The Marie-Curie ITN MINOA (“Mixed-Integer Non-Linear Optimisation Applications”) invites applications for 12 Early Stage Research PhD positions

The MINOA consortium is seeking highly motivated and qualified Early-Stage Researchers (ESRs) that are looking for obtaining a PhD degree in applied mathematics, operations research, engineering and computer science. Once recruited, you will study applications of European and international relevance in areas such as energy, logistics, engineering, natural sciences, and analytics. In total, 12 positions are available within the network.

You will be trained through an innovative training program based on individual research projects motivated by these applications. As special challenges, you will work on dynamic aspects and optimisation in real time, optimisation under uncertainty, multilevel optimisation or on non-commutativity in quantum computing. You will devise new effective algorithms and computer implementations and will validate your methods for the applications with respect to metrics that you will define. You will derive recommendations, both for optimised MINO applications and for the effectiveness of the novel methodologies. Personally, you will belong to a new generation of highly-skilled researchers that will strengthen Europe's human capital base in R&I in the fast growing field of mathematical optimisation. Your ESR research project will be pursued in joint supervision between experienced practitioners from leading European industries and leading optimisation experts, covering a wide range of scientific fields.

The MINOA project has started on Jan 1st, 2018, is funded under Horizon 2020 and will be carried out for a total of four years. The network consists of 11 academic partner institutions and six industrial partners from six different countries in Europe. The ESR project descriptions, the starting dates and other details are contained in the corresponding attachment.

The call for applications is open until 4th May, 2018. The deadline might be extended until all positions are filled.

Who can apply?

You are eligible to apply for a position within the MINOA network, if

- you hold a M.Sc. degree by the starting date of the fellowship, in one of the following areas: Mathematics, Computer Science, or in a closely related field
- you have not resided or carried out your main activity (work, studies, etc) in the country of your host organisation for more than 12 months in the 3 years immediately prior to your recruitment
- at the time of recruitment, you are in the first four years (full-time equivalent research experience) of your research career (after having obtained your M.Sc. degree) and have not been awarded a doctoral degree
- you are proficient in the English language.

Further specific requirements and restrictions set by hosting countries and institutions might be listed in the ESR fellowship descriptions.

What can you expect from a position in the MINOA ITN?

Once recruited, we will offer:

- the possibility to work with us in a prestigious Horizon 2020 project
- A full-time contract for 36 months
- The competitive gross employer costs for all ESR (PhD) positions is around 36.172-41.425 Euros/year plus a mobility allowance of about 600 Euros/month and a family allowance of 500 Euros ca. per month, where applicable.
- At least one internship (also known as ‘secondment’) to an industrial partner and one to an academic partner in the MINOA network, in order to gain new insights into research and into work in the industry. Details can be found in each project description.
- Participation in local events as well as in network-wide summer schools with internationally well-known teachers. This furthermore offers the possibility to get to know other Phd students from all over the world.

How can you apply?

With a **single** application, you may apply for more than one fellowship within MINOA (maximum 12, i.e., one per project partner), in order of preference.

You will need to provide us with the following documents:

a) Application form (see attachment)
b) Letter of motivation (max. 1 page)
c) Copies of degree and academic transcripts (with grades and rankings)
d) Brief summary of Master's thesis (max. 1 page)
e) Short CV including a publication list (if any)

All the above-mentioned documents **must** be collected in a single pdf file and have to be uploaded on EasyChair on

https://easychair.org/conferences/?conf=minoa2018

after creating an account on EasyChair.
Please include your data for “author 1” and tick the “corresponding author” box.
As title and as abstract, please choose “Application for MINOA”.
As keywords, please give the same ranking of the ESRs you apply to as you have given in the application form.
We will only consider applications if they are uploaded there.

What happens after you have applied?

We will come back to you soon after the application deadline is over. Shortlisted candidates will be invited for an interview (traveling to each partner's site may not be necessary). Winners will be announced around mid June 2018. Applications received after the deadline might still be considered if the corresponding positions have not been filled yet.

Fellow: ESR01	**Host institution:** Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Exact Optimisation Approaches for Energy Market Design (EMD)

Objectives: The goal is to develop effective solution approaches for an optimal splitting of a market area in different price zones so that social welfare is maximised. The relevance is due to the fact that European energy markets do not respect all intrazonal network constraints at the spot markets, leading to inefficiencies that could be attenuated by an optimal configuration of price zones. This multi-level optimisation model contains a graph partitioning problem in its upper level. Each level is convex-quadratic. Improved solution approaches will be developed for the exact solution of EMD, by decomposition and by generating tight cutting planes. As the data is subject to future predictions, the problem will be studied under uncertainty. Starting from simplified single-level models, tractable robust counterparts shall be developed for EMD under uncertainty. Scenario separation will be used as suggested in the adversarial approach from robust optimisation, as well as adjustable robust optimisation techniques. This project aims to advance the state-of-the-art in solving challenging EMD, with the possibility of advancing general methods for solving (robust) multi-level optimisation problems. As second application, the ESR will study aircraft deconfliction problems, together with ESR3.

