.45-11.10	Winnifried Wollner	A priori error analysis for optimization with elliptic PDE constraints	→ p. 99
11.10-11.35	Christian Kahle	L^2 a-priori error estimation for the obstacle problem using localization	→ p. 58
11.35-12.00	Michael Hinze	A fully certified RBM for PDEOPT with control constraints	→ p. 56
‖ **Session:**	***Infinite dimensional nonsmooth optimization***	Chair: Axel Kröner	**E51**
10.45-11.10	Marc Herrmann	Discrete total variation with FE and applications to imaging	→ p. 52
11.10-11.35	Masoumeh Mohammadi	A priori error estimates for a linearized fracture control problem	→ p. 69
11.35-12.00	Kurt Chudej	Optimal flight of a hang-glider through a thermal	→ p. 37
‖ **Session:**	***Optimization under uncertainties***	Chair: Claudia Schillings	**E52**
10.45-11.10	Michael Burger	Bayesian estimation of road roughness	→ p. 35
11.10-11.35	Ilka Riedel	Robust sensor placement for data assimilation problems	→ p. 78
11.35-12.00	Burcu Aydogan	An application of stochastic control: algorithmic trading for market orders	→ p. 26
12.00-13.30	Lunch break		

13.30-14.15	IP3: **Stephan Schmidt**: Shape optimization: higher order and non-smoothness (→p. 80) Chair: Volker Schulz		**HS3**
14.15-14.45	Coffee break		
‖ **Session:**	***Shape and topology optimization***	Chair: Martin Berggren	**HS9**
14.45-15.10	Markus Muhr	Numerical shape optimization for nonlinear ultrasound focusing	→ p. 71
15.10-15.35	Caroline Geiersbach	Stochastic gradient algorithm for PDE constrained optimization under uncertainty	→ p. 44
15.35-16.00	Kathrin Welker	On techniques for shape optimization problems constrained by VI	→ p. 97
‖ **Session:**	***Mixed integer PDE-constrained optimization***	Chair: Martin Siebenborn	**HS10**
14.45-15.10	Paul Manns	A linear bound on the integrality gap for sum-up rounding	→ p. 67
15.10-15.35	Mirko Hahn	Trust-region steepest descent for mixed-integer optimal control	→ p. 49
15.35-16.00	Massimo De Mauri	A fast heuristics for optimal control of hybrid electric vehicles	→ p. 39
‖ **Session:**	***Feedback control for large-scale systems***	Chair: Christian Vollmann	**E51**
14.45-15.10	René Pinnau	Optimal guidance of crowds by external agents	→ p. 77
15.10-15.35	Francesco Cesarone	Robustification of sample-and-hold controllers for the consensus problem	→ p. 36
15.35-16.00			
‖ **Session:**	***Computational inverse problems***	Chair: Gennadij Heidel	**E52**
14.45-15.10	Huu Nhu Vu	Bouligand–Landweber iteration for a non-smooth ill-posed problem	→ p. 73
15.10-15.35	Max Nimmer	On the robust PCA	→ p. 74
15.35-16.00	Sergey Shevtsov	Lay-up optimization for a tube-like high loaded composite structure	→ p. 83
17.00	Guided City Tour (→ p. 11)		
19.00	Reception Electoral Palace (→ p. 11)		

Tuesday, Sept. 11

8.00-8.45	Registration		
8.45-9.30	IP4: **Ira Neitzel**: On second order suffcient conditions for PDE-constrained optimization (→p. 72) Chair: Michael Hinze		**HS3**
9.30-10.15	IP5: **Tobias Breiten**: Taylor expansions of value functions associated with infinite-horizon optimal control problems (→p. 34) Chair: Peter Benner		**HS3**
10.15-10.45	Coffee break		
II **Session:**	***Shape and topology optimization***	Chair: Stephan Schmidt	**HS9**
10.45-11.10	Laura Bittner	Probabilistic lifespan shape optimization for devices under load	→ p. 31
11.10-11.35	Anders Bernland	CutFEM shape optimization of compression driver phase plugs	→ p. 30
11.35-12.00	Jolan Wauters	Multi-obj. optim. of the Stall charact. of an unmanned arial vehicle	→ p. 94
12.00-12.25	Martin Berggren	Topology optimization for substrate-integrated microwave devices	→ p. 29
II **Session:**	***Discretization and adaptivity***	Chair: Winnifred Wollner	**HS10**
10.45-11.10	Hamdullah Yücel	Goal-oriented a posteriori error est. for Dirichl. boundary ctrl. prob.	→ p. 100
11.10-11.35	Johannes Pfefferer	Optimal control problems in nonconvex domains with regularity constraint	→ p. 76
11.35-12.00	Niklas Behringer	FE error est. for opt. ctrl. prob. with pointwise tracking	→ p. 27
II **Session:**	***Infinite dimensional nonsmooth optimization***	Chair: Daniel Wachsmuth	**E51**
10.45-11.10	Luise Blank	Variable metric forw.-backw. method for min. nonsm. fcts. in Banach sp.	→ p. 32
11.10-11.35	Andrea Walther	Optimization by successive abs-linearization in function spaces	→ p. 93
11.35-12.00	Olga Ebel	A non-reg. appr. for dealing with non-smoothness in PDEOPT	→ p. 40
12.00-12.25	Alexandra Schwartz	2nd order opt. cond. for cardinality-constr. opt. prob.	→ p. 81
II **Session:**	***Linear algebra in computational optimization***	Chair: Paul Goulart	**E52**
10.45-11.10	Sarah-Alexa	MOR for port-Hamiltonian diff. alg. systems	→ p. 50
11.10-11.35	Carina Costa	Subsp. version of an augm. Lag. TR algorithm for equality constr. opt.	→ p. 38
11.35-12.00	Gennadij Heidel	An efficient low-rank method for opt. prob. governed by fract. PDEs	→ p. 51
12.00-12.25	Carmela Scalone	A gradient system for low-rank matrix completion	→ p. 79
12.25-14.00	Lunch break		

14.00-14.45	IP6: **Paul Goulart**: Operator splitting methods and software for convex optimisation (→p. 46) Chair: Peter Benner		**HS3**
14.45-15.15	Coffee break		
‖ **Session:**	***Shape and topology optimization***	Chair: Caroline Geiersbach	**HS9**
15.15-15.40	Eddie Wadbro	Continuous transp. as a material distr. topology opt. prob.	→ p. 92
15.40-16.05	Fabian Klemens	Opt. appr. using MRI meas. to identify filter top. and flow charact.	→ p. 60
16.05-16.30	Diaraf Seck	Shape identification problems	→ p. 82
16.30-16.55	Neset Ozkan Tan	A remark on totally ordered cones	→ p. 86
‖ **Session:**	***Discretization and adaptivity***	Chair: Christina Brandt	**HS10**
15.15-15.40	Max Winkler	Error estimates for bilinear boundary control problems	→ p. 98
15.40-16.05	Sebastian Engel	Opt. err. est. for the semi-discrete opt.ctrl. prob. of the wave eq.	→ p. 42
16.05-16.30	Christian Vollmann	Finite element discretization of nonlocal diffusion models	→ p. 90
16.30-16.55	Hadi Minbashian	Dual. based err. est. with space-time reconstr. of dG sol. for hyp. prob.	→ p. 68
‖ **Session:**	***Optimization under uncertainties***	Chair: Michael Burger	**E51**
15.15-15.40	Mark Eifert	Eval. of receding hor. ctrls. for opt. energy conversion and storage	→ p. 41
15.40-16.05	Andreas van Barel	Robust opt. of PDEs: combining MG/OPT and multilevel Monte Carlo	→ p. 88
16.05-16.30	Fabian Girrbach	Opt.-based inertial motion tracking in the presence of uncertainties	→ p. 45
16.30-16.55	Gisèle Mophou	Opt. ctrl. with average state for a heat eq. with missing data	→ p. 70
‖ **Session:**	***Model order reduction and low-rank approximation for nonlinear problems***	Chair: Jan Heiland	**E52**
15.15-15.40	Peter Benner	Space-time Galerkin POD for optimal control of nonlinear PDEs	→ p. 28
15.40-16.05	Roman Weinhandl	A low-rank appr. for parameter-dependent nonl. FSI problems	→ p. 95
16.05-16.30	Björn Liljegren-Seiler	Structure-preserving model order reduction of gas network systems	→ p. 64
16.30-16.55	Marc Steinbach	Model reduction for optimal control of drinking water networks	→ p. 85
19.00	Dinner and wine tasting (→ p. 11)		

Wednesday, Sept. 12

8.00-8.45	Registration		
8.45-9.30	IP7: **Simon Funke**: Automated adjoints for finite element models (→p. 43) Chair: Roland Herzog		**HS3**
9.30-10.00	Coffee break		
II **Session:**	***Machine learning and PDEs***	Chair: Ekkehard Sachs	**HS9**
10.00-10.25	Claudia Totzeck	Consensus-based global optimization	→ p. 87
10.25-10.50	Mohamed H. Aissa	Comparing stoch. opt. meth. with grad.-based opt. meth./surrogates	→ p. 25
10.50-11.15	Stefanie Günther	Simultaneous parallel-in-layer opt. for training of deep ResNets	→ p. 48
11.15-11.40			
II **Session:**	***Mathematical imaging***	Chair: Andreas Weinmann	**HS10**
10.00-10.25	José Vidal Núñez	Var. mesh denoising and surface fairing using the TV of the normal	→ p. 89
10.25-10.50	Richard Huber	Joint reconstruction in multi-spectral electron tomography	→ p. 57
10.50-11.15	Andreas Weinmann	TV and related methods for the restauration of manifold-valued data	→ p. 96
11.15-11.40	Andreas Langer	Convergent domain decomposition methods for TV minimization	→ p. 63
II **Session:**	***Infinite dimensional nonsmooth optimization***	Chair: Andrea Walther	**E 51**
10.00-10.25	Daniel Wachsmuth	Iterative methods to solve control problems with L^0 control cost	→ p. 91
10.25-10.50	Florian Mannel	An algorithm that is 20 times faster than semismooth Newton methods	→ p. 66
10.50-11.15	Axel Kröner	Opt. ctrl. of the semilin. heat eq. subject to state and control constr.	→ p. 62
11.15-11.40	Tobias Keil	Strong stationarity conditions for the opt. ctrl. of a CHNS system	→ p. 59
II **Session:**	***Model order reduction and low-rank approximation for nonlinear problems***	Chair: Marc Steinbach	**E 52**
10.00-10.25	Sebastian Peitz	Data driven feedback ctrl. of nonl. PDEs using the Koopman op.	→ p. 75
10.25-10.50	Christian Himpe	Linear model reduction for nonlinear input-output systems	→ p. 55
10.50-11.15	Martin Hess	A localized spectral-element RBM for incompr. flow problems	→ p. 54
11.15-11.40	Patrik Knopf	Optimal control of a Vlasov-Poisson plasma by an external magnetic field	→ p. 61
11.40-13.00	Lunch break		

Additional Information

Organizing Committee and Secretary

- Peter Benner MPG Magdeburg
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Ask for help

The local participants wear name badges with a **yellow stripe**. Whenever you are lost or have a question, please feel free to ask one of them!

Campus, Rooms (and) Maps

The conference takes place at Campus I of Trier University. Please find maps of the Campus and the room plans of the buildings A/B and E below. The Mensa is also located on Campus I.

- **Address:** Trier University Campus I
  Universitätsring 15
  D-54296 Trier Germany

- The **registration** desk is located in front of HS 3 in building B.

- The **plenary talks** take place in HS 3 (ground floor building B).

- The **sessions** are held in HS9, HS10, E51 and E52 (ground floor building E).

How to get to Trier University

- **By Car:** From any of the main routes to Trier, follow the signs to the University. On Campus I, you can use the free parking in the Besucherparkplätze Ost (visitor parking lot east) (recommended for building A, B, C, V, DM, N and P, Audimax/Mensa, Studihaus, library and laboratory building) or the Besucherparkplätze West (visitor parking lot west) (recommended for Audimax/Mensa, library, building D, E and N). For route planners or sat navs, please use this address: Universitätsring.

- **By Bus:** Your name badge is your **bus ticket**! Just show it to the bus driver, the price is included in the conference fee!

  - From the main train station (Hauptbahnhof)
    - **Route 3:** direction Kürenz or Tarforst, weekdays every ten minutes, bus stop Universität
    - **Route 83/85:** direction Tarforst/Bonerath, early mornings, evenings and weekends every half an hour, bus stop Universität
    - **Route 30:** direction Pluwig, every half an hour, bus stop Universität Süd
    - **Route 81:** direction Tarforst, early mornings, evenings and weekends every half an hour, bus stop Universität Süd
  - From Porta Nigra/Karl-Marx-Haus/Kaiserthermen
    - **Route 6:** direction Tarforst, weekdays every twenty minutes, bus stop Universität Süd
  - From Porta Nigra/Gartenfeld/Petrisberg/Campus II
    - **Route 4:** direction Irsch, weekdays every half an hour, bus stop Universität Hauptgebäude
    - **Route 85:** early mornings, evenings and weekends every half an hour, bus stop Universität

  The **timetables** of the buses routes 3, 4, 6, 30, 81, 83 and 85 can be found below.
  Further information at `https://www.vrt-info.de/en/`
  (**Be aware:** bus routes 13, 14 and 16 are NOT active from 23 July - 22 Oct.)

Social Events

- The **guided city tour** starts on Monday at 17.00 in front of the tourist office, next to Porta Nigra (Bus: Route 3 from Universität Tarforst direction Igel or Feyen). The **welcome reception** starts at 19.00 and is hosted in the Rococo Hall of the electoral palace, next to the Konstantin Basilika (Bus: Route 30).
- The **conference dinner** takes place on Tuesday at 19.00 in the 'Viehmarkttherme'
  (Bus: - Route 3 from Universität Tarforst direction Igel or Feyen,
  - Route 6 from Universität Süd direction Porta Nigra
  both to bus station "Karl Marx Haus").

Please, always wear your name badge! It is your ticket to all events!

Equipment

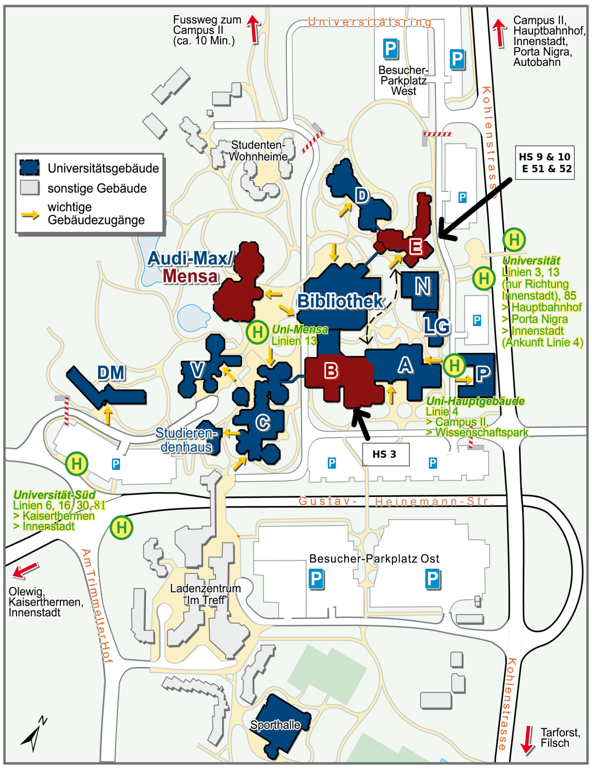
The conference rooms are equipped with a beamer (HDMI and VGA) and chalkboards. All speakers are encouraged to bring their own notebook and pointer, and a USB stick with a PDF version of the talk.

