GOR Gesellschaft für Operations Research e.V.

Kackertstr. 7, 52072 Aachen, Tel.: +49 (0) 241 80 23830, Fax: +49 (0) 241 80 623830

GOR-Arbeitsgruppe: Praxis der Mathematischen Optimierung

Prof. Dr. Josef Kallrath,
Am Mahlstein 8
D-67273 Weisenheim am Berg
Tel: +49 172 747-0689
Fax: +49 621 60-6678297

Herewith we would like to invite you to the 98th meeting of the GOR working group "Real World Mathematical Optimization" at the German Aerospace Center (DLR) (http://www.dlr.de/dlr/desktopdefault.aspx/tabid-10254/) in Braunschweig, Germany. This meeting is being held as a symposium with the topic

Mathematical Optimization in Aeronautics and Space

The workshop takes place on May 18th and 19th, 2017. The workshop language will be English.

Please note that the participation in a GOR-AG-Workshop for non-members is subject to a registration fee, unless you are a speaker or a host.

Please register yourself online using https://www.redseat.de/pmo98/ as soon as possible, but ideally not later than May 10th, 2017. The latest information on the meeting is available on the homepage of the GOR (http://www.gor-ev.de/arbeitsgruppen/praxis-der-mathematischen-optimierung).

If you are interested to give a presentation, please, select a lecturing duration of 15+5, 25+5 or 40+5 minutes and contact one of us below.

Yours sincerely,

Josef Kallrath, Jens Schulz, Julia Kallrath & Anke Tröltzsch

(GOR AG) (DLR, Köln)

josef.kallrath@web.de jens.schulz@lhsystems.com julia.kallrath@h-da.de Anke.Troeltzsch@dlr.de

Mathematical Optimization in Aeronautics and Space

DLR (http://www.dlr.de/) is the national aeronautics and space research center of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space program. DLR is also the umbrella organization for the nation's largest project management agency.

DLR has approximately 8000 employees at 20 locations in Germany: Cologne (headquarter), Augsburg, Berlin, Bonn, Braunschweig, Bremen, Bremerhaven, Dresden, Göttingen, Hamburg, Jena, Jülich, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Oldenburg, Stade, Stuttgart, Trauen, and Weilheim. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C.

DLR's mission comprises the exploration of Earth and the Solar System and research for protecting the environment. This includes the development of environment-friendly technologies for energy supply and future mobility, as well as for communications and security. DLR's research portfolio ranges from fundamental research to the development of products for tomorrow. In this way, DLR contributes the scientific and technical expertise that it has acquired to the enhancement of Germany as a location for industry and technology.

This two-day event will attempt to give a small insight into mathematical optimization in aeronautics and space. Experts from universities, research institutions, industry and software companies are welcome to present selected problems and available solutions.

Talks could be either 15+5 min, 25+5 min or 40+5 min.

Please contact:

Katja Pleß
DLR Braunschweig
Lilienthalplatz 7
38108 Braunschweig
Germany

Tel.: 0531/295-3665
E-mail: katja.pless@dlr.de

Jens Schulz (jens.schulz@lhsystems.com), Julia Kallrath (julia.kallrath@h-da.de) or Josef Kallrath (josef.kallrath@web.de) if you are interested in presenting.

Presentations from the following speakers have been confirmed:

Liana Amaya Moreno (Helmut Schmidt University, Hamburg, Germany)
Free-flight Trajectory Planning

Prof. Dr. Hans Georg Bock (Heidelberg University, Heidelberg, Germany)
A Multiple Shooting Method for Initial Satellite Orbit Determination

M. Sc. Benedikt Grüter (Institute of Flight System Dynamics, Technical University of Munich)
Optimal Arrival Management by Primal Decomposition

Časlav Ilić (DLR, Institute of Aerodynamics and Flow Technology, Braunschweig)
Collaborative computationally intensive multi-disciplinary optimization for overall aircraft design

Prof. Dr. Josef Kallrath (GOR, Weisenheim am Berg, Germany)
Mathematical Optimization in Astronomy, Astrophysics and Space Engineering

Prof. Dr. Ekaterina Kostina (Heidelberg University, Heidelberg, Germany)
Optimal Control Methods for Collision Avoidance in Air Traffic Control

Elisabeth Lobe (PhD candidate, DLR, Simulation and Software Technology, Braunschweig)
Solving QUBO Problems on an Adiabatic Quantum Annealer

M. Sc. Patrick Piprek (Institute of Flight System Dynamics, Technical University of Munich)
Extended Trapezoidal Collocation Framework for Trajectory Optimization Models with Full-Implicit Equations of Motion

Dr. Tobias Stollenwerk (Research Scientist, DLR, Simulation and Software Technology)
Adiabatic Quantum Computing with Application in Aerospace

Roland Wagner (RICAM Linz, Linz, Austria)
Control Algorithms for Astronomical Adaptive Optics

