University of Freiburg

FRIAS Workshop on

Robust Optimization and Control (ROC 2014)

August 20, 2014, 9:30-16:30

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I WELCOME

Dear Participants,

Welcome to Freiburg at the interactive FRIAS Workshop on Robust Optimization and Control!

The aim of this interactive workshop is to bring together experts in the field of robust optimization. Topics of interest are convex and non-convex robust optimization theory and algorithms, uncertainty analysis for dynamic systems, as well as applications in robust process control. The workshop will consist of invited and contributed talks discussing reviews and personal opinions as well as new research results in the field of robust optimization and control.

The workshop consists of 2 keynote lectures and various contributed talks, and after each talk we reserved time for discussion. Lunch will take place in the *Hotel am Stadtgarten* at own cost. A final panel discussion will have a focus on the input of the non-presenting participants and point out future directions for research. The scientific program of the workshop ends at 16:30.

The workshop is organized by Boris Houska, Moritz Diehl, Christine Paasch, and Savannah Cook. Support by the Freiburg Institute for Advanced Studies (FRIAS) as well as the Initial Training Network TEMPO (EU-FP7 Grant No 607957) is gratefully acknowledged.

We wish all of you a pleasant day in Freiburg and we are looking forward to a hopefully exciting, interesting and inspiring workshop!

Boris Houska and Moritz Diehl
Freiburg, August 2014

II Program overview

Program for Wednesday, August, 2014.

09:00	Registration
09:30	Introduction (**Boris Houska**)
09:40	Generalized Gauss Inequalities (**Paul Goulart**)
10:30	Discussion
10:40	Coffee Break
11:10	NA (**Bart Van Parys**)
11:30	Discussion
11:40	Two-Stage Robust Integer Programming (**Daniel Kuhn**)
12:30	Discussion
12:40	Lunch in *Hotel am Stadtgarten* (own cost)
14:00	Data-driven Distributionally Robust Optimization Using the Wasserstein Metric: Performance Guarantee and Tractable Reformulations (**Peyman Mohajerin Esfahani**)
14:20	Discussion
14:30	Guaranteed Parameter Estimation (**Mario E. Villanueva**)
14:50	Discussion
15:00	Set-Valued Integrators and Their Application in Robust Optimal Control (**Boris Houska**)
15:20	Discussion
15:30	Coffee Break
16:00	Wrap up panel discussion
16:30	End

III ABSTRACTS

09:40-10:30	Paul Goulart

Generalized Gauss Inequalities

This talk will describe methods for computing sharp upper bounds on the probability of a random vector falling outside of a convex set, for situations in which limited information is available about the vectors probability distribution. Such bounds are of interest across many applications areas in control theory, mathematical finance, machine learning and signal processing.

If only the first two moments of the distribution are available, then a sharp Chebyshev-like bound can be computed via solution of a single semidefinite program. However, the resulting bounds can be very conservative since they are typically achieved by a discrete worst-case distribution. The talk will show that considerable improvement is possible if the probability distribution can be assumed unimodal, in which case a less pessimistic Gauss-like bound can be computed instead. Additionally, both the Chebyshev- and Gauss-like bounds for such problems can be derived as special cases of a generalised definition of unmodality.

Short Biography:

Paul Goulart is currently a senior researcher in the Automatic Control Laboratory at ETH Zurich, and will join the University of Oxford in September 2014 as an Associate Professor in Control Engineering. He received BSc and MSc degrees in Aeronautics and Astronautics from the Massachusetts Institute of Technology (MIT). He was selected as a Gates Scholar at the University of Cambridge, where he received a PhD in Control Engineering in 2007. From 2007 to 2011 he was a lecturer in control systems in the Department of Aeronautics at Imperial College London. His research interests include model predictive control, robust optimization and control of fluid flows.

11:10-11:30	Bart Van Parys

NA

NA

11:40-12:30	Daniel Kuhn

Two-Stage Robust Integer Programming

Over the last two decades, robust optimization has emerged as a computationally attractive approach to formulate and solve single-stage decision problems affected by uncertainty. More recently, robust optimization has been successfully applied to multi-stage problems with continuous recourse. This paper takes a step towards extending the robust optimization methodology to problems with integer recourse, which have largely resisted solution so far. To this end, we approximate two-stage robust integer programs by their corresponding K-adaptability

problems, in which the decision maker pre-commits to K second-stage policies here-and-now and implements the best of these policies once the uncertain parameters are observed. We study the approximation quality and the computational complexity of the K-adaptability problem, and we propose two mixed-integer linear programming reformulations that can be solved with off-the-shelf software. We demonstrate the effectiveness of our reformulations for stylized instances of supply chain design, vertex packing, route planning and capital budgeting problems.

Short Biography:

Daniel Kuhn is Associate Professor at the College of Management of Technology at EPFL where he holds the Chair of Risk Analytics and Optimization (RAO). His current research interests are focused on the modeling of uncertainty, the development of efficient computational methods for the solution of stochastic and robust optimization problems and the design of approximation schemes that ensure their computational tractability. This work is primarily application-driven, the main application areas being energy systems, operations management and engineering.

Before joining EPFL, Daniel Kuhn was a faculty member in the Department of Computing at Imperial College London (2007-2013) and a postdoctoral research associate in the Department of Management Science and Engineering at Stanford University (2005-2006). He holds a PhD degree in Economics from University of St. Gallen and an MSc degree in Theoretical Physics from ETH Zurich. He serves on the editorial boards of several academic journals including Energy systems, Operations Research and Mathematical Programming.