Expected Results: theoretical insights into the structure of EMD, development and implementation of algorithms for the solution of tractable robust counterparts of EMD, its extension to aircraft deconfliction, one journal paper per ESR year

Planned secondments:

- IBM France (Bonami, 3 months) at the end of the first year, about general-purpose decomposition implementations
- Universiteit van Tilburg (de Klerk, 2 months) at the beginning of the second year, to learn about non-convex tractable relaxations for energy networks.

Supervisor: Frauke Lers, Martin Schmidt **Mentor:** Etienne de Klerk (Universiteit van Tilburg)

Notes: For information on studying in Erlangen-Nürnberg visit https://www.fau.de/studium/

The hosting group:
FAU, with some 40000 students the second largest university in Bavaria and founded in 1743, employs about 650 professors and around 3500 teaching staff. FAU has 10 Collaborative Research Centres, 19 Research Units, and 10 Research Training Groups, all funded by the DFG (German Research Foundation). In the German Initiative of Excellence the university receives funding for a graduate school and a cluster of excellence. The optimisation group at FAU has key expertise in modeling and solving complex and very large-scale planning and optimisation problems from logistics, energy, production, engineering, and the natural sciences. The chair “Wirtschaftsmathematik” currently consists of three professors, 6 postdocs and about 15 PhD students. Each year about three PhD students finish their thesis. The group participates in many projects funded by the DFG, the BMBF, or the BMWi, e.g., with the German Aerospace Center (DLR) and German Railways. In particular, the group collaborates in the Collaborative Research Center TRR 154 “Mathematical Modelling, Simulation and Optimisation Using the Example of Gas Networks“.

Fellow: ESR02	**Host institution:** CNR-IASI Rome, Italy	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Exact methods for non-linear optimisation problems on graphs

Objectives: The goal is to advance the state-of-the-art in the solutions of graph problems related to cliques, cycles, and cuts optimisation with nonlinear functions. One such problem is the max-cut problem that is equivalent to the general Quadratic Unconstrained Binary Optimisation (QUBO). These problems have recently received a renewed great attention as they are the typical target of computing devises based on quantum techniques. State-of-the-art algorithms able to provide solutions with certified qualities also for very large sparse instances are based on low-rank reformulations of semidefinite relaxations. On the other hand, separation procedures have been proposed that make it possible to exploit the linear relaxations to possibly obtain exact optima. The research will focus on combining these techniques to improve the solution times of the existing algorithms and to extend their scope to problems (e.g., Max-Sat), where the objective function is a polynomial of degree greater than two. Another case is the optimisation of a nonlinear function over cycles. This is a generalization of the separation problem of cycle inequalities for max-cut. The contribution to the objective function will depend on the membership of an edge to a cycle and to a particular subset of the cycle. This problem arises in the distribution of power energy to solve the optimal transmission switching (OTS) problem. A subproblem of OTS is Unit Commitment (UC) that is usually disregarded or considered as a separate problem. The connections between the two problems will also be taken into account. In particular, UC is a Mixed-Integer Nonlinear Problem with convex function and semicontinuous variables. Improvements in the solution of this class of problems will be investigated to obtain global advances. Other graph optimisation problems are related to clique optimisation, in particular the identification of subcliques partitioning the graph and defining clusters. This has application in the study of Big Data graphs and in data protection.

Expected Results: Theoretical results about non-linear optimisation problems on graphs with convex as well as non-convex functions, applications in power energy, data science, statistical physics, quantum computing. One journal paper per ESR year, Ph.D. degree.

Planned secondments:

- Siemens, Munich, Germany (3 months, beginning of second year) to learn about the application in unit commitment and power energy problems.
- CNRS-LIX Ecole Polytechnique, Paris, France (4 months, month 18) to learn about extensions to mixed-integer non convex programming.