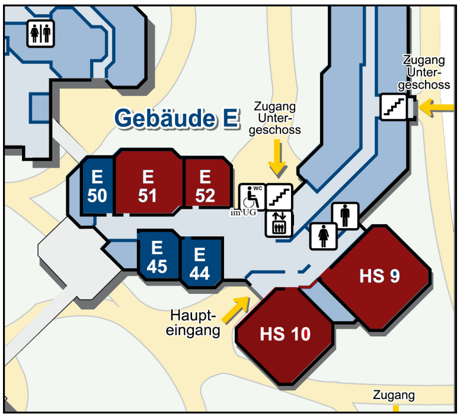
Internet

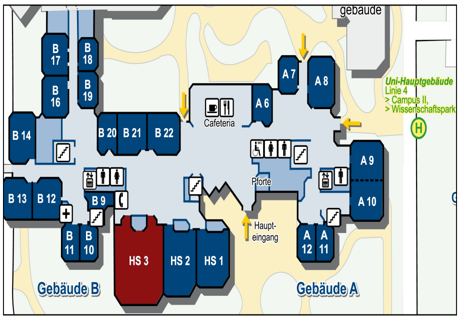
The internet can be accessed via WIFI through **eduroam**.

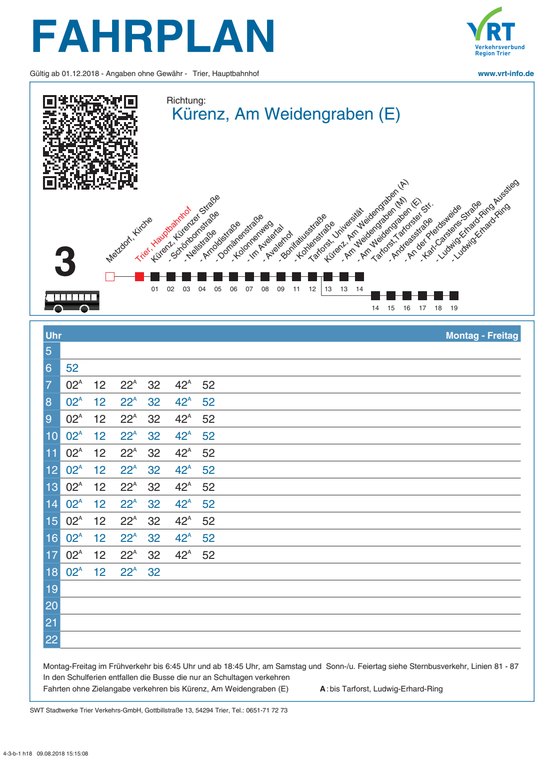
Lunch and Coffee Breaks

Lunch can be taken at the **Mensa**. Lunch vouchers are included in the conference fee, just show your name badge.
The coffee breaks take place in front of HS 3 and in the lobby of building E.









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VRT Verkehrsverbund Region Trier

Gültig ab 01.12.2018 - Angaben ohne Gewähr - Trier, Hauptbahnhof

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Richtung:
Kürenz, Am Weidengraben (E)

3

Metzdorf, Kirche	
Trier, Hauptbahnhof	
Kürenz, Kürenzer Straße	01
- Schönbornstraße	02
- Nellstraße	03
- Arnoldistraße	04
- Domänenstraße	05
- Kolonnenweg	06
- Im Avelertal	07
- Avelerhof	08
- Bonifatiusstraße	09
- Kohlenstraße	11
Tarforst, Universität	12
Kürenz, Am Weidengraben (A)	13
- Am Weidengraben (M)	13
- Am Weidengraben (E)	14
Tarforst,Tarforster Str.	14
- Andreasstraße	15
- An der Pferdsweide	16
- Karl-Carstens-Straße	17
- Ludwig-Erhard-Ring Ausstieg	18
- Ludwig-Erhard-Ring	19

Uhr						Montag - Freitag
5						
6	52					
7	02^A	12	22^A	32	42^A	52
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Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren
Fahrten ohne Zielangabe verkehren bis Kürenz, Am Weidengraben (E) **A**: bis Tarforst, Ludwig-Erhard-Ring

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

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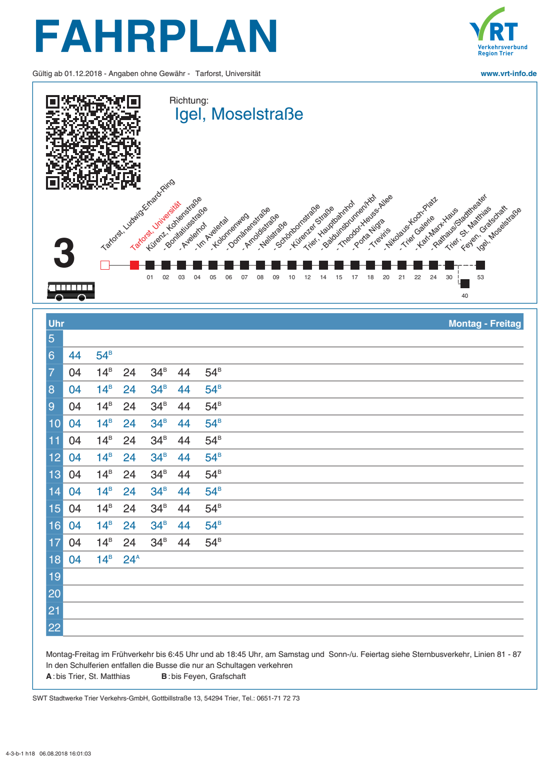

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VRT Verkehrsverbund Region Trier

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Richtung:
Igel, Moselstraße

3

Tarforst, Ludwig-Erhard-Ring	
Tarforst, Universität	
Kürenz, Kohlenstraße	01
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- Nellstraße	08
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- Kürenzer Straße	10
Trier, Hauptbahnhof	12
- Balduinsbrunnen/Hbf	14
- Theodor-Heuss-Allee	15
- Porta Nigra	17
- Treviris	18
- Nikolaus-Koch-Platz	20
- Trier Galerie	21
- Karl-Marx-Haus	22
- Rathaus/Stadttheater	24
Trier, St. Matthias	30
Feyen, Grafschaft	40
Igel, Moselstraße	53

Uhr						Montag - Freitag
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6	44	54^B				
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Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren
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Trier, Porta Nigra	
Trier, Hauptbahnhof	
- Balduinsbrunnen/Hbf	02
- SWT Stadtwerke	03
- Gartenfeldstraße	05
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Tarforst, Petrisberg Aussicht	11
Trier, Petrisberg	12
Tarforst, Am Wasserturm	13
Kürenz, Am Wissenschaftspark	14
- Kuno-Stapel-Straße	15
- Martin-Schunck-Straße	16
- Universität, Campus 2	17
- Behringstraße	18
- Kohlenstraße	20
Tarforst, Universität	21
- Tarforster Straße	23
- An der Mäswiese	24
Filsch, Filscher Häuschen	25
Irsch, Höhenfriedhof	25
- Hockweiler Straße	29

Uhr	Montag - Freitag	
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Gültig 06.08.2018 bis 08.12.2018
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Trier, Porta Nigra

4

Irsch, Hockweiler Straße	
Tarforst, Universität, Hptgeb.	
Kürenz, Kohlenstraße	02
- Universität, Campus 2	04
- Behringstraße	05
- Martin-Schunck-Straße	06
- Kuno-Stapel-Straße	07
- Am Wissenschaftspark	08
Tarforst, Am Wasserturm	10
Trier, Petrisberg	11
Tarforst, Petrisberg Aussicht	12
Trier, Schützenstraße	15
- Kurfürstenstraße	16
- Helenenstraße	17
- Gartenfeldstraße	18
- SWT Stadtwerke	19
- Balduinsbrunnen/Hbf	21
- Theodor-Heuss-Allee	22
- Porta Nigra	24

Uhr	Montag - Freitag	
5		
6		
7	53	
8	23	53
9	23	53
10	23	53
11	23	53
12	23	53
13	23	53
14	23	53
15	23	53
16	23	53
17	23	53
18		
19		
20		
21		
22		

Gültig 06.08.2018 bis 08.12.2018
Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-4-b-0 h18 06.08.2018 15:58:23

FAHRPLAN

Gültig ab 01.12.2018 - Angaben ohne Gewähr - Trier, Porta Nigra www.vrt-info.de

Richtung:
Tarforst, K.-Carstens-Straße

6

Trier, Porta Nigra	
- Treviris	01
- Nikolaus-Koch-Platz	03
- Trier Galerie	04
- Karl-Marx-Haus	05
- Rathaus/Stadttheater	07
- Südallee/Kaiserstraße	08
- Kaiserthermen	09
- Charlottenstraße	11
- Amphitheater	12
Olewig, Tiergarten	13
- Retzgrubenweg	14
- Brettenbach	15
- Hunsrückstraße	16
- Kleeburger Weg	17
- Universität Süd	19
Trimmelter Hof, Kreuzflur	20
- Hofberg	21
- Januarius-Zick-Straße	22
- Fritz-von-Wille-Straße	23
- Langflur	23
- An der Schule	24
- Augustinusstraße	25
- Karl-Carstens-Straße	26

Uhr	Montag - Freitag			
5				
6				
7	06	26	46	
8	06	26	46	
9	06	26	46	
10	06	26	46	
11	06	26	46	
12	06	26	46	56^{A}
13	06	26	46	
14	06	26	46	
15	06	26	46	
16	06	26	46	
17	06	26	46	
18	06	26		
19				
20				
21				
22				

Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren
A : nur an Schultagen

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-6-b-1 h18 09.08.2018 15:24:38

FAHRPLAN

Gültig ab 01.12.2018 - Angaben ohne Gewähr - Olewig, Universität Süd www.vrt-info.de

Richtung:
Trier, Porta Nigra

6

Tarforst, K.-Carstens-Straße	
Olewig, Universität Süd	
- Kleeburger Weg	02
- Hunsrückstraße	03
- Brettenbach	04
- Retzgrubenweg	05
- Tiergarten	07
Trier, Amphitheater	08
- Charlottenstraße	09
- Kaiserthermen	11
- Südallee/Kaiserstraße	13
- Rathaus/Stadttheater	14
- Karl-Marx-Haus	15
- Nikolaus-Koch-Platz	17
- Treviris	19
- Porta Nigra	21

Uhr	Montag - Freitag				
5					
6	33	53			
7	03^{A}	13	23^{A}	33	53
8	13	33	53		
9	13	33	53		
10	13	33	53		
11	13	33	53		
12	13	33	53		
13	13	33	53		
14	13	33	53		
15	13	33	53		
16	13	33	53		
17	13	33	53		
18	13				
19					
20					
21					
22					

Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren
A : nur an Schultagen

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-6-b-1 h18 06.08.2018 16:03:13

FAHRPLAN

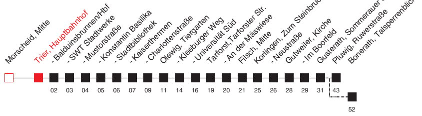
Verkehrsverbund Region Trier

Gültig ab 06.08.2018 - Angaben ohne Gewähr - Trier, Hauptbahnhof

www.vrt-info.de

Richtung:
Pluwig, Ruwerstraße

30



Morscheid, Mitte	
Trier, Hauptbahnhof	
- Balduinsbrunnen/Hbf	02
- SWT Stadtwerke	03
- Mustorstraße	04
- Konstantin Basilika	05
- Stadtbibliothek	06
- Kaiserthermen	07
- Charlottenstraße	09
Olewig, Tiergarten	11
- Kleeburger Weg	14
- Universität Süd	16
Tarforst,Tarforster Str.	19
- An der Mäswiese	20
Filsch, Mitte	21
Korlingen, Zum Steinbruch	25
- Neustraße	26
Gutweiler, Kirche	28
- Im Boofeld	29
Gusterath, Sommerauer Straße	31
Pluwig, Ruwerstraße	43
Bonerath, Talsperrenblick	52

Uhr	Montag - Freitag
5	
6	53^{B}
7	03$^{A}_{C}$ 18$^{A}_{C}$ 23^{B} 23$^{A}_{D}$ 28$^{A}_{C}$ 28$^{A}_{D}$ 53
8	23 53
9	23^{B} 53
10	23 53
11	23^{B} 53
12	23^{B} 53
13	13^{C} 23 53
14	23^{B} 53
15	23^{B} 53
16	23^{B} 53
17	23^{B} 53
18	23^{B}
19	
20	
21	
22	

Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
In den Schulferien entfallen die Busse die nur an Schultagen verkehren

Fahrten ohne Zielangabe verkehren bis Pluwig, Ruwerstraße

A: bis Trier, Kaiserthermen

B: bis Bonerath, Talsperrenblick

C: nur an Schultagen

D: Schnellbus, nur an Schultagen

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-30-b-1 h18 09.08.2018 15:16:59

FAHRPLAN

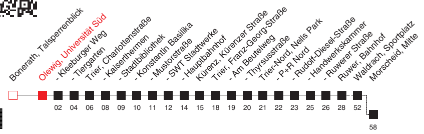
Verkehrsverbund Region Trier

Gültig ab 06.08.2018 - Angaben ohne Gewähr - Olewig, Universität Süd

www.vrt-info.de

Richtung:
Waldrach, Sportplatz

30



Bonerath, Talsperrenblick	
Olewig, Universität Süd	
- Kleeburger Weg	02
- Tiergarten	04
Trier, Charlottenstraße	06
- Kaiserthermen	08
- Stadtbibliothek	09
- Konstantin Basilika	10
- Mustorstraße	11
- SWT Stadtwerke	12
- Hauptbahnhof	14
Kürenz, Kürenzer Straße	15
Trier, Franz-Georg-Straße	18
- Am Beutelweg	19
- Thyrsusstraße	20
Trier-Nord, Nells Park	21
- P+R Nord	22
- Rudolf-Diesel-Straße	23
- Handwerkskammer	25
- Ruwerer Straße	26
Ruwer, Bahnhof	28
Waldrach, Sportplatz	52
Morscheid, Mitte	58

Uhr	Montag - Freitag
5	
6	51
7	11$^{A}_{C}$ 21^{B} 51
8	21 51
9	21^{B} 51
10	21 51
11	21^{B} 51
12	21^{B} 51
13	21 51
14	21^{B} 51
15	21^{B} 51
16	21^{B} 51
17	21^{B} 51
18	
19	
20	
21	
22	

In den Schulferien entfallen die Busse die nur an Schultagen verkehren
Montag-Freitag im Frühverkehr bis 6:45 Uhr und ab 18:45 Uhr, am Samstag und Sonn-/u. Feiertag siehe Sternbusverkehr, Linien 81 - 87
Fahrten ohne Zielangabe verkehren bis Waldrach, Sportplatz **A**: bis Trier, Hauptbahnhof **B**: bis Morscheid, Mitte **C**: nur an Schultagen

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-30-b-1 h18 06.08.2018 16:04:23