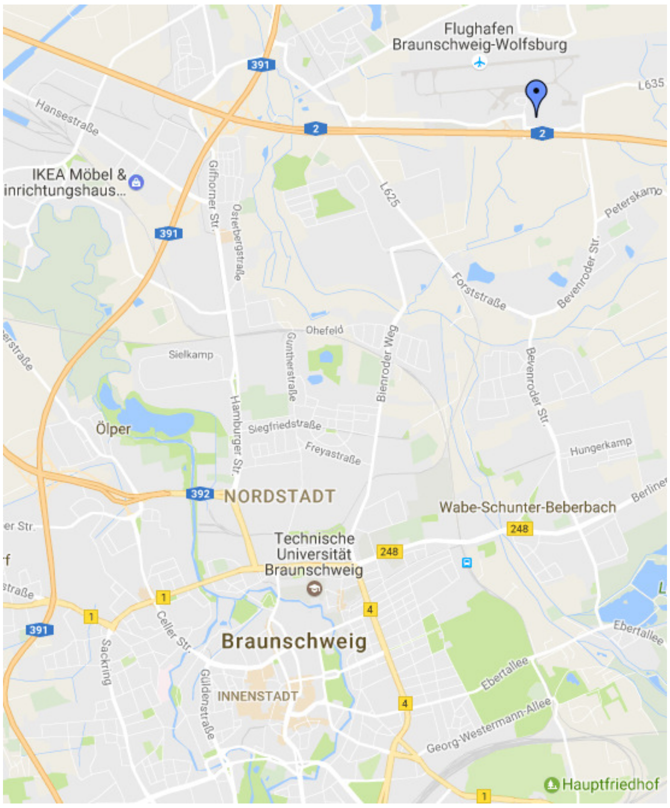
Dr. Michael Weyrauch (Physikalisch-Technische Bundesanstalt, Braunschweig)
Optimizing an exponentially large number of parameters: An example from many-body quantum theory

GOR Gesellschaft für Operations Research e.V.

