Conference Overview

	Saturday September 13	Sunday September 14	Monday September 15	Tuesday September 16	Wednesday September 17
8:00	Registration		Registration		
8:30				Registration	Registration
9:00	**Workshops**		**Conference Opening & Keynote 1**	**Announcements & Keynote 2**	**Announcements & Keynote 3**
10:00		Registration			
10:30	Coffee Break	**Tutorials**	Coffee Break	Coffee Break	Coffee Break
11:00	**Workshops**		**Posters 1**	**Posters 4**	**Posters 7**
12:30	Lunch	Lunch	Lunch	Lunch	**Conf. Closing** Lunch
14:00	**Workshops**	**Tutorials**	**Posters 2**	**Posters 5**	
15:30	Coffee Break		Coffee Break	Coffee Break	
16:00	**Workshops**	Coffee Break	**Posters 3**	**Posters 6**	
16:30		**Tutorials**			
18:30			Welcome Reception	City Tour & Conference Dinner	

PPSN XIII Conference Program and Book of Abstracts

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PPSN XIII
13th International Conference on Parallel Problem Solving from Nature

PPSN XIII

Welcome

Welcome to the 13th International Conference on Parallel Problem Solving from Nature (PPSN XIII). This biennial event constitutes one of the most important and highly regarded international conferences in evolutionary computation and bio-inspired metaheuristics. Continuing with a tradition that started in Dortmund in 1990, PPSN XIII takes place during September 13–17, 2014 in Ljubljana, Slovenia. It is organized by the Jožef Stefan Institute and held at GR – Ljubljana Exhibition and Convention Centre.

PPSN XIII received 217 submissions from 44 countries. After an extensive peer-review process where most papers were evaluated by at least four reviewers, the Program Committee Chairs went through all the reports and ranked the papers. The top 90 manuscripts were finally selected for inclusion in the conference proceedings published as Vol. 8672 of Lecture Notes in Computer Science (LNCS) by Springer, and for presentation at the conference. This represents an acceptance rate of 41%, which guarantees that PPSN will continue to be one of the most respected conferences for researchers working in natural computing around the world.

PPSN XIII features three distinguished keynote speakers: Jadran Lenarčič (Jožef Stefan Institute, Slovenia), Thomas Bäck (Leiden University, The Netherlands), and A. E. (Gusz) Eiben (VU University Amsterdam, The Netherlands).

The meeting begins with seven workshops: "Scaling Behaviours of Landscapes, Parameters and Algorithms" (Ender Özcan, Andrew J. Parkes), "Advances in Multimodal Optimization" (Mike Preuss, Michael G. Epitropakis, Xiaodong Li), "Semantic Methods in Genetic Programming" (Colin Johnson, Krzysztof Krawiec, Alberto Moraglio, Michael O'Neill), "In Search of Synergies Between Reinforcement Learning and Evolutionary Computation" (Madalina M. Drugan, Bernard Manderick), "Natural Computing for Protein Structure Prediction" (José Santos Reyes, Gregorio Toscano, Julia Handl), "Workshop on Nature-Inspired Techniques for Robotics" (Claudio Rossi, Nicolas Bredeche, Kasper Stoy), and "Student Workshop on Bioinspired Optimization Methods and their Applications – BIOMA 2014" (Jurij Šilc, Aleš Zamuda). The workshops offer an ideal opportunity for the conference members to explore specific topics in evolutionary computation, bio-inspired computing, and metaheuristics in an informal and friendly setting.

PPSN XIII also includes nine free tutorials: "Theory of Evolutionary Computation" (Anne Auger, Benjamin Doerr), "Low or No Cost Distributed Evolutionary Computation" (JJ Merelo), "Cartesian Genetic Programming" (Julian F. Miller), "Multimodal Optimization" (Mike Preuss), "Theory of Parallel Evolutionary Algorithms" (Dirk Sudholt), "Automatic Design of Algorithms via Hyper-heuristic Genetic Programming" (John R. Woodward, Jerry Swan, Michael Epitropakis), "Evolutionary Bilevel Optimization" (Ankur Sinha, Pekka Malo, Kalyanmoy Deb), "Parallel Experiences in Solving Complex Problems" (Enrique Alba), and "Algorithm and Experiment Design with HeuristicLab – An Open Source Optimization Environment for Research and Education" (Stefan Wagner, Gabriel Kronberger).

The conference organizers wish to express our sincere gratitude to the Steering Committee members for generously sharing the experience from past PPSN conferences with us, the numerous Program Committee members and external reviewers for providing thorough evaluations of all 217 submissions, and the Program Chairs for managing the reviewing process and editing the conference proceedings. Thanks to all the keynote and tutorial speakers for their participation, which greatly contributes to the quality of the conference. We acknowledge the support of the sponsoring institutions and the conference partners for participating in the organization of the meeting in various ways. Finally, thanks to all the attendees for making PPSN XIII a lively and inspiring event.

We wish you a successful scientific meeting and a pleasant stay in Ljubljana.

Bogdan Filipič
General Chair, PPSN XIII

Organizing Committee

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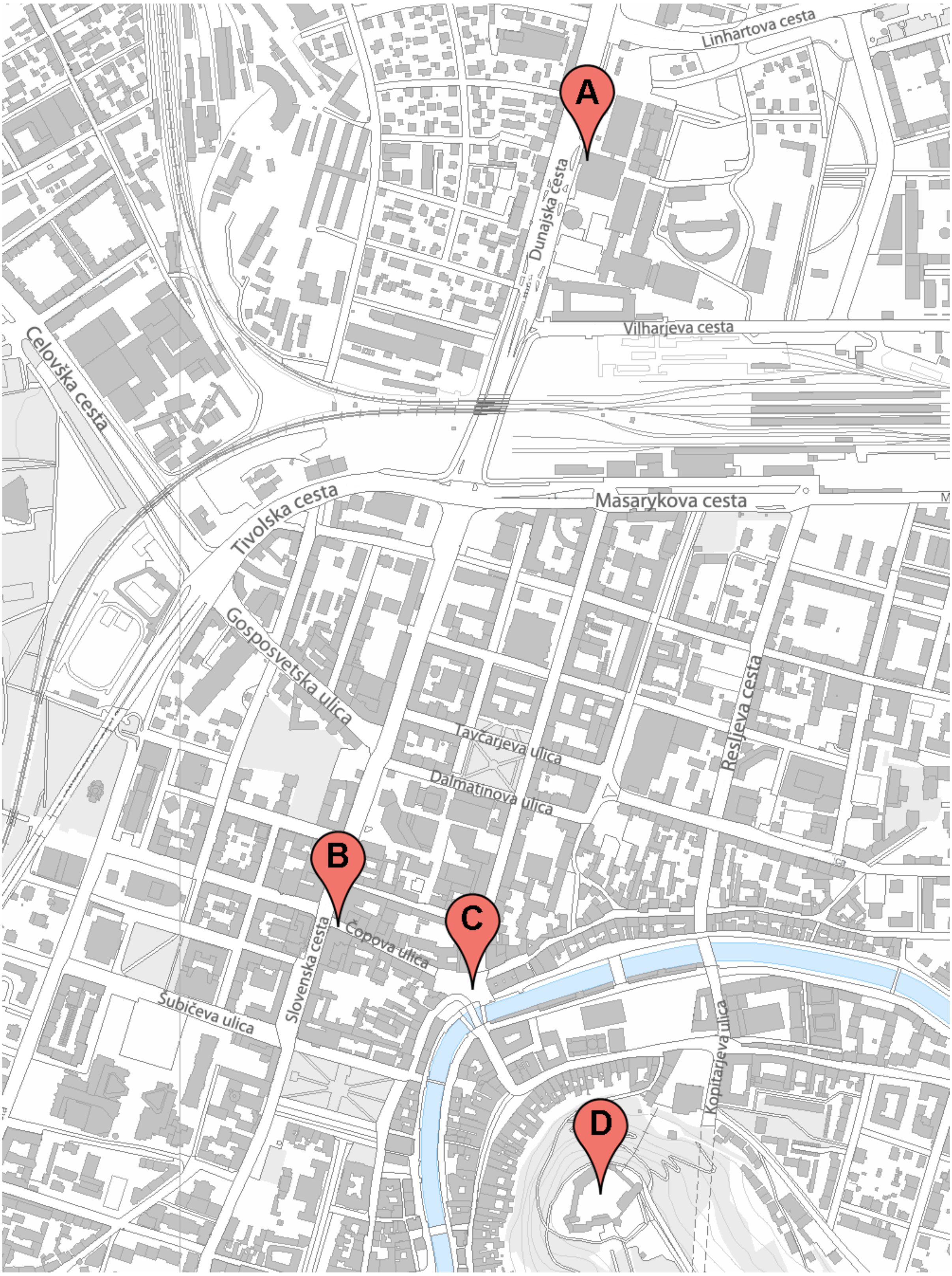
Conference Information



Ljubljana map with important conference locations:
A – conference venue (Dunajska cesta 18),
B – welcome reception (Čopova ulica 11),
C – guided city tour start (Prešernov trg/Prešeren square),
D – conference dinner (Ljubljanski grad/Ljubljana Castle)

Venue

PPSN XIII takes place at GR – Ljubljana Exhibition and Convention Centre.

Conference venue

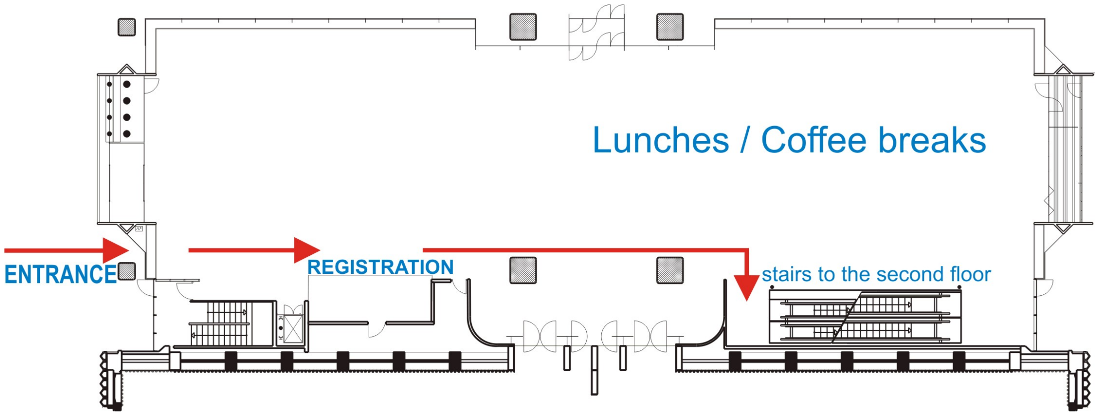
Conference Hall at the Convention Centre

Registration Desk

The registration desk is located at the entrance of the Urška Hall within the GR – Exhibition and Convention Centre. It is open all days of the conference.

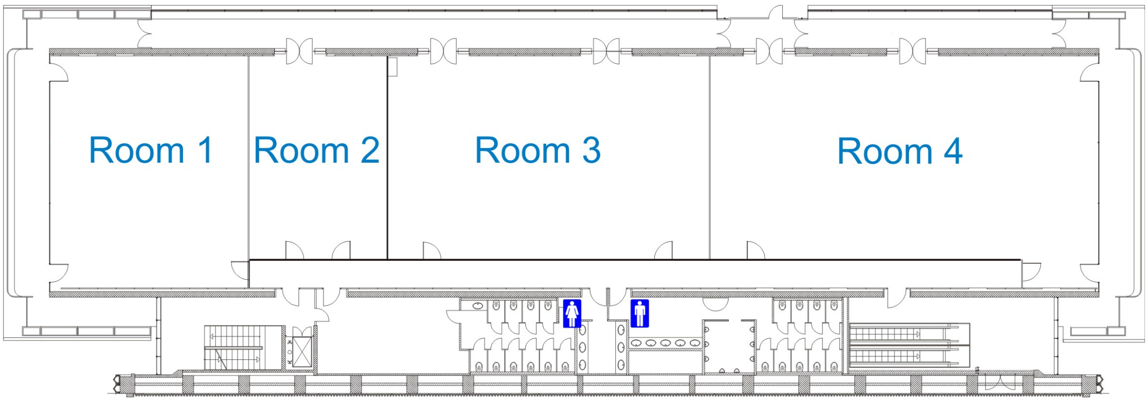
Lunches and Coffee Breaks

Lunches and coffee breaks are included in the conference fee. They take place on the ground floor of the conference hall.

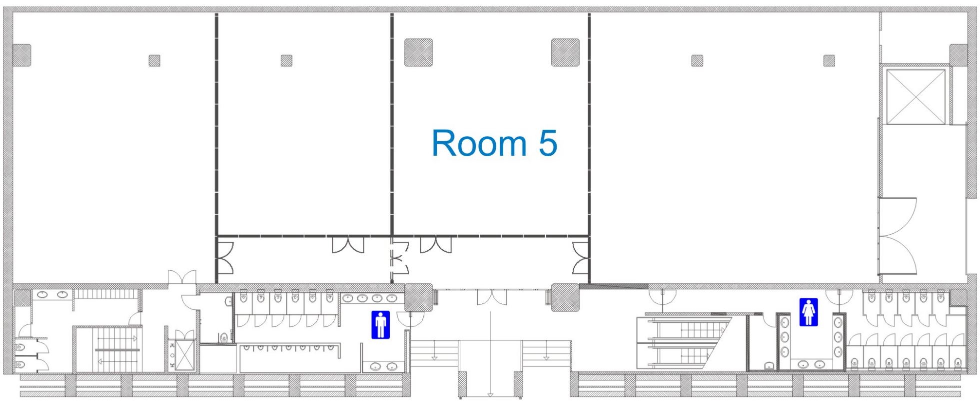


Ground floor with entrance, registration desk and lunch/coffee break corner

Room Plan



Second floor



Underground floor

Instructions for Poster Presenters

The poster presentation format is A0 (118.9 cm high and 84.1 cm wide, i.e., 46.8 in × 33.1 in, respectively). Each poster session starts with a short plenary introduction of the presented papers, and takes place in one of the conference rooms. During this introduction, the session chair summarizes the main contributions of each paper. The poster presenters should set up their posters on their assigned poster boards at least 15 minutes before the session. During the session, the presenters are expected to stand next to their posters in order to discuss their work. Please, do not forget to remove your posters after the session.

Wi-Fi Access

The conference venue offers free wireless internet access to all participants. The needed access information is in the registration materials. In addition, the Ljubljana city center is covered by the WiFreeLjubljana wireless network that is available free of charge for up to 60 minutes a day.

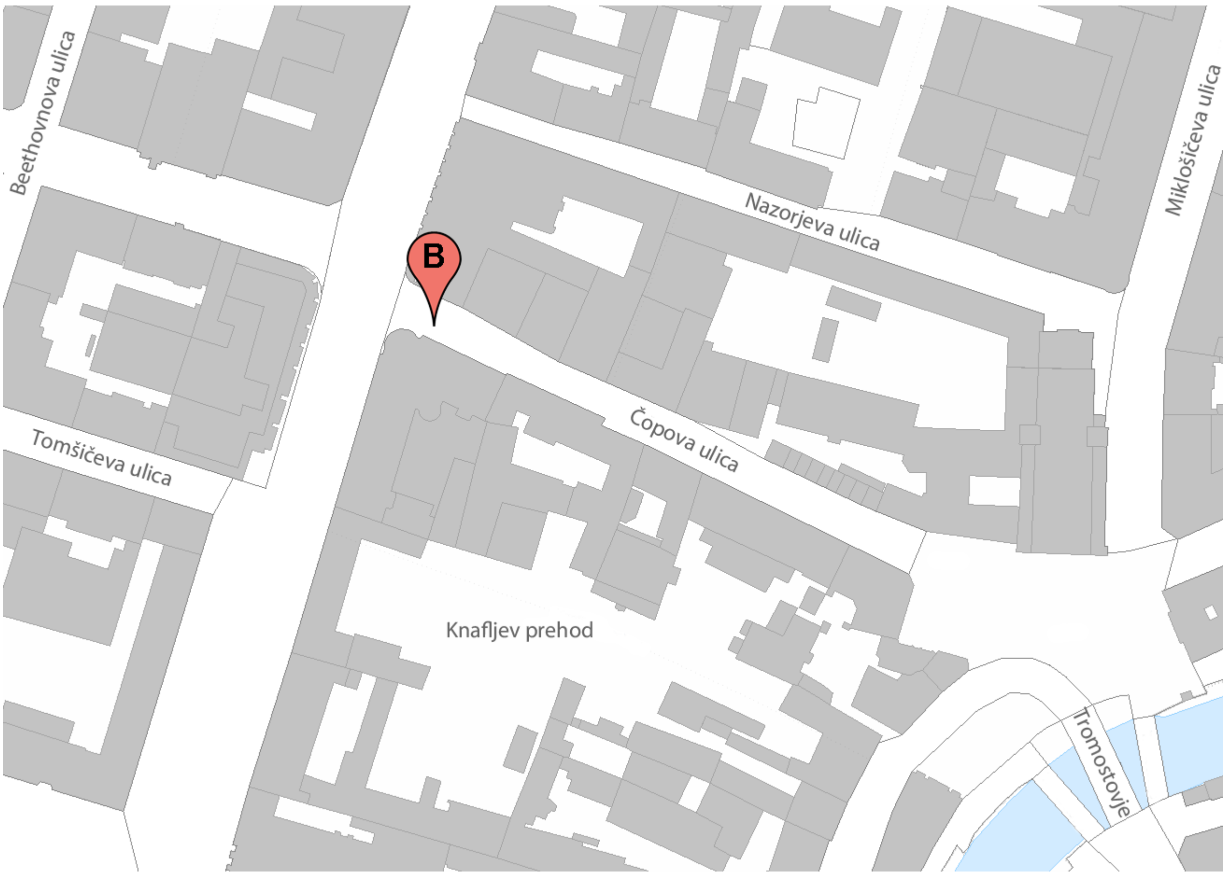
Social Events

Welcome Reception

The welcome reception takes place in the Old Post building. The Old Post is located in the city center at the crossing of the Slovenska cesta and Čopova ulica.