Supervisor: Claudio Gentile, Giovanni Rinaldi **Mentor:** Paolo Ventura (CNR), Claudia D'Ambrosio (CNRS)

Notes: For information on studying in Rome visit
http://www.iasi.cnr.it
http://www.cnr.it
http://www.diag.uniroma1.it/~abro/en
https://romexperiencetravel.it/2017/06/29/quartieri-migliori-studenti-roma/

Fellow: ESR03	**Host institution:** CNRS at LIX, Ecole Polytechnique, Palaiseau, France	**Starting date:** Sept-Nov 2018	**Duration:** 36 months

Project Title: Mixed-Integer Bi-Level Non-Linear Optimisation and Applications (MIBNOA)

Objectives: We mean to advance the state of the art in Mixed-Integer Bi-Level Non-Linear Optimisation (MIBNO). A MIBNO is an optimisation problem $P(x, y)$ subject to constraints of the type $y \in Y(x)$, where x, y are decision variables of P (called the upper level subproblem), and $Y(x) = \arg\min_{y \in Y(x)} Q_x(y)$ is the set of optima of another optimisation problem (called the lower level subproblem) parametrised by x. MIBNO arise in practice in a variety of situations, for example when controlling a dynamical system with monotone evolution functions, such as the observability of the state of a transportation network. From a methodological point of view, general solution algorithms for large-scale, linear MIBO are still relatively ill-studied; usually, the lower level subproblem is used to generate cuts relative to the upper level subproblem, and these cuts are then used within cutting plane or branch-and-bound algorithms. For the nonlinear case, there appear to be two main existing strategies, either based on the reformulation of the lower-level problem with its convex hull, or on a reformulation two a single level but semi-infinite program. We plan instead to generalize the cutting-plane based approaches by means of generating problem-specific non-linear cutting planes, in particular SOCP and SDP cuts. In this case, we aim at generalizing cutting plane methods for mixed integer bi-level linear programming problems that start with a relaxation where the lower-level problem and all linking constraints in the upper-level problem are neglected. Iteratively, the relaxation is solved, the solution of the upper-level problem is fixed in the lower-level problem to find an optimal solution to it. If the linking constraints are satisfied, the solution of the upper and lower level are an optimal solution to the bi-level problem. Otherwise, linear cuts are adjoined to the relaxation. In the case of mixed integer non-linear bi-level programming problems we propose to use stronger, i.e., non-linear (SDP/SOCP) cuts, since the lower-level problem is a MINLP.

Expected Results: New solution algorithms for MIBNO and their application to: (i) well location in an oilfield (lower level is minimum distance between different branches of two wells); (ii) Unit Commitment (lower level is a variant of AC Optimal Power Flow); (iii) aircraft deconfliction with speed regulation (lower level is a minimum distance between two aircraft).

Planned secondments:

- FAU (Liers, Schmidt, 3 months, end of 1st year) to learn about multilevel Energy Market Design problems
- IBM France (Bonami, 3 months, end of 2nd year) to learn about commercial decomposition software

Supervisor: Claudia D'Ambrosio, Leo Liberti **Mentor:** Martin Schmidt (FAU)

Notes: CNRS (*Centre Nationale de la Recherche Scientifique*, http://www.cnrs.fr/index.php) is the largest state employer for public research in France. It organises most of its research staff by affiliating them to collaborating universities. Ecole Polytechnique (http://www.polytechnique.edu/en) is the most prestigious engineering university in France. It is located in the south-western outskirts of Paris.

Fellow: ESR04	**Host institution:** CWI, Amsterdam, The Netherlands	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Relaxation Methods in Classical and Quantum Computation

Objectives: Many problems in real-life applications and in scientific areas are very hard and most probably cannot be solved optimally with the current computing tools. To address this difficulty two complementary routes can be followed: search for fast approximate solutions and, with large-scale quantum computers getting closer to realization, understand and exploit the advantage of quantum effects in computations. The project focusses on non-local games, which are models used to quantify the effect of quantum entanglement between physically separated physical systems. A fundamental problem is to compute the maximum winning probability of a non-local game, depending whether classical or quantum correlations are assumed between the systems, and a separation between the classical and quantum values shows the advantage offered by entanglement. This computation is challenging since it involves solving nonlinear optimisation problems, with binary variables in the classical case, and with variables that can be instantiated to positive semi-definite matrices of arbitrary size in the quantum setting. Research questions include designing efficient hierarchies for good approximations of the classical and quantum optimum values, getting more insight on the complexity of some quantum graph parameters, and on the amount of entanglement needed at optimality, which is related to some matrix factorization rank questions. Tools to be used include conic optimization, semidefinite optimization and polynomial optimization (in possibly non-commutative variables).