FAHRPLAN

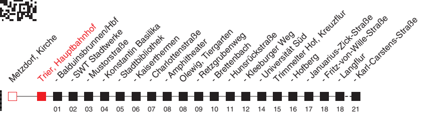
Verkehrsverbund Region Trier

Gültig ab 01.12.2018 - Angaben ohne Gewähr - Trier, Hauptbahnhof

www.vrt-info.de

Richtung:
Tarforst, K.-Carstens-Straße

81



Metzdorf, Kirche	
Trier, Hauptbahnhof	
- Balduinsbrunnen/Hbf	01
- SWT Stadtwerke	02
- Mustorstraße	03
- Konstantin Basilika	04
- Stadtbibliothek	05
- Kaiserthermen	06
- Charlottenstraße	07
- Amphitheater	08
Olewig, Tiergarten	08
- Retzgrubenweg	09
- Brettenbach	10
- Hunsrückstraße	11
- Kleeburger Weg	12
- Universität Süd	14
Trimmelter Hof, Kreuzflur	15
- Hofberg	16
- Januarius-Zick-Straße	17
- Fritz-von-Wille-Straße	18
- Langflur	18
- Karl-Carstens-Straße	21

Uhr	Montag - Freitag	Samstag	Sonn- und Feiertag
5	15 45		
6	15 45		
7		15 45	
8		15 45	15 45
9		15 45	15 45
10		00 15 30 45	15 45
11		00 15 30 45	15 45
12		00 15 30 45	15 45
13		00 15 30 45	15 45
14		00 15 30 45	15 45
15		00 15 30 45	15 45
16		00 15 30 45	15 45
17		00 15 30 45	15 45
18	45	00 15 30 45	15 45
19	00 15 30 45	00 15 30 45	15 45
20	15 45	15 45	15 45
21	15 45	15 45	15 45
22	15 45	15 45	15 45
23	15 45	15 45	15 45
0	15 45^{A} 45^{B}	15 45	15
1	45^{A} 45^{B}	45	
2	45^{A} 45^{B}	45	

A: nur während der Uni-Vorlesungszeiten in der Nacht von Donnerstag auf Freitag **B**: nur in der Nacht von Freitag auf Samstag

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-81-b-1 h18 09.08.2018 15:17:27

FAHRPLAN

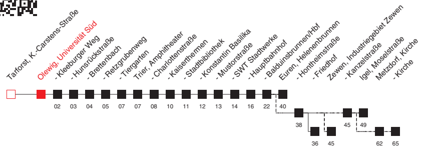
Verkehrsverbund Region Trier

Gültig ab 01.12.2018 - Angaben ohne Gewähr - Olewig, Universität Süd

www.vrt-info.de

Richtung:
Euren, Helenenbrunnen

81



Tarforst, K.-Carstens-Straße	
Olewig, Universität Süd	
- Kleeburger Weg	02
- Hunsrückstraße	03
- Brettenbach	04
- Retzgrubenweg	05
- Tiergarten	07
Trier, Amphitheater	07
- Charlottenstraße	08
- Kaiserthermen	10
- Stadtbibliothek	11
- Konstantin Basilika	12
- Mustorstraße	13
- SWT Stadtwerke	14
- Hauptbahnhof	16
- Balduinsbrunnen/Hbf	22
Euren, Helenenbrunnen	40
- Hontheimstraße	38
- Friedhof	36
Zewen, Industriegebiet Zewen	45
- Kanzelstraße	45
Igel, Moselstraße	49
Metzdorf, Kirche	62
- Kirche	65

Uhr	Montag - Freitag	Samstag	Sonn- und Feiertag
4	54^{B}		
5	24^{B} 54^{B}		
6	24^{B}	57	
7		27$^{E}_{F}$ 57	57
8		27^{D} 57	27^{D} 57
9		27^{D} 42 57^{A}	27^{D} 57
10		12 27$^{E}_{F}$ 42 57^{A}	27^{D} 57
11		12 27^{D} 42 57^{A}	27^{D} 57
12		12 27^{D} 42 57^{A}	27$^{E}_{F}$ 57
13		12 27$^{E}_{F}$ 42 57^{A}	27^{D} 57
14		12 27^{D} 42 57^{A}	27^{D} 57
15		12 27^{D} 42 57^{A}	27^{D} 57
16		12 27$^{E}_{F}$ 42 57^{A}	27^{D} 57
17		12 27^{D} 42 57^{A}	27$^{E}_{F}$ 57
18	27^{D} 42 57^{A}	12 27^{D} 42 57^{A}	27^{D} 57
19	12 27$^{E}_{F}$ 57	12 27$^{E}_{F}$ 57	27^{D} 57
20	27^{D} 57	27^{D} 57	27^{D} 57
21	27^{D} 57	27^{D} 57	27^{D} 57
22	27$^{E}_{F}$ 57	27$^{E}_{F}$ 57	27$^{E}_{F}$ 57
23	27^{D} 57	27^{D} 57	27^{D} 57
0	28$^{C,G}_{H,I}$	28$^{C}_{G}$	
1	28$^{C,G}_{H,I}$	28$^{C}_{G}$	
2	28$^{D,H}_{I}$	28^{D}	

Vor den Feiertagen: Tag der d. Einheit und Allerheiligen = Vorfeiertagsverkehr wie in der Nacht Fr/Sa

Fahrten ohne Zielangabe verkehren bis Euren, Helenenbrunnen

A: bis Euren, Friedhof

B: bis Zewen, Industriegebiet Zewen

C: bis Zewen, Kanzelstraße

D: bis Igel, Moselstraße

E: bis Metzdorf, Kirche

F: bedient auch von Euren, Hontheimstraße bis Igel, Moselstraße

G: bedient Euren, Hontheimstraße

H: nur freitags

I: nur in der Nacht von Freitag auf Samstag

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-81-b-1 h18 06.08.2018 16:05:30

FAHRPLAN

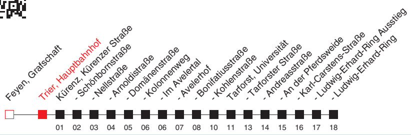
Gültig ab 01.12.2018 - Angaben ohne Gewähr - Trier, Hauptbahnhof

www.vrt-info.de

Richtung:

Tarforst, Ludwig-Erhard-Ring

83



Uhr	Montag - Freitag	Uhr	Samstag	Uhr	Sonn- und Feiertag
5	15 45	5		5	
6	15 45	6		6	
7		7	15 45	7	
8		8	15 45	8	15 45
9		9	15 45	9	15 45
10		10	00 15 30 45	10	15 45
11		11	00 15 30 45	11	15 45
12		12	00 15 30 45	12	15 45
13		13	00 15 30 45	13	15 45
14		14	00 15 30 45	14	15 45
15		15	00 15 30 45	15	15 45
16		16	00 15 30 45	16	15 45
17		17	00 15 30 45	17	15 45
18	45	18	00 15 30 45	18	15 45
19	00 15 30 45	19	00 15 30 45	19	15 45
20	15 45	20	15 45	20	15 45
21	15 45	21	15 45	21	15 45
22	15 45	22	15 45	22	15 45
23	15 45	23	15 45	23	15 45
0	15 45^{B} 45^{A}	0	15 45	0	15
1	45^{B} 45^{A}	1	45	1	
2	45^{B} 45^{A}	2	45	2	

Vorlesungszeiten: 22.10.-21.12.2018 / 02.01.-08.02.2019 / 08.04.-07.06.2019 / 17.06.-12.07.2019 / 28.10.-20.12.2019 / 06.01.-15.02.2020

Vor den Feiertagen: Tag der d. Einheit und Allerheiligen = Vorfeiertagsverkehr wie in der Nacht Fr/Sa

Vorlesungszeiten ohne Gewähr

A: nur während der Uni-Vorlesungszeiten in der Nacht von Donnerstag auf Freitag **B**: nur in der Nacht von Freitag auf Samstag

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-83-b-1 h18 09.08.2018 15:17:50

FAHRPLAN

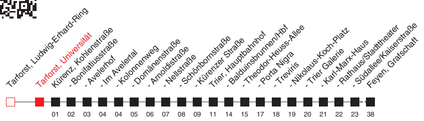
Gültig ab 01.12.2018 - Angaben ohne Gewähr - Tarforst, Universität

www.vrt-info.de

Richtung:

Feyen, Grafschaft

83



Uhr	Montag - Freitag	Uhr	Samstag	Uhr	Sonn- und Feiertag
5	02 32	5		5	
6	02 32	6		6	
7		7	02 32	7	
8		8	02 32	8	02 32
9		9	02 32 47	9	02 32
10		10	02 17 32 47	10	02 32
11		11	02 17 32 47	11	02 32
12		12	02 17 32 47	12	02 32
13		13	02 17 32 47	13	02 32
14		14	02 17 32 47	14	02 32
15		15	02 17 32 47	15	02 32
16		16	02 17 32 47	16	02 32
17		17	02 17 32 47	17	02 32
18	32 47	18	02 17 32 47	18	02 32
19	02 17 32 47$^{A}_{B}$	19	02 17 32	19	02 32
20	02 32	20	02 32	20	02 32
21	02 32	21	02 32	21	02 32
22	02 32	22	02 32	22	02 32
23	02 32^{C}	23	02 32^{E}	23	02 32
0	02 32^{D}	0	02 32^{E}	0	02
1	32^{D}	1	32^{E}	1	
2	32^{D}	2	32^{E}	2	

Vorlesungszeiten: 22.10.-21.12.2018 / 02.01.-08.02.2019 / 08.04.-07.06.2019 / 17.06.-12.07.2019 / 28.10.-20.12.2019 / 06.01.-15.02.2020

Vor den Feiertagen: Tag der d. Einheit und Allerheiligen = Vorfeiertagsverkehr wie in der Nacht Fr/Sa

Den Linienverlauf mit allen Haltestellen siehe Liniennetzplan.

Vorlesungszeiten ohne Gewähr

A: bis Trier, Karl-Marx-Haus

B: nur in den Vorlesungszeiten der Universität Trier

C: verkehrt täglich, freitags zusätzliche Rückfahrt ab Feyen über Weismark

D: nur in der Nacht von Freitag auf Samstag, Rückfahrt ab Feyen über Weismark

E: Rückfahrt ab Feyen über Weismark

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-83-b-1 h18 06.08.2018 16:01:55

FAHRPLAN

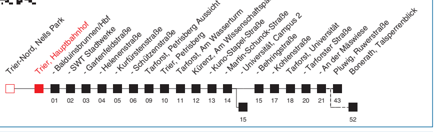
Gültig ab 06.08.2018 - Angaben ohne Gewähr - Trier, Hauptbahnhof

www.vrt-info.de

Richtung:

Pluwig, Ruwerstraße

85



Uhr	Montag - Freitag	Uhr	Samstag	Uhr	Sonn- und Feiertag
5	15$^{A,D}_{E}$ 45$^{A,D}_{E}$	5		5	
6	15$^{A,D}_{E}$ 45$^{A,D}_{E}$	6		6	
7		7	45^{B}	7	
8		8	45	8	45
9		9	45	9	45
10		10	15^{A} 45^{B}	10	45
11		11	15^{A} 45	11	45
12		12	15^{A} 45	12	45^{B}
13		13	15^{A} 45^{B}	13	45
14		14	15^{A} 45	14	45
15		15	15^{A} 45	15	45
16		16	15^{A} 45^{B}	16	45
17		17	15^{A} 45	17	45^{B}
18	45	18	15^{A} 45	18	45
19	15^{A} 45^{B}	19	15^{A} 45^{B}	19	45
20	45	20	45	20	45
21	45	21	45	21	45
22	45^{B}	22	45^{B}	22	45^{B}
23	45	23	45	23	45
0	45$^{A}_{C}$	0	45^{A}	0	
1	45$^{A}_{C}$	1	45^{A}	1	
2	45^{C}	2	45	2	

Vor den Feiertagen: Tag der d. Einheit und Allerheiligen = Vorfeiertagsverkehr wie in der Nacht Fr/Sa

Den Linienverlauf mit allen Haltestellen siehe Liniennetzplan.

Fahrten ohne Zielangabe verkehren bis Pluwig, Ruwerstraße

A: bis Kürenz, Universität, Campus 2

B: bis Bonerath, Talsperrenblick

C: nur freitags, auch 02.10. und 30.10.2017

D: Anruf-Sammel-Taxi, 30 Minuten vor Fahrtbeginn bestellen, Telefon: 0651-717-3333

E: Für die Benutzung eines Anruf-Sammel-Taxi ist zusätzlich zum Fahrpreis ein AST-Zuschlag im Taxi zu zahlen.

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

4-85-b-1 h18 09.08.2018 15:18:17

FAHRPLAN

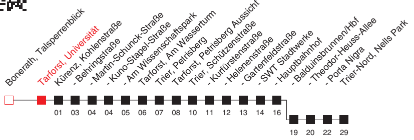
Gültig ab 06.08.2018 - Angaben ohne Gewähr - Tarforst, Universität

www.vrt-info.de

Richtung:

Trier, Hauptbahnhof

85



Uhr	Montag - Freitag	Uhr	Samstag	Uhr	Sonn- und Feiertag
5	57	5		5	
6	27	6		6	
7		7	27	7	
8		8	27	8	
9		9	27^{A}	9	27^{A}
10		10	27^{A}	10	27^{A}
11		11	27^{A}	11	27^{A}
12		12	27^{A}	12	27^{A}
13		13	27^{A}	13	27^{A}
14		14	27^{A}	14	27^{A}
15		15	27^{A}	15	27^{A}
16		16	27^{A}	16	27^{A}
17		17	27^{A}	17	27^{A}
18	27^{A}	18	27^{A}	18	27^{A}
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Vorlesungszeiten: 22.10.-21.12.2018 / 02.01.-08.02.2019 / 08.04.-07.06.2019 / 17.06.-12.07.2019 / 28.10.-20.12.2019 / 06.01.-15.02.2020

Vor den Feiertagen: Tag der d. Einheit und Allerheiligen = Vorfeiertagsverkehr wie in der Nacht Fr/Sa

Den Linienverlauf mit allen Haltestellen siehe Liniennetzplan.

Vorlesungszeiten ohne Gewähr

Fahrten ohne Zielangabe verkehren bis Trier, Hauptbahnhof **A**: bis Trier-Nord, Nells Park

SWT Stadtwerke Trier Verkehrs-GmbH, Gottbillstraße 13, 54294 Trier, Tel.: 0651-71 72 73

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Abstracts

Comparing stochastic optimization methods with Gradient-Enhanced Surrogates and Gradient-Based optimization Methods

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Automated optimization is a standard tool nowadays in industry and academics. Two main families of optimization algorithms are established: the first, stochastic global optimization, is purely explorative but shows deceptive convergence rates for high-dimensional problems; the second, Gradient-based, converges much faster but is rather exploitative. Combining those two approaches in a kind of hybridization gave birth to an entire research field, memetic algorithms.

Stochastic methods, however, need metamodels such as Kriging to have a better convergence. Those metamodels can also profit from gradients to predict more accurately global optima. Gradient-enhanced Kriging (GeK) requires indeed fewer samples to reach similar accuracy levels than ordinary kriging. Recalling that samples are time-consuming simulations (e.g. CFD, FEM ..), the reduction of the number of samples is highly beneficial. At the same time, the correlation matrix which summarizes the samples mutual influence has an additio- nal number of rows and columns (the product of the number of samples by the number of dimensions).

The GeK is usually combined with adjoint methods to compute the gradients. It has been however repeatedly reported that the GeK becomes too time-consuming for high-dimensional problems. To solve this issue, we propose a GPU implementation of the GeK using cuSolver and cuBlas libraries of Nvidia to achieve a speedup of 5x- to 10x. The adjoint is used to provide the gradients of the objective function with regard to the design variables. These derivatives are forwarded along with the CFD design evaluation to the Gradient-enhanced surrogate. As a sampling refinement criteria, the surrogate uses the weighed Expected Improvement which is tuned initially toward exploration and gradually favors more exploitation.