The Old Post

The meeting point is at the Old Post's side entrance in the Čopova ulica, on Monday, September 15, at 18:30.



Guided City Tour

A two-hour guided city tour begins in front of the Town Hall and continues through the historical city center, well known for its unique architectural appearance, which is the result of the legacy of the Baroque and Art Nouveau periods and, most notably, the work of the famous 20th century architect Jože Plečnik. The tour ends with the funicular trip to the Ljubljana Caste.

Prešeren square

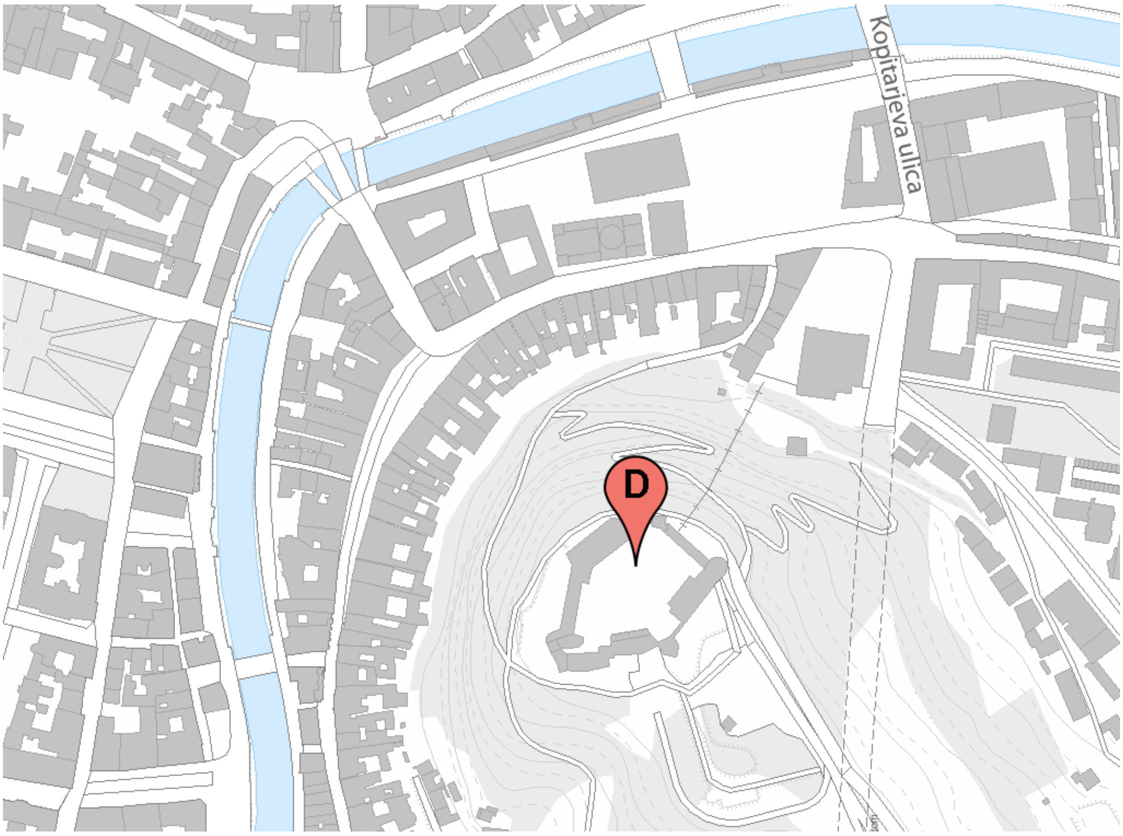
The meeting point is on the Prešeren square, on Tuesday, September 16, at 18:30.

Conference Dinner

The conference dinner is organized at the Ljubljana Castle—a mighty medieval fortress. The Ljubljana Castle, a symbol of the Slovenian capital, is an interesting tourist point, the idyllic grounds for long strolls just a glance away from the lively city centre. The castle offers many cultural, historic and entertaining events throughout the year. The dinner is served in the Palatium, which is one of the most representative spaces in the castle. Renovated in 2003, its oblong Medieval form has been retained, along with its four Renaissance bay windows, and it has been technically equipped in an imaginative way (a rising multilevel stage, movable ceiling beams, concealed lighting).

Ljubljana Castle and Palatium

The meeting point is in the castle's courtyard after the guided city tour, on Tuesday.



Workshops

Saturday, September 13

	Room 1	Room 2	Room 3	Room 4	Room 5
8:00	Registration				
9:00	**Workshop 1** Session 1	**Workshop 2** Session 1	**Workshop 3** Session 1	**Workshop 4** Session 1	
10:30	Coffee Break				
11:00	**Workshop 1** Session 2	**Workshop 2** Session 2	**Workshop 3** Session 2	**Workshop 4** Session 2	
12:30	Lunch				
14:00	**Workshop 1** Session 3	**Workshop 2** Session 3	**Workshop 3** Session 3	**Workshop 5** Session 1	**Workshop 6** Session 1
15:30	Coffee Break				
16:00	**Workshop 1** Session 4	**Workshop 2** Session 4	**Workshop 7** Session 1	**Workshop 5** Session 2	**Workshop 6** Session 2

Workshop 1: Student Workshop on Bioinspired Optimization Methods and their Applications (BIOMA 2014)
Workshop 2: Semantic Methods in Genetic Programming (SMGP)
Workshop 3: Workshop on Nature-Inspired Techniques for Robotics
Workshop 4: Scaling Behaviours of Landscapes, Parameters and Algorithms
Workshop 5: Advances in Multimodal Optimization
Workshop 6: In Search of Synergies between Reinforcement Learning and Evolutionary Computation
Workshop 7: Natural Computing for Protein Structure Prediction

Room 1: September 13, from 9:00 to 17:30

Workshop 1
Student Workshop on Bioinspired Optimization Methods and their Applications (BIOMA 2014)

Organizers: Jurij Šilc and Aleš Zamuda

Natural phenomena, like the evolution of species, emergent behavior of biological societies, and functioning of the vertebrate immune system, have inspired computer scientists to design advanced problem-solving techniques, known as evolutionary algorithms, ant colony optimization, and artificial immune systems. These and many other bioinspired algorithms that continue to emerge, overcome many limitations of traditional algorithms and have been widely accepted in science, engineering and business. Parallel solving intricate optimization problems in these domains is of particular interest to both designers and practitioners of bioinspired algorithms.

The aim of this workshop is to provide an international forum for doctoral students to discuss a range of topics that are current in research. The workshop provides an excellent opportunity to share provocative ideas, interesting preliminary work, or innovative research directions related to the use of bioinspired optimization techniques and their respective applications. The purpose of the workshop is as well to support the development of networks for young researchers in this area, both with senior researchers and with other graduate students.

Revised and extended versions of selected papers from the workshop will be invited for submission to the Informatica – An International Journal of Computing and Informatics.

9:00–10:30 Session 1 Chair: Aleš Zamuda

9:00 Analysis of Two Algorithms for Multi-Objective Min-Max Optimization
Simone Alicino and Massimiliano Vasile

9:30 Comparison Between Single and Multi Objective Genetic Algorithm Approach for Optimal Stock Portfolio Selection
Nejc Cvörnjek, Miran Brezočnik, Timotej Jagrič, and Gregor Papa

10:00 Simulation-Based GA Optimization for Production Planning
Juan Esteban Diaz Leiva and Julia Handl

11:00–12:30 Session 2 Chair: Peter Korošec

11:00 Multi-Population Adaptive Inflationary Differential Evolution
Marilena Di Carlo, Massimiliano Vasile, and Edmondo Minisci

11:30 Automated Slogan Production Using a Genetic Algorithm
Polona Tomašič, Gregor Papa, and Martin Žnidaršič

12:00 A Comparison of Search Spaces and Evolutionary Operators in Facial Composite Construction
Joseph James Mist, Stuart James Gibson, and Christopher John Solomon

14:00–15:30 Session 3 Chair: Gregor Papa

14:00 Local Search Based Optimization of a Spatial Light Distribution Model
David Kaljun and Janez Žerovnik

14:30 Parallel CUDA Implementation of the Desirability-Based Scalarization Approach for Multi-Objective Optimization Problems
Eren Akca, Ökkes Tolga Altınöz, Sadi Uçkun Emel, Asım Egemen Yilmaz, Murat Efe, and Tayfur Yaylagul

15:00 Differential Evolution for Self-Adaptive Triangular Brushstrokes
Uroš Mlakar, Janez Brest, and Aleš Zamuda

16:00–17:30 Session 4 Chair: Jurij Šilc

16:00 Extended Finite-State Machine Inference with Parallel Ant Colony Based Algorithms
Daniil Chivilikhin, Vladimir Ulyantsev, and Anatoly Shalyto

16:30 Empirical Convergence Analysis of Genetic Algorithm for Solving Unit Commitment Problem
Domen Butala, Dejan Velušček, and Gregor Papa

17:00 General discussion
Peter Korošec, Gregor Papa, Jurij Šilc, and Aleš Zamuda

Room 2: September 13, from 9:00 to 17:30

Workshop 2
Semantic Methods in Genetic Programming (SMGP)

Organizers: Colin Johnson, Krzysztof Krawiec, Alberto Moraglio, and Michael O'Neill

Genetic programming (GP)—the application of evolutionary computing techniques to the creation of computer programs—has been a key topic in computational intelligence in the last couple of decades. In the last few years a rising topic in GP has been the use of semantic methods. The aim of this is to provide a way of exploring the input-output behaviour of programs, which is ultimately what matters for problem solving. This contrasts with much previous work in GP, where operators transform the program code and the effect on program behaviour is indirect. This new approach has produced substantially better results on a number of problems, both benchmark problems and real-world applications in areas such as pharmacy; and, has been grounded in a body of theory, which also informs algorithm design. All aspects of research related to Semantic Methods in Genetic Programming will be considered, including both theoretical and empirical work.

There will be a special issue of the journal Genetic Programming and Evolvable Machines on the subject of Semantic Methods in Genetic Programming, and selected authors from the workshop will be encouraged to submit extended versions of their papers for the special issue.

9:00–10:30 Session 1 Chair: Alberto Moraglio

9:00 Introduction

9:05 Semantically-meaningful Numeric Constants for Genetic Programming
Jerry Swan, John Drake, and Krzysztof Krawiec

9:30 Information Theory, Fitness, and Sampling Semantics
Colin G. Johnson and John R. Woodward

9:55 Asymptotic Genetic Improvement Programming via Type Functors and Catamorphisms
Zoltan A. Kocsis and Jerry Swan

11:00–12:30 Session 2 Chair: Colin Johnson

11:00 Introduction to Geometric Semantic Genetic Programming
Alberto Moraglio

11:15 Semantic Operators for Evolutionary Art
Joao Correia and Penousal Machado

11:40 A Framework for Measuring the Generalization Ability of Geometric Semantic Genetic Programming (GSGP) for Black-Box Boolean Functions Learning
Andrea Mambrini, Yang Yu, and Xin Yao

12:05 Guarantees of Progress for Geometric Semantic Genetic Programming
Tomasz P. Pawlak and Krzysztof Krawiec

14:00–15:30 Session 3 Chair: Michael O'Neill

14:00 Analysis of Semantic Building Blocks via Groebner Bases
Jerry Swan, Geoffrey K. Neumann, and Krzysztof Krawiec

14:25 An Efficient Implementation of GSGP using Higher-Order Functions and Memoization
Alberto Moraglio

14:50 The Influence of Population Size on Geometric Semantic GP
Mauro Castelli, Luca Manzoni, Sara Silva, and Leonardo Vanneschi

16:00–17:30 Session 4 Chair: Krzysztof Krawiec

16:00 A Study of Semantic Geometric Crossover Operators in Regression Problems
Julio Albinati, Gisele L. Pappa, Fernando E. B. Otero, and Luiz Otávio V. B. Oliveira

16:25 Self-tuning Geometric Semantic GP
Mauro Castelli, Luca Manzoni, Sara Silva, and Leonardo Vanneschi

16:50 Geometric Semantic Grammatical Evolution
Alberto Moraglio, James McDermott, and Michael O'Neill

17:15 Closing Discussion

Room 3: September 13, from 9:00 to 15:30

Workshop 3
Workshop on Nature-Inspired Techniques for Robotics

Organizers: Claudio Rossi, Nicolas Bredeche, and Kasper Stoy

In recent years, there have been a growing number of nature-inspired approaches to robotics, from designing control architecture to robot morphologies, from considering single robot to adaptive collective systems, from bio-inspired decision models to bio-inspired learning algorithms.

The purpose of the workshop on Nature-inspired techniques for robotics is to analyze the state-of-art/state-of-knowledge in this field. The workshop is intended as a melting pot for engineers, researchers and experts working on different disciplines, fostering interdisciplinary debate between fields such as neuro-evolution, evolutionary design, artificial life, evolutionary robotics, development and learning in robotics, adaptive collective robotic systems, etc.

9:00–10:30 Session 1: Invited presentations part 1 Chair: Nicolas Bredeche

9:00 Welcome Remarks
Claudio Rossi and Nicholas Bredeche

Asynchronous Situated Coevolution: from experimentation to formalization
Abraham Prieto

On the use of algorithms inspired from natural selection
Stéphane Doncieux

Damage recovery is a reality gap problem
Jean-Baptiste Mouret

For the Good of the Cause: Hypothesis-Catching for Swarm Robots
Heiko Hamann

11:00–12:30 Session 2: Research spotlight (contributed presentations) Chair: Claudio Rossi

11:00 A Nature-Inspired Control Technique for Adaptive Hexapedal Walking on Challenging Surfaces
Xiaofeng Xiong, Florentin Wörgötter, and Poramate Manoonpong

Effects of Packing and Dynamics in a Self-Assembling System
Dhananjay Ipparthi, Massimo Mastrangeli, Navneet Bhalla, and Marco Dorigo

Diversity-based Coevolution of Behaviourally Heterogeneous Multirobot Systems
Jorge Gomes, Pedro Mariano, and Anders Lyhne Christensen

Additional Stability for Single-Unit Pattern Generators
Gregory Morse, Lisa B. Soros, and Kenneth O. Stanley

Evaluation Strategies for Distributed Embodied Evolution
Pedro Trueba, Abraham Prieto, and Francisco Bellas

Evolutionary algorithms to automatically obtain central pattern generators for biped and hexapod robotic structures
José Santos Reyes

Environment-driven embodied evolutionary robotics
Nicholas Bredeche

14:00–15:30 Session 3: Invited presentations part 2 Chair: Claudio Rossi

14:00 Making MONEE: combining environment- and task-driven evolution with swarm robots
Evert Haasdijk

Bio-inspired, Automated Design of Machine Bodies and Adaptive Brains
Sebastian Risi

Concluding remarks and discussion

Room 4: September 13, from 9:00 to 12:30

Workshop 4
Scaling Behaviours of Landscapes, Parameters and Algorithms

Organizers: Ender Özcan and Andrew J. Parkes

All too often heuristics and meta-heuristics for combinatorial optimisation problems require significant parameter tuning to work most effectively. Often this tuning is performed without any a priori knowledge as to how good values of parameters might depend on features of the problem. This lack of knowledge can lead to lot of computational effort and also has the danger of being limited to only problem instances that are similar to those that have been seen before. The aim of the workshop is to support the development of methods to give deeper insight into problem classes, and how to obtain and exploit structural information. The target participants will be those that:

1. work on the theory of search algorithms, but are seeking ways for the theory to have a practical impact;
2. work on direct applications, but are frustrated with the trial-and-error approaches that often are often used, and would like to bring 'theoretically-inspired methods' into their work;
3. work on flexible frameworks supporting interchangeability and reusability of components and a closer integration between parameter selection and the algorithm.