Expected Results: Efficient SDP-based approximation hierarchies for hard optimization problems related to graph parameters, non-local games and other questions in quantum information; new classes of games whose quantum value can be computed efficiently by SDP; deeper insight about completely positive semi-definite matrices and related matrix factorization ranks. One journal paper per ESR year, Ph.D. degree

Planned secondments:

- UoC (2 months, end of first year) to learn about algebraic techniques for exploiting symmetry in optimisation and state-of-the-art algorithms for spin glasses.
- Cray (2 months, end of second year), to learn about large-scale SDP and industrial applications.
- UNI-KLU (1 month, beginning of 3rd year) to study more methods for solving large-scale SDP.

Supervisor: Monique Laurent **Mentor:** Frank Vallentin (UoC)

Notes: The project might possibly be adapted in mutual agreement depending on the interests and expertise of the successful applicant. The research will be carried out at CWI in Amsterdam and, after successful completion of a PhD thesis, the doctoral degree will be awarded at Tilburg University where M. Laurent holds a part-time full professorship. For information about CWI and Tilburg University, see https://www.cwi.nl/ and https://www.tilburguniversity.edu/about/schools/economics-and-management/organization/departments/eor.htm.

The hosting group:
CWI is the national research center for mathematics and computer science in the Netherlands, located at Science Park in Amsterdam, nearby the University of Amsterdam. CWI also hosts QuSoft, a new research center about quantum software. The ESR will be hosted by the research group Networks & Optimization at CWI and will be able to collaborate with other CWI research groups and QuSoft. CWI has a staff of about 160 researchers, including 45 postdocs and 70 PhD students. It is internationally oriented, with about 30 nationalities being represented in its staff. CWI offers courses for professional and personal development such as presentation, communication and academic writing skills, scientific integrity, and Dutch language courses. The ESR will be able to follow advanced classes within the national education programmes by LNMB http://www.lnmb.nl/pages/courses/ in operations research and by Mastermath https://elo.mastermath.nl/ in mathematics. An active student activity committee organizes regular social acitivities for PhDs and postdocs accross CWI.

Fellow:	Host institution:	Starting date:	Duration:
ESR05	IBM France	October 2018	36 months

Project Title: Benders Decomposition for Convex Mixed-Integer Nonlinear Optimisation

Objectives: Benders decomposition is one of the common algorithmic techniques to solve large-scale linear and mixed-integer linear optimisation problems. It is the tool of choice to solve two stage stochastic optimisation problems giving rise to countless applications with uncertainty in the data (demands forecasts, prices, etc.). However, there is little literature and no existing off-the-shelf software to apply Benders decomposition in the context of mixed-integer nonlinear optimisation. IBM has recently made available an automatic Benders decomposition for mixed integer linear optimization within its leading optimisation software ILOG® CPLEX® Optimization Studio.
Our objective is to research extensions to Benders decomposition in mixed-integer nonlinear settings. We plan to exploit the new automatic Benders scheme of CPLEX to develop efficient implementations for various problem classes based on this research.
The ESR will work on uncertain energy management problems (starting from Unit Commitment) where renewables need to be taken into account in a stochastic fashion.

Expected Results: Library of applications for MINO featuring a decomposition structure. Extension of Benders decomposition to convex mixed-integer optimisation problems with quadratic constraints and/or objective. Prototypical software implementations and validation. Extensions to more general nonlinear problems. Ph.D. degree.

Planned secondments:

- CNRS (3 months, d'Ambrosio, Liberti, end 1st year) to learn about MIBNO problems
- UNIBO (3 months, Lodi, Malaguti, beginning of 3rd year) to learn about large-scale non-linear Big Data applications

Supervisor: Andrea Lodi (UNIBO, E. Polytechnique, Montreal), Claudia D'ambrosio (CNRS, E. Polytechnique, Paris)
Mentor: Pierre Bonami (IBM)

The hosting group:
IBM is a leader in the decision optimization market. It develops two leading software CPLEX (for mathematical optimization) and CP Optimizer (for constraint programming). The PhD candidate will work within the CPLEX team. The team is composed of about 10 specialists in all aspects of mathematical optimization, spread around the world. Besides developing one of the leading linear and mixed-integer programming solvers, the members of the CPLEX team regularly publish in Mathematical Optimization journals and attend conferences of the field.
The student will be physically located in IBM France Gentilly lab in Paris and will be enrolled in the PhD program of DEI at University of Bologna.