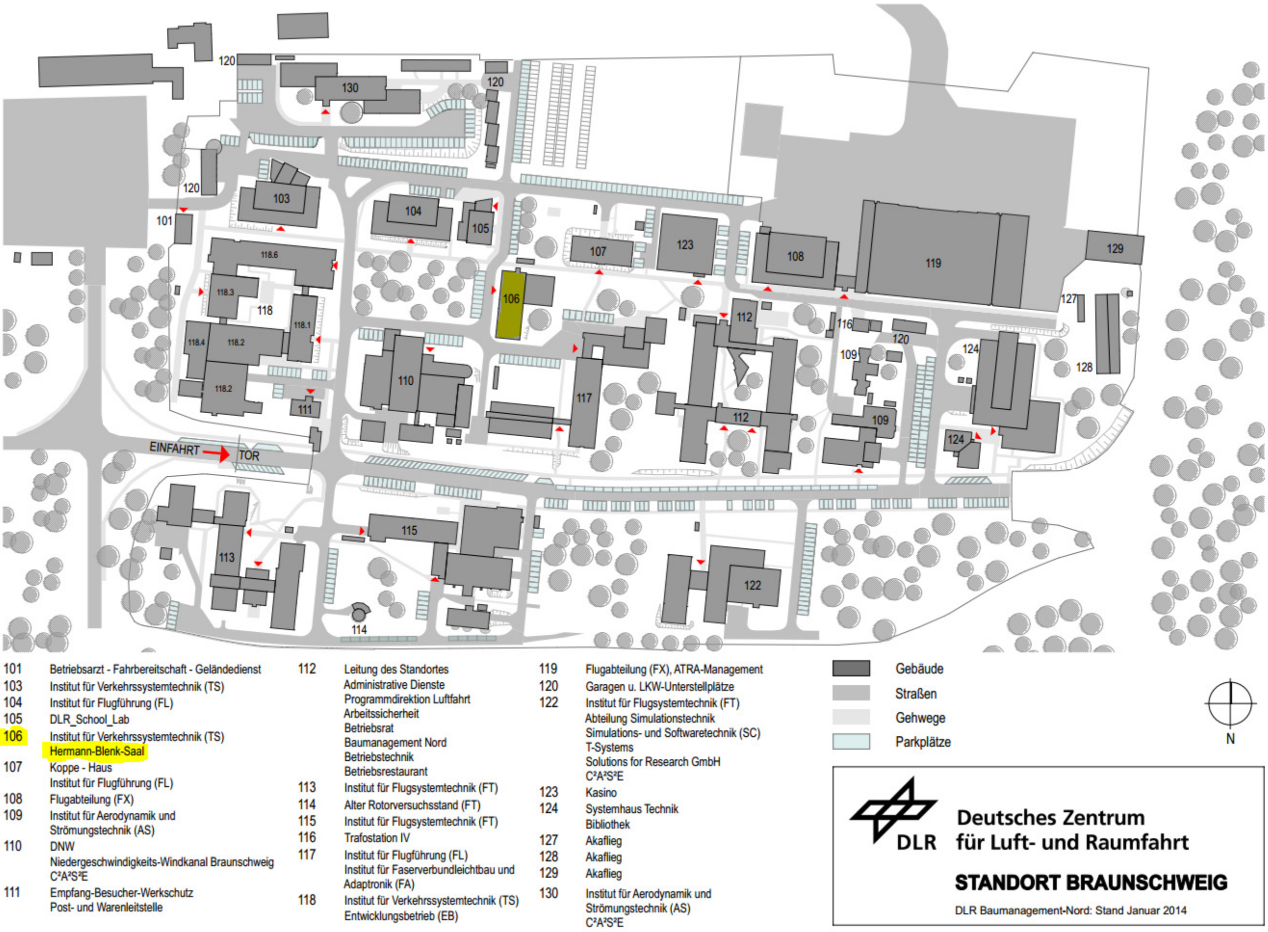
Location

Address: **DLR Braunschweig**
Lilienthalplatz 7
38108 Braunschweig

Room: Hermann-Blenk-Saal



Parking: There are only some parking possibilities at the DLR. Please contact Katja Pleß, when you will arrive with the car.



Arrival:

Please take the bus route 436 from the central railway station in the direction 'Flughafen' until bus stop 'DLR'.

Excursion:

On Thursday afternoon, an excursion will be arranged (Guided Tour at the DLR site Braunschweig). Furthermore, for up to 20 participants (first registered, first served) it will be possible to experience the “Virtual-Reality-System”, *e.g.*, flying through a 3D Mars surface, rendered from real Mars photos and developed by members of the facility Simulation and Software Technology in Braunschweig.

The place for the **conference dinner** on Thursday evening: “Restaurant Gastwerk” http://www.gastwerk.net/

Hotel list:

City Braunschweig:

- Penta Hotel
- Intercity Hotel
- Hotel Fürstenhof
- Mercure Hotel

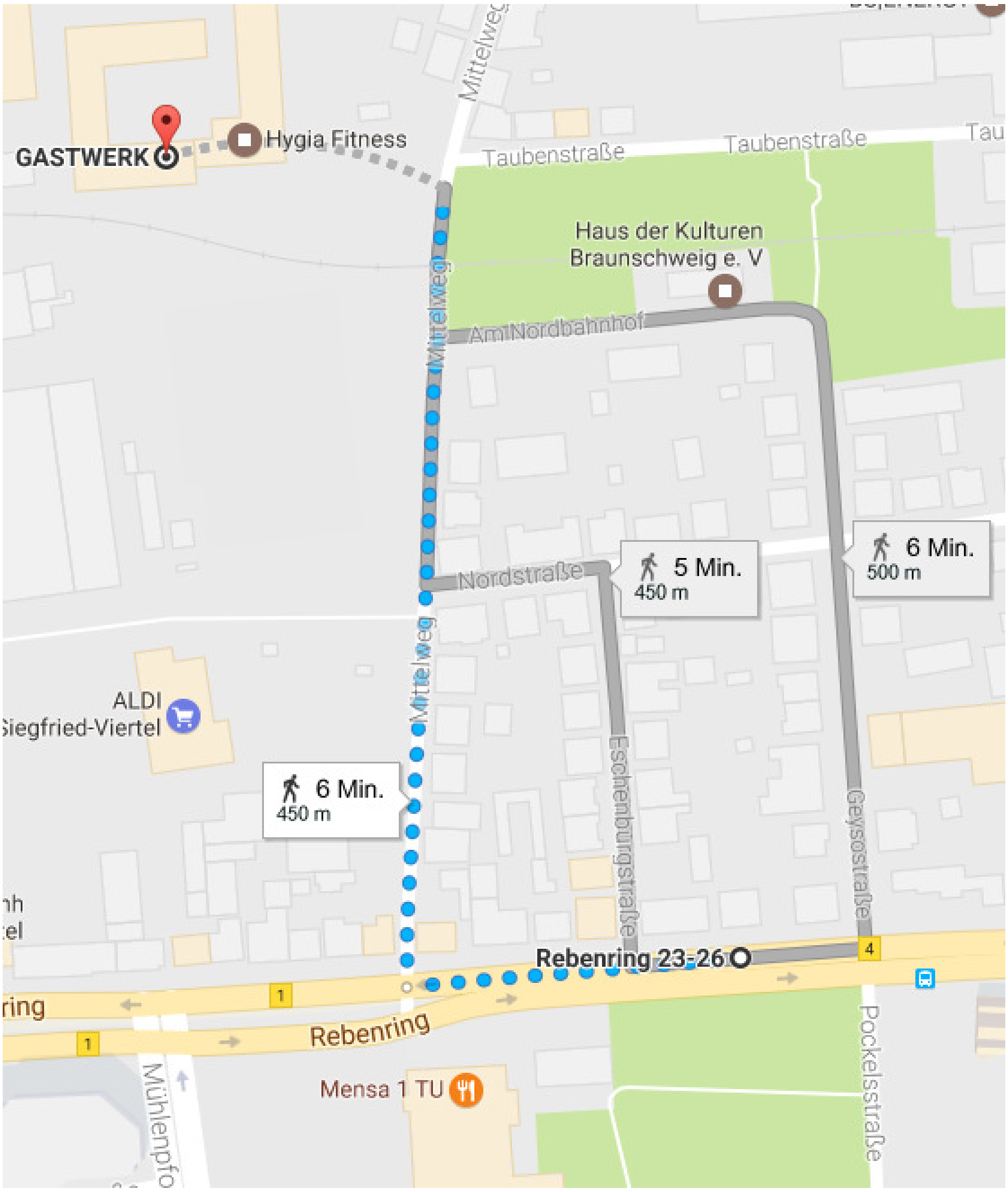
Outside City:

- EHM Hotel Braunschweig Seminarius

Conference dinner:
Gastwerk: 18:00 Uhr

Im Panther Business Center
Mittelweg 7
38106 Braunschweig
http://www.gastwerk.net/

Arrival to the restaurant:
Please take the bus route 426 from the bus stop ‘DLR’ (Platform A) in the direction 'Hamburger Straße' until bus stop 'Pockelstraße'.
Then follow the way marked in the map:



GOR Gesellschaft für Operations Research e.V.

Joseph-Sommer-Straße 34, 41812 Erkelenz, Tel.: 02431 9026710, Fax: 02431 9026711

98th Meeting of the GOR Working Group
„Real World Mathematical Optimization“

Mathematical Optimization in Aeronautics and Space

German Aerospace Center (DLR), Braunschweig, May 18 & 19, 2017
DLR Braunschweig, Lilienthalplatz 7, 38108 Braunschweig
Room: Hermann-Blenk-Saal

Thursday, May 18 - 2017: 09:30 – 21:00

09:30-10:00 **Welcomes** to the first day ; coffee and refreshments

10:00-10:10 **Opening and Welcome** (Josef Kallrath & Anke Tröltzsch)

10:10-10:30 **Anke Tröltzsch** (DLR, Cologne)
Begrüßung und Vorstellung – DLR Aktivitätsfelder

10:30-11:15 **Prof. Dr. Hans Georg Bock** (Heidelberg University, Heidelberg
A Multiple Shooting Method for Initial Satellite Orbit Determination

11:15-11:45 **Liana Amaya Moreno** (Helmut Schmidt University, Hamburg, Germany)
Free-flight Trajectory Planning 25+5

11:50-12:50 ------------------------------ Lunch Break ---------------------------------

13:00-14:00 **Visit & Guided Tour:** Guided Tour at the DLR site Braunschweig
"Virtual-Reality-System"

14:05-15:15 **Zur freien Verfügung** (im Umfeld der Kantine oder Seminarraum)
Für Gespräche, Spaziergang, Mittagsschlaf ….

15:15-15:45 ------------------------------ Coffee Break --------------------------------

15:45-16:15 **Patrick Piprek** (Institute of Flight System Dynamics, TU Munich)
Extended Trapezoidal Collocation Framework for Trajectory Optimization Models with Full-Implicit Equations of Motion

16:15-16:45 **Roland Wagner** (RICAM Linz, Linz, Austria)
Control Algorithms for Astronomical Adaptive Optics

16:45-17:30 **Prof. Dr. Josef Kallrath** (GOR, Weisenheim am Berg, Germany)
Mathematical Optimization in Astronomy, Astrophysics and Space Engineering

17:30-18:00 ----- Bus oder Taxifahrt zum Conference Dinner -----

18:00-21:00 **Conference Dinner** at "Restaurant Gastwerk" http://www.gastwerk.net/
Celebrating the 98th meeting of our GOR Working Group
----- Taking a Group Photograph for the OR News and Press -------

Friday, May 19 - 2017: 09:30 – 16:00

09:00-09:30 Welcomes to second day ; coffee and refreshments

09:30-10:15 Dr. Michael Bussieck & **Frederik Fiand** (GAMS GmbH, Cologne, Germany)
BEAM-ME - Acceleration Strategies for Energy System Models on High Performance Computers

10:15-10:45 ------------------------------ Coffee Break ---------------------------------

10:45-11:15 **Elisabeth Lobe** (PhD candidate, DLR, Simulation and Software Technology)
Solving QUBO Problems on an Adiabatic Quantum Annealer

11:20-11:50 **Dr. Tobias Stollenwerk** (Simulation and Software Technology, DLR)
Adiabatic Quantum Computing with Application in Aerospace

11:55-12:55 ------------------------------ Lunch Break ----------------------------------

13:00-13:45 **Prof. Dr. Ekaterina Kostina** (Heidelberg University, Heidelberg, Germany)
Optimal Control Methods for Collision Avoidance in Air Traffic Control

13:45-14:05 **Benedikt Grüter** (Institute of Flight System Dynamics, TU Munich)
Optimal Arrival Management by Primal Decomposition

14:10-14:40 ------------------------------ Coffee Break ---------------------------------

14:40-15:10 **Dr. Michael Weyrauch** (Physikalisch-Technische Bundesanstalt, Braunschweig)
Optimizing an exponentially large number of parameters: An example from many-body quantum theory