9:00–10:30 Session 1 Chair: Andrew J. Parkes

9:00 Welcome and Introductions

9:05 Extension of NILS to the Multi-Objective Optimization. Case study: The Multi-Objective Permutation Flowshop Scheduling Problem
Marie-Eléonore Marmion and Aymeric Blot

9:30 On the Big-Valley Hypothesis for the Permutation Flowshop Scheduling Problem with Total Flow Time Criterion
and
An Analysis of the Smoothness and Neutrality of the Permutation Flowshop Scheduling Problem with Total Flow Time Criterion
Valentino Santucci, Marco Baioletti, and Alfredo Milani

10:05 Automatic Design of Evolutionary Algorithms for Multi-Objective Optimization
Leonardo C. T. Bezerra, Manuel López-Ibáñez, and Thomas Stützle

11:00–12:30 Session 2 Chair: Andrew J. Parkes

11:00 There's method in my serendipity: Using Random Parameters in Distributed Evolutionary Algorithms
Juan J. Merelo Guervós, Mario García-Valdez, Leonardo Trujillo, and Francisco Fernández de Vega

11:25 Experiences of a MapReduce-based Discrete Implementation of a PSO algorithm
Simone A. Ludwig

11:50 CHAMP: Creating Heuristics via Many Parameters
Shahriar Asta, Ender Özcan, and Andrew Parkes

12:15 General Discussion

Room 4: September 13, from 14:00 to 17:30

Workshop 5
Advances in Multimodal Optimization

Organizers: Mike Preuss, Michael G. Epitropakis, and Xiaodong Li

The workshop attempts to bring together researchers from evolutionary computation and related areas who are interested in Multimodal Optimization. This is a currently forming field, and we aim for a highly interactive and productive meeting that makes a step forward towards defining it. The Workshop will provide a unique opportunity to review the advances in the current state-of-the-art in the field of Niching methods. Further discussion will deal with several experimental/theoretical scenarios, performance measures, real-world and benchmark problem sets and outline the possible future developments in this area. Positional statements, suggestions, and comments are very welcome!

14:00–15:30 Session 1 Chair: Mike Preuss

14:00 Introduction to Advances in Multimodal Optimization
Organizers

14:10 Discussion: most important research questions in MMO, attempt to define MMO

14:30 Evolutionary Level Set Approximation Applied in Biological Systems Identification
Michael Emmerich and Alexander Nezhinsky

14:50 Discussion: collect applications and use cases (design optimization, soft constraints, etc.) for MMO

15:10 Maximizing Diversity for Multimodal Optimization
Fabricio Olivetti de Franca

16:00–17:30 Session 2 Chair: Michael G. Epitropakis

16:00 Discussion: benchmark problems for MMO

16:20 Realistic Performance Assessment for Multimodal Optimization
Simon Wessing and Mike Preuss

16:40 Discussion: performance measuring in MMO

17:00 Workshop Wrap-up
Organizers

Room 5: September 13, from 14:00 to 17:30

Workshop 6
In Search of Synergies between Reinforcement Learning and Evolutionary Computation

Organizers: Madalina M. Drugan and Bernard Manderick

A recent trend in machine learning is the transfer of knowledge from one area to another. In this workshop, we focus on potential synergies between reinforcement learning and evolutionary computation: reinforcement learning (RL) addresses sequential decision problems in an initially unknown stochastic environment, requiring lots of computational resources while the main strength of evolutionary computation (EC) is its general applicability and computational efficiency. Although at first they seem very different, these two learning techniques address basically the same problem: the maximization of the agent's reward in a potentially unknown environment that is not always completely observable. Possibly, these machine learning methods can benefit from an exchange of ideas resulting in a better theoretical understanding and/or empirical efficiency. There are already few examples that exploit the potential synergy between EC and RL. One example is multi-objective reinforcement learning. This is a variant of reinforcement learning that uses multiple rewards instead of a single one. Techniques from multi-objective EC are used for multi-objective RL in order to improve the exploration-exploitation tradeoff. An example in the other direction is the problem of selecting the best genetic operator that is similar to the problem of an RL-agent has to choose between alternatives while maximizing its cumulative expected reward.

The main goal of this workshop is to solicit research and to start the discussion on potential synergies between RL and EC. We want to bring together researchers from machine learning, optimization, and artificial intelligence interested in searching difficult environments that are moreover possibly dynamic, uncertain and partially observable. We also encourage submissions describing applications of EC and RL for games, neural networks, and other real-world applications. Ideally, this workshop will help researchers with a background in either RL or EC to find synergies between their work as well as new challenges and ideas.

14:00–15:30 Session 1: Reinforcement Learning into Evolutionary Computation **Chair: Bernard Manderick**

14:00 'Guided' Restarts Hill-Climbing
David Catteeuw, Madalina M. Drugan, and Bernard Manderick

14:20 A Method for Auxiliary Objectives Selection using Reinforcement Learning: An Overview
Arina Buzdalova and Maxim Buzdalov

14:40 Schemata Monte Carlo Network Optimization
Pedro Isasi, Madalina M. Drugan, and Bernard Manderick

15:00 Discussion panel
Bernard Manderick

16:00–17:30 Session 2: Evolutionary Computation in Reinforcement Learning **Chair: Madalina Drugan**

16:00 Annealing-Pareto Multi-Objective Multi-Armed Bandit Algorithm
Saba Q. Yahyaa, Madalina M. Drugan, and Bernard Manderick

16:20 A Q-learning Based Evolutionary Algorithm for Sequential Decision Making Problems
Haobo Fu, Peter R. Lewis, and Xin Yao

16:40 Schemata bandits
Madalina M. Drugan, Pedro Isasi, and Bernard Manderick

17:00 Discussion panel
Madalina Drugan

Room 3: September 13, from 16:00 to 18:00

Workshop 7
Natural Computing for Protein Structure Prediction

Organizers: José Santos Reyes, Gregorio Toscano, and Julia Handl

Independent of its starting conformation, a protein in its natural environment folds into a unique three dimensional structure, the native structure. Understanding the native structure of a protein is crucial, as the structure can provide insight into the functional roles of a protein and the specific mechanisms of its biological function. As the output of experimentally determined protein structures lags behind the output of protein sequences, the computational prediction of protein structure remains a 'holy grail' of computational biology.

The aim of this workshop is to provide a forum for the exchange and communication of ideas, proposals and results related to the use of nature-inspired techniques in problems related to computational protein structure prediction. In tackling this important problem, nature-inspired techniques are currently being used in a variety of ways, but presentations related to this work are often distributed across a range of sessions / conferences / journals dependent on the particular sub-problem considered / algorithm used. It is hoped that this workshop will act as a meeting point for those authors and attendants of the PPSN conference who have a current or developing interest in this area.

16:00–18:00 Session 1 Chair: José Santos Reyes

16:00 Cellular automata for modeling protein folding in lattice models
José Santos, Pablo Villot, and Martin Diéguez

16:30 Evolutionary Multi Objective Optimisation with Diversity as Objective for the Protein Structure Similarity Problem
Sune S. Nielsen, Wiktor Jurkowski, Grégoire Danoy, Juan Luis Jiménez Laredo, Reinhard Schneider, El-Ghazali Talbi, and Pascal Bouvry

17:00 Low-resolution conformational exploration for Rosetta Ab initio by bi-level optimisation of structural features
Shaun M. Kandathil, Simon C. Lovell, and Julia Handl

17:30 Memetic, Multi-Objective, Off-Lattice, and Multiscale Evolutionary Algorithms for De novo and Guided Protein Structure Modelling
Amarda Shehu and Kenneth A. De Jong

Tutorials

Sunday, September 14

	Room 4	Room 3	Room 1/2
8:00	Registration		
10:30	**Tutorial 1** Theory of Evolutionary Computation *A. Auger, B. Doerr*	**Tutorial 2** Low or No Cost Distributed Evolutionary Computation *J. J. Merelo*	**Tutorial 3** Cartesian Genetic Programming *J. F. Miller*
12:30	Lunch		
14:00	**Tutorial 4** Multimodal Optimization *M. Preuss*	**Tutorial 5** Theory of Parallel Evolutionary Algorithms *D. Sudholt*	**Tutorial 6** Automatic Design of Algorithms via Hyper-heuristic Genetic Programming *J. R. Woodward, J. Swan, M. Epitropakis*
16:00	Coffee Break		
16:30	**Tutorial 7** Evolutionary Bilevel Optimization *A. Sinha, P. Malo, K. Deb*	**Tutorial 8** Parallel Experiences in Solving Complex Problems *E. Alba*	**Tutorial 9** Algorithm and Experiment Design with HeuristicLab - An Open Source Optimization Environment for Research and Education *S. Wagner, G. Kronberger*

Room 4: September 14, from 10:30 to 12:30

Tutorial 1
Theory of Evolutionary Computation

Anne Auger, INRIA, France
Benjamin Doerr, Ecole Polytechnique de Paris, France

Theory has always accompanied the development of evolutionary methods. It aims at detecting and explaining at a deep level the working principles, guiding the design of new algorithms and rigorously proving what has been observed. In this introductory tutorial, we target those researchers that have no or little experience with theoretical work. We will (i) explain the aims of theoretical research in evolutionary computation and give easy-to-understand examples of its success, (ii) teach the audience how to read a theoretical result and gain from it, (iii) present some very elementary theoretical methods that are useful not only for writing theory papers, but also help you in planning your experimental work and foreseeing its success.

Room 3: September 14, from 10:30 to 12:30

Tutorial 2
Low or No Cost Distributed Evolutionary Computation

JJ Merelo, University of Granada, Spain

Having a grid or cluster or money to pay for cloud is great, but the need to do science and the performance it should have is not always in sync with what is provided by your friendly funding agency. However, nowadays there are many resources attached to the Internet which you can tap when free or when they are offered to you voluntarily. In this tutorial we will talk about which resources can be used for performing mid to big scale distributed evolutionary computation experiments, what kind of languages and storage tools are available to do it and how you should adapt your algorithm to leverage those resources. It will include an introduction of how to use cloud computing resources and adapt them to the need of evolutionary algorithms and an invitation to open science and how all of us will profit from it.

Room 1/2: September 14, from 10:30 to 12:30

Tutorial 3
Cartesian Genetic Programming

Julian F. Miller, University of York, UK

Cartesian Genetic Programming (CGP) is a well-known, popular and efficient form of Genetic Programming. Cartesian Genetic Programming is a highly cited technique that was developed by Julian Miller in 1999 and 2000 from some earlier joint work of Julian Miller with Peter Thomson in 1997. In its classic form, it uses a very simple integer based genetic representation of a program in the form of a directed graph. Graphs are very useful program representations and can be applied to many domains (e.g., electronic circuits, neural networks). In a number of studies, CGP has been shown to be comparatively efficient to other GP techniques. It is also very simple to program. Since then, the classical form of CGP has been developed made more efficient in various ways. Notably by including automatically defined functions (modular CGP) and self-modification operators (self-modifying CGP). SMCGP was developed by Julian Miller, Simon Harding and Wolfgang Banzhaf. It uses functions that cause the evolved programs to change themselves as a function of time. Using this technique it is possible to find general solutions to classes of problems and mathematical algorithms (e.g., arbitrary parity, n-bit binary addition, sequences that provably compute pi and e to arbitrary precision, and so on). This tutorial is will cover the basic technique, advanced developments and applications to a variety of problem domains. The first edited book on CGP was published by Springer in September 2011. CGP has its own dedicated website.

Room 4: September 14, from 14:00 to 16:00

Tutorial 4
Multimodal Optimization

Mike Preuss, University of Münster, Germany

Multimodal optimization is currently getting established as a research direction that collects approaches from various domains of evolutionary computation that strive for delivering multiple very good solutions at once. We start with discussing why this is actually useful and therefore provide some real-world examples. From that on, we set up several scenarios and list currently employed and potentially available performance measures. This part also calls for user interaction: currently, it is very open what the actual targets of multimodal optimization shall be and how the algorithms shall be compared experimentally. As there has been little work on theory (not runtime complexity; rather the limits of different mechanisms) in the area, we present a high-level modelling approach that provides some insight in how niching can actually improve optimization methods if it fulfils certain conditions. While the algorithmic ideas for multimodal optimization (as niching) originally stem from biology and have been introduced into evolutionary algorithms from the 70s on, we only now see the consolidation of the field. The vast number of available approaches is getting sorted into collections and taxonomies start to emerge. We present our version of a taxonomy, also taking older but surpisingly modern global optimization approaches into account. We highlight some single mechanisms as clustering, multiobjectivization and archives that can be used as additions to existing algorithms or building blocks of new ones. We also discuss recent relevant competitions and their results, point to available software and outline the possible future developments in this area.

Room 3: September 14, from 14:00 to 16:00

Tutorial 5
Theory of Parallel Evolutionary Algorithms

Dirk Sudholt, University of Sheffield, UK

Evolutionary algorithms (EAs) have given rise to many parallel variants, fuelled by the rapidly increasing number of CPU cores and the ready availability of computation power through GPUs and cloud computing. A very popular approach is to parallelize evolution in island models, or coarse-grained EAs, by evolving different populations on different processors. These populations run independently most of the time, but they periodically communicate genetic information to coordinate search. Many applications have shown that island models can speed up computation time significantly, and that parallel populations can further increase solution diversity. However, there is little understanding of when and why island models perform well, and what impact fundamental parameters have on performance. This tutorial will give an overview of recent theoretical results on the runtime of parallel evolutionary algorithms. These results give insight into the fundamental working principles of parallel EAs, assess the impact of parameters and design choices on performance, and contribute to the design of more effective parallel EAs.

Room 1/2: September 14, from 14:00 to 16:00

Tutorial 6
Automatic Design of Algorithms via Hyper-heuristic Genetic Programming

John R. Woodward, University of Stirling, UK
Jerry Swan, University of Stirling, UK
Michael Epitropakis, University of Stirling, UK

How can we automatically design algorithms for a given problem domain? The aim of this tutorial is to demonstrate how we can use genetic programming to improve human-written programs. The resulting algorithms are therefore part man-made part machine-made. While there are often many algorithms suitable for a specific task (e.g., the Lin-Kernighan for the travelling salesman problem) there is often an over-arching structure which defines their functionality. There are commonalities between these algorithms (that define their purpose) and the differences (which give different performance). The invariant parts of a family of algorithms can be extracted by examining existing algorithms, and variations of the algorithm can be generated using genetic programming resulting in novel behaviour but with a predefined purpose. Therefore we have a method of mass-producing tailor-made algorithms for specific purposes. This is perhaps best illustrated by the following example; typically a travelling salesman algorithm is developed by hand and when executed returns a solution to a specific instance of the problem (i.e., an ordered list of cities). What we are advocating is a method that automatically generates travelling salesman algorithms in this example. An additional yet centrally important advantage of this approach is that the resulting algorithm is 'unique' and bespoke to the specific set of problem instances used to train the algorithm. Continuing the travelling salesman example, two logistics companies will have two different probability distributions of customers and therefore require two different algorithms if they are to achieve better performance compared to using a standard off-the-shelf travelling salesman problem algorithm. This method has been applied to a rapidly increasing number of domains including; data mining/machine learning, combinatorial problems including bin packing (on and off line), traveling salesman problems, Boolean satiability, job shop scheduling, exam timetabling, image recognition, black-box function optimization, layout of wind farms, and components of metaheuristics themselves. A step-by-step guide will be given, taking the novice through the distinct stages of the process of automatic design and a number of examples will be given to illustrate and reinforce the method in practice.