Fellow: ESR06	**Host institution:** M.A.I.O.R. S.r.l., Italy	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Integrating Planning and Real-Time Operations in Public Transport Systems

Objectives: Managing a public transport system is a highly complex task, which requires making many intertwined decisions. The usual paradigm is to perform them sequentially (from line planning to timetabling to vehicle scheduling to crew scheduling), gradually introducing a finer and finer representation of the operational constraints. Hence, early steps only consider partial information on the system, possibly resulting in suboptimal decisions that later steps cannot revert. Even the last steps typically do not take into account the uncertainty in the actual behaviour of the system, possibly resulting in costly on-line adaptations during operations. M.A.I.O.R. is an Italian company specialized in the development of decision-support systems for public transport operators and regulators. In this project, driven by the needs of actual customers for which M.A.I.O.R. can obtain real-world data, innovative algorithms will be developed that improve on the state-of-the art by better incorporating, at each step, information about the following one(s). The focus will be on devising methods for on-line mitigation of disturbances due to unforeseen conditions, and then incorporating information provided by these methods into earlier stages of the decision chain. This will require a sophisticated combination of different techniques such as decomposition/column generation, methods for uncertain optimization, and the efficient solution of specific nonlinear and combinatorial subproblems. The research will be performed in collaboration with the Operations Research Group at the Department of Computer Science of the University of Pisa, which has a long-standing collaboration with M.A.I.O.R. and expertise in the required algorithmic techniques. The ESR will get her/his Ph.D. Title from the Doctorate School in Computer Science of the University of Pisa.

Expected Results: Deep understanding of methods for on-line disturbances mitigation in public transport systems, expertise in the development and implementation of solution methods for specific classes of nonlinear and/or combinatorial problems, computer codes that can be readily integrated with M.A.I.O.R. software in order to be able to perform meaningful tests on real-world data, one journal paper per ESR year, Ph.D. degree.

Planned secondments:

- UNIBO (3 months, Malaguti, Monaci, first half of 2nd year), to get acquainted with disruption management and models for robust scheduling
- TUDO (3 months, Buchheim, beginning of 3rd year) to learn about space-dependent optimum control problems.

Supervisor: Antonio Frangioni (University of Pisa) **Mentor:** Samuela Carosi (M.A.I.O.R.)

Notes: For information on M.A.I.O.R. visit www.maior.it, for the Operations Research Group check www.di.unipi.it/optimize, for the Doctorate School in Computer Science visit www.di.unipi.it/en/phd.

Fellow: ESR07	**Host institution:** TU Dortmund, Germany	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Effective algorithms for combinatorial optimal control

Objectives: Optimisation problems containing both combinatorial constraints and partial differential equations (PDEs) are very challenging in theory and practice. The PDE constraints can be used to model diffusion processes, such as the heating of a metallic workpiece, subject to point-wise temperature constraints. The combinatorial structure describes the possible heating points and their allowed combinations and related costs. Beyond the direct discretization approach, which leads to huge non-convex mixed-integer optimisation problems that can be solved to optimality only in very small dimension, few specific approaches to such problems have been presented in the literature. The goal of the project is to develop new algorithmic techniques for solving such combinatorial optimal control problems, building on recent structural results showing that for many such problems the feasible region in terms of the control variables is convex (after relaxing integrality), so that the PDE constraint can be replaced by cutting planes in an outer approximation fashion. This approach exploits the problem structure much better than direct discretization. The objective of the project is to exploit and extend these results from an algorithmic point of view and to make the approach more effective in practice, where the focus is on concepts and methods from discrete optimisation. The first step is to use state-of-the-art methods of outer approximation to address the problem. In a second phase, new types of approaches will be developed. One possible direction is to relax the added cutting planes in a Lagrangian fashion, allowing to solve the underlying combinatorial problem by any tailored combinatorial algorithm.

Expected Results: Survey of literature concerning optimal control problems with discrete variables and combinatorial structures; Implementation of a basic algorithmic framework for solving combinatorial optimal control problems; Development of new algorithmic techniques for a faster solution of combinatorial optimal control problems; Implementation of the techniques and their application to real-world problems. The ESR is expected to publish her/his results in high-ranked scientific journals and to obtain a Ph.D. degree.

Planned secondments:

- University Heidelberg, Germany (3 months, in 1st year), for studying numerical methods for mixed-integer optimal control problems
- Ortec, Netherlands (2 months, in 3rd year) to learn about industrial space-dependent energy distribution problems

Supervisor: Christoph Buchheim **Mentor:** Ekaterina Kostina (Heidelberg)

Notes: For information on TU Dortmund University, in particular concerning international Ph.D. students, please visit http://www.tu-dortmund.de/uni/en