This work compares the performance under similar computational budget of the gradient-based optimization using adjoint solver and the metamodel-assisted Differential Evolution method using Gradient-Enhanced Kriging. The benchmark case is the inlet guide vane LS89 which has been optimized with pure GBM and hybrid methods.

Joint work with: Tom Verstraete and Arnaud Chatel

An application of stochastic control: algorithm trading for market orders

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One of the main trends in finance lies in the class of algorithmic trading with a quantitative approach for its analysis and stochastic optimization. Stochastic control theory is a mathema- tical field which studies the controlled variables performing the behavior of the a dynamical system to achieve a desired goal. We consider the optimal market orders for the high-frequency trading formulated as a solution of a stochastic control problem and the associated Hamilton- Jacobi-Bellman (HJB) partial differential equation (PDE). We aim to find optimal strategy for the algorithmic trading to be profitable.

Finite Element Error Estimates for Optimal Control Problems with Pointwise Tracking

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We consider a linear-quadratic elliptic optimal control problem with point evaluations of the state variable in the cost functional:

$$\text{Minimize } \frac{1}{2}\sum_{i\in \mathrm{I}}(u(x_i)-\xi_i)^2 \;+\; \frac{\alpha}{2}\|q\|^2_{L^2(\Omega)} \tag{1a}$$

subject to

$$\begin{aligned} -\Delta u &= q \qquad \text{in } \Omega \\ u &= 0 \qquad \text{on } \partial\Omega, \end{aligned} \tag{1b}$$

and

$$a \le q(x) \le b \quad \text{for a.a } x \in \Omega. \tag{1c}$$

The state variable is discretized by conforming linear finite elements. For control discretization, three different approaches are considered. The main goal is to significantly improve known a priori discretization error estimates for this problem. We prove optimal error estimates for cellwise constant control discretizations in two and three space dimensions. Further, in two space dimensions, optimal error estimates for variational discretization and for the post- processing approach are derived.
The talk will focus on the main ideas for the proof, in particular on deriving optimal error estimates in two space dimensions.

Joint work with: Dominik Meidner and Boris Vexler

Space-time Galerkin POD for Optimal Control of Nonlinear PDEs

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The method of *proper orthogonal decomposition* (POD) is a standard method for the reduction of dynamical models. In the context of partial differential equations, POD can be seen as the use of snapshots of the solution at certain discrete time points to reveal dominant states which are then used for optimal low-dimensional space parametrizations. If a Galerkin scheme was used for spatial discretization, the dominant states – the so called POD modes – can be identified as the basis of a subspace of the original ansatz space.

If also the time is discretized through a Galerkin scheme, one can transpose the classical POD to provide also optimal low-dimensional ansatz spaces for the time component; see [1]. In total, the newly developed space-time Galerkin POD method provides an optimized space-time Galerkin discretization of low dimension.

In this talk, we present the theoretical framework of this POD extension and address its benefits for the use in optimal control. We show applicability of this approach for an optimal control problem for the *Burgers* equation and discuss its efficiency in comparison to established gradient-based methods. If time permits, we will further expand on how general nonlinearities can be efficiently treated through interpolation.

Joint work with: Manuel Baumann and Jan Heiland

References

[1] M. Baumann, P. Benner, J. Heiland, *Space-Time Galerkin POD with application in optimal control of semi-linear parabolic partial differential equations.* SIAM Journal on Scientific Computing (to appear in 2018).
Preprint on Arxiv: http://arxiv.org/abs/1611.04050.

Topology optimization for substrate-integrated microwave devices

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Emerging wireless technology, such as 5G, is expected to operate at successively shorter wave lengths, eventually down to the millimeter range. High performance, low cost, and a com- pact design with high integration of antennas and circuits will be required of corresponding hardware. For instance, at short wave length, waveguides can be integrated on printed circuit boards using the Substrate Integrated Waveguide (SIW) concept. Currently, the design strat- egy is dominated by low-dimensional parametric numerical simulations, requiring extensive knowledge, ingenuity, and experience in high-frequency technology. In contrast, due to an effi- cient algorithmic exploitation of very high-dimensional design spaces, the use of density-based topology optimization has the prospect of generating devices with superior performance over a wide frequency band. One challenge with applying topology optimization is the dispersive nature of wave propagation in the SIW in combination with time-domain methods, which is advantageous to use for wide-frequency cases. We have developed a wave-splitting approach for dispersive wave propagation, which allows efficient implementation of the time-domain 3D Maxwell equations and corresponding adjoint equations in order to carry

As an example, Fig. 1 shows the geometry and the performance of an optimized SIW-to-rectangular waveguide transition. The SIW is connected to the center of the west side of the transition and the rectangular waveguide is normal to the page. The objective is to optimize the distribution of a metallic material (black color) in the transition area such that the coupling between the two waveguides is maximized over the frequency band 22–26 GHz. This optimization problem has 35,405 design variables and is solved in 110 iterations by Svanberg's GCMMA algorithms.

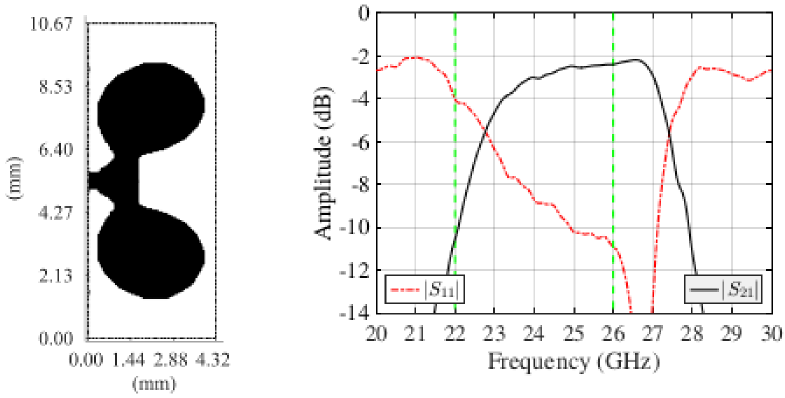

Figure 1: Left: the optimized transition. Right: the reflection coefficient, $|S11|$, and the coupling coefficient, $|S21|$ of the optimized transition.

Joint work with: Emadeldeen Hassan (Umeå University) and Fabian Lurz, Benedict Scheiner and Fabian Michler at Professor Robert Weigel's group (FAU Erlangen)

CutFEM shape optimization of compression driver phase plugs

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Compression drivers are a form of electroacoustic transducers with considerably higher efficiency than direct radiating loudspeakers. Such devices are frequently employed to feed mid-to-high-frequency horns for public address systems and for applications demanding high acoustic power [2]. To increase the radiation resistance, the membrane in a compression driver is placed in a shallow chamber from which the sound can exit only through narrow channels that typically connect to a waveguide or an acoustic horn. The design of the transition section, the *phase plug*, is crucial to avoid resonances and to achieve uniform output power over the desired frequency range.

We consider shape optimization of the phase plug of the generic compression driver in Figure 1, with dimensions, as well as electrical and mechanical parameters, chosen to be con- sistent with commercially available devices. The geometry is described by a level-set function, and the Helmholtz equation for the acoustic pressure is discretized on a fixed, structured finite element mesh using the CutFEM approach. Furthermore, we use a filtering strategy, similar to one used in a previous study on acoustic horn optimization [1], in which the nodal values of the Laplacian of the level set function act as design parameters. The method is compu- tationally robust and inexpensive, since remeshing between design updates can be avoided. Viscous and thermal losses are accounted for in a postprocessing step by solving the linearized, compressible Navier-Stokes equations on the final optimized geometries.

Two optimized drivers, and the corresponding sound pressure levels (SPL) at the output, can be found in Figure 1. The objective function is chosen to maximize SPL for the solution labeled J max , and to minimize the difference to an ideal, hypothetical, design for the solution labeled J diff . It is observed that the latter solution exhibits a more uniform frequency response.

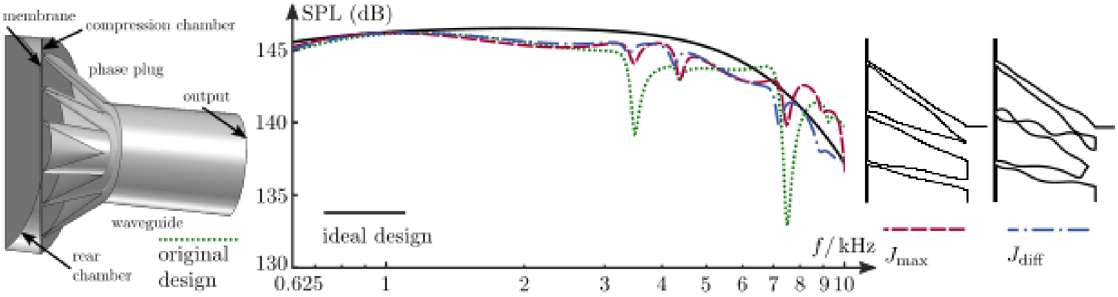

Figure 2: Left: Original design of generic compression driver considered. Middle: SPL for an excitation of 1 W. Right: Cut through the symmetry plane of two optimized phase plugs.

Joint work with: Eddie Wadbro and Martin Berggren

References:

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How regularity theory benefits shape calculus: Probabilistic lifespan optimization for devices under load

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Mechanic devices under load are exposed to strong forces that cause stress states in the material. These stress states influence the reliability of the component and can be calculated by solving a linearized elasticity equation. Since it is impossible to predetermine when and where the device will break, it is essential to combine a stochastic approach with the usual deterministic lifetime calculation.
The objective functionals J that result from this approach determine the survival probability of the component, depending on its shape Ω as well as on the stress tensor $\sigma(u(\Omega))$, and shall be minimized by shape calculus methods. Unfortunately, these shape functionals are typically undefined on Sobolev spaces and, therefore, can not be treated by usual methods.
We solve this problem by application of regularity theory for elliptic PDE and show existence and uniqueness of solutions $u(\Omega)$ and shape derivatives $u'(\Omega)$ in classical function spaces. Finally, we prove the existence of Eulerian derivatives $dJ(\Omega)$ and shape gradients $grad\ J(\Omega)$ for this class of demanding objective functionals.

Joint work with: Prof. Dr. Hanno Gottschalk

Variable metric forward-backward method for minimizing nonsmooth functionals in Banach spaces

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We consider the minimization of the sum of a smooth possibly nonconvex and a nonsmooth but convex functional in a Banach space. The Banach space, not necessarily reflexive, shall be given by the intersection of a reflexive space and a dual space of a separable space like e.g. $H^1 \cap L^\infty$. These arise often in the context of pde constrained optimization. Motivated by the gradient projection method we extend the variable metric forward-backward algorithm given in finite dimensions to Banach spaces and to the use of a Armijo type backtracking. In addition, due to the intersection of two spaces we can relax the requirement of the uniformly norm equivalency of the variable metric to the underlying norm. Hence there is more flexibility to include second order information and speed up the method. We give the conditions to deduce a type of gradient related descent property and which provide global convergence results. Moreover, we give examples which fulfill the requirements on the involved spaces and the variable metric. Finally, we present numerical results. In particular, we demonstrate the efficency on a convexly constrained nonconvex problem in structural topology optimization. Here one can clearly see that choosing the wrong inner product leads to mesh dependency and including second order information appropriately can speed up the method drastically.

Joint work with: Christoph Rupprecht

Fast regularized reconstructions for dynamic tomographic applications

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Solving an inverse problem means to compute a quantity of interest, which is not directly measurable, given measurements related to the searched-for quantity via a physical model. Inverse problems appear in many technical and physical applications and are commonly solved in a static setup. However, recently the focus turned on dynamic inverse problems where a spatial-temporal quantity from temporal data has to be determined. A huge class of dynamic inverse problems are tomographic imaging applications such as dynamic computer to- mography, magnet resonance tomography or new tomographic applications such as magnetic particle imaging (MPI).

MPI is capable of capturing fast dynamic processes in 3D volumes, based on the nonlinear response of the magnetic nanoparticles to an applied magnetic field. The image reconstruction is computationally demanding due to a non-sparse system matrix. Therefore, efficient numerical methods for solving the Tikhonov-type regularized minimization problems are needed. In this talk, we present some edge-preserving and spatio-temporal regularization methods and how to efficiently solve the resulting minimization problems. Results are presented for simulated and experimental measurement data for MPI.

Taylor expansions of value functions associated with infinite-horizon optimal control problems

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Optimal feedback laws for nonlinear control problems are intimately related to the computation of the optimal value function which is known to satisfy the Hamilton-Jacobi-Bellman (HJB) equation. In order to overcome the curse of dimensionality, approximation techniques for the HJB equation have received increasing interest over the last years. Under suitable assumptions on the control system, Taylor series expansions of the value function exist and can be used to design polynomial feedback laws that locally approximate the optimal feedback law. Such an approach will be discussed in detail for two different examples: a bilinear control problem for the Fokker-Planck equation and a distributed control problem for the Navier-Stokes equations. The well-posedness of certain multilinear operator equations that have to be solved are analyzed and error estimates for the obtained control law as well as the closed-loop system are given. Numerical examples are obtained by techniques from model reduction and tensor calculus

Bayesian Estimation of Road Roughness

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In the vehicle development process, it is highly important to know as much as possible about the customer-specific market situation. The vehicle is designed to meet region- and customer-specific durability requirements. Thus, it is a primary goal to collect data and information about the environment, the vehicle will be used in. In order to assess vertical loads, the vertical road input is the most decisive impact factor; it is, additionally, roughly independent from the vehicles that travel on it. It is common practice to describe road roughness by scalar indices which can be computed from the corresponding road profiles. A widely used index is the International Roughness Index (IRI). Here, we focus on this index concept as well as on the ISO roughness coefficient, denoted by C.

A straightforward way to obtain road profiles and, whence, roughness information is to directly measure the profile. This is possible, e.g., using expensive and complex laser scanners and the resulting resolution decreases with increasing speed of the measurement vehicle. Consequently, it is desirable to develop alternatives. In contrast to direct profile measurement, we propose and discuss an algorithmic approach to derive road roughness indices on the basis of comparably simple vehicle models (e.g. a quarter-car model) and vehicle measurements.

The algorithms use a stochastic modelling approach that gives a road profile on a certain segment as realization of a stochastic process. The stochastic process, typically a Gaussian process, is, in turn, characterized by the roughness indices. Thus, the latter are computed by solving an suitable inverse problem directly for the roughness coefficients in the Bayesian way.

The treatment as a Bayesian inverse problem additionally allows for quantifying uncertainty of the derived roughness indices in terms of assumed model and measurement errors.

Robustification of sample-and-hold controllers for the consensus problem

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Consensus problems in multi-agent systems have attracted the attention of a large number of researchers and significant developments have been achieved. Its importance is due to wide applications in several areas such as formation flight, traffic control, networked control and flocking problems. The consensus problem usually refers to the problem of how to design a distributed protocol so that the states of a group of networked dynamical agents reach agreement. In the current literature, most research activities focuses on the dynamics of the agents and the topology structure of the network (undirected, directed or switching). In addition, issues such as network-induced disturbances, network-induced delay and communication sensor noise have also been taken into account.
In this talk we focus on the robustification of sample-and-hold controllers for the consensus problem, with respect to disturbances and/or observation errors. Direct networks of multiple agents with nonlinear and bounded function describing the drift dynamics are considered in this work. For the disturbance-free system, the sampled-data control law is induced from a nonlinear consensus protocol (continuous or not) by implementing feedback stabilization methods, in sample-and-hold sense. Under the edge agreement framework, the consensus in a strongly connected network can be achieved over some suitable finite time. Then, we show that if disturbances and observation errors occur, they can be managed.