Room 4: September 14, from 16:30 to 18:30

Tutorial 7
Evolutionary Bilevel Optimization

Ankur Sinha, Aalto University School of Business, Helsinki, Finland
Pekka Malo, Aalto University School of Business, Helsinki, Finland
Kalyanmoy Deb, Michigan State University, East Lansing, MI, USA

Many practical optimization problems should better be posed as bilevel optimization problems in which there are two levels of optimization tasks. A solution at the upper level is feasible if the corresponding lower level variable vector is optimal for the lower level optimization problem. Consider, for example, an inverted pendulum problem for which the motion of the platform relates to the upper level optimization problem of performing the balancing task in a time-optimal manner. For a given motion of the platform, whether the pendulum can be balanced at all becomes a lower level optimization problem of maximizing stability margin. Such nested optimization problems are commonly found in transportation, engineering design, game playing and business models. They are also known as Stackelberg games in the operations research community. These problems are too complex to be solved using classical optimization methods simply due to the 'nestedness' of one optimization task into another. Evolutionary Algorithms (EAs) provide some amenable ways to solve such problems due to their flexibility and ability to handle constrained search spaces efficiently. Clearly, EAs have an edge in solving such difficult yet practically important problems. In the recent past, there has been a surge in research activities towards solving bilevel optimization problems. In this tutorial, we will introduce principles of bilevel optimization for single and multiple objectives, and discuss the difficulties in solving such problems in general. With a brief survey of the existing literature, we will present a few viable evolutionary algorithms for both single and multi-objective EAs for bilevel optimization. Our recent studies on bilevel test problems and some application studies will be discussed. Finally, a number of immediate and future research ideas on bilevel optimization will also be highlighted.

Room 3: September 14, from 16:30 to 18:30

Tutorial 8 Parallel Experiences in Solving Complex Problems

Enrique Alba, University of Malaga, Spain

This talk introduces the basic concepts of two fields of research: parallelism and metaheuristics. We will revise the main concepts, tools, metrics, open issues, and application domains related to parallel models of search, optimization, and learning techniques. The very special kind of algorithms searching in a decentralized manner and later parallelized will be shown to solve complex problems at unseen levels of efficiency and efficacy. Facts, methodology, and general open issues will be presented in this talk.

Room 1/2: September 14, from 16:30 to 18:30

Tutorial 9
Algorithm and Experiment Design with HeuristicLab – An Open Source Optimization Environment for Research and Education

Stefan Wagner, University of Applied Sciences Upper Austria, Austria
Gabriel Kronberger, University of Applied Sciences Upper Austria, Austria

HeuristicLab is an open source system for heuristic optimization that features many metaheuristic optimization algorithms (e.g., genetic algorithms, genetic programming, evolution strategies, taboo search, simulated annealing) as well as many optimization problems (e.g., traveling salesman, regression, classification, vehicle routing, knapsack, job shop scheduling, simulation-based optimization). It is based on C# and the Microsoft .NET Framework and is used as development platform for several research and industry projects as well as for teaching metaheuristics in university courses. This tutorial demonstrates how to apply HeuristicLab in research and education for creating, executing and analyzing metaheuristic optimization algorithms. It includes many interactive live demonstrations in which it will be shown how to parameterize and execute evolutionary algorithms to solve combinatorial optimization problems as well as data analysis problems. The participants will see how to assemble different algorithms and parameter settings to large scale optimization experiments with HeuristicLab's graphical user interface and how to execute such experiments on multi-core or cluster systems. Furthermore, the experiment results will be compared using HeuristicLab's interactive charts for visual and statistical analysis. To complete the tutorial, it will be sketched briefly how HeuristicLab can be extended with further optimization problems and how custom optimization algorithms can be modeled using the graphical algorithm designer.

Keynotes

Monday – Wednesday, September 15–17

	Monday September 15	Tuesday September 16	Wednesday September 17
8:00	Registration		
8:30		Registration	Registration
9:00	**Conference Opening & Keynote 1**	**Announcements & Keynote 2**	**Announcements & Keynote 3**
10:30	Coffee Break	Coffee Break	Coffee Break
11:00	**Posters 1**	**Posters 4**	**Posters 7**
12:30	Lunch	Lunch	**Conference Closing**
			Lunch
14:00	**Posters 2**	**Posters 5**	
15:30	Coffee Break	Coffee Break	
16:00	**Posters 3**	**Posters 6**	
18:30	Welcome Reception	City Tour & Conference Dinner	

Room 4: September 15, from 9:15 to 10:30 Chair: Bogdan Filipič

Keynote 1
Some Computational Aspects of Robot Kinematic Redundancy

Jadran Lenarčič, Jožef Stefan Institute, Slovenia

Computations in robotics cover a rich spectrum of problems at the junction of mechanics, computer science, engineering and mathematics. In this talk the emphasis will be given to robot kinematics, its analysis, design and optimization with respect to different tasks. This will include a brief discussion on the direct and inverse kinematics problems of serial and parallel mechanisms, kinematic singularities, workspace determination, manipulability, as well as kinematic flexibility. Examples will present peculiarities in robot and human motion performing different tasks, such as the manipulation of heavy objects or the vertical jump, with the focus on kinematic redundancy. Redundant robots possess too many degrees of freedom; their number exceeds the number required by the task. Therefore, redundancy gives to the robot an immense source of freedom and enables it to solve different tasks in an infinite number of ways. The robot can simultaneously solve additional secondary tasks of lower priority. We will discuss various aspects in robot programming and design in comparison with humans.

Room 4: September 16, from 9:15 to 10:30 Chair: Günter Rudolph

Keynote 2
Solving Optimization Problems in Industry: An Arms Race

Thomas Bäck, Leiden University, The Netherlands

Many industries use simulation tools for virtual product design, and there is a growing trend towards using simulation in combination with optimization algorithms. The requirements for optimization under such circumstances are often very strong, involving many design variables and constraints and a strict limitation of the number of function evaluations to a surprisingly small number (often around one thousand or less). Tuning optimization algorithms for such challenges has led to very good results obtained by variants of evolution strategies. Evolutionary algorithms are nowadays standard solvers for such applications. In the presentation, sample cases from industry are presented, their challenges are discussed in more detail. Results of an experimental comparison of contemporary evolution strategies on the BBOB test function set for a small number of function evaluations are presented and discussed, and further enhancements of contemporary evolution strategies are outlined. Our practical examples are motivated by industrial applications. A typical challenge is to find innovative solutions to a design optimization task. Based on a suitable definition of innovative solutions, an application of this concept to an airfoil design optimization task is discussed in the presentation. Discussing these applications and the variants of evolution strategies applied, the capabilities of these algorithms for optimization cases with a small number of function evaluations are illustrated.

Room 4: September 17, from 9:15 to 10:30 Chair: Marc Schoenauer

Keynote 3
In Vivo Veritas: Towards the Evolution of Things

A. E. (Gusz) Eiben, VU University Amsterdam, The Netherlands

Evolutionary Computing (EC) is the research field concerned with artificial evolutionary processes in digital spaces, inside computers. In about three decades the EC community learned the 'art of taming evolution' and developed several evolutionary algorithm variants to solve optimization, design, and machine learning problems. In all these applications, the reproductive entities are digital. This holds even in evolutionary robotics where the evolved code is ported to a robot body and in evolutionary design where the evolved design is constructed physically after the evolutionary process terminates. In this talk I present a vision about the next big breakthrough: the creation of artificial evolutionary processes in physical spaces. In other words, I envision the "Evolution of Things", rather than just the evolution of digital objects, leading to a new field of Embodied Artificial Evolution. After presenting this vision I elaborate on some of the technical challenges and relate the main algorithmic/technical requirements to the current know-how in EC. Finally, I will speculate about possible applications, their societal impacts, and argue that these developments will radically change our lives.

Poster Sessions

Monday – Wednesday, September 15–17

	Monday September 15	Tuesday September 16	Wednesday September 17
8:00	Registration		
8:30		Registration	Registration
9:00	**Conference Opening & Keynote 1**	**Announcements & Keynote 2**	**Announcements & Keynote 3**
10:30	Coffee Break	Coffee Break	Coffee Break
11:00	**Posters 1**	**Posters 4**	**Posters 7**
12:30	Lunch	Lunch	**Conference Closing**
			Lunch
14:00	**Posters 2**	**Posters 5**	
15:30	Coffee Break	Coffee Break	
16:00	**Posters 3**	**Posters 6**	
18:30	Welcome Reception	City Tour & Conference Dinner	

Monday, September 15

11:00–12:30 Room 3: Poster Session 1

11:00–11:20 Poster Introduction, *Chair: Enrique Alba*

S1.1 Proc. p. 40
Online Black-Box Algorithm Portfolios for Continuous Optimization
Petr Baudiš and Petr Pošík

S1.2 Proc. p. 110
Self-Adaptive Genotype-Phenotype Maps: Neural Networks as a Meta-Representation
Luís F. Simões, Dario Izzo, Evert Haasdijk, and A. E. Eiben

S1.3 Proc. p. 181
Derivation of a Micro-Macro Link for Collective Decision-Making Systems: Uncover Network Features Based on Drift Measurements
Heiko Hamann, Gabriele Valentini, Yara Khaluf, and Marco Dorigo

S1.4 Proc. p. 252
Natural Gradient Approach for Linearly Constrained Continuous Optimization
Youhei Akimoto and Shinichi Shirakawa

S1.5 Proc. p. 322
A Study on Multimemetic Estimation of Distribution Algorithms
Rafael Nogueras and Carlos Cotta

S1.6 Proc. p. 394
Compressing Regular Expression Sets for Deep Packet Inspection
Alberto Bartoli, Simone Cumar, Andrea De Lorenzo, and Eric Medvet

S1.7 Proc. p. 465
On the Locality of Standard Search Operators in Grammatical Evolution
Ann Thorhauer and Franz Rothlauf

S1.8 Proc. p. 538
Clustering-Based Selection for Evolutionary Many-Objective Optimization
Roman Denysiuk, Lino Costa, and Isabel Espírito Santo

S1.9 Proc. p. 611
Discovery of Implicit Objectives by Compression of Interaction Matrix in Test-Based Problems
Paweł Liskowski and Krzysztof Krawiec

S1.10 Proc. p. 682
Using a Family of Curves to Approximate the Pareto Front of a Multi-Objective Optimization Problem
Saúl Zapotecas Martínez, Víctor A. Sosa Hernández, Hernán Aguirre, Kiyoshi Tanaka, and Carlos A. Coello Coello

S1.11 Proc. p. 822
Combining Evolutionary Computation and Algebraic Constructions to Find Cryptography-Relevant Boolean Functions
Stjepan Picek, Elena Marchiori, Lejla Batina, and Domagoj Jakobovic

S1.12 Proc. p. 852 Coupling Evolution and Information Theory for Autonomous Robotic Exploration
Guohua Zhang and Michèle Sebag

S1.13 Proc. p. 892 Unbiased Black-Box Complexity of Parallel Search
Golnaz Badkobeh, Per Kristian Lehre, and Dirk Sudholt

14:00–15:30 Room 1/2: Poster Session 2

14:00–14:20 Poster Introduction, *Chair: Jürgen Branke*

S2.1 Proc. p. 120 The Baldwin Effect Hinders Self-Adaptation
Jim Smith

S2.2 Proc. p. 171 A Taxonomy of Heterogeneity and Dynamics in Particle Swarm Optimisation
Harry Goldingay and Peter R. Lewis

S2.3 Proc. p. 243 An Immune-Inspired Algorithm for the Set Cover Problem
Ayush Joshi, Jonathan E. Rowe, and Christine Zarges

S2.4 Proc. p. 332 Factoradic Representation for Permutation Optimisation
Olivier Regnier-Coudert and John McCall

S2.5 Proc. p. 404 Inferring and Exploiting Problem Structure with Schema Grammar
Chris R. Cox and Richard A. Watson

S2.6 Proc. p. 424 Population Exploration on Genotype Networks in Genetic Programming
Ting Hu, Wolfgang Banzhaf, and Jason H. Moore

S2.7 Proc. p. 528 A Provably Asymptotically Fast Version of the Generalized Jensen Algorithm for Non-dominated Sorting
Maxim Buzdalov and Anatoly Shalyto

S2.8 Proc. p. 621 Local Optimal Sets and Bounded Archiving on Multi-objective NK-Landscapes with Correlated Objectives
Manuel López-Ibáñez, Arnaud Liefooghe, and Sébastien Verel

S2.9 Proc. p. 721 Evolution-In-Materio: Solving Machine Learning Classification Problems Using Materials
Maktuba Mohid, Julian Francis Miller, Simon L. Harding, Gunnar Tufte, Odd Rune Lykkebø, Mark K. Massey, and Mike C. Petty

S2.10 Proc. p. 761 Application of Evolutionary Methods to Semiconductor Double-Chirped Mirrors Design
Rafał Biedrzycki, Jarosław Arabas, Agata Jasik, Michał Szymański, Paweł Wnuk, Piotr Wasylczyk, and Anna Wójcik-Jedlińska

S2.11 A Memetic Algorithm for Multi Layer Hierarchical Ring Network Design
Proc. p. 832 *Christian Schauer and Günther Raidl*

S2.12 A Generalized Markov-Chain Modelling Approach to $(1, \lambda)$-ES Linear Optimization
Proc. p. 902 *Alexandre Chotard and Martin Holeňa*

S2.13 Runtime Analysis of Evolutionary Algorithms on Randomly Constructed High-Density Satisfiable 3-CNF Formulas
Proc. p. 942 *Andrew M. Sutton and Frank Neumann*

16:00–17:30 Room 3: Poster Session 3

16:00–16:20 Poster Introduction, *Chair: Jim Smith*

S3.1 How to Assess Step-Size Adaptation Mechanisms in Randomised Search
Proc. p. 60 *Nikolaus Hansen, Asma Atamna, and Anne Auger*

S3.2 On Low Complexity Acceleration Techniques for Randomized Optimization
Proc. p. 130 *Sebastian Urban Stich*

S3.3 Reevaluating Exponential Crossover in Differential Evolution
Proc. p. 201 *Ryoji Tanabe and Alex Fukunaga*

S3.4 Combining Model-Based EAs for Mixed-Integer Problems
Proc. p. 342 *Krzysztof L. Sadowski, Dirk Thierens, and Peter A. N. Bosman*

S3.5 Bent Function Synthesis by Means of Cartesian Genetic Programming
Proc. p. 414 *Radek Hrbacek and Vaclav Dvorak*

S3.6 Generic Postprocessing via Subset Selection for Hypervolume and Epsilon-Indicator
Proc. p. 518 *Karl Bringmann, Tobias Friedrich, and Patrick Klitzke*

S3.7 Multi-objective Quadratic Assignment Problem Instances Generator with a Known Optimum Solution
Proc. p. 559 *Mădălina M. Drugan*

S3.8 Optimized Approximation Sets for Low-Dimensional Benchmark Pareto Fronts
Proc. p. 569 *Tobias Glasmachers*

S3.9 Racing Multi-objective Selection Probabilities
Proc. p. 631 *Gaétan Marceau-Caron and Marc Schoenauer*

S3.10 Randomized Parameter Settings for Heterogeneous Workers in a Pool-Based Evolutionary Algorithm
Proc. p. 702
Mario García-Valdez, Leonardo Trujillo, Juan Julián Merelo-Guérvos, and Francisco Fernández-de-Vega

S3.11 Evolving Neural Network Weights for Time-Series Prediction of General Aviation Flight Data
Proc. p. 771
Travis Desell, Sophine Clachar, James Higgins, and Brandon Wild

S3.12 Scheduling the English Football League with a Multi-objective Evolutionary Algorithm
Proc. p. 842
Lyndon While and Graham Kendall

S3.13 On the Use of Evolution Strategies for Optimization on Spherical Manifolds
Proc. p. 882
Dirk V. Arnold

Tuesday, September 16

11:00–12:30 Room 3: Poster Session 4

11:00–11:20 Poster Introduction, *Chair: Evert Haasdijk*

S4.1 Maximum Likelihood-Based Online Adaptation of Hyper-Parameters in CMA-ES
Proc. p. 70
Ilya Loshchilov, Marc Schoenauer, Michèle Sebag, and Nikolaus Hansen

S4.2 Stopping Criteria for Multimodal Optimization
Proc. p. 141
Simon Wessing, Mike Preuss, and Heike Trautmann

S4.3 An Extended Michigan-Style Learning Classifier System for Flexible Supervised Learning, Classification, and Data Mining
Proc. p. 211
Ryan J. Urbanowicz, Gediminas Bertasius, and Jason H. Moore

S4.4 On the Life-Long Learning Capabilities of a NELLI*: A Hyper-Heuristic Optimisation System
Proc. p. 282
Emma Hart and Kevin Sim

S4.5 A New EDA by a Gradient-Driven Density
Proc. p. 352
Ignacio Segovia Domínguez, Arturo Hernández Aguirre, and S. Ivvan Valdez

S4.6 Recurrent Cartesian Genetic Programming
Proc. p. 476
Andrew James Turner and Julian Francis Miller