The hosting group: Since its founding 49 years ago, TU Dortmund University has developed a special profile, encompassing 16 faculties ranging from science and engineering to social sciences and cultural studies. The university currently has circa 34,600 students and 6,200 staff members, including 300 professors. The curriculum is comprised of around 80 programs of study, both traditional and innovative, some even unique to this university. Research at TU Dortmund University is particularly renowned in the four profile areas ‘Production and Logistics’, ‘Chemical Biology and Biotechnology’, ‘Modeling, Simulation and Optimization of Complex Processes and Systems’ and ‘Youth, School and Education Research’.
The Discrete Optimization group at TU Dortmund University provides the perfect environment for the recruited ESR. The research of the group spans from combinatorics to mixed-integer non-linear optimization, with applications in logistics and a special focus on robust optimization. Frequent visiting scholars and many national and international scientific contacts of the group will allow the ESR to build her/his own network quickly. As member of the Discrete Optimization group, the ESR will get an insight into various research activities, including interdisciplinary projects. A wide range of soft-skill courses are offered for PhD students at TU Dortmund University. Moreover, the recruited ESR will benefit from advice and support offered by the International Office and by the Familiy Service Office at TU Dortmund University.

Fellow:	**Host institution:**	**Starting date:**	**Duration:**
ESR08	Ruprecht-Karls Universität Heidelberg	October 2018	36 months

Project Title: Efficient methods for optimal online operation of complex switched systems

Objectives: The goal of the project is to develop efficient numerical methods for designing the optimal operation of complex switched systems, such as production plants for different scenarios like start-up and shut-down and operation under changing loads and demands. Start-up and shut-down of production plants and realization of load changes present a very complex networked process due to strong coupling and reuse of substance and energy flows. The operation of plants is performed under numerous constraints on the specifications on the product properties, energy consumption, waste production, yield of the plant and safety. This leads to very complex mixed integer control problems with switched DAEs. The ESR will first investigate appropriate convex reformulations such problems based on partial outer convexification, lifting and relaxation strategies. The next step is the development of a quadratic expansion of the optimal control problem along the optimal solution and development of a path following method to solve a sequence of MIQP. The convergence properties of the algorithm as well as strategies for an optimal choice of path parameter will be investigated. The rounding scheme for computing integer feedback solutions will be developed. The results of the investigation of mixed integer nonlinear problems in optimal operation of complex switched systems will be applied for general quadratic 0/1-programming.

Expected Results: tight convex relaxations for design of optimal operation of complex switched systems, computationally tractable path following methods for computing integer feedback controls, deep understanding of the potential of the quality of approximations to hard MINO applications by adiabatic quantum computing

Planned secondments:

- CNR, Rome (1.5 months, end of 1st year) for research on the potential of quantum computing
- Siemens, Munich (3 month, beginning of 2nd year), to study production plant modelling

Supervisor: Ekaterina Kostina, Gerhard Reinelt **Mentor:** Michael Jünger**,** U of Cologne

The hosting group:
IWR is a central research institution of the Heidelberg University in scientific computing and computational sciences. IWR owns an excellent computational infrastructure on several levels starting with appropriate workplaces for each researcher up to the parallel system with 5000 Xeon Haswell cores. IWR has an own Heidelberg Graduate School of "Mathematical and Computational Methods for the Sciences", one of the 39 structured graduate schools established within the German Excellence Initiative, with 160 doctoral students working on interdisciplinary research topics. In addition, ESR will have access to the complete infrastructure of Heidelberg University, a leading German university.
The research groups of Kostina and Reinelt are internationally recognized for their work in theory, numerical methods and applications of nonlinear optimisation and optimal control of complex dynamic processes, and in the development, implementation and analysis of algorithms for solving hard combinatorial or mixed-integer problems. They are also involved in many collaboration optimization projects partially together with industry in areas such as chemical, biochemical and biological process engineering,
aerospace and mechanical engineering and robotics.

Fellow: ESR09	**Host institution:** University of Bologna, Italy	**Starting date:** November 2018	**Duration:** 36 months

Project Title: Optimisation and Big Data in Large Scale Networks

Objectives: Networks are a common modelling tool used to describe interaction between different entities. They are used in many areas, such as transportation, logistics, information technology, telecommunications and social analysis. In many of these applications, real systems are characterised by a large amount of data, which makes the associated networks of very large size. In addition, data usually have an inherent uncertain component that has to be taken into account when optimisation is carried out. This leads to highly sophisticated models that are typically non-linear, hence extremely challenging to be solved. All these aspects limit the applicability of available optimisation algorithms that are capable to deal with (some of) these aspects. In this project, the ESR will address problems that represent the natural extension of classical network problems when some of the aforementioned complicating aspects (large data, uncertainty, non-linearities) take place. One prototype problem that the ESR will study is the Heaviest k-Subgraph problem (HkSP): given an undirected graph with profits on edges, determine k vertices such that the associated subgraph has a maximum profit. This problem is known to be NP-hard and models a fundamental issue in social networks, namely the detection of densely connected communities. For this problem, we intend to propose mathematical formulations based on the Integer (Non)Linear paradigm, allowing to derive heuristic and exact approaches for instances arising from real world applications. Hence, we expect to deal with very large graphs, for which decomposition techniques, such as Dantzig Wolfe decomposition, may be needed. Furthermore, the ESR will consider the case in which the profits associated with edges are subject to uncertainty. For this variant of the problem, we will develop robust approaches, possibly using again decomposition techniques based on Benders Decomposition.