15:15-15:45 **Časlav Ilić** (DLR, Institute of Aerodynamics and Flow Technology)
Collaborative computationally intensive multi-disciplinary optimization for overall aircraft design

15:45-16:00 **Final Discussion – End of the Workshop – Coffee Break**

Location: DLR Braunschweig, Lilienthalplatz 7, 38108 Braunschweig
Room: "Hermann-Blenk-Saal" 4th floor

The Speakers

Liana Amaya Moreno is a researcher and teaching assistant at the Helmut Schmidt University Hamburg within the research group Applied Mathematics working under the supervision of Univ.-Prof. Dr. Armin Fügenschuh. Her main research interest is mixed-integer linear and nonlinear programming. Her current work focuses on the Free-flight Trajectory Planning, more precisely, investigating advantages and drawbacks of different approaches used to formulate such problem.

Michael R. Bussieck is a Senior Research Analyst at GAMS Software GmbH. From 1999 to 2004 he worked at the GAMS Development headquarters in Washington DC, USA. He received his Ph.D. from Technical University Braunschweig, Germany.

Frederik Fiand is an Optimization Analyst at GAMS Software GmbH. He received his diploma degree in Financial Mathematics and Mathematical Economics from the Technical University of Braunschweig, Germany, where he also held a position as research associate at the Institute for Mathematical Optimization from 2013 to 2015.

Benedikt Grüter is research associate at the Institute of Flight System Dynamics of the Technical University of Munich. After graduating RWTH Aachen University in 2014 he joined the Trajectory Optimization Research Group, which focuses on the application of optimal control methods in the context of aeronautical optimization. His research interests comprise the problems of optimal air traffic management, combining discrete optimization methods and optimal control.

Časlav Ilić is a research engineer at the Institute of Aerodynamics and Flow Technology of the German Aerospace Center (DLR). He graduated aeronautical engineering at the University of Belgrade, Serbia, and computational engineering at the University of Erlangen-Nuremberg, Germany. His special focus is on adjoint gradient-based optimization methods in aerodynamics and collaborative multi-disciplinary optimization approaches.

Josef Kallrath obtained his PhD in astrophysics from Bonn University (Germany) in 1989. He is professor at the University of (Gainesville, FL, www.astro.ufl.edu/∼kallrath), and solves real-world problems in industry using a broad spectrum of methods in scientific computing, from modeling physical systems to supporting decisions processes by mathematical optimization. He has written review articles on the subject, about 70 research papers in astronomy and applied mathematics, and several books on mixed integer optimization, as well as one on eclipsing binary stars.

He leads the Real World Optimization Working Group of the German Operations Research Society. His current research interests are polylithic modeling and solution approaches to solve large-scale or difficult optimization problems, for instance, by decomposition techniques such as column generation, or hybrid methods.

Ekaterina Kostina is Professor of Numerical Optimization at Heidelberg University. After completing her university studies and PhD in mathematics in Minsk (Belarus), she accepted a position as research assistant at Heidelberg Universitys Interdisciplinary Center for Scientific Computing (IWR) in 1997. From 2006 to 2015 she held the Chair of Numerical Optimization at the University of Marburg. She is a founding member of the national Committee for Mathematical Modeling, Simulation and Optimization (KoMSO). Prof. Kostinas research focuses on the development of numerical methods of non-linear optimization and optimal control and their application to complex dynamic processes in science and technology. Along with colleagues from the IWR, she also contributes to the Heidelberg Collaboratory for Industrial Optimization (HCO).

Elisabeth Lobe is a research associate and PhD candidate at the DLR Institute Simulation and Software Technology in the Department for Software for Space Systems and Interactive Visualization. She received her Master's degree in Mathematics at the Otto-von-Guericke University of Magdeburg, Germany, in 2016. Besides her work in the group Modeling and Simulation, which mainly focuses on the development of the software tool Virtual Satellite, she is involved in the project Quantum Computing, where in particular the capabilities of adiabatic quantum annealing in solving combinatorial optimization problems are investigated.

Patrick Piprek is a research associate and PhD candidate at the Institute of Flight System Dynamics (FSD) of the Technical University Munich (TUM). He got his Master's degree in Aerospace from TUM in 2016. Since then, he has been working at the FSD in the trajectory optimization research group. His main research areas are robust optimal control and optimal control of implicit and differential-algebraic models.

Tobias Stollenwerk received is German diploma in physics in 2007 from the University of Bonn. Afterwards he worked as a research assistant in computational photonics for two years in Bonn. From 2009 to 2013 he did his Ph.D. in theoretical condensed matter physics in the group of Johann Kroha at the University of Bonn. Since 2013 he has been working at the German Aerospace Center with a focus on quantum computing. In 2016 and 2017 he was a visiting researcher at the Quantum Artificial Intelligence Laboratory at NASA Ames for several month, each.

Roland Wagner is a research assistant at RICAM in Linz, Austria. He is member of the Austrian Adaptive Optics team, which is part of instrument consortia for the to-be-built European Extremely Large Telescope. His main research interests are inverse problems, image processing and mathematical methods in adaptive optics.