S4.7 Proc. p. 498 — A Multiobjective Evolutionary Optimization Framework for Protein Purification Process Design
Richard Allmendinger and Suzanne S. Farid

S4.8 Proc. p. 641 — Shake Them All!: Rethinking Selection and Replacement in MOEA/D
Gauvain Marquet, Bilel Derbel, Arnaud Liefooghe, and El-Ghazali Talbi

S4.9 Proc. p. 711 — PaDe: A Parallel Algorithm Based on the MOEA/D Framework and the Island Model
Andrea Mambrini and Dario Izzo

S4.10 Proc. p. 751 — A Geometrical Approach to the Incompatible Substructure Problem in Parallel Self-Assembly
Navneet Bhalla, Dhananjay Ipparthi, Eric Klemp, and Marco Dorigo

S4.11 Proc. p. 782 — Random Partial Neighborhood Search for University Course Timetabling Problem
Yuichi Nagata and Isao Ono

S4.12 Proc. p. 912 — Level-Based Analysis of Genetic Algorithms and Other Search Processes
Dogan Corus, Duc-Cuong Dang, Anton V. Eremeev, and Per Kristian Lehre

S4.13 Proc. p. 922 — Maximizing Submodular Functions under Matroid Constraints by Multiobjective Evolutionary Algorithms
Tobias Friedrich and Frank Neumann

14:00–15:30 Room 1/2: Poster Session 5

14:00–14:20 Poster Introduction, *Chair: Carlos Cotta*

S5.1 Proc. p. 80 — Run-Time Parameter Selection and Tuning for Energy Optimization Algorithms
Ingo Mauser, Marita Dorscheid, and Hartmut Schmeck

S5.2 Proc. p. 151 — VLR: A Memory-Based Optimization Heuristic
Hansang Yun, Myoung Hoon Ha, and Robert Ian McKay

S5.3 Proc. p. 222 — A Cooperative Evolutionary Approach to Learn Communities in Multilayer Networks
Alessia Amelio and Clara Pizzuti

S5.4 Proc. p. 272 — Viability Principles for Constrained Optimization Using a (1+1)-CMA-ES
Andrea Maesani and Dario Floreano

S5.5 Proc. p. 292 — Adaptation in Nonlinear Learning Models for Nonstationary Tasks
Wolfgang Konen and Patrick Koch

S5.6 From Expected Improvement to Investment Portfolio Improvement: Spreading the Risk in Kriging-Based Optimization
Proc. p. 362
Rasmus K. Ursem

S5.7 Improving Genetic Programming with Behavioral Consistency Measure
Proc. p. 434
Krzysztof Krawiec and Armando Solar-Lezama

S5.8 Automatic Design of Evolutionary Algorithms for Multi-Objective Combinatorial Optimization
Proc. p. 508
Leonardo C. T. Bezerra, Manuel López-Ibáñez, and Thomas Stützle

S5.9 Start Small, Grow Big? Saving Multi-objective Function Evaluations
Proc. p. 579
Tobias Glasmachers, Boris Naujoks, and Günter Rudolph

S5.10 MH-MOEA: A New Multi-Objective Evolutionary Algorithm Based on the Maximin Fitness Function and the Hypervolume Indicator
Proc. p. 652
Adriana Menchaca-Mendez and Carlos A. Coello Coello

S5.11 Balancing Bicycle Sharing Systems: An Analysis of Path Relinking and Recombination within a GRASP Hybrid
Proc. p. 792
Petrina Papazek, Christian Kloimüllner, Bin Hu, and Günther Raidl

S5.12 Evolving DPA-Resistant Boolean Functions
Proc. p. 812
Stjepan Picek, Lejla Batina, and Domagoj Jakobovic

S5.13 On the Runtime Analysis of Fitness Sharing Mechanisms
Proc. p. 932
Pietro S. Oliveto, Dirk Sudholt, and Christine Zarges

16:00–17:30 Room 3: Poster Session 6

16:00–16:20 Poster Introduction, *Chair: Rasmus K. Ursem*

S6.1 Towards a Method for Automatic Algorithm Configuration: A Design Evaluation Using Tuners
Proc. p. 90
Elizabeth Montero and María Cristina Riff

S6.2 A Differential Evolution Algorithm for the Permutation Flowshop Scheduling Problem with Total Flow Time Criterion
Proc. p. 161
Valentino Santucci, Marco Baioletti, and Alfredo Milani

S6.3 Novelty Search in Competitive Coevolution
Proc. p. 233
Jorge Gomes, Pedro Mariano, and Anders Lyhne Christensen

S6.4 On the Effectiveness of Sampling for Evolutionary Optimization in Noisy Environments
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Wednesday, September 17

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S7.1 Proc. p. 50
Shuffle and Mate: A Dynamic Model for Spatially Structured Evolutionary Algorithms
Carlos M. Fernandes, Juan L. J. Laredo, Juan Julian Marelo, Carlos Cotta, Rafael Nogueras, and Agostinho C. Rosa

Paper Abstracts

Proc. p. 40 Online Black-Box Algorithm Portfolios for Continuous Optimization
S1.1 *Petr Baudiš and Petr Pošík*

In black-box function optimization, we can choose from a wide variety of heuristic algorithms that are suited to different functions and computation budgets. Given a particular function to be optimized, the problem we consider in this paper is how to select the appropriate algorithm. In general, this problem is studied in the field of algorithm portfolios; we treat the algorithms as black boxes themselves and consider *online* selection (without learning mapping from problem features to best algorithms a priori and dynamically switching between algorithms during the optimization run). We study some approaches to algorithm selection and present two original selection strategies based on the UCB1 multi-armed bandit policy applied to unbounded rewards. We benchmark our strategies on the BBOB workshop reference functions and demonstrate that algorithm portfolios are beneficial in practice even with some fairly simple strategies, though choosing a good strategy is important.

Proc. p. 50 Shuffle and Mate: A Dynamic Model for Spatially Structured Evolutionary Algorithms
S7.1 *Carlos M. Fernandes, Juan L. J. Laredo, Juan Julian Marelo, Carlos Cotta, Rafael Nogueras, and Agostinho C. Rosa*

This paper studies a self-organized framework for modeling dynamic topologies in spatially structured Evolutionary Algorithms (EAs). The model consists of a 2-dimensional grid of nodes where the individuals interact and self-organize into clusters. During the search process, the individuals move through the grid, following a pre-defined simple rule. In order to evaluate the model, a dynamic cellular Genetic Algorithm (dcGA) is built over the proposed topology and four different movement rules are tested. The results show that when the ratio between the number of nodes in the grid and the population size is above 4:1, the individuals self-organize into highly dynamic clusters and significantly improve results attained by standard cGAs with static topologies on a set of deceptive and multimodal functions.

Proc. p. 60 How to Assess Step-Size Adaptation Mechanisms in Randomised Search
S3.1 *Nikolaus Hansen, Asma Atamna, and Anne Auger*

Step-size adaptation for randomised search algorithms like evolution strategies is a crucial feature for their performance. The adaptation must, depending on the situation, sustain a large diversity or entertain fast convergence to the desired optimum. The assessment of step-size adaptation mechanisms is therefore non-trivial and often done in too restricted scenarios, possibly only on the sphere function. This paper introduces a (minimal) methodology combined with a practical procedure to conduct a more thorough assessment of the overall population diversity of a randomised search algorithm in different scenarios. We illustrate the methodology on evolution strategies with σ-self-adaptation, cumulative step-size adaptation and two-point adaptation. For the latter, we introduce a variant that abstains from *additional* samples by constructing two particular individuals within the *given* population to decide on the step-size change. We find that results on the sphere function alone can be rather misleading to assess mechanisms to control overall population diversity. The most striking flaws we observe for self-adaptation: on the linear function, the step-size increments are rather small, and on a moderately conditioned ellipsoid function, the adapted step-size is 20 times smaller than optimal.

Proc. p. 70 Maximum Likelihood-Based Online Adaptation of Hyper-Parameters in CMA-ES
S4.1
Ilya Loshchilov, Marc Schoenauer, Michèle Sebag, and Nikolaus Hansen

The Covariance Matrix Adaptation Evolution Strategy (CMA-ES) is widely accepted as a robust derivative-free continuous optimization algorithm for non-linear and non-convex optimization problems. CMA-ES is well known to be almost parameterless, meaning that only one hyper-parameter, the population size, is proposed to be tuned by the user. In this paper, we propose a principled approach called self-CMA-ES to achieve the online adaptation of CMA-ES hyper-parameters in order to improve its overall performance. Experimental results show that for larger-than-default population size, the default settings of hyper-parameters of CMA-ES are far from being optimal, and that self-CMA-ES allows for dynamically approaching optimal settings.

Proc. p. 80 Run-Time Parameter Selection and Tuning for Energy Optimization Algorithms
S5.1
Ingo Mauser, Marita Dorscheid, and Hartmut Schmeck

Energy Management Systems (EMS) promise a great potential to enable the sustainable and efficient integration of distributed energy generation from renewable sources by optimization of energy flows. In this paper, we present a run-time selection and meta-evolutionary parameter tuning component for optimization algorithms in EMS and an approach for the distributed application of this component. These have been applied to an existing EMS, which uses an Evolutionary Algorithm. Evaluations of the component in realistic scenarios show reduced run-times with similar or even improved solution quality, while the distributed application reduces the risk of over-confidence and over-tuning.

Proc. p. 90 Towards a Method for Automatic Algorithm Configuration: A Design Evaluation Using Tuners
S6.1
Elizabeth Montero and María Cristina Riff

Metaheuristic design is an incremental and difficult task. It is usually iterative and requires several evaluations of the code to obtain an algorithm with good performance. In this work, we analyse the design of metaheuristics by detecting components which are strictly necessary to obtain a good performance (in term of solutions quality). We use a collective strategy where the information generated by a tuner is used to detect the components usefulness. We evaluate this strategy with two well-known tuners EVOCA and I-RACE to analyse which one is more suitable and provides better results to make this components detection. The goal is to help the designer either to evaluate during the design process different options of the code or to simplify her/his final code without a loss in the quality of the solutions.

Proc. p. 100 Parameter Prediction Based on Features of Evolved Instances for Ant
S7.2 Colony Optimization and the Traveling Salesperson Problem
Samadhi Nallaperuma, Markus Wagner, and Frank Neumann

Ant colony optimization performs very well on many hard optimization problems, even though no good worst case guarantee can be given. Understanding the reasons for the performance and the influence of its different parameter settings has become an interesting problem. In this paper, we build a parameter prediction model for the Traveling Salesperson problem based on features of evolved instances. The two considered parameters are the importance of the pheromone values and of the heuristic information. Based on the features of the evolved instances, we successfully predict the best parameter setting for a wide range of instances taken from TSPLIB.

Proc. p. 110 Self-Adaptive Genotype-Phenotype Maps: Neural Networks as a Meta-
S1.2 Representation
Luís F. Simões, Dario Izzo, Evert Haasdijk, and A. E. Eiben

In this work we investigate the usage of feedforward neural networks for defining the genotype-phenotype maps of arbitrary continuous optimization problems. A study is carried out over the neural network parameters space, aimed at understanding their impact on the locality and redundancy of representations thus defined. Driving such an approach is the goal of placing problems' genetic representations under automated adaptation. We therefore conclude with a proof-of-concept, showing genotype-phenotype maps being successfully self-adapted, concurrently with the evolution of solutions for hard real-world problems.

Proc. p. 120 The Baldwin Effect Hinders Self-Adaptation
S2.1 *Jim Smith*

The "end-game" of evolutionary optimisation is often largely governed by the efficiency and effectiveness of searching regions of space known to contain high quality solutions. In a traditional EA this role is done via mutation, which creates a tension with its other different role of maintaining diversity. One approach to improving the efficiency of this phase is self-adaptation of the mutation rates. This leaves the fitness landscape unchanged, but adapts the shape of the probability distribution function governing the generation of new solutions. A different approach is the incorporation of local search – so-called Memetic Algorithms. Depending on the paradigm, this approach either changes the fitness landscape (Baldwinian learning) or causes a mapping to a reduced subset of the previous fitness landscape (Lamarkian learning). This paper explores the interaction between these two mechanisms. Initial results suggest that the reduction in landscape gradients brought about by the Baldwin effect can reduce the effectiveness of self-adaptation. In contrast Lamarkian learning appears to enhance the process of self-adaptation, with very different behaviours seen on different problems.

Proc. p. 130 On Low Complexity Acceleration Techniques for Randomized Optimiza-
S3.2 tion
Sebastian Urban Stich

Recently it was shown by Nesterov (2011) that techniques form convex optimization can be used to successfully accelerate simple derivative-free randomized optimization methods. The appeal of those schemes lies in their low complexity, which is only $\Theta(n)$ per iteration—

compared to $\Theta(n^2)$ for algorithms storing second-order information or covariance matrices. From a high-level point of view, those accelerated schemes employ correlations between successive iterates—a concept looking similar to the evolution path used in Covariance Matrix Adaptation Evolution Strategies (CMA-ES). In this contribution, we (i) implement and empirically test a simple accelerated random search scheme (SARP). Our study is the first to provide numerical evidence that SARP can effectively be implemented with adaptive step size control and does not require access to gradient or advanced line search oracles. We (ii) try to empirically verify the supposed analogy between the evolution path and SARP. We propose an algorithm CMA-EP that uses only the evolution path to bias the search. This algorithm can be generalized to a family of low memory schemes, with complexity $\Theta(mn)$ per iteration, following a recent approach by Loshchilov (2014). The study shows that the performance of CMA-EP heavily depends on the spectra of the objective function and thus it cannot accelerate as consistently as SARP.

Proc. p. 141 Stopping Criteria for Multimodal Optimization
S4.2 *Simon Wessing, Mike Preuss, and Heike Trautmann*

Multimodal optimization requires maintenance of a good search space coverage and approximation of several optima at the same time. We analyze two constitutive optimization algorithms and show that in many cases, a phase transition occurs at some point, so that either diversity collapses or optimization stagnates. But how to derive suitable stopping criteria for multimodal optimization? Experimental results indicate that an algorithm's population contains sufficient information to estimate the point in time when several performance indicators reach their optimum. Thus, stopping criteria are formulated based on summary characteristics employing objective values and mutation strength.

Proc. p. 151 VLR: A Memory-Based Optimization Heuristic
S5.2 *Hansang Yun, Myoung Hoon Ha, and Robert Ian McKay*

We suggest a novel memory-based metaheuristic optimization algorithm, VLR, which uses a list of already-visited areas to more effectively search for an optimal solution. We chose the Max-cut problem to test its optimization performance, comparing it with state-of-the-art methods. VLR dominates the previous best-performing heuristics. We also undertake preliminary analysis of the algorithm's parameter space, noting that a larger memory improves performance. VLR was designed as a general-purpose optimization algorithm, so its performance on other problems will be investigated in future.

Proc. p. 161 A Differential Evolution Algorithm for the Permutation Flowshop Scheduling Problem with Total Flow Time Criterion
S6.2 *Valentino Santucci, Marco Baioletti, and Alfredo Milani*

In this paper a new discrete Differential Evolution algorithm for the Permutation Flowshop Scheduling Problem with the total flowtime criterion is proposed. The core of the algorithm is the distance-based differential mutation operator defined by means of a new randomized bubble sort algorithm. This mutation scheme allows the Differential Evolution to directly navigate the permutations search space. Experiments were held on a well known benchmark suite and the results show that our proposal outperforms state-of-the-art algorithms on the majority of the problems.

Proc. p. 171 A Taxonomy of Heterogeneity and Dynamics in Particle Swarm Optimisation
S2.2
Harry Goldingay and Peter R. Lewis

We propose a taxonomy for heterogeneity and dynamics of swarms in PSO, which separates the consideration of homogeneity and heterogeneity from the presence of adaptive and non-adaptive dynamics, both at the particle and swarm level. It supports research into the separate and combined contributions of each of these characteristics. An analysis of the literature shows that most recent work has focussed on only parts of the taxonomy. Our results agree with prior work that both heterogeneity, where particles exhibit different behaviour from each other at the same point in time, and dynamics, where individual particles change their behaviour over time, are useful. However while heterogeneity does typically improve PSO, this is often dominated by the improvement due to dynamics. Adaptive strategies used to generate heterogeneity may end up sacrificing the dynamics which provide the greatest performance increase. We evaluate exemplar strategies for each area of the taxonomy and conclude with recommendations.