Expected Results: A survey on problems and state-of-the-art approaches for optimisation of social networks, with emphasis on the HkSP and related problems, Integer Programming models for the deterministic as well as for the stochastic HkSP, and approximate/exact algorithms; scientific articles, to be collected in the Ph.D. thesis.

Planned secondments:

- UNIPI (Frangioni, 3 months, 1st year) on decomposition methods for nonlinear and uncertain transportation problems.
- Cray (3 months, Haus, 2nd year) on Data Analytics and Big Data.

Supervisor: Enrico Malaguti, Michele Monaci **Mentor: Utz-Uwe Haus (Cray)**

Notes: For information on the research group visit
http://or.dei.unibo.it/

The hosting group:
UNIBO is the second largest university in Italy and one of the most active in research and technology transfer. It stands among the most important institutions of higher education in EU with 87,000 enrolled students, 2,857 Academic staff, 1,198 post-docs and 1,606 PhDs.
This project will be hosted by the Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi” (DEI). The DEI department consists of around 120 scientists, whose research and education activities cover the following fields of Industrial and Information Engineering: Automation, Bioengineering, Electric Drives and Systems, Electrical and Electronic Measurements, Electrical Engineering, Electromagnetic Fields, Electronics, Operations Research and Telecommunications. DEI offers one undergraduate and three graduate international programmes taught in English, as well as five undergraduate and six graduate programmes taught in Italian. The Department offers also four international Ph.D. programmes. The Operations Research group at DEI has an internationally-recognized visibility in the design and implementation of models and algorithms for mathematical programming optimization problems, as witnessed by the record of publications of the members of the group. The group has also been involved in many industrial projects arising from applications in transportation, logistics, energy production, telecommunications and engineering.

Fellow:	Host institution: Alpen-Adria-Universität Klagenfurt, Austria	Starting date:	Duration:
ESR10		October 2018	36 months

Project Title: Solving Semidefinite Programs via Augmented Lagrangian and Dual Factorization

Objectives: The successful use of Lagrangian methods for solving semidefinite programs (SDP) naturally leads to the idea of using augmented Lagrangian techniques in order to improve the performance of the algorithm. The boundary point method, proved to be very efficient for computing bounds on several hard problems, e.g., colouring problems, but performs poorly on semi-definite programs arising from max-cut relaxations. Thus, the ESR will investigate other versions of applying augmented Lagrangian methods. The goal is to combine regularization methods with the idea of formulating the dual slack matrix variable as low-rank. The resulting algorithms will be applied for solving semidefinite problems arising, e.g., in the computation of certificates of collision avoidance in real-time for unmanned aerial vehicles. This subject is of high interest in transportation engineering where one aims to compute directions using a barrier function. These directions can be found by solving a semi-definite problem with a few constraints, however, the time for computing the solution is crucial since the directions have to be computed in real-time.

Expected Results: Efficient augmented Lagrangian algorithm for solving SDP relaxations in combinatorial optimisation, a better understanding of the penalty parameter and update rules, implementation (code will be made available under a public license), one journal paper per ESR year, Ph.D. degree.

Planned secondments:

- Optit, Bologna (3 months, end of 1st year) to learn about the application of piecewise linearisations arising in the optimisation of industrial energy production
- University Heidelberg (1 month, beginning of 2nd year), to learn about (large-scale) nonlinear optimisation methods
- Universiteit van Tilburg (1 month, end of 2nd year), to compare, evaluate and validate the respective approaches.