Michael Weyrauch is a Senior Scientist in the group "Fundamental Physics for Metrology" at the Physikalisch Technische Bundesanstalt in Braunschweig, Germany.

Free-fligh Trajectory Planning

Liana Amaya Moreno
Helmut Schmidt University
Holstenhofweg 85, 22043 Hamburg, Germany
e-mail: lamayamo@hsu-hh.de

Free-flight emerged as a dynamic alternative to the traditional network approach of Flight Trajectory Planning. Free-flight trajectories are not aligned to the air travel network (ATN), instead, the full 4D space (3D+time) is used for the computation of fuel-efficient trajectories that minimize the travel costs. From a computational point of view, the challenge is to find a trajectories, composed of adjacent segments connecting two points (on the earth's surface), that avoid head-winds and benefit from tail-winds. The wind field usually differs in various flight levels (altitudes), therefore both the speed of the aircraft and a flight altitude must be assigned to each of the segments composing the trajectory so that the fuel consumption during the whole flight time is minimized. Moreover, a time constraint is always enforced in order not to incur extra costs due to early or late arrival. This problem is computationally difficult, therefore it is solved in practice, in two subsequent stages: a horizontal phase, in which the segments of a 2D trajectory are computed, and then a vertical phase, in which different flight levels are assigned to the segments. We propose a nonlinear programming model for the computation of free-flight trajectories. This model requires continuous formulations of the problem's input data such as the fuel consumption and the weather data, hence approximation techniques are required. We integrate the formulation of these approximations into our NLP model using AMPL as modelling language along with the solvers SNOPT, KNITRO and MINOS. We present numerical results on test instances using real-world data provided by our project partner Lufthansa Systems AG and compare the resulting trajectories in terms of the fuel consumption, the trajectories, and the computation times.

A Multiple Shooting Method for Initial Satellite Orbit Determination

Hans Georg Bock
Heidelberg University
Im Neuenheimer Feld 205, Heidelberg, Germany
e-mail: bock@iwr.uni-heidelberg.de

E.Kostina, S. M. Lenz, J. P. Schlöder, G.Gienger, G. Ziegler
Heidelberg University
Im Neuenheimer Feld 205, Heidelberg, Germany
e-mail: Ekaterina.Kostina@iwr.uni-heidelberg.de

After a satellite has been launched, the determination of its initial orbit is one of the primary tasks to be accomplished by mission control: e.g., in order to prepare for high-precision orbit determination or orbital transfers. This task is particularly time critical after faulty launches. Tracking measurements acquired by ground stations are the basis for the determination of the unknown orbit parameters. In this presentation, the orbit determination problem is tackled by a newly developed multiple shooting method for a reliable and fast solution of this parameter estimation problem. For the generation of initial guesses, the method incorporates special projection techniques specifically tailored to the available measurement data. Original tracking data of the launch and early orbit phases of the Artemis satellite and the second pair of Cluster-II satellites are used for tests of the method. Both scenarios constitute particularly challenging benchmark problems, because the satellites were launched into orbits significantly different from the expected ones. A comparison to the widely employed single shooting method reveals that the newly developed method significantly improves the convergence behavior.

BEAM-ME - Acceleration Strategies for Energy System Models on High Performance Computers

Michael R. Bussieck
GAMS Development Corporation
1217 Potomac Street, NW, Washington, DC 20007, USA
e-mail: MBussieck@gams.com

Frederik Fiand
GAMS Software GmbH
P.O. Box 4059, 50216 Frechen, Germany
e-mail: FFiand@gams.com

BEAM-ME is a project funded by the German Federal Ministry for Economic Affairs and Energy and addresses the need for new and improved solution approaches for energy system models of vast size. The project unites various partners with complementary expertise from the fields of algorithms, computing and application development.

The main focus is on problems that can be modeled as large-scale linear programs (LPs) that are computationally intractable for state-of-the-art solvers. A distinctive characteristic of the LPs arising from the BEAM-ME energy models is their block-diagonal structure with both linking variables and linking constraints. The structure and the size of the problems allow to parallelize the solving procedure and to implement it on supercomputers.

We provide an overview on the large variety of challenges we are facing within this project, present current solutions approaches and provide first results.

Optimal Arrival Management by Primal Decomposition

Benedikt Grüter
Institute of Flight System Dynamics, Technical University of Munich
Boltzmannstr. 15, 85748 Garching b. München, Germany
e-mail: benedikt.grueter@tum.de

Optimal arrival management is a challenging application for optimal control and combinatorial optimization methods, which can be utilized simultaneously to find optimal sequences and trajectories. A primal decomposition approach is introduced, reformulating the resulting mixed-integer optimal control problem as a bi-level optimization. The upper level of this decomposition determines the runway sequencing, where the solution of the lower level problems define the optimal trajectories of each individual aircraft.

The two levels of the decomposed, discrete optimal control problem for all arriving aircraft are coupled via the objective functions of the lower level problems and the final time constraints imposed by the upper level. Besides the objective values, first and second order derivative information w.r.t. the optimization variables of the upper level problem can be passed to the upper level. This enables forming a quadratic program, facilitating the solution of the bi-level problem and improving convergence time.