Joint work with: Pierdomenico Pepe (University of L'Aquila) and Nicola Guglielmi (Gran Sasso Science Institute)

Optimal Flight of a Hang-Glider through a Thermal

Kurt Chudej

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Hang-gliding is a fascinating sport in the Alpes. Favourable thermal updrafts allow interesting flights over a long range or for a long time interval. The optimal control problem is challenging due to the realistic modelling of the thermals and the multiple local minima. We present new numerical results of 3D trajectories of hang-gliders from an interdisciplinary project involving flight mechanics, meteorology, sports, optimal control, nonlinear optimization and scientific computing. Additionally we present a comparison between a real tandem-flight from the Wallberg near lake Tegernsee (Upper Bavaria) with the computed numerical results.

Joint work with: Dominik Regensburger, Universität Bayreuth, Lehrstuhl für Ingenieurmathematik; current address: Gabrieli-Gymnasium, Eichstätt

Subspace Version of an Augmented Lagrangian Trust Region Algorithm for Equality Constrained Optimization

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In this work, we present subspace properties of an Augmented Lagrangian Trust Region (AL- TR) method for equality constrained optimization proposed by Wang and Yuan (Optimization Methods & Software, 30:3, 559-582, 2015). Under suitable conditions, we show that the trial step obtained from the trust region subproblem is in the subspace spanned by all the gradient vectors of the objective function and of the constraints computed until the current iteration. The analysis is an extension of that presented by Wang and Yuan (Numer. Math. 104:241- 269, 2006) for the standard trust region subproblem. Based on this observation, a subspace version of the ALTR algorithm is proposed for large scale equality constrained optimization problems in which the number of constraints is much lower than the number of variables. The convergence analysis of the subspace algorithm is also presented.

Joint work with: Prof. Dr. Geovani Nunes Grapiglia

A Fast Heuristics for Optimal Control of Hybrid Electric Vehicles

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The expression Hybrid Electric Vehicles (HEVs) is used to define a class of terrestrial vehicles whose power-train combines a conventional combustion engine (ICE) with one or more electric motor/generators. In the last decade, with more than 12 millions of vehicles sold worldwide since 1997, HEVs have gained a good popularity and they are now expected to be a core segment of the automotive market of the future. The reason of this success lies on the fact that HEVs can provide better performances, lower pollutant emissions and lower fuel consumption with respect to traditional vehicles.

There are different approaches to the hybridization of vehicles, but, all of them exploit the electric propulsion to improve efficiency via regenerative braking, start and stop technologies and more efficient ICE usage policies. However, fully benefiting of the potentialities of a hybrid vehicle requires the ability to solve very demanding optimal control problems in real-time. Specifically, the most used drive-train topologies deploy mechanical components like clutches and stepped gearboxes that have to be represented by means of discrete variables. This leaves to the control engineers in the automotive field the challenge of developing fast solution methods for Mixed-Integer Optimal Control Problems (MIOCPs).

Among the various existing approaches to optimal control, direct methods, like Multiple Shooting, are the most suited to deal with the high complexity of the dynamical description of a hybrid vehicle. Such approaches retrieve the solution of an optimal control problem via the solution a large but structured optimization problem. However, direct methods applied to hybrid vehicles control result in large Mixed-Integer Non-Linear Problems (MINLPs) to be solved. Large MINLPs are very expensive to solve, and consequently, very hard to deal with in real time. Nevertheless, by giving up on global optimality, it is possible to use heuristic methods which are able of providing good solutions in short amounts of time.

We present a novel heuristic technique for the control for hybrid vehicles. The approach exploits the particular structure of MINLPs arising from the application of direct optimization methods to rapidly retrieve a close-to-optimal solutions. Borrowing ideas from the original work of Sebastian Sager [1], the control problem is reformulated in such way to provide a tight lower bounding relaxed control law via the solution of a single continuous non-linear problem. Afterward, a discrete control law that minimizes its maximum integral distance with respect to the relaxed one, while respecting the defined set of path and boundary constraints, is found thanks to few iterations of a tailored linear outer approximation algorithm. The performances of the proposed approach will be exposed with the help of a realistic case of study.

Joint work with: Joris Gillis, Goele Pipelers and Jan Swevers

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A Non-Regularized Approach for Dealing with Non-Smoothness in PDE Constrained Optimization

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So far, there is only a very limited number of optimization algorithms for non-smooth optimal control problems, as well as optimality conditions which are not based on regularizations and substitute assumptions for the non-smoothness. In this talk, we consider optimization problems constrained by non-smooth PDEs, where the non-smoothness is caused by the continuous but non-smooth operators abs(), min() and max() and present a new approach to deal with this kind of optimization problems. The key idea of the presented optimization method is to locate stationary points by appropriate decomposition of the original problem into several smooth branch problems, which can be solved by classical means. Suitable optimality conditions and subsequent evaluation of the information given by the respective dual variables lead to the next branch problem and thus to successive reduction of the functional value. Numerical results for this concept are discussed taking into account a nonlinear model problem with non-smooth PDE constraints.

Joint work with: Stephan Schmidt (University of Würzburg), Andrea Walther (Paderborn University)

Evaluation of Receding Horizon Controllers for Optimal Energy Conversion and Storage in Vehicular Energy Management

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The basic energy management problem may be defined as the task of optimally controlling the conversion of energy from one type to another within a system that includes a buffer to realize the ability to schedule generation while maintaining constraints on power delivery. Solutions to the problem in the form of online controllers are sought that demonstrate good performance in minimizing the cost of generation with varying prediction horizon lengths.

Many different types of energy management strategies are possible. Two classes of strategies based on receding horizon controllers are compared in this study. One class represents an indirect methodology that employs convex relaxation and a single terminal end constraint. The second class represents a direct methodology applied to a convex system. Strategies belonging to this class that minimize fuel use or maximize efficiency over a prediction horizon with a single or zone-type terminal are investigated. The main contribution of the paper is not the final choice of a control strategy for a particular application but the introduction of a methodology based on turnpike theory to compare the performance of control strategies and it's application on the two classes of strategies under investigation.

Optimal Error Estimates for the Semi-Discrete Optimal Control Problem of the Wave Equation with Time-Depending Bounded Variation Controls

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We will consider a control problem (P) for the wave equation with a standard tracking-type cost functional and a semi-norm in the space of functions with bounded variations (BV) in time. The considered controls in BV act as a forcing function on the wave equation with homogeneous Dirichlet boundary. This control problem is interesting for practical applications because the semi-norm enhances optimal controls which are piecewise constant, see for example [1].
In this talk we focus on a finite element approximation of (P). In this semi-discretized version, only the state equation is discretized and the controls will not be changed. Under specific assumptions we can present optimal convergence rates for the controls, states, and cost functionals.

Joint work with: B. Vexler and P. Trautmann

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Automated adjoints for finite element models

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Adjoints of partial differential equations (PDEs) play an key role in solving optimization problems constrained by physical laws. The adjoint model efficiently computes gradient and Hessian information, and hence allows the use of derivative based optimization algorithms. While deriving the adjoint model associated with a linear stationary PDE model is straightforward, the derivation and implementation of adjoint models for non-linear or time-dependent PDE models is notoriously difficult.

In this talk, we solve this problem by automatically deriving adjoint models for finite element models. Our approach raises the level of abstraction of algorithmic differentiation from the level of individual floating point operations to that of entire systems of differential equations. For each differential equation, the algorithm analyses and exploits the high-level mathematical structure inherent in finite element methods to derive its adjoint. We demonstrate that this strategy has advantages over traditional algorithmic differentiation: the adjoint model is robustly obtained with minimal code changes, yields close-to-optimal performance and inherits the parallel performance of the forward model.

The library dolfin-adjoint implements this idea as an extension to the FEniCS Project [1]. Recently, a major update to dolfin-adjoint has been a released. This talk will showcase some of the new features, including differentiation with respect to Dirichlet boundary conditions, automated shape derivatives, and the experimental integration with a machine learning framework. In addition, we show applications where dolfin-adjoint has already been employed.

Joint work with: S. Mitusch, J. Dokken, S. Schmidt

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A Stochastic Gradient Algorithm for PDE Constrained Optimization under Uncertainty

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Models incorporating uncertain inputs, such as random forces or material properties, have been of increasing interest in PDE constrained optimization. Stochastic approximation algorithms have been largely unexploited in this field. In this talk, an iterative algorithm using stochastic gradients for general constrained optimization problems in Hilbert spaces is presented. Convergence of the algorithm will be proven, relying on the use of directions of sufficient decrease and exogenous step size rules. The algorithm's efficiency and complexity is also reviewed. The approach will be demonstrated on a model problem with random elliptic PDE constraints as well as a structural topology optimization problem using a phase field representation for shapes.

Joint work with: Georg Pflug

Optimization-based Inertial Motion Tracking in the Presence of Uncertainties

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Inertial motion tracking focuses on estimating the relative position and orientation (pose) of a moving object. To this end, inertial sensors (3D accelerometers and 3D gyroscopes) are placed on the object of interest. For systems with a high degree of freedom, such as humans, multiple sensors can be placed on different moving segments resulting in a sensor network. Constrained sensor networks are subject to correlations between sensor measurements and their uncertainties which can be exploited fur applications such as human motion tracking.

Each sensor's pose can be estimated by integrating the gyroscope data and double integrating the accelerometer data in time. For ideal sensors, this would allow us to estimate the pose correctly. Unfortunately, such sensors do not exist, and each sensor is subject to different error sources which lead to a drifting estimate over time.

To obtain highly accurate state estimates, it is crucial to model the uncertainty of the sensors, as well as those of aiding sources and make use of the system constraints. In combination with reliable identification of sensor and system parameters such as scale factors of the inertial sensors or the displacement between different sensors, a good tracking performance can be achieved.

In this talk, we give an overview of the methods we use to tackle uncertainties in our optimization-based estimation framework for inertial motion tracking. Besides showing the importance of uncertainty modeling, we present different methods for the propagation of the arrival cost and the computation of state uncertainties. Finally, we show how an optimization-based estimator can recover from an imperfect and therefore uncertain calibration of sensor and system parameters in a real-time motion tracking scenario. The results show improved performance in comparison to traditional Kalman filtering.

Joint work with: Raymond Zandbergen (Xsens Technologies B.V.) , Tijmen Hageman (Xsens Technologies B.V.) , Giovanni Bellusci (Xsens Technologies B.V.) and Moritz Diehl (IMTEK)

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Operator Splitting Methods and Software for Convex Optimisation

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This talk will present a general purpose solution method for convex optimisation problems with quadratic objectives based on the alternating direction method of multipliers (ADMM). We employ a novel operator splitting technique that requires the solution of a quasi-definite linear system with the same coefficient matrix in each iteration. Our algorithm is very robust, placing no requirements on the problem data such as positive definiteness of the objective function or linear independence of the constraint functions. For large-scale semidefinite programs (SDPs), we also employ decomposition strategies based on identifying chordal sparsity in the problem data to split large constraints into multiple smaller constraints.

It is well-known that the iterates generated by ADMM will diverge if the optimisation problem is not feasible. Nevertheless, we show that it is possibly to reliably detect primal and dual infeasible problems from the algorithm iterates for a wide class of convex optimization problems including both quadratic and general conic programs. In particular, we show that in the limit the ADMM iterates either satisfy a set of first-order optimality conditions or produce a certificate of either primal or dual infeasibility. Based on these results, we propose termination criteria for detecting primal and dual infeasibility in ADMM.

We have implemented our algorithm for quadratic programs in the open-source C-language solver OSQP (for quadratic programs) and in a Julia language prototype for general conic problems. OSQP has a small footprint, is library-free, and has been extensively tested on many problem instances from a wide variety of application areas. OSQP is the default QP solver in the Python package CVXPY and supports interfaces to several other programming languages.

A Space Transformation Framework for Nonlinear Optimization

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We present a space transformation framework for nonlinear optimization. Instead of tackling the problem in the original space, each iteration of this framework seeks for a trial step by modeling and approximately solving the optimization problem in another space. We establish the global convergence and worst case iteration complexity of the framework.

We show that the framework can be specialized to a parallel space decomposition framework for nonlinear optimization, which can be regarded as an extension of the domain decomposition method for PDEs. A feature of the decomposition framework is that it incorporates the restricted additive Schwarz methodology into the synchronization phase of the method. A key ingredient in the original Schwarz method, and in our approach too, is to find the best strategy for handling the overlap between subdomains: we will discuss here the so-called weighted, and restricted additive Schwarz method for nonconvex optimization. Another feature that will be discussed is the introduction of a coarse space in our approach, which is instrumental for performance in Schwarz methods. Several variants of our methods will be compared numerically on two kinds of problems: problems involving differential operators, and more general algebraic problems based on the cutest problems collection.

Joint work with: Luis Nunes Vicente (University of Coimbra, Portugal) and Zaikun Zhang (The Hong Kong Polytechnic University)

Simultaneous Parallel-in-Layer Optimization for Training of Deep Residual Networks

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The forward propagation through residual neural networks (ResNet) has been shown to be equivalent to solving an initial value problem whose nonlinear dynamics are parameterized by the weights. Training a ResNet is therefore related to minimizing a regularized loss function with respect to those weights.

In order to develop faster, more efficient, and more effective training algorithms, we leverage recent advances in parallel-in-time integration and optimization methods. We replace the forward and backward propagation through the ResNet by an iterative, non-intrusive multigrid-in-time technique that allows for computational concurrency across the neural network layers. Distributing the time domain of the nonlinear dynamics across multiple processors allows for a parallel-in-layer optimization technique where speedup over serial-in-layer optimization methods can be achieved through the greater concurrency. Additionally, the multigrid iterations enable a simultaneous optimization framework where weight updates are based on inexact gradient information. Weight updates can thus be employed at an early stage of the propagation process which potentially further reduces the overall training runtime.

Joint work with: Lars Ruthotto and Jacob B. Schroder and Nicolas R. Gauger

Trust-Region Steepest Descent for Mixed-Integer Optimal Control

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Optimization with differential equations and mesh-dependent integer control variables is widely considered to be an especially difficult branch of mixed-integer optimization because it combines the computational intractability of mixed-integer optimization with the high-dimensional nature of problems with mesh-dependent controls. We examine a subclass of problems with a single mesh-dependent binary control variable that can be reformulated as an optimization problem over measurable sets. Using this approach, we derive a trust-region steepest descent algorithm that avoids the computational effort usually associated with enumerating the integer search space. We demonstrate that the algorithm converges and discuss the practical advantages and drawbacks of our approach, as well as its theoretical limitations.

Joint work with: Sebastian Sager (Otto-von-Guericke University) and Sven Leyffer (Argonne National Laboratory)

Model Order Reduction for port-Hamiltonian Differential-Algebraic Systems

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Port-based network modelling of large multi-physics systems leads naturally to their formulation as port-Hamiltonian differential-algebraic systems. The port-Hamiltonian structure is closely related to the properties of the system, e.g. passivity. Furthermore, the state space dimension of such systems can easily become very large, as they arise from electrical circuits, multi-body systems or semi-discretization of partial differential equations. Thus, there is an immediate need for structure-preserving model order reduction methods. While reducing the order of differential-algebraic equations, keeping the algebraic constraints unchanged is important. Otherwise, properties like stability can be lost. Thus, our aim is to decouple the underlying ordinary differential equation and the algebraic constraints in a structurepreserving manner and to adapt model reduction methods for ordinary port-Hamiltonian systems to port-Hamiltonian differential-algebraic systems, such that the structure and the algebraic constraints are preserved.