Supervisor: Angelika Wiegele, Franz Rendl **Mentor:** Andrea Betinelli (OPTIT)

Notes: For information on studying in Klagenfurt visit https://www.aau.at/en/international/studying-in-klagenfurt/

Fellow: ESR11	**Host institution:** Tilburg University, The Netherlands	**Starting date:** September 2018	**Duration:** 36 months

Project Title: Interior point methods for convex relaxations of MINO problems

Objectives: Convex relaxation is a standard technique used for integer optimisation problems, and in particular for mixed-integer nonlinear optimisation (MINO) problems. A recurring practical question is how one may solve the convex relaxations. One of the most useful tools for this purpose is the class of optimisation algorithms known as interior point methods. A drawback here is that it is necessary to compute a Hessian matrix at each step, which is computationally expensive. In very recent work, it has become clear that suitable Hessian matrices may be computed (approximately) through sampling techniques. Thus is particularly useful for certain convex relaxations of binary problems where the Hessian is very expensive to compute. Thus, the ESR will work on the following objectives: Survey convex (and in particular semi-definite optimisation) relaxations of various MINO problems, including the quadratic assignment problem (QAP), and problems from energy networks; implement an interior point method that uses the sampling procedure, possibly by modifying existing solvers; test the new implementation on instances of the QAP and energy network problems, in particular nonlinear mixing problems like the pooling problem that arises in the chemical process and refinery industries; investigate reformulations leading to SDP relaxations for problems in quantum computing. The individual research project has synergy with the one of Klagenfurt University, where different novel approaches to solving semi-definite programs will be investigated, namely augmented Lagrangian-type approaches. The intended applications are also different, but ESR11 and ESR10 will work together closely to evaluate and validate the new approaches on different MINO applications

Expected Results: Detailed survey (journal paper or Ph.D. thesis) on interior point methods where the Hessian is computed by sampling techniques, an effective software implementation of a sampling-based interior point method for certain convex relaxations, its validation on relaxations of various MINO problems, including problems from industry (energy network problems).

Planned secondments:

- Secondment (3 months, beginning of 1st year) with one of the industrial partners.
- CWI (Laurent, 3 months, 2nd year), to apply the methods to SDP relaxations from arising in quantum computing.

Supervisor: Etienne de Klerk **Mentor:** Monique Laurent (CWI)

Notes: For information on studying in Tilburg visit https://www.tilburguniversity.edu/about/organization/working-at/phds/

Fellow: ESR12	**Host institution:** University of Cologne, Germany	**Starting date:** October 2018	**Duration:** 36 months

Project Title: Optimisation with limited quantum resources

Objectives: Quantum Computing is an emerging technology that may complement digital computing in the future and opens up new avenues in finding optimum or high-quality approximative solutions for hard optimisations problems. This project will concentrate on the following two aspects: (a) Entanglement is the quantum mechanical feature which gives the basic physical resource for the design of quantum devices not realizable by classical physical means. The theory of "nonlocal games" can be used to quantify how much one can gain by using entanglement. Nonlocal games are also, surprisingly, related to the finding of approximate solutions of hard optimisation problems. The ESR will investigate nonlocal games with tools from polynomial optimisation (in commutative and non-commutative variables, tensor decompositions). This research will take place in close interaction with CWI and also with the institute of theoretical physics at UoC. (b) With the availability of machines build by the D-Wave company, adiabatic quantum computing is already a reality. In a nutshell, these machines, and approximate solutions to Ising spin glass problems on a special class of graphs, the Chimera graphs. The ESR will investigate how the quality of such solutions compares with combinatorial optimisation via branch and bound using linear and semi-definite relaxations. This research will take place in close interaction with CNR and UHEI. The ESR will build on the theory of nonlocal games in order to gain a better understanding of the advantage of quantum entanglement in finding better quality approximate solutions of hard MINO problems in general and, as an application, to the specific quadratic binary optimisation problem addressed by the D-Wave adiabatic quantum computing machines.

Expected Results: a unifying framework for nonlocal games based on polynomial optimisation, a deeper understanding of the quality of approximations to hard quadratic binary optimisation problems by adiabatic quantum computing, one scientific article per year

Planned secondments:

- CNR (1.5 months, 1st year) to foster the cooperation on (b),
- FAU (1.5 months, end of 2nd year),
- M.A.I.O.R. SRL (3 months, 1st year) to learn about combinatorial optimisation problems arising in public transport.

Supervisor: Frank Vallentin, Michael Jünger **Mentor:** Giovanni Rinaldi (CNR)

Notes: For information on studying in Cologne visit https://www.portal.uni-koeln.de/studyincologne.html

The hosting group: Since its establishment in 1388, the University of Cologne has been a center of science and scholarship in Europe. Today, it is one of the leading German research universities. We offer our students an exceptionally broad and diverse subject base and encourage them to follow their own academic interests. This allows them to develop both intellectually and personally. We are firmly committed to the advancement of human knowledge through basic research, but with an eye to transfer and application in the real word.
The research groups Jünger and Vallentin at the Department of Mathematics and Computer Science are internationally well recognized for their work on combinatorial optimisation and semidefinite programming. Several competitive national and international projects are executed by the group.

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