14:00-14:20	Peyman Mohajerin Esfahani

Data-driven Distributionally Robust Optimization Using the Wasserstein Metric: Performance Guarantee and Tractable Reformulations

We consider uncertain optimization problems in which a sample dataset of the uncertain parameters, rather than the exact knowledge of the underlying probably distribution, is available. Employing a distributionally robust approach and results from measure concentration literature, we develop a computationally tractable framework whose optimal solution enjoys finite-sample probabilistic guarantees. In this study, the ambiguity set is characterized via the Wasserstein metric, and particular cases of design criterion including chance constrained problems are discussed. Finally, we illustrate the performance of our theoretical results on a problem of reserve scheduling in power grids motivated by increasing integration of intermittent renewable energy sources.

14:30-14:50	Boris Houska

Set-Valued Integrators and Their Application in Robust Optimal Control

In this talk we present a variety of methods for bounding the reachable set of uncertain nonlinear differential equations, which is an import sub-task of robust optimal control methods. In the first part of the talk we introduce a first-discretize-then-bound approach to enclose the reachable set via propagation of a Taylor model with ellipsoidal remainder additionally accounting for truncation errors that are inherent to the discretization. In contrast to existing algorithms that proceed in two phases—an a priori enclosure phase, followed by a tightening phase—the proposed algorithm first predicts a continuous-time enclosures and then seeks a maximal step-size for which validity of the predicted enclosure can be established. It is shown that this reversed approach leads to a natural step-size control mechanism, which no longer relies on the availability of an a priori enclosure.

The second part of the talk presents a framework for constructing and analyzing enclosures of the reachable set of nonlinear ordinary differential equations (ODEs) using continuous-time set-propagation methods. The focus is on convex enclosures that can be characterized in terms of their support functions. A generalized differential inequality is introduced, whose solutions describe such support functions for a convex enclosure of the reachable set under mild conditions. It is shown that existing continuous-time bounding methods that are based on standard differential inequalities or ellipsoidal set propagation techniques can be recovered as special cases of this generalized differential inequality.

15:00-15:20	Mario E. Villanueva

Guaranteed Parameter Estimation

Using mathematical models to describe processes has become a key component in our understanding of complex processes and systems. Such models are built by selecting an appropriate structure and then estimating the unknown model parameters. Among the available techniques to account for uncertainty in parameter estimation, guaranteed parameter estimation aims to determine all the model parameters that are consistent with the measurements under given uncertainty scenarios [1]. We consider nonlinear dynamic systems and uncertainty in the form of bounded measurement errors. The solution approach relies on set-inversion algorithms, where the parameter set is approximated at an arbitrary precision by the union of boxes. Such algorithms were first developed for algebraic models in the early 1990s by Moore [2] and Jaulin and Walter [3] using interval analysis; and then extended to dynamic systems using ODE bounding techniques [4,5]. Nonetheless the kind of problem that could be tackled with such algorithms was restricted to a few uncertain parameters. The main computational bottleneck for guaranteed parameter estimation in higher-dimensional dynamic systems appears to be the ability to compute tight bounds on parametric solutions of the dynamic system.

In this presentation, we will focus on some recent developments in ODE bounding techniques with higher-order convergence properties [3]. We will also introduce optimization-based domain reduction techniques in order to enhance the convergence speed of the set-inversion algorithm as well as simple strategies that avoid recomputing the ODE bounds wherever possible. Finally we will present a challenging case study in anaerobic digestion is presented for a model describing complex liquid-gas transfer and pH self-regulation mechanisms and featuring multiple time scales. The results demonstrate that the proposed improvements allow tackling guaranteed parameter estimation in up to seven parameters within reasonable computational

times.

References:

[1] Walter, E. (ed.) (1990). Parameter Identifications with Error Bound, Mathematics & Computers in Simulation, vol. 32. Elsevier.

[2] Moore, R.E. (1992). Parameter sets for bounded-error data. Mathematics & Computers in Simulation, vol. 34 (2), p. 113-119.

[3] Jaulin, L. and Walter, E. (1993). Set inversion via interval analysis for nonlinear bounded-error estimation. Automatica, vol. 29 (4), pp. 1053-1064.

[4] Jaulin, L. (2002). Nonlinear bounded-error state estimation of continuous-time systems. Automatica, vol. 38, pp. 1079-1082.

[5] Raissi, T., Ramdani, N. and Candau, Y. (2004). Set membership state and parameter estimation for systems described by nonlinear differential equations. Automatica, vol. 40, pp. 1771-1777.

[6] Villanueva, M.E., Houska, B. and Chachuat, B. (2013). Unified framework for the propagation of continuous-time enclosures for parametric nonlinear ODEs. Journal of Global Optimization, in revision.

IV List of participants

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V Space for notes

VI LOCATIONS AND PHONE NUMBERS

The workshop site is located at:

University of Freiburg
Freiburg Institute for Advanced Studies (FRIAS)
Albertstrasse 19
Seminar Room.

Internet Connection:

- FRIAS WLAN, password: `summer4u`

Badges:

- Please return your name tags to Savannah Cook after the workshop

Lunch:

Gästehaus Am Stadtgarten
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