An efficient low-rank method for optimization problems governed by fractional PDEs

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Modelling, simulation and optimization of systems governed by fractional and nonlocal PDEs have attracted considerable interest in recent literature. The non-locality of the operator leads to a dense discretized system. This presents a major difficulty for standard solvers, since the solution of large, dense problems is computationally very expensive.
We present a method to overcome these for a fractional Laplacian control problem by exploiting well-known approximation results for the underlying operator and extending them to the control case. In the discrete case on tensor grids, these properties lead to a low Kronecker rank structure, which allows a cheap computation of matrix-vector products. We use this structure to construct a direct solver for the optimal control problem, whose computational complexity is independent of the problem dimension. We show our novel approach to outperform existing standard methods.

Joint work with: Venera Khoromskaia, Boris Khoromskij, Volker Schulz

Discrete Total Variation with Finite Elements and Applications to Imaging

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The total variation (TV)-seminorm is considered for piecewise polynomial, globally continuous (CG) or discontinuous (DG) finite element (FE) functions on simplicial meshes. A novel, discrete variant (DTV) based on a nodal quadrature formula is defined. DTV has favorable properties, compared to the original TV-seminorm for FE functions. These include a convenient dual representation in terms of the supremum over the space of Raviart–Thomas finite element functions, subject to a set of simple constraints. It can therefore be shown that a variety of algorithms for classical image reconstruction problems, including TV-L 2 and TV-L 1 , can be implemented in low and higher-order finite element spaces with the same efficiency as their counterparts originally developed for images on Cartesian grids.

Joint work with: Roland Herzog, Stephan Schmidt, José Vidal and Gerd Wachsmuth

Intrinsic KKT Conditions on Smooth Manifolds

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We formulate Karush-Kuhn-Tucker (KKT) conditions for equality and inequality constrained optimization problems on smooth manifolds. Under the Guignard constraint qualification, local minimizers are shown to admit Lagrange multipliers. We also investigate other constraint qualifications and provide results parallel to those in Euclidean space. Illustrating numerical examples will be presented.

Joint work with: Ronny Bergmann

A Localized Spectral-Element Reduced Basis Method for Incompressible Flow Problems

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We consider the incompressible Navier-Stokes equations in channels and cavities which exhibit bifurcations with changing parameter values, such as Reynolds number, Grashof number or geometry. Applications of interest are contraction-expansion channels, found in many biological systems, such as the human heart for instance, or cavities used in semiconductor crystal growth. The use of spectral element methods in computational fluid dynamics allows highly accurate computations by using high-order spectral element ansatz functions. Typically, an exponential error decay can be observed under p-refinement.
Applying the reduced basis model reduction to flow problems allows to reconstruct the field solution over a parameter range of interest from a few high-order solves. In particular, we use clustering in snapshot space to identify regions in parameter space, where solutions are alike. Thus constructed local ROMs can outperform global ROMs in many scenarios. For instance this method can reconstruct bifurcation branches with a local ROM for each respective branch automatically. Care must be taken when choosing the criterion for selecting which local ROM to use for a new parameter and that approximation accuracy can degrade in the transition region between local ROMs.
Using the software framework Nektar++ as a high-fidelity spectral element solver, we develop the ITHACA-SEM software framework for the model reduction based on Nektar++ simulations.

Joint work with: Gianluigi Rozza (SISSA, Italy), Max Gunzburger (Florida State University, USA), Annalisa Quaini (University of Houston, USA) and Alessandro Alla (PUC Rio, Brazil)

Linear Model Reduction for Nonlinear Input-Output Systems

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Model reduction for linear input-output systems typically involves the computation of a Galerkin or Petrov-Galerkin projection, which is applied to the linear operators of the vector field and output functional. The resulting reduced system then acts only upon reduced spaces and produces elements of reduced spaces, without resorting to any original system's unredu- ced components. This is due to the special structure of linear systems. Similarly, composing projections for a nonlinear system's vector field yields a mapping from and to a reduced state-space, yet in an intermediary step, the original system's state has to be reconstructed, the nonlinear vector field applied, and the resulting new state has to be reduced. Hence for non-linear systems, hyper-reduction is usually a secondary step to mitigate this so-called lifting bottleneck.

This chaining of reduction techniques raises the question: how well can a (linear) projection-based method approximate nonlinear system dynamics? Furthermore, at what point in the projection construction should the system be linearized and how nonlinear can the system be? To answer these question we focus on Gramian-based methods from a linear and nonlinear point-of-view: We compare different projections for several reduced order model variants, highlight the differences between linear and nonlinear model reduction, and motivate linear model reduction for nonlinear systems from a scientific computing perspective.

Joint work with: Peter Benner and Sara Grundel

A fully certified reduced basis method for PDE constrained optimal control with control constraints

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With this talk we present a novel reduced-basis approach for optimal control problems with constraints, which seems to deliver lower dimensional RB spaces as reported in the literature so far for the same problem class, but with the same approximation properties, and which allows to prove an error equivalence as known from a finite element a posteriori error analysis. Numerical tests confirm our theoretical findings.

Joint work with: Ahmad Ahmad Ali

Joint Reconstruction in Multi-Spectral Electron Tomography

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In recent years, the need for visualisation of minuscule structures has increased significantly in various fields, particularly with respect to elemental mappings depicting their chemical makeup. To this end, Scanning Transmission Electron Microscopy and spectroscopic methods are used to obtain data channels corresponding to different elements, which are then combined with tomography to obtain 3D density distributions for each chemical element at nano scale [5]. However, obtained data suffers severely from Poisson noise, rendering standard tomography methods such as Filtered Backprojection, SART or SIRT, which typically reconstruct each channel independently, unable to yield satisfactory results. While reconstruction methods with stronger smoothing succeed in removing the noise, there is an issue of losing details in the process. To this point, we propose a joint reconstruction approach that exploits information from all available channels for each reconstruction, as physical modelling suggests complementing information between channels. This approach consists in a multi-data Tikhonov approach [4] featuring multi-channel Total Generalized Variation (TGV) [1,2] as regularisation and Kullback-Leibler data fidelity terms. The use of multi-channel TGV is of particular importance for this approach, as it penalises noise substantially, while promoting joint edge sets and preserving common features between the channels. Solution of such a Tikhonov approach corresponds to solution of a convex, non-smooth optimisation problem which is solved using a primal dual algorithm [3]. In particular, parallel implementation on the GPU is possible and allows for swift execution leading to an efficient reconstruction algorithm. Numerical experiments, both with artificial and real data sets, confirm clear improvements when using this method compared to standard methods, as it succeeds in removing noise substantially, while maintaining details and features otherwise lost.

Joint work with: Kristian Bredies (University of Graz) , Georg Haberfehlner (Graz University of Technology) , Martin Holler (Univesity of Graz) and Gerald Kothleitner (Graz University of Technology)

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L^2 a-priori error estimation for the obstacle problem using localization

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We consider the standard obstacle problem in a convex and polyhedrally bounded domain Ω with forcing $f \in L^\infty(\Omega)$, i.e. the variational inequality:
Find $u \in \mathcal{K}_\Psi := \{v \in H^1_0(\Omega) | v \geq \Psi \text{ a.e. in} \Omega\}$ such that

$$(\nabla u, \nabla(v-u)) \geq (f, v-u) \; \forall v \in \mathcal{K}_\Psi. \tag{VI}$$

Here Ψ is the given obstacle. Under the reasonable assumption of inactivity close to the boundary $\partial\Omega$ we derive optimal error estimates for a numerical approximation of (VI) based on a regularisation approach. Namely we obtain second order convergence (up to logarithmic terms) with respect to the spatial discretization, which is assumed to be quasi-uniform. No discrete maximum principle is required.

Joint work with: Dominik Hafemeyer and Johannes Pfefferer

Strong stationarity conditions for the optimal control of a Cahn-Hilliard-Navier-Stokes system

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This talk is concerned with the optimal control of two immiscible fluids with non-matched densities. For the mathematical formulation of the fluid phases, we use a coupled Cahn-Hilliard/Navier-Stokes system which has recently been introduced by Abels, Garcke and Grün in [1]:

$$\partial_t\varphi + v\nabla\varphi - \mathrm{div}(m(\varphi)\nabla\mu) = 0, \tag{1}$$

$$-\Delta\varphi + \partial\Psi_0(\varphi) - \mu - \kappa\varphi = 0, \tag{2}$$

$$\begin{aligned}\partial_t(\rho(\varphi)v) + \mathrm{div}(v\otimes\rho(\varphi)v) - \mathrm{div}(2\eta(\varphi)\epsilon(v)) + \nabla p&\\ +\mathrm{div}(v\otimes J) - \mu\nabla\varphi &= 0,\end{aligned} \tag{3}$$

$$v|_{\partial\Omega} = \partial_n\varphi|_{\partial\Omega} = \partial_n\mu|_{\partial\Omega} = 0, \tag{4}$$

$$\mathrm{div} v = 0, (v,\varphi)|_{t=0} = (v_a, \varphi_a). \tag{5}$$

The free energy density Ψ_0 associated with the underlying Ginzburg-Landau energy in the Cahn-Hilliard system is given by the double-obstacle potential. As a consequence, the system (1)-(2) becomes a variational inequality of fourth order.
We propose a suitable time discretization for the above system and verify the existence of solutions to the semi-discrete Cahn-Hilliard/Navier-Stokes system.
The optimal control problem is formulated by introducing an appropriate objective functional and a distributed control u which enters the Navier-Stokes equation (3) on the right-hand side.
We establish the existence of optimal controls and further investigate the sensitivity of the associated control-to-state operator verifying a Lipschitz estimate. A characterization of the directional derivative of the constraint mapping is provided involving a system of variational inequalities and equations. Finally, we present strong stationarity conditions for the optimal control problem which are derived via an variational approach pioneered by Mignot and Puel, cf. [2].

Joint work with: Prof. Michael Hintermüller

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An optimisation approach using MRI measurements to identify filter topologies and flow characteristics

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In filtration processes, e.g. for water treatment, the deposition of organic or inorganic substances on or in a membrane leads to a loss of productivity and an increase in maintenance and operating costs. There is still a lack of models to describe the processes that can depict morphological changes in the porosity of membranes and the surface layers that are formed.

Therefore, a deeper knowledge of the underlying processes is of great importance. In this talk, the coupling of magnetic resonance imaging (MRI) measurements and computational fluid dynamics (CFD) simulation for the application on porous media, e.g. filters, will be investigated. The coupling is done by formulating a topology optimisation problem, with a porous media model as side condition. The method has shown to reduce the noise of MRI measurements, and to identify the underlying topology for pure solid objects. The unconstrained optimisation problem uses projection functions, which emulate the corresponding physical model, to map the control to a numerical porosity in the domain. One challenge thereby is to find the correlation between numerical porosity and physical permeability to identify porous media topologies in the fluid domain. Here, this correlation is analysed and the results are applied to the given application.

Joint work with: G. Thäter, G. Guthausen and M. J. Krause

Optimal control of a Vlasov-Poisson plasma by an external magnetic field

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We consider the three dimensional Vlasov-Poisson system in the plasma physical case. It describes the time evolution of the distribution function of a very large number of electrically charged particles. These particles move under the influence of a self-consistent electric field that is given by Poisson's equation. Our intention is to control the distribution function of the plasma by an external magnetic field. At first we will introduce the basics for variational calculus. Then we discuss a model problem where the distribution function is to be controlled in such a way that it matches a desired distribution function at some certain point of time as closely as possible. Those model problems will be analyzed with respect to the following topics:

- existence of a globally optimal solution,
- necessary conditions of first order for locally optimal solutions,
- derivation of an optimality system,
- sufficient conditions of second order for locally optimal solutions,
- uniqueness of the optimal control under certain conditions.

Optimal control of the semilinear heat equation subject to state and control constraints

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In this talk we discuss optimality conditions for an optimal control problem governed by a semi-linear heat equation with a bilinear term coupling control and state and subject to state constraints. The control enters affine in the cost function. We derive first and second order optimality conditions, taking advantage of the Goh transform.

Joint work with: Frederic Bonnans (INRIA Saclay) and M. Soledad Aronna (EMAp/FGV)

Convergent Domain Decomposition Methods for Total Variation Minimization

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Total variation regularisation is an important tool to solve inverse imaging problems. In particular, in the last decades, in the literature, there have been introduced many different approaches and algorithms for minimizing the total variation. These standard techniques are iterative-sequentially formulated and therefore not able to solve large scale simulations in acceptable computational time. For such large problems we need to address methods that allow us to reduce the problem to a finite sequence of subproblems of a more manageable size, perhaps computed by one of the standard techniques. With this aim, we introduce domain decomposition methods for total variation minimization. The main idea of domain decomposition is to split the space of the initial problem into several smaller subspaces. By restricting the function to be minimized to the subspaces, a sequence of local problems, which may be solved easier and faster than the original problem, is constituted. Then the solution of the initial problem is obtained via the solutions of the local subproblems by glueing them together. In the case of domain decomposition for the non-smooth and non-additive total variation the crucial difficulty is the correct treatment of the interfaces of the domain decomposition patches. Due to the non-smoothness and non-additivity, one encounters additional difficulties in showing convergence of more general subspace correction strategies to global minimizers. In particular there do exist counterexamples indicating failure of splitting techniques. Nevertheless, in this talk we propose overlapping domain decomposition algorithms for the total variation minimization problem with the guarantee of convergence to a minimizer of the original functional. The analysis is based on the relation between the primal (original) total variation minimization problem and its (pre-)dual formulation. To the best of our knowledge, this is the first successful approach of a domain decomposition strategy for total variation minimization with a rigorous convergent analysis in an infinite dimensional setting. We provide numerical experiments, showing the successful application of the algorithms.

Structure-preserving model order reduction of gas network systems

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Applications in which conservation laws are involved typically lead to hyperbolic systems. This is also the case in the modeling of gas network systems, where Euler equations are used to model the flow through pipes. Depending on the size of the network one easily ends up with a large-scale problem. For an efficient simulation of such systems we consider model order reduction. Model order reduction has shown to be an efficient tool for the acceleration of many kind of simulations. Its application to hyperbolic systems, however, remains a challenging task, and has only recently gained a lot of attention. So called structure-preserving methods leading to physically meaningful and reliable reduced models are needed, as the standard approaches often fail in that case.
We discuss recent structure-preserving model reduction methods and its applicability for gas network systems with a focus on the port-Hamiltonian framework.

Joint work with: N. Marheineke

A new approach for the numerical solution of shape optimization problems

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Shape optimization is a branch of nonlinear optimization in which the object to be optimized is the shape of a domain. We focus on shape optimization problems with PDE constraints and their numerical solution. A significant difficulty is rooted in the fact that shapes do not carry the structure of a vector space. This fact has implications on the choice of transformations applied to a computational mesh during the optimization process, concerning preserving mesh quality.

Many of the previously proposed methods can generate spurious descent directions, produced mainly by numerical errors in the discretization of the problems. These directions perform movements of the mesh nodes even when they do not represent an improvement of the objective function in the continuous version of the problem. Most of the times these spurious directions can generate low-quality meshes and even mesh structure destruction. This new method aims to avoid mesh structure destruction via the use of a specific subset of test functions in the variational problem used for the computation of the shape gradient. Besides the description of the method; in this talk, we will present several numerical experiments that confirm our theoretical results.

Joint work with: Tommy Entling, Roland Herzog and Gerd Wachsmuth

An algorithm that is 20 times faster than semismooth Newton methods

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We present an algorithm for the efficient solution of structured nonsmooth operator equa- tions in Banach spaces. Here, the term structured indicates that we consider equations which are composed of a smooth and a semismooth mapping. Equations of this type occur, for instance, as optimality conditions of structured optimization problems such as LASSO in machine learning.

