Evolutionary Local Branching Matheuristics for Combinatorial Optimisation

Supervisor: Prof. Dr. Steffen Rebennack; Dr. John Alasdair Warwicker
Host Institution: Stochastic Optimization Group (SOP), Institute of Operations Research (IOR), Karlsruhe Institute of Technology (KIT), Germany

Research Work

Matheuristics (MAs) concern the interoperation of Mathematical Programming (MP) and Metaheuristics (MHs), in which one of the techniques is used to design or enhance existing models from the other. For example, consider mixed-integer programs, whose solution methods often take advantage of the solutions of a series of auxiliary linear programs (LPs). Heuristic solvers can be used to solve such LPs, using metaheuristic approaches such as local search or evolutionary algorithms.

In particular, local branching is a technique for solving MP problems. In this technique, branches are formed in the search space, of which one constitutes a local search in a given neighbourhood. The size of the neighbourhood should be sufficiently large to ensure the existence of an improved solution, but not too large to be computationally expensive. In order to ensure fast solutions to the neighbourhood search, heuristics, such as evolutionary algorithms, should be utilized.

The goal of this project is to analyse the effectiveness of different evolutionary-based approaches in augmenting the local branching algorithm. While the performance of evolutionary approaches to combinatorial optimization is well understood, hybridising them within a MP framework is yet to be thoroughly studied.

Alongside initial studies on benchmark functions from evolutionary computation, an analysis on real-world combinatorial optimisation problems from the transport industry, such as vehicle routing and scheduling, would showcase the effectiveness of evolutionary MA methods.

This project answers the following questions:

- How can evolutionary algorithms (EAs) enhance to performance of the local branching heuristic?
- Based on the problem structure, which EAs work well in this MA approach, and which do not?
- How can the insights from the previous questions extend to real-world routing problems?

Note: One PhD student will start in the SOP group on the project “Theoretical and Empirical Analyses of Matheuristics” in October 2023 (expected date). There is an opportunity for collaboration and discussion in this area.

CV of Prof. Dr. Steffen Rebennack

Name: Prof. Dr. Steffen Rebennack
E-mail: steffen.rebennack@kit.edu

Work Experience:
2017 – Present
Professor in Stochastic Optimization, Institute of Operations Research (IOR), Karlsruhe Institute of Technology (KIT)
2015-2017
Associate Professor (tenured), Division of Economics and Business, Colorado School of Mines, USA
2010-2015
Assistant Professor (tenure track), Division of Economics and Business, Colorado School of Mines, USA

Education:
2010
PhD in Industrial & Systems Engineering, University of Florida, USA
2010
Master of Science, Management, University of Florida, USA
2010
Master of Science, Industrial & Systems Engineering, University of Florida, USA
2006
Diplom, Mathematics, Ruprecht-Karls-Universität Heidelberg

Selected Journal Publications:

C. Füllner, S Rebennack (2022). Non-convex nested Benders decomposition; *Mathematical* Programming 196 (1-2), 987-1024

S. Rebennack, V. Krasko (2020). Piecewise Linear Function Fitting via Mixed-Integer Linear Programming; *INFORMS Journal on Computing* 32(2):507-530.

G. Steeger, T. Lohmann, S. Rebennack (2018). Strategic Bidding for a Price-Maker Hydroelectric Producer: Stochastic Dual Dynamic Programming and Lagrangian Relaxation; *IISE Transactions*, 50(11):929-942.

T. Lohmann, S. Rebennack (2017). Tailored Benders Decomposition for a Long-Term Power Expansion Model with Short-Term Demand Response; *Management Science*, 63(6), 2027-2048.

S. Rebennack (2016). Combining Sampling-based and Scenario-based Nested Benders Decomposition Methods: Application to Stochastic Dual Dynamic Programming, *Mathematical Programming*, 156(1), 343-389.

Selected Academic Service:
Co-editor-in-chief, European Journal of Operations Research (2018-Present).
Associate Editor, Operations Research Forum (2019 – Present).
Advisory Editor, Springer Optimization and its Applications (2017 – Present).