Collaborative computationally intensive multi-disciplinary optimization for overall aircraft design

Časlav Ilić
German Aerospace Center (DLR)
Lilienthalplatz 7, 38108 Braunschweig, Germany
e-mail: caslav.ilic@dlr.de

We present the work on establishing a multi-disciplinary optimization (MDO) platform for computationaly intensive aircraft design across the institutes of the German Aerospace Center (DLR), performed in the scope of DLR projects Digital-X and VicToria. The "platform" in this sense comprises the choice of the optimization methods and couplings between disciplinary analyses based on low- to high-fidelity modeling of relevant physical phenomena, and, crucially, the choice of process implementation framework and execution infrastructure and organization of collaboration among the team members. The goal is to have team members from different institutes directly involved in the MDO activity, from planning to execution and inspection of results. We demonstrate these elements on a gradient-free MDO process developed during the Digital-X project, discuss what we learned from it, and provide an outlook of a hybrid gradient-free/gradient-based MDO process to be developed in the VicToria project.

Mathematical Optimization
in
Astronomy, Astrophysics and Space Engineering

Josef Kallrath
GOR Arbeitsgruppe
Praxis der mathematischen Optimierung
Am Mahlstein 8, 67273 Weisenheim am Berg, Germany
e-mail: josef.kallrath@web.de

In this lecture, various decision problems occurring in Astronomy/Astrophysics and space engineering are treated as mathematical optimization problems leading to mixed integer programming problems.

In astronomy and astrophysics least squares problems are typical minimization problems. In space science we find cargo accommodation problems for a space vehicles, 3-dimensional packing problems arising in space engineering, payload design, spacecraft design as a multi-criteria decision-making, or trajectory design combining low-thrust and gravity assist manoeuvres.

The basic objects of optimization models: indices, data, variables, constraints and objective functions. Depending on the constraints and objective function, we obtain Linear Programming (LP), Mixed Integer Linear Programming (MILP), Nonlinear Programming (NLP) or Mixed Integer Nonlinear Programming (MINLP) problems. These problems can be easily coded in Algebraic Modeling Systems, such as GAMS, and solved by existing solvers or by tailor made algorithms.

After an introductory overview and a comparison of scientific work in Astronomy/Astrophysik versus modeling real world optimization problems, two problems are discussed in detail:

- *Launch campaign analysis for commercial communication satellites* treated as a Linear Programming problem.
- *On-orbit satellite servicing* treated as a space based vehicle routing problem.

Finally, fitting data to models and least squares problems leads to nonlinear optimization. If these problems are nonlinear and non-convex, we are facing several local minima might occur. One often sees global search, *e.g.*, Simulated Annealing, applied in such situations. However, if we can formulate the model algebraically, deterministic global optimization methods can be used, which allow us to determine the global minimum up to pre-specified accuracy ϵ. This is illustrated by determining the orbital elements of a binary star.

Keywords: Modeling, Mathematical optimization, Linear Programming, Mixed Integer Programming, Least Squares problems, deterministic global optimization, binary stars, space engineering.

Optimal Control Methods for Collision Avoidance in Air Traffic Control

Ekaterina Kostina
Heidelberg University
Im Neuenheimer Feld 205, Heidelberg, Germany
e-mail: Ekaterina.Kostina@iwr.uni-heidelberg.de

The steady increase of the air traffic together with strict requirements on safety, efficiency, capacities and environment represents a formidable challenge to air traffic control (ATC). Mastering this challenge ATC will require sophisticated methods of decision support, planning and control.

The core task of ATC is separation management, which is the task of separating all aircraft in an allocated airspace as efficiently as possible in order to avoid collisions. In this talk we discuss the capabilities of a separation management based on optimal control and its applications. We present an optimization framework that generates collision-free trajectories for all aircraft within a regarded airspace. The principle advantage of our approach is that the optimization framework has full information of the traffic situation in an airspace volume, so it may generate solutions that incorporate information of all airspace users. This should prevent solutions that could otherwise yield even more severe situations later in time. As an optimality measure we use a cost function that aims to assess the deviation from a nominal flight trajectory as filed by the user.

The resulting optimal control problem has many state constraints and it is relatively complex to apply Pontryagin's Maximum Principle for numerical solution. That is why the optimization process is based on the direct solution method and uses multiple shooting discretization with an SQP method to solve the resulting nonlinear problem.

The results of the numerical experiments are very promising and reveal enormous potential both in improving of ATC and also the ability of mathematical methods to solve reliably very complex problems in real time and better than human controllers. Indeed, the methods safely resolve complex conflicts in separation management involving several aircraft. They guarantee prescribed separation margins while maintaining minimal deviations from original flight plans. As a side effect, they also lead to remarkable fuel savings of 5%.

This talk is based on joint work with M. Poppe (DFS) and L. Walter.