The new algorithm combines a semismooth Newton method with a quasi-Newton method. This hybrid approach retains the local superlinear convergence of both these methods under standard assumptions. Since it is known that quasi-Newton methods cannot achieve superlinear convergence in semismooth settings, this is quite satisfying from a theoretical point of view.

The most striking feature of the new method, however, is its numerical performance. On nonsmooth PDE-constrained optimal control problems it is at least an order of magnitude faster than semismooth Newton methods.

These speedups persist when globalization techniques are added. Most notably, the hybrid approach can be embedded in a matrix-free limited-memory truncated trust-region framework to efficiently solve nonconvex and nonsmooth large-scale real-world optimization problems. In this challenging environment it dramatically outperforms semismooth Newton methods, sometimes by a factor of twenty and more.

All these topics are addressed in the talk.

Joint work with: Armin Rund

A linear bound on the integrality gap for Sum-Up Rounding

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We consider the integrality gap between a relaxed continuous control trajectory and an integer feasible one that is constructively obtained in linear runtime by a family of sum-up-rounding algorithms. Such algorithms are typically invoked when solving Mixed-Integer Optimal Control Problems (MIOCPs) and serve to construct integer feasible approximations from optimal solutions of a particular relaxation. We give a constructive proof of a bound on the integrality gap in the presence of additional constraints on the discrete control. Our bound is linear in both the discretization granularity and the number of discrete choices of the control and asymptotically tight. Furthermore, we point out which types of convergence of the related control and state trajectories can be obtained with this result at hand. This result completes recent work on the approximation of feasible points of the relaxed problem by points of the combinatorial problem.

Joint work with: Christian Kirches and Felix Lenders

Duality based error estimation with space-time reconstruction of discontinuous Galerkin solutions for hyperbolic problems

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Duality based error estimation is a well-known approach to produce high quality goal-oriented meshes. In this regard, the interplay between regularity of primal and dual solutions is crucial in error representation. However, in the case of discontinuous solutions of hyperbolic conservation laws, the formal approach of duality argument leads to a dual problem with discontinuous coefficients making the dual problem ill-posed, in many cases. In general, to avoid such complications some artificial viscosity is added to primal and/or dual problem in order to feed the methodology with enough regularity [1].

In this talk, we will show some first results of an ongoing work which tries to by-pass the regularity issues by providing a formulation of the error estimate in terms of the residual of the primal and dual problems instead of their solutions. Therefore, it allows to obtain an error representation while keeping both the primal and dual problems intact. On the other hand, since the arising error representation depends on the dual and primal residuals, we will provide a space-time reconstruction of the discontinuous Galerkin solutions in the sense of [2] which are regular enough to make the error representation well-defined. The efficiency of the proposed duality based error estimate is demonstrated by series of numerical experiments.

Joint work with: Jan Giesselmann (MathCCES, RWTH Aachen University)

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A Priori Error Estimates for a Linearized Fracture Control Problem

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A linearized control model for fracture propagation is considered. The linear-quadratic problem is discretized by a conforming finite element method. The a priori error estimate is discussed for the discretization scheme. First, a quasi-best approximation result is proved for the lower level optimization problem concerning the fracture propagation such that the total energy is minimized. Next, a convergence result for the upper level optimization model, in which the vector valued displacement field is controlled to approach as close as possible to the desired state, is presented. The theoretical results are verified with numerical experiments.

Joint work with: Winnifried Wollner

Optimal control with average state for a heat equation with missing data

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We are concerned with the optimal control of heat equation equations with unknown boundary condition and with the diffusivity coefficient depending on a parameter. Using the notion of the no-regret control and least (or low) regret control developed by J.L. Lions, we first prove that the least regret control problem associate to the boundary heat equation has a unique solution. Then we show that this solution converges to the no-regret control that we characterize by a singular optimality system.

Numerical shape optimization for nonlinear ultrasound focusing

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In this talk, we will discuss how the focusing capability and precision of high-intensity ultrasound devices can be improved by using shape optimization. Typical applications arise, for example, in medicine where ultrasound waves with high-power sources are used in the extracorporeal treatment of kidney stones or certain types of cancer.
We use a nonlinear wave model for sound propagation given by Westervelt's equation. The shape optimization problem is then formulated by employing an L 2 -tracking type cost functional. In this way, we achieve desired high pressure values in the focal region and low pressure values in the sensitive region around it to avoid tissue damages. We follow the optimize first, then discretize approach, relying on shape calculus. A gradient-based optimization algorithm is employed to find a locally optimal shape. The implementation is realized within the framework of isogeometric analysis, where geometry representation as well as the approximation space for the PDE-solution share the same spline ansatz-functions.
Our results are supported by numerical experiments in a 2D setting.

Joint work with: Vanja Nikolić, Barbara Wohlmuth and Linus Wunderlich

On Second Order Sufficient Conditions for PDE-Constrained Optimization

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It is well known that nonconvex optimization problems may admit critical points that are not necessarily (local) minima. Second order sufficient conditions for optimality (SSC) are therefore of interest when e.g. analysing the convergence of solution algorithms or deriving error estimates for approximate solutions. Many real world processes are modeled by nonlinear partial differential equations (PDEs), which then in general results in nonconvex optimization problems even if for simple convex objective functionals. In this context, the analysis of SSC is complicated by regularity or differentiability issues of the solution operator of the PDE. In this talk, we aim at giving an overview about the challenges and implications of SSC for certain classes of nonconvex optimization problems.

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

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In this talk, we present the iterative regularization of a non-smooth nonlinear ill-posed problem where the forward mapping is merely directionally but not Gâteaux differentiable. Using the Bouligand derivative of the forward mapping, a Landweber-type iteration is obtained that converges strongly for exact data as well as in the limit of vanishing data if the iteration is stopped according to the discrepancy principle. The analysis is based on the asymptotic stability of the proposed iteration, which is shown to hold under a generalized tangential cone condition. This is verified for an inverse source problem with a non-smooth Lipschitz continuous nonlinearity. Numerical examples illustrate the convergence of the iterative method.

Joint work with: Christian Clason

On the Robust PCA

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Given $n \geq d$ points $x_i \in \mathbb{R}^d$, $i = 1, ..., n$, the classical Principal Component Analysis (PCA) finds a hyperplane $H(A, b) := \{At + b : t \in \mathbb{R}^r\}$, $r \ll d$, such that the sum of the **squared Euclidean distances** from the points to the hyperplane becomes minimal. More precisely, a collection of orthogonal columns of A can be obtained successively by solving a line fitting problem (r = 1), projecting the data on the orthogonal complement of the line and repeating this process until the desired number of columns is found. Unfortunately, the PCA is not robust against outliers so that several procedures for a 'robust PCA' were proposed in the literature. In this talk we are interested in two approaches:

1. Find a hyperplane such that the sum of **Euclidean distances** of the points from the hyperplane becomes minimal, or
2. successively find directions such that the sum of the Euclidean distances of the projected points to the line becomes minimal.

We also discuss the role of the bias b. Then, we provide numerical algorithms for minimizing the functionals on Stiefel, resp. Grassmannian manifolds. Numerical examples demonstrate the performance of our approaches.

Joint work with: S. Setzer and G. Steidl

Data driven feedback control of nonlinear PDEs using the Koopman operator

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We present a new framework for optimal control of PDEs using Koopman operator-based reduced order models (K-ROMs). By introducing a finite number of constant controls, the dynamic control system is transformed into a set of autonomous systems and the corresponding optimal control problem into a switching time optimization problem. This way, a nonlinear infinite-dimensional control problem is transformed into a low-dimensional linear problem. Using a recent convergence result for Extended Dynamic Mode Decomposition (EDMD), we prove convergence of the K-ROM-based solution towards the solution of the full system.

This result is then extended to continuous control inputs using linear interpolation between two Koopman operators corresponding to constant controls, which results in a bilinear control system. Convergence can be proved when the PDE depends linearly on the control, and we show that this approach is also valid for mildly nonlinear dependencies.

To illustrate the results, we consider the 1D Burgers equation and the 2D Navier–Stokes equations. The numerical experiments show remarkable performance concerning both solution times as well as accuracy.

Joint work with: Stefan Klus

Optimal control problems in non-convex domains with regularity constraint

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

Joint work with: Benedikt Berchtenbreiter and Boris Vexler (Technical University of Mu- nich).

Optimal Guidance of Crowds by External Agents

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The control of of crowds by external agents can be found in many applications, like, e.g., herding of sheep, opinion-formation, or in evacuation scenarios. In this talk, we present some results on the connection of the control problems on the microscopic, individual level and the corresponding meanfield limit. In particular, we are interested in the asymptotic behavior of minimizers and the link of different approaches for the derivation of the first-order optimality condition.

Joint work with: M. Burger, C. Totzeck and O. Tse

Robust sensor placement for data assimilation problems

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We consider optimal sensor placement for state and parameter estimation problems. This work is motivated by an engineering application, where the goal is to estimate the displacement in a certain point from temperature measurements. To make this estimation more robust, we simultaneously estimate uncertain parameters, to keep the model up-to-date. Therefore we use self-calibrating data assimilation techniques. The quality of the estimation depends strongly on the position of the measurement devices. We present optimal experimental design techniques for such data assimilation problems to obtain the optimal sensor positions. As the sensor placement problem is nonlinear, the optimal solution will depend on the actual state and parameters, therefore we apply a robust optimization approach.

Joint work with: Roland Herzog (TU Chemnitz)

A gradient system for low rank matrix completion

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In this talk we present a numerical method to find the closest low rank completion of a matrix which is known only from a rate of its entries. This problem is known as the low rank matrix completion and became very popular thanks to its interesting applications. Given the matrix M to recover, the method consists in fixing the rank to r and then looking for the matrix X in the manifold of rank-r matrices that is closest to M , where the distances are measured in the Frobenius norm.
The method, to solve this particular matrix nearness problems, works on two levels. In the inner iteration, based on a suitable constrained gradient system, we compute the fixed norm matrix that best fits the data entries. The outer iteration optimizes the norm by employing a Newton-like technique.

Joint work with: Prof. Nicola Guglielmi (Gran Sasso Science Institute, L'Aquila)

Shape Optimization: Higher Order and Non-Smoothness

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Many optimization problems fall into the category of shape optimization, meaning the geometry of the domain is the unknown to be found. With respect to PDE constrained optimization, natural applications are drag minimization in fluid dynamics or the shaping of acoustic devices, but many tomography and image or object reconstruction problems also fall into this category. In particular with respect to the latter, there are still many open questions with respect to the regularization term, such that finding non-smooth objects is fostered.

While gradient descent approaches are becoming well-established nowadays for applications, there is still no canonical approach to solve large scale problems with PDEs via a shape-Newton scheme. One possible reason for this is the plethora of different modeling approaches, in particular different parametrizations versus the so-called Hadamard approach. Depending on the choices made, regularity of the state and symmetry of second directional shape derivatives can both be issues, which have in the past often been prohibitive.

The intention of this presentation is to provide an overview about the different approaches for Newton-like schemes with the aim to arrive at a standard procedure to solve large scale real world problems using a shape Newton scheme. Key ingredient here is the interplay between the adjoint equation and material derivatives. Computer algebra systems can be used to help determining appropriate shape Hessian representations on a formal symbolic level. This methodology will be exemplified with a shape-Newton scheme for the incompressible Navier–Stokes equations, which is created by an auto-symbolic derivation and implementation of the shape KKT-system in variational form within the FEniCS finite element framework.

Joint work with: M. Herrmann, J. Vidal, R. Herzog, J. Dokken, S. Funke

Second-Order Optimality Conditions for Cardinality-Constrained Optimization Problems

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Recently, it has been shown that cardinality-constrained optimization problems can be reformulates as continuous problems with a complementarity-type constraint. Howecer, since classical MPCC theory cannot be applied directly to this reformulation, special first-order necessary optimality conditions and relaxations schemes have been developed for the continuous reformulation.
In this presentation, we complement the existing results by developing necessary and sufficient second-order optimality conditions for the continuous reformulation, from which we also can obtain analogous conditions for the original cardinality-constrained problem. Furthermore, we show how the new second-order results can be used to improve the convergence theory of relaxation methods by locally guaranteeing the existence of solutions of the relaxed problems and their convergence.

This research is supported by the 'Excellence Initiative' of the German Federal and State Governments and the Graduate School of Computational Engineering at Technische Universität Darmstadt.

Joint work with: Max Bucher (TU Darmstadt, Graduate School CE)

Shape Identification problems

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The aim of this talk is to investigate shape identification problems. In fact, the main question that shall be interested us is how one can recognize a domain of R n in which an overdetermined problem with PDE is satisfied namely for elliptic PDE cases. Characterization results of shape recognition will be given. Our approach is relied on shape optimization tools, PDE techniques and diffential and semi differential geometries.

Lay-up optimization for a tube-like high loaded composite structure

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Fiber reinforced composites are widely used in the aircraft industry for production of spars, wings, stingers, etc., which have to withstand the loading forces with varied intensity and direction. Such composite structures are usually manufactured with orthotropic material properties that provide better ratio of mechanical stiffness to the weight and decreased failure probability in comparison to the structures made from isotropic materials. In this study we investigated the behavior of the tube-like glass fiber reinforced composite structure loaded by bending forces, which cause the strains along the tube, and distributed torque leading to the twist deformations. The analysis of various lay-up schemes and its angles is performed for three most critical loading scenarios by the three-dimensional finite element simulations. The curvilinear coordinate system is intended on the external surface of the tube to define the external loads and structural anisotropy of the laminate. Lay-up scheme and mechanical properties vary with each simulation, but it is assumed them to be invariable along the tube and depend from chosen lay-up scheme. For each lay-up scheme the elastic moduli and their angular dependencies are determined both by the finite element method and classical laminates theory. Multiobjective optimization is implemented on the final stage of investigation to define the lay-up scheme, which provides minimal total strain energy and peak of von Mises stress. Selection of the best lay-up scheme from several optimal solutions is based on expert evaluation taking into account complexity of manufacturing, weight of ready structure, its natural vibration modes and other requirements and constraints.

Joint work with: Igor Zhilyaev, Natalia Snezhina, Mikhail Flek and Jiing-Kae Wu

Optimum experimental design for interface identification problems

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In many applications, which are modeled by partial differential equations, there is a small number of spatially distributed materials or parameters distinguished by interfaces. It is thus preferable to treat the shape as variable instead of the parameter itself in order to achieve high spatial resolutions. The identification of these interfaces leads to infinite dimensional optimization problems since shapes are typically interpreted as points on a manifold.
In this talk we present an optimum experimental design approach for this class of shape optimization problems. Starting from an algorithm for the interface identification in diffusion processes we develop a method which describes optimal sensor placements in space and time. In particular, we comment on the challenges arising compared to classical OED in vector spaces.

Joint work with: Tommy Etling, Roland Herzog (TU Chemnitz)

Model Reduction for Optimal Control of Drinking Water Networks

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Daily operations planning of drinking water supply networks leads to optimal control of large nonlinear DAE models defined on the network graph. Based on snapshots of the node pressures over time, we perform a proper orthogonal decomposition that is turned into a clustering of nodes and arcs by a suitable algorithm. The reduced network model is then obtained by an optimal reallocation of arc flows in the clustered graph, based on flow snapshots corresponding to the pressure snapshots. We discuss the theoretical basis of our approach and presents preliminary computational results.