Proc. p. 181 Derivation of a Micro-Macro Link for Collective Decision-Making Systems: Uncover Network Features Based on Drift Measurements
S1.3
Heiko Hamann, Gabriele Valentini, Yara Khaluf, and Marco Dorigo

Relating microscopic features (individual level) to macroscopic features (swarm level) of self-organizing collective systems is challenging. In this paper, we report the mathematical derivation of a macroscopic model starting from a microscopic one for the example of collective decision-making. The collective system is based on the application of a majority rule over groups of variable size which is modeled by chemical reactions (micro-model). From an approximated master equation we derive the drift term of a stochastic differential equation (macro-model) which is applied to predict the expected swarm behavior. We give a recursive definition of the polynomials defining this drift term. Our results are validated by Gillespie simulations and simulations of the locust alignment.

Proc. p. 191 Messy Coding in the XCS Classifier System for Sequence Labeling
S7.3
Masaya Nakata, Tim Kovacs, and Keiki Takadama

The XCS classifier system for sequence labeling (XCS-SL) is an extension of XCS for sequence labeling, a form of time-series classification where every input has a class label. In XCS-SL a classifier condition consists of some sub-conditions which refer back to previous inputs. Each sub-condition is a memory. A condition has n sub-conditions which represent an interval from the current time t_0 to a previous time t_{-n}. A problem of this representation (called interval coding) is, even if only one input at t_{-n} is needed, the condition must consist of n sub-conditions to refer to it. We introduce a messy coding based condition where each sub-condition messily refers to a single previous time. Unlike the original coding, the set of sub-conditions does not necessarily represent an interval, so it can represent compact conditions. The original XCS-SL evolutionary mechanism cannot be used with messy coding and our main innovation is a novel evolutionary mechanism. Results on a benchmark show that, compared to the original interval coding, messy coding results in a smaller population size and does not require as high a population size limit. However, messy coding requires more training with a high population size limit. On a real world sequence labeling task messy coding evolved a solution that achieved higher accuracy with a smaller population size than the original interval coding.

Proc. p. 201 Reevaluating Exponential Crossover in Differential Evolution
S3.3 *Ryoji Tanabe and Alex Fukunaga*

Exponential crossover in Differential Evolution (DE), which is similar to 1-point crossover in genetic algorithms, continues to be used today as a default crossover operator for DE. We demonstrate that exponential crossover exploits an unnatural feature of some widely used synthetic benchmarks such as the Rosenbrock function – dependencies between adjacent variables. We show that for standard DE as well as state-of-the-art adaptive DE, exponential crossover performs quite poorly on benchmarks without this artificial feature. We also show that shuffled exponential crossover, which removes this kind of search bias, significantly outperforms exponential crossover.

Proc. p. 211 An Extended Michigan-Style Learning Classifier System for Flexible Supervised Learning, Classification, and Data Mining
S4.3 *Ryan J. Urbanowicz, Gediminas Bertasius, and Jason H. Moore*

Advancements in learning classifier system (LCS) algorithms have highlighted their unique potential for tackling complex, noisy problems, as found in bioinformatics. Ongoing research in this domain must address the challenges of modeling complex patterns of association, systems biology (i.e. the integration of different data types to achieve a more holistic perspective), and 'big data' (i.e. scalability in large-scale analysis). With this in mind, we introduce ExSTraCS (Extended Supervised Tracking and Classifying System), as a promising platform to address these challenges using supervised learning and a Michigan-Style LCS architecture. ExSTraCS integrates several successful LCS advancements including attribute tracking/feedback, expert knowledge covering (with four built-in attribute weighting algorithms), a flexible and efficient rule representation (handling datasets with both discrete and continuous attributes), and rapid non-destructive rule compaction. A few novel mechanisms, such as adaptive data management, have been included to enhance ease of use, flexibility, performance, and provide groundwork for ongoing development.

Proc. p. 222 A Cooperative Evolutionary Approach to Learn Communities in Multilayer Networks
S5.3 *Alessia Amelio and Clara Pizzuti*

In real-world complex systems objects are often involved in different kinds of connections, each expressing a different aspect of object activity. Multilayer networks, where each layer represents a type of relationship between a set of nodes, constitute a valid formalism to model such systems. In this paper a new approach based on Genetic Algorithms to detect community structure in multilayer networks is proposed. The method introduces an extension of the modularity concept and adopts a genetic representation of a multilayer network that allows cooperation and co-evolution of individuals, in order to find an optimal division of the network, shared among all the layers. Moreover, the algorithm relies on a label propagation mechanism and a local search strategy to refine the result quality. Experiments show the capability of the approach to obtain accurate community structures.

Proc. p. 233 Novelty Search in Competitive Coevolution
S6.3 *Jorge Gomes, Pedro Mariano, and, anders Lyhne Christensen*

One of the main motivations for the use of competitive coevolution systems is their ability to capitalise on arms races between competing species to evolve increasingly sophisticated solutions. Such arms races can, however, be hard to sustain, and it has been shown that the competing species often converge prematurely to certain classes of behaviours. In this paper, we investigate if and how novelty search, an evolutionary technique driven by behavioural novelty, can overcome convergence in coevolution. We propose three methods for applying novelty search to coevolutionary systems with two species: (i) score both populations according to behavioural novelty; (ii) score one population according to novelty, and the other according to fitness; and (iii) score both populations with a combination of novelty and fitness. We evaluate the methods in a predator-prey pursuit task. Our results show that novelty-based approaches can evolve a significantly more diverse set of solutions, when compared to traditional fitness-based coevolution.

Proc. p. 243 An Immune-Inspired Algorithm for the Set Cover Problem
S2.3 *Ayush Joshi, Jonathan E. Rowe, and Christine Zarges*

This paper introduces a novel parallel immune-inspired algorithm based on recent developments in the understanding of the germinal centre reaction in the immune system. Artificial immune systems are relatively new randomised search heuristics and work on parallelising them is still in its infancy. We compare our algorithm with a parallel implementation of a simple multi-objective evolutionary algorithm on benchmark instances of the set cover problem taken from the OR-library. We show that our algorithm finds feasible solutions faster than the evolutionary algorithm using less parameters and communication effort.

Proc. p. 252 Natural Gradient Approach for Linearly Constrained Continuous Optimization
S1.4 *Youhei Akimoto and Shinichi Shirakawa*

When a feasible set of an optimization problem is a proper subset of a multidimensional real space and the optimum of the problem is located on or near the boundary of the feasible set, most evolutionary algorithms require a constraint handling machinery to generate better candidate solutions in the feasible set. However, some standard constraint handling such as a resampling strategy affects the distribution of the candidate solutions; the distribution is truncated into the feasible set. Then, the statistical meaning of the update of the distribution parameters will change. To construct the parameter update rule for the covariance matrix adaptation evolution strategy from the same principle as unconstrained cases, namely the natural gradient principle, we derive the natural gradient of the log-likelihood of the Gaussian distribution truncated into a linearly constrained feasible set. We analyze the novel parameter update on a minimization of a spherical function with a linear constraint.

Proc. p. 262 Evolutionary Constrained Optimization for a Jupiter Capture
S7.4 *Jérémie Labroquère, Aurélie Héritier, Annalisa Riccardi, and Dario Izzo*

This investigation considers the optimization of multiple gravity assist capture trajectories in the Jupiter system combining the well known Differential Evolution algorithm with different classes of constraint handling techniques. The trajectories are designed to reach a desired target orbit around Jupiter with minimum fuel consumption while satisfying mission design constraints on maximum thrust level, maximum time of flight and minimum closest distance to the planet. The advanced constraints handling techniques are compared for different set of constraints on the challenging mission design problem. For each method the trade off between performance, efficiency and the structure of the feasible space is analyzed in light of the results obtained.

Proc. p. 272 Viability Principles for Constrained Optimization Using a (1+1)-CMA-ES
S5.4 *Andrea Maesani and Dario Floreano*

Viability Evolution is an abstraction of artificial evolution which operates by eliminating candidate solutions that do not satisfy viability criteria. Viability criteria are defined as boundaries on the values of objectives and constraints of the problem being solved. By adapting these boundaries it is possible to drive the search towards desired regions of solution space, discovering optimal solutions or those satisfying a set of constraints. Although in previous work we demonstrated the feasibility of the approach by implementing it on a simple genetic algorithm, the method was clearly not competitive with the current evolutionary computation state-of-the-art. In this work, we test Viability Evolution principles on a modified (1+1)-CMA-ES for constrained optimization. The resulting method shows competitive performance when tested on eight unimodal problems.

Proc. p. 282 On the Life-Long Learning Capabilities of a NELLI*: A Hyper-Heuristic Optimisation System
S4.4 *Emma Hart and Kevin Sim*

Real-world applications of optimisation techniques place more importance on finding approaches that result in acceptable quality solutions in a short time-frame and can provide robust solutions, capable of being modified in response to changes in the environment than seeking elusive global optima. We demonstrate that a hyper-heuristic approach NELLI* that takes inspiration from artificial immune systems is capable of life-long learning in an environment where problems are presented in a continuous stream and change over time. Experiments using 1370 bin-packing problems show excellent performance on unseen problems and that the system maintains memory, enabling it to exploit previously learnt heuristics to solve new problems with similar characteristics to ones solved in the past.

Proc. p. 292 Adaptation in Nonlinear Learning Models for Nonstationary Tasks
S5.5 *Wolfgang Konen and Patrick Koch*

The adaptation of individual learning rates is important for many learning tasks, particularly in the case of nonstationary learning environments. Sutton has presented with the Incremental Delta Bar Delta algorithm a versatile method for many tasks. However, this algorithm was formulated only for linear models. A straightforward generalization to nonlinear models is possible, but we show in this work that it poses some obstacles, namely the stability of the learning algorithm. We propose a new self-regulation of the model's activation which ensures stability. Our algorithm shows better performance than other approaches on a nonstationary benchmark task. Furthermore we show how to derive this algorithm from basic loss functions.

Proc. p. 302 On the Effectiveness of Sampling for Evolutionary Optimization in Noisy Environments
S6.4 *Chao Qian, Yang Yu, Yaochu Jin, and Zhi-Hua Zhou*

Sampling has been often employed by evolutionary algorithms to cope with noise when solving noisy real-world optimization problems. It can improve the estimation accuracy by averaging over a number of samples, while also increasing the computation cost. Many studies focused on designing efficient sampling methods, and conflicting empirical results have been reported. In this paper, we investigate the effectiveness of sampling in terms of rigorous running time, and find that sampling can be ineffective. We provide a general sufficient condition under which sampling is useless (i.e., sampling increases the running time for finding an optimal solution), and apply it to analyzing the running time performance of (1+1)-EA for optimizing OneMax and Trap problems in the presence of additive Gaussian noise. Our theoretical analysis indicates that sampling in the above examples is not helpful, which is further confirmed by empirical simulation results.

Proc. p. 312 Evolving Mixtures of n-gram Models for Sequencing and Schedule Optimization
S7.5 *Chung-Yao Chuang and Stephen F. Smith*

In this paper, we describe our work on Estimation of Distribution Algorithms (EDAs) that address *sequencing problems*, i.e., the task of finding the best ordering of a set of items or an optimal schedule to perform a given set of operations. Specifically, we focus on the use of probabilistic models that are based on n-gram statistics. These models have been used extensively in modeling statistical properties of sequences. We start with an EDA that uses a bigram model, then extend this scheme to higher-order models. However, directly replacing the bigram model with a higher-order model often results in premature convergence. We give an explanation on why this is the case along with some empirical support for our intuition. Following that, we propose a technique that combines multiple models of different orders, which allows for smooth transition from lower-order models to higher-order ones. Furthermore, this technique can also be used to incorporate other heuristics and prior knowledge about the problem into the search mechanism.

Proc. p. 322 A Study on Multimemetic Estimation of Distribution Algorithms
S1.5 *Rafael Nogueras and Carlos Cotta*

Multimemetic algorithms (MMAs) are memetic algorithms in which memes (interpreted as non-genetic expressions of problem-solving strategies) are explicitly represented and evolved alongside genotypes. This process is commonly approached using the standard genetic procedures of recombination and mutation to manipulate directly information at the memetic level. We consider an alternative approach based on the use of estimation of distribution algorithms to carry on this self-adaptive memetic optimization process. We study the application of different EDAs to this end, and provide an extensive experimental evaluation. It is shown that elitism is essential to achieve top performance, and that elitist versions of multimemetic EDAs using bivariate probabilistic models are capable of outperforming genetic MMAs.

Proc. p. 332 Factoradic Representation for Permutation Optimisation
S2.4 *Olivier Regnier-Coudert and John McCall*

It is known that different classes of permutation problems are more easily solved by selecting a suitable representation. In particular, permutation representations suitable for Estimation of Distribution algorithms (EDAs) are known to present several challenges. Therefore, it is of interest to investigate novel representations and their properties. In this paper, we present a study of the factoradic representation which offers new modelling insights through the use of three algorithmic frameworks, a Genetic Algorithm (GA) and two EDAs. Four classic permutation benchmark problems are used to evaluate the factoradic-based algorithms in comparison with published work with other representations.

Our experiments demonstrate that the factoradic representation is a competitive approach to apply to permutation problems. EDAs and more specifically, univariate EDAs show the most robust performance on the benchmarks studied. The factoradic representation also leads to better performance than adaptations of EDAs for continuous spaces, overall similar performance to integer-based EDAs and occasionally matches results of specialised EDAs, justifying further study.

Proc. p. 342 Combining Model-Based EAs for Mixed-Integer Problems
S3.4 *Krzysztof L. Sadowski, Dirk Thierens, and Peter A. N. Bosman*

A key characteristic of Mixed-Integer (MI) problems is the presence of both continuous and discrete problem variables. These variables can interact in various ways, resulting in challenging optimization problems. In this paper, we study the design of an algorithm that combines the strengths of LTGA and iAMaLGaM: state-of-the-art model-building EAs designed for discrete and continuous search spaces, respectively. We examine and discuss issues which emerge when trying to integrate those two algorithms into the MI setting. Our considerations lead to a design of a new algorithm for solving MI problems, which we motivate and compare with alternative approaches.

Proc. p. 352 A New EDA by a Gradient-Driven Density
S4.5 *Ignacio Segovia Domínguez, Arturo Hernández Aguirre, and S. Ivvan Valdez*

This paper introduces the Gradient-driven Density Function (∇_dD) approach, and its application to Estimation of Distribution Algorithms (EDAs). In order to compute the ∇_dD, we also introduce the Expected Gradient Estimate (EGE), which is an estimation of the gradient, based on information from other individuals. Whilst EGE delivers an estimation of the gradient vector at the position of any individual, the ∇_dD delivers a statistical model (e.g. the normal distribution) that allows the sampling of new individuals around the direction of the estimated gradient. Hence, in the proposed EDA, the gradient information is inherited to the new population. The computation of the EGE vector does not need additional function evaluations. It is worth noting that this paper focuses in black-box optimization. The proposed EDA is tested with a benchmark of 10 problems. The statistical tests show a competitive performance of the proposal.

Proc. p. 362 From Expected Improvement to Investment Portfolio Improvement: Spreading the Risk in Kriging-Based Optimization
S5.6 *Rasmus K. Ursem*

The increasing use of time-consuming simulations in the industry has spawned a growing interest in coupling optimization algorithms with fast-to-compute surrogate models. A major challenge in this approach is to select the approximated solutions to evaluate on the real problem. To address this, the Kriging meta-model offers both an estimate of the mean value and the standard error in an unknown point. This feature has been exploited in a number of so-called prescreening utility functions that seek to maximize the outcome of an expensive evaluation. The most widely used are the Probability of Improvement (PoI) and Expected Improvement (ExI) functions. This paper studies this challenge from an investment portfolio point-of-view. In short, the PoI favors low risk investments whereas the ExI promotes high risk investments. The paper introduces the investment portfolio improvement (IPI) approach as a strategy mixing the two extremes. The novel approach is applied to seven benchmark problems and two real world examples from the pump industry.

Proc. p. 373 Distance Measures for Permutations in Combinatorial Efficient Global Optimization
S6.5 *Martin Zaefferer, Jörg Stork, and Thomas Bartz-Beielstein*

For expensive black-box optimization problems, surrogate-model based approaches like Efficient Global Optimization are frequently used in continuous optimization. Their main advantage is the reduction of function evaluations by exploiting cheaper, data-driven models of the actual target function. The utilization of such methods in combinatorial or mixed search spaces is less common. Efficient Global Optimization and related methods were recently extended to such spaces, by replacing continuous distance (or similarity) measures with measures suited for the respective problem representations. This article investigates a large set of distance measures for their applicability to various permutation problems. The main purpose is to identify, how a distance measure can be chosen, either a-priori or online. In detail, we show that the choice of distance measure can be integrated into the Maximum Likelihood Estimation process of the underlying Kriging model. This approach has robust, good performance, thus providing a very nice tool towards selection of a distance measure.