Supervision Activities:
4 PhD students (1 in progress)

CV of Dr. John Warwicker

Name: Dr. John Alasdair Warwicker
E-mail: john.warwicker@kit.edu

Work Experience:
2019 – Present
Postdoctoral Researcher, Karlsruhe Institute of Technology, Germany
2018 – 2019
Research Assistant, The University of Sheffield, UK

Education:
2018
PhD in Computer Science, The University of Sheffield, UK
Thesis Title: On the Runtime Analysis of Selection Hyper-heuristics for Pseudo-Boolean Optimisation Problems

2015
(MMath) Master of Mathematics Degree, Loughborough University, UK (Grade: First Class)

Selected Journal Publications:

J. A. Warwicker, S. Rebennack (2023). A Unified Framework for Bivariate Clustering and Regression Problems via Mixed-Integer Linear Programming; *Discrete Applied Mathematics, 336: 15-36.*

A. Lissovoi, P. S. Oliveto, J. A. Warwicker (2023). When Move Acceptance Selection Hyper-heuristics outperform Metropolis and Elitist Evolutionary Algorithms and When Not; *Artificial Intelligence*, 314: 103804.

J. A. Warwicker, S. Rebennack (2022). Generating Optimal Robust Continuous Piecewise Linear Regression with Outliers through Combinatorial Benders Decomposition; *IISE Transactions* (To Appear).

J. A. Warwicker, S. Rebennack (2022). A Comparison of Two Mixed-Integer Linear Programs for Piecewise Linear Function Fitting; *INFORMS Journal of Computing*, 34(2):1042-1047.

A. Lissovoi, P. S. Oliveto, J. A. Warwicker (2020). Simple Hyper-heuristics Control the Neighbourhood Size of Randomised Local Search Optimally for LeadingOnes. *Evolutionary Computation*; 28(3):437-461.

Academic Service:
Organisation Committee Member, MathSEE Symposium 2023, 27-29 September 2023, Karlsruhe Institute of Technology, 2023.

Supervision Activities:

PhD Student: Theoretical and Empirical Analyses of Matheuristics (expected start date: October 2023)

Bachelor Thesis: Linearisations of the Non-linear Optimal Power Flow Problem

Master Thesis: Decomposition Algorithms for Stochastic Programs and Application to Leveraged Least Trimmed Absolute Deviations

Research Group

The stochastic optimization (SOP) group belongs to the institute of Operations Research (IOR) at KIT. The SOP group is chaired by Prof. Dr. Steffen Rebennack.

Stochastic Optimization:
The stochastic optimization group at KIT focuses on optimization problems under uncertainty. In such problems, some of the input data are not known with certainty at the time of decision making. We assume, however, that we have some information about the distribution of the uncertain input parameters. This information is incorporated into the mathematical programming models to yield optimal decisions under uncertainty.

Research Areas:

- Stochastic Optimization / Stochastic Programming
- Power Systems Modelling and Optimization
- Decomposition Methods
- Large-scale Optimization
- Global Optimization
- Quadratic Optimization
- Mixed-integer (non)-Linear Optimization
- Calculation of Piecewise Linear Functions

Team:

Chair

Prof. Dr. Steffen Rebennack.

Research Associates

Dr. John Alasdair Warwicker (the student will work closely with Dr. Warwicker during the project)
Dr. Markus Gabl

PhD Students

Christian Füllner
Anil Kaya
Paul-Niklas Kandora
Mohammad jan Nazami
(One further student will join in October 2023).

Conferences:
Prof. Dr. Rebennack was chair of the organizing committee, and member of the program committee, of the International Conference on Operations Research (OR 2022), held at Karlsruhe Institute of Technology (September 6-9). Additional group members assisted with the organization of the conference.

Further Information

University information

Karlsruhe Institute of Technology (KIT) is one of eleven universities of excellence in Germany. Research at KIT is aimed at creating new findings, applications, and solutions to master the global challenges facing humankind with pathbreaking contributions – in particular in the areas of energy, mobility, and information.

Karlsruhe is located in the state of Baden-Württemberg in southern Germany, on the French border. Nearby locations include the black forest, the Bavarian alps and the Rhineland-Palatinate wine region. Visits to France, Switzerland and Luxembourg are possible with a train ride.
Germany currently offers a 49-Euro monthly ticket, which enables unlimited travel around Germany on regional trains.

A number of accommodation opportunities are available, both associated with KIT, and private residencies.