Joint work with: Sara Grundel and Petar Mlinarić

A Remark On Totally Ordered Cones

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In this study, we show that every Banach space with a Schauder basis has a totally ordering cone that produce an order structure. Indeed, it is a lexicographical-like order structure since it can be considered as a generalisation of lexicographical order in finite dimensional spaces. We also provide order structural properties that are associated with this cone structure.

Consensus-Based Global Optimization

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We discuss a first-order stochastic swarm intelligence model in the spirit of consensus formation, namely a consensus-based optimization algorithm, which may be used for the global optimization of a function in multiple dimensions. The algorithm allows for passage to the mean-field limit resulting in a nonstandard, nonlocal, degenerate, parabolic PDE. Exploiting tools from PDE analysis we provide convergence results that help to understand the asymptotic behavior of the swarm intelligence model. In fact, under some assumptions it is possible to show the convergence of the algorithm to a state located arbitrary close to the global minimum of the objective function. Further, one can obtain a convergence rate. Numerical results underline the feasibility of the approach.

Joint work with: René Pinnau, Oliver Tse, Stephan Martin, José A. Carrillo, Young-Pil Choi

Robust optimization of PDEs: Combining MG/OPT and Multilevel Monte Carlo

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The multilevel Monte Carlo method can be used to efficiently generate a gradient (or Hessian vector product) for robust PDE constrained optimization problems [1]. Considering multiple levels reduces the computational time by orders of magnitude. These quantities are normally returned at the finest level. A gradient (or Hessian) based optimization algorithm is built around this code to do the actual optimization. The optimization algorithm must only supply a point in which it needs the gradient, and a requested accuracy for the gradient. It is not aware of any details of the gradient calculation. The optimization steps must then be done only on the finest level. For some PDEs this may result in rather slow convergence. However, this could be improved by also allowing the optimization to use information of the gradient on the multiple levels that exist in the multilevel Monte Carlo algorithm. Optimization steps can then be done on these levels also. A framework for this exists, called MG/OPT (multigrid optimization) [2]. It is equivalent or similar (depending on the precise problem) to executing multigrid techniques on the gradient equation. Like any multigrid method, it speeds up the slow convergence for the low frequency components in the solution, resulting in fewer optimization iterations. In this talk we investigate how the MLMC method can be integrated in the MG/OPT framework, and compare the performance of this approach for a tracking type robust optimization problem constrained by a model elliptic diffusion PDE with lognormal diffusion coefficient.

Joint work with: Stefan Vandewalle

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Variational mesh denoising and surface fairing using the total variation of the normal

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In this talk we present a novel approach to solve a surface mesh denoising problem. The goal is to remove noise while preserving shape features such as sharp edges. The total variation of the normal vector field in various norms serves as a regularizing functional to achieve this goal. We propose a novel technique for the numerical treatment of this problem, based on a level-set representation of the surface and Galerkin finite element discretization.

Joint work with: Roland Herzog, Stephan Schmidt and Marc Herrmann

Finite element discretization of nonlocal diffusion models

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We are interested in finite element discretizations of steady-state nonlocal diffusion problems, where the operator of interest is characterized by a certain kernel function. This kernel is a two-point function accounting for interactions between two points in space. In many applications interactions are assumed to occur only up to a certain distance. Consequently, during the assembly process one is faced with the difficulty of integrating over the intersection between the Euclidean ball and an element of the underlying grid. Here, we propose another model allowing for slightly more general supports of the kernel function including, e.g., rectangular norm balls, leading to a significant reduction of computational effort. We present analysis and numerical results in comparison to the standard model while focusing on the asymptotic behavior as interaction sets shrink to points or increase to the whole space, as well as the case neither near these cases.

Joint work with: Marta D'Elia, Max Gunzburger and Volker Schulz

Iterative methods to solve control problems with L^0 control cost

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We consider problems with L^0-control cost of the type

$$\min J(u) := f(u) + \frac{\alpha}{2}\|u\|^2_{L^2(\Omega)} + \|u\|_0,$$

where $\|u\|_0$ denotes the measure of the set $\{x \in \Omega : u(x) \neq 0\}$. Here, we have in mind to choose f as some observation functional of the solution of a partial differential equation with control u. We propose to use a proximal gradient method, which is similar to a hard-thresholding iteration. We prove that for weak limit points $\overline{u}$ of the iterates (u_k) in $L^2(\Omega)$ it holds

$$F(\overline{u}) \leq \liminf F(u_k),$$

which is remarkable as the mapping $u \mapsto \|u\|_0$ is *not* sequentially weakly lower semi-continuous in $L^2(\Omega)$. Under an additional compactness assumption on $u \mapsto \nabla f(u)$, we obtain that each weak limit point is a strong limit point. In addition, we will report on numerical experiments.

Continuous transportation as a material distribution topology optimization problem

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Transportation problems have a long history in science. Already in 1781, Monge studied the problem of how to minimize the work required to move a commodity with a given initial mass distribution to a pre-specified target mass distribution. Monge's problem formulation considers the computation of transport paths, which distinguishes it from route planning problems that are restricted to an existing network. The seminal work by Monge has been generalized by many researchers. During the last few decades, there has been a renewed activity in studying these transportation problems. Currently, the problem is well understood from a theoretical perspective; however, the numerical treatment of the problem has this far received little, if any, attention.

Flow network problems are by far the most investigated domain of transportation theory, and have resulted in a row of now mature tools from linear, integer, and constraint pro- gramming. This should come as no surprise, since most transportation is undertaken on an existing infrastructure. However, from an economics perspective, it is on the other hand of interest to target not only transportation cost, but also the cost for road construction. Such considerations come into play also on a smaller scale, for instance in agriculture or forestry, when temporary or otherwise designated roads must be paved. Here, we consider a version of this problem aiming to minimize a combination of road construction and transportation cost by determining, at each point, the local direction of transportation. Here, we aim to solve numerically a continuous transportation problem using *material distribution* based topology optimization. The rationale for this is that road design is effectively a material distribution problem, and transportation is nothing but flow of matter.

Here, we consider a commodity that is produced or consumed at the space dependent rate q and transported with velocity $\mathbf{u}$, where $|\mathbf{u}| = v$, and $v : \mathbb{R}^2 \mapsto \mathbb{R}^+$ is a space dependent transportation speed. Moreover, we assume that the production, transport, and consumption of the product are all confined to be inside a region $\Omega \subset \mathbb{R}^2$. To model and solve the problem to minimize a combination of road construction and transportation cost, we use two design fields. The first of these, α is a material indicator function for the road layout, which in turn determines the transportation speed ($v = v_{max}$ where $\alpha = 1$, and $v = v_{min}$ where $\alpha = 0$). The second design field is determines at each point the local direction of transport.

This presentation covers the modeling of the problem, highlights how it can be formulated as a material distribution topology optimization problem, and shows optimized road designs for a few test cases where the supply and demand positions are concentrated around given points as well as distributed over given subdomains of Ω. By solving the optimization problem for a sequence of different weightings between road construction and transportation cost, we obtain a sequence of road designs corresponding to different trade-offs between these costs. Such solutions and their corresponding relative road construction and transportation cost may provide guidance when making decisions regarding if and where to construct roads to increase transportation efficiency.

Joint work with: Daniel Noreland

Optimization by Successive Abs-Linearization in Function Spaces

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For finite dimensional problems that are unconstrained and piecewise smooth the optimization based on successive piecewise linearisation is well analysed yielding for example linear or even quadratic convergence under reasonable assumptions on the function to be optimised. In this talk we consider related problems in function spaces, where the nonsmoothness stems from the absolute value function interpreted as Nemytskii operator. We present a quadratic overestimation method called SALOP that is based on successive abs-linearizations to solve the optimization problem and show convergence results for different stationarity concepts.

Joint work with: Olga Ebel, Stephan Schmidt, and Andreas Griewank

Multi-Objective Optimization of the Stall Characteristics of an Unmanned Aerial Vehicle

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The widespread use of unmanned aerial vehicles (UAV) has become clear over recent years. These aircraft are often characterized by a blended wing body (BWB), noted by their tailless design and swept wings: the former to increase its efficiency and the latter to ensure longitudinal static stability, i.e. the natural desire of the airplane to remain in its equilibrium position. The consequence of the swept wing is an increased likelihood of flow separation initiating at the tip, resulting in a nose-up pitching moment which pulls the plane further into stall, commonly referred to as tip-stall.

The presence of tip-stall has led to a renewed interest in the use of devices to counter it, such as wing fences. These aerodynamic devices can be seen as planes placed on top of the wing aligned with the flow and developed from the idea of stopping the transverse component of the boundary layer flow. The straightforward design and application has led to an extensive usage from the '50s to '80s and still persists up to this day.

The influence of the design parameters of wing fences on the flight behavior of the UAVs is yet to be laid bare. Therefore, these are optimized in order to obtain the design that would fence off the appearance of a pitch-up moment at high angles of attack, without a significant loss of lift and controllability. This brings forth a constrained multi-objective optimization problem. The influence of the design parameters on the aerodynamic coefficients is assessed through CFD simulations. The $\gamma - Re_\theta$ model is used to correctly model the low Reynolds effects that characterize the flow over a UAV.

The high computational cost that is attributed to this model encourages the use of efficient global optimization (EGO) techniques. A framework is developed around surrogate mo- deling, namely kriging. Furthermore, a Generalized Asynchronous Multi-objective Optimization (GAMO) infill criteria is realized that allows multiple points to be selected to be evalu-ated in an asynchronous manner while the balance between design space exploration and ob-jective exploitation is adapted during the optimization process. The result is a wing fence design that extends the flight envelope of the aircraft, ob-tained with a feasible budget. Both the framework and the infill methodology lend themselves to be used within a wider range of aeronautical design problems and further pave the way to extending the capabilities of aircraft.

Joint work with: Joris Degroote

A Low-Rank Approach for Parameter-Dependent Nonlinear Fluid-Structure Interaction Problems

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Optimization of fluid structure interaction applications requires the repeated evaluation of the same simulation model for varying design parameters. Consider a parameter-dependent nonlinear fluid-structure interaction problem where $m_1 \in \mathbb{N}$ different fluid densities and solids with $m_2 \in \mathbb{N}$ different shear moduli and $m_3 \in \mathbb{N}$ different first Lamé parameters are involved. A bilinear finite element discretization with $n \in \mathbb{N}$ degrees of freedom results in linear systems of equations of the form

$$(A_0 + \rho_f^{i_1} A_1 + \mu_s^{i_2} A_2 + \lambda_s^{i_3} A_3)x = b \tag{1}$$

where $i_1 \in \{1, ..., m_1\}$, $i_2 \in \{1, ..., m_2\}$ and $i_3 \in \{1, ..., m_3\}$. The fluid densities are given by $\rho_f^{i_1}$, the shear moduli by $\mu_s^{i_2}$ and the first Lamé parameters by $\lambda_s^{i_3}$. The right hand side $b \in \mathbb{R}^n$ and the matrices $A_0,\ A_1,\ A_2,\ A_3 \in \mathbb{R}^{n\times n}$ are related to bilinear finite element discretizations of functionals involved in the weak formulation of the nonlinear fluid-structure interaction problem. The nonlinearity, the convection term coming from the Navier-Stokes equations, takes influence on A_1 only. Finding approximations of (1) for all possible sample combinations $(\rho_f^{i_1}, \mu_s^{i_2}, \lambda_s^{i_3})$ would lead to tackling $m_1m_2m_3$ equations of the form (1). We will see how this problem can be translated into a matrix equation of the form

$$A_0X + A_1XD_1 + A_2XD_2 + A_3XD_3 = B$$

where $B \in \mathbb{R}^{n\times m_1m_2m_3}$ and $D_1, D_2, D_3 \in \mathbb{R}^{m_1m_2m_3\times m_1m_2m_3}$. In (2) the unknown is a matrix $X \in \mathbb{R}^{n\times m_1m_2m_3}$. X can then be represented as a tensor which gives rise to a low-rank method that provides faster convergence and requires less memory than tackling (1) directly $m_1m_2m_3$ times.

Joint work with: Prof. Dr. Peter Benner and Prof. Dr. Thomas Richter

Total variation and related higher order methods for the restauration of manifold-valued images and data

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Nonlinear manifolds appear as data spaces in various applications. One example in image processing is diffusion tensor imaging, where the data sitting in every voxel is a positive matrix representing the diffusibility of water molecules measured at the corresponding spatial location. Another example is color image processing, where instead of the RGB representation often other formats such as HSI or HSV are used which employ a circle to represent the hue of a color. A third example are registration problems (e.g., between a camera and an ultrasound devise) where time series of euclidean motions appear. Since the measured data is often noisy, regularization of these nonlinear data is necessary. In this talk, we propose algorithms for the variational regularization of manifold-valued data using non-smooth functionals. In particular, we deal with algorithms for TV regularization and with higher order methods including the TGV denoising of manifold-valued data. We further consider the situation of an indirect data term. We present concrete applications in medical imaging tasks.

Joint work with: Kristian Bredies, Laurent Demaret, Martin Storath, Martin Holler

On Techniques for Shape Optimization Problems Constrained by Variational Inequalities

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In this talk, the differential-geometric structure of certain shape spaces is investigated and applied to the theory of shape optimization problems. In particular, shape optimization problems constrained by variational inequalities (VIs) are treated from an analytical and numerical point of view in order to formulate approaches aiming at semi-smooth Newton methods on shape vector bundles. Shape optimization problems constrained by VIs are very challenging because of the necessity to operate in inherently non-linear and non-convex shape spaces. In classical VIs, there is no explicit dependence on the domain, which adds an unavoidable source of non-linearity and non-convexity due to the non-linear and non-convex nature of shape spaces.

Joint work with: Björn Führ and Volker Schulz

Error Estimates for Bilinear Boundary Control Problems

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In this talk we consider bilinear boundary control problems, this is, the (possibly non-constant) Robin coefficient of a reaction-diffusion equation with boundary conditions of third kind is the control variable. These kind of problems arise for instance in stem cell division which can be modeled by a reaction-diffusion system describing the concentration of proteins forming the cell plasma and the cell wall. To understand these chemical reactions in a better way one is mainly interested in the unknown reaction parameters which can be computed from a bilinear optimal control problem, where the desired state is a given measurement of the protein concentrations. In this talk necessary and sufficient optimality conditions for these optimal control problems are presented. Moreover, regularity of solutions and finite element approximations with corresponding error estimates are discussed. The approximate solutions are obtained by a full discretization of the optimality system with cell-wise constant controls and continuous and linear state variables. In addition, error estimates for an improved control obtained in a postprocessing step by a pointwise evaluation of the projection formula are derived.

A priori error analysis for optimization with elliptic PDE constraints

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We consider finite element solutions to quadratic optimization problems, where the state compactly depends on the control via an elliptic partial differential equation. Exploiting that a suitably reduced optimality system satisfies a Gårding inequality, we derive a priori error estimates for state, dual and control variables. The error estimates for state and dual variable are asymptotically independent of the Tikhonov regularization parameter.

Joint work with: Fernando Gaspoz, Christian Kreuzer, and Andreas Veeser

Goal–Oriented A Posteriori Error Estimation For Dirichlet Boundary Control Problems

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In this talk, we study a posteriori error estimates for the numerical approximation of Dirichlet boundary control of a convection–diffusion equation with pointwise control constraints on a two dimensional convex polygonal domain. The local discontinuous Galerkin method is used as a discretization method. We derive primal–dual weighted error estimates for the objective functional with an error term representing the mismatch in the complementary system due to the discretization. Numerical examples are presented to illustrate the effectiveness of the proposed estimators.