Proc. p. 384 Boosting Search for Recursive Functions Using Partial Call-Trees
S7.6 *Brad Alexander and Brad Zacher*

Recursive functions are a compact and expressive way to solve challenging problems in terms of local processing. These properties have made recursive functions a popular target for genetic programming. Unfortunately, the evolution of substantial recursive programs has proven difficult. One cause of this problem is the difficulty in evolving both correct base and recursive cases using just information derived from running test cases. In this work we describe a framework that exploits additional information in the form of partial call-trees. Such trees - a by-product of deriving input-output cases by hand - guides the search process by allowing the separate evolution of the recursive case. We show that the speed of evolution of recursive functions is significantly enhanced by the use of partial call-trees and demonstrate application of the technique in the derivation of functions for a suite of numerical functions.

Proc. p. 394 Compressing Regular Expression Sets for Deep Packet Inspection
S1.6 *Alberto Bartoli, Simone Cumar,, andrea De Lorenzo, and Eric Medvet*

The ability to generate security-related alerts while analyzing network traffic in real time has become a key mechanism in many networking devices. This functionality relies on the application of large sets of regular expressions describing attack signatures to each individual packet. Implementing an engine of this form capable of operating at line speed is considerably difficult and the corresponding performance problems have been attacked from several points of view. In this work we propose a novel approach complementing earlier proposals: we suggest transforming the starting set of regular expressions to another set of expressions which is much smaller yet classifies network traffic in the same categories as the starting set. Key component of the transformation is an evolutionary search based on Genetic Programming: a large population of expressions represented as abstract syntax trees evolves by means of mutation and crossover, evolution being driven by fitness indexes tailored to the desired classification needs and which minimize the length of each expression.

We assessed our proposals on real datasets composed of up to 474 expressions and the outcome has been very good, resulting in compressions in the order of 74%. Our results are highly encouraging and demonstrate the power of evolutionary techniques in an important application domain.

Proc. p. 404 Inferring and Exploiting Problem Structure with Schema Grammar
S2.5 *Chris R. Cox and Richard A. Watson*

In this work we introduce a model-building algorithm that is able to infer problem structure using generative grammar induction. We define a class of grammar that can represent the structure of a problem space as a hierarchy of multivariate patterns (schemata), and a compression algorithm that can infer an instance of the grammar from a collection of sample individuals. Unlike conventional sequential grammars the rules of the grammar define unordered set-membership productions and are therefore insensitive to gene ordering or physical linkage. We show that when grammars are inferred from populations of fit individuals on shuffled nearest-neighbour NK-landscape problems, there is a correlation between the compressibility of a population and the degree of inherent problem structure. We also demonstrate how the information captured by the grammatical model from a population can aid evolutionary search. By using the lexicon of schemata inferred into a grammar to facilitate variation, we show that a population is able to incrementally learn and then exploit its own structure to find fitter regions of the search space, and ultimately locate the global optimum.

Proc. p. 414 Bent Function Synthesis by Means of Cartesian Genetic Programming
S3.5 *Radek Hrbacek and Vaclav Dvorak*

In this paper, a new approach to synthesize bent Boolean functions by means of Cartesian Genetic Programming (CGP) is proposed. Bent functions have important applications in cryptography due to their high nonlinearity. However, they are very rare and their discovery using conventional brute force methods is not efficient enough. We show that by using CGP we can routinely design bent functions of up to 16 variables. The evolutionary approach exploits parallelism in both the fitness calculation and the search algorithm.

Proc. p. 424 Population Exploration on Genotype Networks in Genetic Programming
S2.6 *Ting Hu, Wolfgang Banzhaf, and Jason H. Moore*

Redundant genotype-to-phenotype mappings are pervasive in evolutionary computation. Such redundancy allows populations to expand in neutral genotypic regions where mutations to a genotype do not alter the phenotypic outcome. Genotype networks have been proposed as a useful framework to characterize the distribution of neutrality among genotypes and phenotypes. In this study, we examine a simple Genetic Programming model that has a finite and compact genotype space by characterizing its genotype networks. We study the topology of individual genotype networks underlying unique phenotypes, investigate the genotypic properties as vertices in genotype networks, and discuss the correlation of these network properties with robustness and evolvability. Using GP simulations of a population, we demonstrate how an evolutionary population diffuses on genotype networks.

Proc. p. 434 Improving Genetic Programming with Behavioral Consistency Measure
S5.7 *Krzysztof Krawiec and Armando Solar-Lezama*

Program synthesis tasks usually specify only the desired output of a program and do not state any expectations about its internal behavior. The intermediate execution states reached by a running program can be nonetheless deemed as more or less preferred according to their information content with respect to the desired output. In this paper, a consistency measure is proposed that implements this observation. When used as an additional search objective in a typical genetic programming setting, this measure improves the success rate on a suite of 35 benchmarks in a statistically significant way.

Proc. p. 444 On Effective and Inexpensive Local Search Techniques in Genetic Programming Regression
S6.6 *Fergal Lane, R. Muhammad Atif Azad, and Conor Ryan*

Local search methods can harmoniously work with global search methods such as Evolutionary Algorithms (EAs); however, particularly in Genetic Programming (GP), concerns remain about the additional cost of local search (LS). One successful such system is *Chameleon*, which tunes internal GP nodes and addresses cost concerns by employing a number of strategies to make its LS both effective and inexpensive. Expense is reduced by an innovative approach to parsimony pressure whereby smaller trees are *rewarded* with local search opportunities more often than bigger trees. This paper investigates three new extensions to Chameleon's original simple setup, seeking ways for an even more effective local search. These are: trying alternative, more cost-reflective parsimony measures such as *visitation length* instead of tree size; varying the reward function to more gently incentivize parsimony than that in the original setup; and having more tuning earlier in runs when smaller trees can be tuned more cheaply and effectively. These strategies were tested on a varied suite of 16 difficult artificial and real-world regression problems. All of these techniques improved performance. We show that these strategies successfully combined to cumulatively improve average test RMSE by 31% over the original and already effective Chameleon tuning scheme. A minimum of 64 simulations were run on every problem/tuning setup combination.

Proc. p. 454 Combining Semantically-Effective and Geometric Crossover Operators for Genetic Programming
S6.7 *Tomasz P. Pawlak*

We propose a way to combine two distinct general patterns for designing semantic crossover operators for genetic programming: geometric semantic approach and semantically-effective approach. In the experimental part we show the synergistic effects of combining these two approaches, which we explain by a major fraction of crossover acts performed by geometric semantic crossover operators being semantically ineffective. The results of the combined approach show significant improvement of performance and high resistance to a premature convergence.

Proc. p. 465 On the Locality of Standard Search Operators in Grammatical Evolution
S1.7 *Ann Thorhauer and Franz Rothlauf*

Offspring should be similar to their parents and inherit their relevant properties. This general design principle of search operators in evolutionary algorithms is either known as locality or geometry of search operators, respectively. It takes a geometric perspective on search operators and suggests that the distance between an offspring and its parents should be less than or equal to the distance between both parents. This paper examines the locality of standard search operators used in grammatical evolution (GE) and genetic programming (GP) for binary tree problems. Both standard GE and GP search operators suffer from low locality since a substantial number of search steps result in an offspring whose distance to one of its parents is greater than the distance between both of its parents. Furthermore, the locality of standard GE search operators is higher than that of standard GP search operators, which allows more focused search in GE.

Proc. p. 476 Recurrent Cartesian Genetic Programming
S4.6 *Andrew James Turner and Julian Francis Miller*

This paper formally introduces Recurrent Cartesian Genetic Programming (RCGP), an extension to Cartesian Genetic Programming (CGP) which allows recurrent connections. The presence of recurrent connections enables RCGP to be successfully applied to partially observable tasks. It is found that RCGP significantly outperforms CGP on two partially observable tasks: artificial ant and sunspot prediction. The paper also introduces a new parameter, *recurrent connection probability*, which biases the number of recurrent connections created via mutation. Suitable choices of this parameter significantly improve the effectiveness of RCGP.

Proc. p. 487 An Analysis on Selection for High-Resolution Approximations in Many-
S6.8 Objective Optimization
Hernán Aguirre, Arnaud Liefooghe, Sébastien Verel, and Kiyoshi Tanaka

This work studies the behavior of three elitist multi- and many-objective evolutionary algorithms generating a high-resolution approximation of the Pareto optimal set. Several search-assessment indicators are defined to trace the dynamics of survival selection and measure the ability to simultaneously keep optimal solutions and discover new ones under different population sizes, set as a fraction of the size of the Pareto optimal set.

Proc. p. 498 A Multiobjective Evolutionary Optimization Framework for Protein Pu-
S4.7 rification Process Design
Richard Allmendinger and Suzanne S. Farid

Increasing demand in therapeutic drugs has resulted in the need to design cost-effective, flexible and robust manufacturing processes capable of meeting regulatory product purity requirements. To facilitate this design procedure, a framework linking an evolutionary multiobjective algorithm (EMOA) with a biomanufacturing process economics model is presented. The EMOA is tuned to discover sequences of chromatographic purification steps, and equipment sizing strategies adopted at each step, that provide the best trade-off with respect to multiple objectives including cost of goods per gram (COG/g), robustness in COG/g, and impurity removal capabilities. The framework also simulates and optimizes subject to various process uncertainties and design constraints. Experiments on an industrially-relevant case study showed that the EMOA is able to discover purification processes that outperform the industrial standard, and revealed several interesting trade-offs between the objectives.

Proc. p. 508 S5.8 Automatic Design of Evolutionary Algorithms for Multi-Objective Combinatorial Optimization

Leonardo C. T. Bezerra, Manuel López-Ibáñez, and Thomas Stützle

Multi-objective evolutionary algorithms (MOEAs) have been the subject of a large research effort over the past two decades. Traditionally, these MOEAs have been seen as monolithic units, and their study was focused on comparing them as blackboxes. More recently, a component-wise view of MOEAs has emerged, with flexible frameworks combining algorithmic components from different MOEAs. The number of available algorithmic components is large, though, and an algorithm designer working on a specific application cannot analyze all possible combinations. In this paper, we investigate the automatic design of MOEAs, extending previous work on other multi-objective metaheuristics. We conduct our tests on four variants of the permutation flowshop problem that differ on the number and nature of the objectives they consider. Moreover, given the different characteristics of the variants, we also investigate the performance of an automatic MOEA designed for the multi-objective PFSP in general. Our results show that the automatically designed MOEAs are able to outperform six traditional MOEAs, confirming the importance and efficiency of this design methodology.

Proc. p. 518 S3.6 Generic Postprocessing via Subset Selection for Hypervolume and Epsilon-Indicator

Karl Bringmann, Tobias Friedrich, and Patrick Klitzke

Most biobjective evolutionary algorithms maintain a population of fixed size μ and return the final population at termination. During the optimization process many solutions are considered, but most are discarded. We present two generic postprocessing algorithms which utilize the archive of all non-dominated solutions evaluated during the search. We choose the best μ solutions from the archive such that the hypervolume or ε-indicator is maximized. This postprocessing costs no additional fitness function evaluations and has negligible runtime compared to most EMOAs. We experimentally examine our postprocessing for four standard algorithms (NSGA-II, SPEA2, SMS-EMOA, IBEA) on ten standard test functions (DTLZ 1–2,7, ZDT 1–3, WFG 3–6) and measure the average quality improvement. The median decrease of the distance to the optimal ε-indicator is 95%, the median decrease of the distance to the optimal hypervolume value is 86%. We observe similar performance on a real-world problem (wind turbine placement).

Proc. p. 528 S2.7 A Provably Asymptotically Fast Version of the Generalized Jensen Algorithm for Non-dominated Sorting

Maxim Buzdalov and Anatoly Shalyto

The non-dominated sorting algorithm by Jensen, generalized by Fortin et al to handle the cases of equal objective values, has the running time complexity of $O(N \log^{K-1} N)$ in the general case. Here N is the number of points, K is the number of objectives and K is thought to be a constant when N varies. However, the complexity was not proven to be the same in the worst case. A slightly modified version of the algorithm is presented, for which it is proven that its worst-case running time complexity is $O(N \log^{K-1} N)$.

Proc. p. 538 Clustering-Based Selection for Evolutionary Many-Objective Optimization
S1.8 *Roman Denysiuk, Lino Costa, and Isabel Espírito Santo*

This paper discusses a selection scheme allowing to employ a clustering technique to guide the search in evolutionary many-objective optimization. The underlying idea to avoid the curse of dimensionality is based on transforming the objective vectors before applying a clustering and the selection of cluster representatives according to the distance to a reference point. The experimental results reveal that the proposed approach is able to effectively guide the search in high-dimensional objective spaces, producing highly competitive performance when compared with state-of-the-art algorithms.

Proc. p. 548 On the Impact of Multiobjective Scalarizing Functions
S7.7 *Bilel Derbel, Dimo Brockhoff, Arnaud Liefooghe, and Sébastien Verel*

Recently, there has been a renewed interest in decomposition-based approaches for evolutionary multiobjective optimization. However, the impact of the choice of the underlying scalarizing function(s) is still far from being well understood. In this paper, we investigate the behavior of different scalarizing functions and their parameters. We thereby abstract firstly from any specific algorithm and only consider the difficulty of the single scalarized problems in terms of the search ability of a $(1+\lambda)$-EA on biobjective NK-landscapes. Secondly, combining the outcomes of independent single-objective runs allows for more general statements on set-based performance measures. Finally, we investigate the correlation between the opening angle of the scalarizing function's underlying contour lines and the position of the final solution in the objective space. Our analysis is of fundamental nature and sheds more light on the key characteristics of multiobjective scalarizing functions.

Proc. p. 559 Multi-objective Quadratic Assignment Problem Instances Generator with
S3.7 a Known Optimum Solution
Mădălina M. Drugan

Multi-objective quadratic assignment problems (mQAPs) are NP-hard problems that optimally allocate facilities to locations using a distance matrix and several flow matrices. mQAPs are often used to compare the performance of the multi-objective meta-heuristics. We generate large mQAP instances by combining small size mQAP with known local optimum. We call these instances *composite mQAPs*, and we show that the cost function of these mQAPs is additively decomposable. We give mild conditions for which a composite mQAP instance has known optimum solution. We generate composite mQAP instances using a set of uniform distributions that obey these conditions.

Proc. p. 569 Optimized Approximation Sets for Low-Dimensional Benchmark Pareto
S3.8 Fronts
Tobias Glasmachers

The problem of finding sets of bounded cardinality maximizing dominated hypervolume is considered for explicitly parameterized Pareto fronts of multi-objective optimization problems. A parameterization of the Pareto front it often known (by construction) for synthetic benchmark functions. For the widely used ZDT and DTLZ families of benchmarks close-to-optimal sets have been obtained only for two objectives, although the three-objective variants of the DTLZ problems are frequently applied. Knowledge of the dominated hypervolume theoretically achievable with an approximation set of fixed cardinality facilitates judgment of (differences in) optimization results and the choice of stopping criteria, two important design decisions of empirical studies. The present paper aims to close this gap. An efficient optimization strategy is presented for two and three objectives. Optimized sets are provided for standard benchmarks.

Proc. p. 579 Start Small, Grow Big? Saving Multi-objective Function Evaluations
S5.9 *Tobias Glasmachers, Boris Naujoks, and Günter Rudolph*

The influence of non-constant population sizes in evolutionary multi-objective optimization algorithms is investigated. In contrast to evolutionary single-objective optimization algorithms an increasing population size is considered beneficial when approaching the Pareto-front. Firstly, different deterministic schedules are tested, featuring different parameters like the initial population size. Secondly, a simple adaptation method is proposed. Considering all results, an increasing population size during an evolutionary multi-objective optimization algorithm run saves fitness function evaluations compared to a fixed population size. In particular, the results obtained with the adaptive method are most promising.

Proc. p. 589 Queued Pareto Local Search for Multi-Objective Optimization
S6.9 *Maarten Inja, Chiel Kooijman, Maarten de Waard, Diederik M. Roijers, and Shimon Whiteson*

Many real-world optimization problems involve balancing multiple objectives. When there is no solution that is best with respect to all objectives, it is often desirable to compute the *Pareto front*. This paper proposes *queued Pareto local search* (QPLS), which improves on existing *Pareto local search* (PLS) methods by maintaining a queue of improvements preventing premature exclusion of dominated solutions. We prove that QPLS terminates and show that it can be embedded in a genetic search scheme that improves the approximate Pareto front with every iteration. We also show that QPLS produces good approximations faster, and leads to better approximations than popular alternative MOEAs.