Solving QUBO Problems on an Adiabatic Quantum Annealer

Elisabeth Lobe
Software for Space Systems and Interactive Visualization
Simulation and Software Technology
German Aerospace Center
Linder Höhe 7, 38108 Braunschweig, Germany
e-mail: elisabeth.lobe@dlr.de

The exploitation of quantum mechanical principles seems to provide a decisive advantage over classical computation technologies. In the recent years there has been big progress in realizing different quantum computer architectures, especially by the Canadian company D-Wave Systems, which developed the first commercially available adiabatic quantum annealer. By adiabatic evolution of quantum mechanical systems it can solve NP-hard discrete optimization problems probabilistically. Due to the restrictions of the hardware architecture the directly mappable problems are limited to quadratic unconstrained binary optimization (QUBO) problems over a so called Chimera interaction graph.

After briefly introducing the physical and quantum computational background including the difficulties in determining the run time and success probability of the D-Wave machine, the presentation will focus on the mapping of more general problems onto their specific problem structure. In addition to the reductions to QUBOs the main part here is the minor embedding with the distribution of the weight of the original node onto several hardware nodes.

Extended Trapezoidal Collocation Framework for Trajectory Optimization Models with Full-Implicit Equations of Motion

Patrick Piprek

Institute of Flight System Dynamics, Technical University of Munich
Bolzmannstrasse 15, 85748 Garching, Germany
e-mail: patrick.piprek@tum.de

This talk presents an approach to optimize simulation models defined by full-implicit equations of motion (EoM), within a full discretization collocation scheme for direct optimal control, in the context of aircraft trajectory optimization. As integration scheme for the collocation, we use the trapezoidal rule.
To set up the optimal control problem, the MATLAB-based toolbox FALCON.m is used. Therefore, we will first of all give an overview on the toolbox and its features, such as analytic gradient calculation. After that, we will give an overview on the developed methodology to introduce implicit EoMs into the optimal control discretization scheme and specifically into the FALCON.m framework.
Finally, we will show that the incorporation of the implicit EoM models yields enhanced results compared to the standard trajectory optimization case with explicit EoM. We will provide a case study for an aircraft approach trajectory.

Adiabatic Quantum Optimization for Aerospace Applications

Tobias Stollenwerk
Simulation and Softwaretechnology - High Performance Computing
German Aerospace Center
Linder Höhe 7, 51147 Köln, Germany
e-mail: elisabeth.lobe@dlr.de

In the recent years quantum annealing became increasingly important. Beside the investigation of fundamental properties it is imperative to find possible real world application for this technology. We will report on our efforts to map real world planning problems from aerospace research to a D-Wave quantum annealer.

Control Algorithms for Astronomical Adaptive Optics

Roland Wagner
RICAM
Altenbergerstrasse 69, 4040 Linz, Austria
e-mail: roland.wagner@ricam.oeaw.ac.at

Modern ground based telescopes like the planned European Extremely Large Telescope (E-ELT) depend heavily on Adaptive Optics (AO) systems, which use measurements of incoming wavefronts from guide stars to reconstruct the turbulence above the telescope and derive the shape of deformable mirror(s) (DM). The main challenge is to have a fast enough algorithm for solving an inverse problem arising in this process as the atmospheric turbulence is constant for approximately only 1 ms.

Even though AO correction is used, the quality of astronomical images still is degraded due to the time delay stemming from the wavefront sensor (WFS) integration time and adjustment of the deformable mirror(s) (DM). This results in a blur which can be mathematically described by a convolution of the original image with the point spread function (PSF). The PSF of an astronomical image varies with the position in the observed field, which is a crucial aspect on ELTs.

We give an overview over different methods developed in our group for the control of modern AO systems. Due to the provoking time constraints and the increased data sizes, the development of new methods is necessary. The methods presented yield a significant speed-up compared to standard AO reconstruction methods. The algorithms have been implemented in a state-of-the-art AO simulation environment and simulation results show that our methods obtain comparable quality while reducing the computational time significantly compared to established methods.

For the post-processing, we present an approach for PSF reconstruction from WFS data combining atmospheric tomography and techniques for PSF reconstruction. Existing, verified techniques are fused together in a novel way to deliver accurate field dependent PSFs in very short time. To enhance the quality of the observed images with the PSF reconstructed from AO data, we opt for a blind deconvolution scheme to also improve the quality of the estimate for PSF. The choice of an efficient representation is crucial to get a sparse system.

Optimizing an exponentially large number of parameters: an example from many-body quantum theory.

Michael Weyrauch
Physikalisch-Technische Bundesanstalt
D-38116 Braunschweig, Germany
e-mail: michael.weyrauch@ptb.de

The Hilbert space used to describe quantum systems grows exponentially with the number of particles (subsystems). As a consequence, the exact description of the ground or excited states of such systems requires an exponentially large number of parameters, which must be determined e.g. by appropriate minimization of the energy.

Such a procedure becomes prohibitive for classical computers even for relatively small number of particles. Within the scope of renormalization group theory, which was developed in the last century in parallel with suitable computer hardware, successful approximation schemes where developed, in order to numerically determine properties of physical many-body systems.

I will describe such methods along with the employed variational optimization strategies for simple model systems.