Proc. p. 600 Distance-Based Analysis of Crossover Operators for Many-Objective Knapsack Problems
S7.8 *Hisao Ishibuchi, Yuki Tanigaki, Hiroyuki Masuda, and Yusuke Nojima*

It has been reported for multi-objective knapsack problems that the recombination of similar parents often improves the performance of evolutionary multi-objective optimization (EMO) algorithms. Recently performance improvement was also reported by exchanging only a small number of genes between two parents (i.e., crossover with a very small gene exchange probability) without choosing similar parents. In this paper, we examine these performance improvement schemes through computational experiments where NSGA-II is applied to 500-item knapsack problems with 2-10 objectives. We measure the parent-parent distance and the parent-offspring distance in computational experiments. Clear performance improvement is observed when the parent-offspring distance is small. To further examine this observation, we implement a distance-based crossover operator where the parent-offspring distance is specified as a user-defined parameter. Performance of NSGA-II is examined for various parameter values. Experimental results show that an appropriate parameter value (parent-offspring distance) is surprisingly small. It is also shown that a very small parameter value is beneficial for diversity maintenance.

Proc. p. 611 S1.9 Discovery of Implicit Objectives by Compression of Interaction Matrix in Test-Based Problems
Paweł Liskowski and Krzysztof Krawiec

In test-based problems, commonly solved with competitive coevolution algorithms, candidate solutions (e.g., game strategies) are evaluated by interacting with tests (e.g., opponents). As the number of tests is typically large, it is expensive to calculate the exact value of objective function, and one has to elicit a useful training signal (search gradient) from the outcomes of a limited number of interactions between these coevolving entities. Averaging of interaction outcomes, typically used to that aim, ignores the fact that solutions often have to master different and unrelated *skills*, which form underlying objectives of the problem. We propose a method for on-line discovery of such objectives via heuristic compression of interaction outcomes. The compressed matrix implicitly defines derived search objectives that can be used by traditional multiobjective search techniques (NSGA-II in this study). When applied to the challenging variant of multi-choice Iterated Prisoner's Dilemma problem, the proposed approach outperforms conventional two-population coevolution in a statistically significant way.

Proc. p. 621 S2.8 Local Optimal Sets and Bounded Archiving on Multi-objective NK-Landscapes with Correlated Objectives
Manuel López-Ibáñez, Arnaud Liefooghe, and Sébastien Verel

The properties of local optimal solutions in multi-objective combinatorial optimization problems are crucial for the effectiveness of local search algorithms, particularly when these algorithms are based on Pareto dominance. Such local search algorithms typically return a set of mutually nondominated Pareto local optimal (PLO) solutions, that is, a PLO-set. This paper investigates two aspects of PLO-sets by means of experiments with Pareto local search (PLS). First, we examine the impact of several problem characteristics on the properties of PLO-sets for multi-objective NK-landscapes with correlated objectives. In particular, we report that either increasing the number of objectives or decreasing the correlation between objectives leads to an exponential increment on the size of PLO-sets, whereas the variable correlation has only a minor effect. Second, we study the running time and the quality reached when using bounding archiving methods to limit the size of the archive handled by PLS, and thus, the maximum size of the PLO-set found. We argue that there is a clear relationship between the running time of PLS and the difficulty of a problem instance.

Proc. p. 631 S3.9 Racing Multi-objective Selection Probabilities
Gaétan Marceau-Caron and Marc Schoenauer

In the context of Noisy Multi-Objective Optimization, dealing with uncertainties requires the decision maker to define some preferences about how to handle them, through some statistics (e.g., mean, median) to be used to evaluate the qualities of the solutions, and define the corresponding Pareto set. Approximating these statistics requires repeated samplings of the population, drastically increasing the overall computational cost. To tackle this issue, this paper proposes to directly estimate the probability of each individual to be selected, using some Hoeffding races to dynamically assign the estimation budget during the selection step. The proposed racing approach is validated against static budget approaches with NSGA-II on noisy versions of the ZDT benchmark functions.

Proc. p. 641 Shake Them All!: Rethinking Selection and Replacement in MOEA/D
S4.8 *Gauvain Marquet, Bilel Derbel, Arnaud Liefooghe, and El-Ghazali Talbi*

In this paper, we build upon the previous efforts to enhance the search ability of MOEA/D (a multi-objective decomposition-based algorithm), by investigating the idea of evolving the whole population simultaneously. We thereby propose new alternative selection and replacement strategies that can be combined in different ways within a generic and problem-independent framework. To assess the performance of our strategies, we conduct a comprehensive experimental study on bi-objective combinatorial optimization problems. More precisely, we consider ρMNK-landscapes and knapsack problems as a benchmark, and experiment a wide range of parameter configurations for MOEA/D and its variants. Our analysis reveals the effectiveness of our strategies and their robustness to parameter settings. In particular, substantial improvements are obtained compared to the conventional MOEA/D.

Proc. p. 652 MH-MOEA: A New Multi-Objective Evolutionary Algorithm Based on the
S5.10 Maximin Fitness Function and the Hypervolume Indicator
Adriana Menchaca-Mendez and Carlos A. Coello Coello

In this paper, we propose an approach that combines a modified version of the maximin fitness function and the hypervolume indicator for selecting individuals into a Multi-Objective Evolutionary Algorithm (MOEA). Our proposed selection mechanism is incorporated into a MOEA which adopts the crossover and mutation operators of the Nondominated Sorting Genetic Algorithm-II (NSGA-II), giving rise to the so-called "Maximin-Hypervolume Multi-Objective Evolutionary Algorithm (MH-MOEA)". Our proposed MH-MOEA is validated using standard test problems taken from the specialized literature, using from three to six objectives. Our results are compared with respect to those produced by MC-MOEA (which is based on the maximin fitness function and a clustering technique), MOEA/D using Penalty Boundary Intersection (PBI), which is based on decomposition and iSMS-EMOA (which is based on the hypervolume indicator). Our preliminary results indicate that our proposed MH-MOEA is a good alternative to solve multi-objective optimization problems having both low dimensionality and high dimensionality in objective function space.

Proc. p. 662 Empirical Performance of the Approximation of the Least Hypervolume
S6.10 Contributor
Krzysztof Nowak, Marcus Märtens, and Dario Izzo

A fast computation of the hypervolume has become a crucial component for the quality assessment and the performance of modern multi-objective evolutionary optimization algorithms. Albeit recent improvements, exact computation becomes quickly infeasible if the optimization problems scale in their number of objectives or size. To overcome this issue, we investigate the potential of using approximation instead of exact computation by benchmarking the state of the art hypervolume algorithms for different geometries, dimensionality and number of points. Our experiments outline the threshold at which exact computation starts to become infeasible, but approximation still applies, highlighting the major factors that influence its performance.

Proc. p. 672 A Portfolio Optimization Approach to Selection in Multiobjective Evolutionary Algorithms
S7.9
Iryna Yevseyeva,, andreia P. Guerreiro, Michael T. M. Emmerich, and Carlos M. Fonseca

In this work, a new approach to selection in multiobjective evolutionary algorithms (MOEAs) is proposed. It is based on the portfolio selection problem, which is well known in financial management. The idea of optimizing a portfolio of investments according to both expected return and risk is transferred to evolutionary selection, and fitness assignment is reinterpreted as the allocation of capital to the individuals in the population, while taking into account both individual quality and population diversity. The resulting selection procedure, which unifies parental and environmental selection, is instantiated by defining a suitable notion of (random) return for multiobjective optimization. Preliminary experiments on multiobjective multidimensional knapsack problem instances show that such a procedure is able to preserve diversity while promoting convergence towards the Pareto-optimal front.

Proc. p. 682 Using a Family of Curves to Approximate the Pareto Front of a Multi-Objective Optimization Problem
S1.10
Saúl Zapotecas Martínez, Víctor A. Sosa Hernández, Hernán Aguirre, Kiyoshi Tanaka, and Carlos A. Coello Coello

The design of selection mechanisms based on quality assessment indicators has become one of the main research topics in the development of Multi-Objective Evolutionary Algorithms (MOEAs). Currently, most indicator-based MOEAs have employed the hypervolume indicator as their selection mechanism in the search process. However, hypervolume-based MOEAs become inefficient (and eventually, unaffordable) as the number of objectives increases. In this paper, we study the construction of a reference set from a family of curves. Such reference set is used together with a performance indicator (namely Δ_p) to assess the quality of solutions in the evolutionary process of an MOEA. We show that our proposed approach is able to deal (in an efficient way) with problems having many objectives (up to ten objective functions). Our preliminary results indicate that our proposed approach is highly competitive with respect to two state-of-the-art MOEAs over the set of test problems that were adopted in our comparative study.

Proc. p. 692 Travelling Salesman Problem Solved 'in materio' by Evolved Carbon Nanotube Device
S7.10
Kester Dean Clegg, Julian Francis Miller, Kieran Massey, and Mike Petty

We report for the first time on finding shortest path solutions for the travelling salesman problem (TSP) using hybrid "in materio" computation: a technique that uses search algorithms to configure materials for computation. A single-walled carbon nanotube (SWCNT) / polymer composite material deposited on a micro-electrode array is configured using static voltages so that voltage output readings determine the path order in which to visit cities in a TSP. Our initial results suggest that the hybrid computation with the SWCNT material is able to solve small instances of the TSP as efficiently as a comparable evolutionary search algorithm performing the same computation in software. Interestingly the results indicate that the hybrid system's search performance on TSPs scales linearly rather than exponentially on these smaller instances. This exploratory work represents the first step towards building SWCNT-based electrode arrays in parallel so that they can solve much larger problems.

Proc. p. 702 S3.10 Randomized Parameter Settings for Heterogeneous Workers in a Pool-Based Evolutionary Algorithm
Mario García-Valdez, Leonardo Trujillo, Juan Julián Merelo-Guérvos, and Francisco Fernández-de-Vega

Recently, several Pool-based Evolutionary Algorithms (PEAs) have been proposed, that asynchronously distribute an evolutionary search among heterogeneous devices, using controlled nodes and nodes outside the local network, through web browsers or cloud services. In PEAs, the population is stored in a shared pool, while distributed processes called workers execute the actual evolutionary search. This approach allows researchers to use low cost computational power that might not be available otherwise. On the other hand, it introduces the challenge of leveraging the computing power of heterogeneous and unreliable resources. The heterogeneity of the system suggests that using a heterogeneous parametrization might be a better option, so the goal of this work is to test such a scheme. In particular, this paper evaluates the strategy proposed by Gong and Fukunaga for the Island-Model, which assigns random control parameter values to each worker. Experiments were conducted to assess the viability of this strategy on pool-based EAs using benchmark problems and the EvoSpace framework. The results suggest that the approach can yield results which are competitive with other parametrization approaches, without requiring any form of experimental tuning.

Proc. p. 711 S4.9 PaDe: A Parallel Algorithm Based on the MOEA/D Framework and the Island Model
Andrea Mambrini and Dario Izzo

We study a coarse grained parallelization scheme (thread based) aimed at solving complex multi-objective problems by means of decomposition. Our scheme is loosely based on the MOEA/D framework. The resulting algorithm, called Parallel Decomposition (PaDe), makes use of the asynchronous generalized island model to solve the various decomposed problems. Efficient exchange of chromosomic material among islands happens via a fixed migration topology defined by the proximity of the decomposed problem weights. Each decomposed problem is solved using a generic single objective evolutionary algorithm (in this paper we experiment with self-adaptive differential evolution (jDE)). Comparing our algorithm to MOEA/D-DE we find that it is attractive in terms of performances and, most of all, in terms of computing time. Experiments with increasing numbers of threads show that PaDe scales well, being able to fully exploit the number of underlying available cores.

Proc. p. 721 S2.9 Evolution-In-Materio: Solving Machine Learning Classification Problems Using Materials
Maktuba Mohid, Julian Francis Miller, Simon L. Harding, Gunnar Tufte, Odd Rune Lykkebø, Mark K. Massey, and Mike C. Petty

Evolution-in-materio (EIM) is a method that uses artificial evolution to exploit the properties of physical matter to solve computational problems without requiring a detailed understanding of such properties. EIM has so far been applied to very few computational problems. We show that using a purpose-built hardware platform called Mecobo, it is possible to evolve voltages and signals applied to physical materials to solve machine learning classification problems. This is the first time that EIM has been applied to such problems. We evaluate the approach on two standard datasets: Lenses and Iris. Comparing our technique with a well-known software-based evolutionary method indicates that EIM performs reasonably well. We suggest that EIM offers a promising new direction for evolutionary computation.

Proc. p. 731 S6.11 An Analysis of Migration Strategies in Island-Based Multimemetic Algorithms
Rafael Nogueras and Carlos Cotta

Multimemetic algorithms (MMAs) are memetic algorithms that explicitly represent and evolve memes (computational representations of problem solving methods) as a part of solutions. We consider an island-based model of MMAs and provide a comparative analysis of six migrant selection strategies and two migrant replacement operators. We use a test suite of four hard pseudoboolean functions to examine qualitative behavioral differences at the genetic and memetic level, and provide a sound statistical analysis of performance. The results indicate the choice of migrant selection operator is more important than that of migrant replacement, and that policies based on fitness or pure genetic diversity do not compare favorably to more holistic strategies.

Proc. p. 741 S7.11 Tuning Evolutionary Multiobjective Optimization for Closed-Loop Estimation of Chromatographic Operating Conditions
Richard Allmendinger, Spyridon Gerontas, Nigel J. Titchener-Hooker, and Suzanne S. Farid

Purification is an essential step in the production of biopharmaceuticals. Resources are usually limited during development to make a full assessment of operating conditions for a given purification process commonly consisting of two or more chromatographic steps. This study proposes the optimization of all operating conditions simultaneously using an evolutionary multiobjective optimization algorithm (EMOA). After formulating the closed-loop optimization problem, which is subject to constraints and resourcing issues, four state-of-the-art EMOAs — NSGAII, MOEA/D, SMS-EMOA, and ParEGO — were tuned and evaluated on test problems created from real-world data available in the literature. The simulation results revealed that the performance of an EMOA depends on the setting of the population size, and constraint and resourcing issue-handling strategies adopted. Tuning these algorithm parameters revealed that the EMOAs, in particular SMS-EMOA and ParEGO, are able to discover reliably within 100 evaluations operating conditions that lead to high levels of yield and product purity.

Proc. p. 751 S4.10 A Geometrical Approach to the Incompatible Substructure Problem in Parallel Self-Assembly
Navneet Bhalla, Dhananjay Ipparthi, Eric Klemp, and Marco Dorigo

The inherent massive parallelism of self-assembly is one of its most appealing attributes for autonomous construction. One challenge in parallel self-assembly is to reduce the number of incompatible substructures that can occur in order to increase the yield in target structures. Early studies demonstrated how a simple approach to component design led components to self-assemble into incompatible substructures. Approaches have been proposed to reduce the number of incompatible substructures by increasing component complexity (e.g. using mechanical switches to determine substructure conformation). In this work, we show how a geometrical approach to self-assembling target structures from the inside-out eliminates incompatible substructures and increases yield. The advantages of this approach includes the simplicity of component design, and the incorporation of additional techniques to reduce component interaction errors. An experiment using millimeter-scale, 3D printed components is used to provide physical evidence to support our geometrical approach.

Proc. p. 761 Application of Evolutionary Methods to Semiconductor Double-Chirped Mirrors Design
S2.10
Rafał Biedrzycki, Jarosław Arabas, Agata Jasik, Michał Szymański, Paweł Wnuk, Piotr Wasylczyk, and Anna Wójcik-Jedlińska

This paper reports on a successful application of evolutionary computation techniques to the computer aided design of a dedicated highly dispersive mirror which is used in an ultrafast laser. The mirror is a GaAs plate coated with many interleaving layers of GaAs/AlAs and SiO_2/Si_3N_4 layers whose thickness undergo optimization. We report and compare results obtained by leading global optimization techniques: Covariance Matrix Adaptation Evolution Strategy and Differential Evolution, as well as few efficient local optimization methods: Nelder-Mead and variable metric. The evolutionary designed mirror has been manufactured by the Molecular Beam Epitaxy technology and the measurements confirmed successful implementation of the instrument.

Proc. p. 771 Evolving Neural Network Weights for Time-Series Prediction of General Aviation Flight Data
S3.11
Travis Desell, Sophine Clachar, James Higgins, and Brandon Wild

This work provides an extensive analysis of flight parameter estimation using various neural networks trained by differential evolution, consisting of 12,000 parallel optimization runs. The neural networks were trained on data recorded during student flights stored in the National General Aviation Flight Database (NGAFID), and as such consist of noisy, realistic general aviation flight data. Our results show that while backpropagation via gradient and conjugate gradient descent is insufficient to train the neural networks, differential evolution can provide strong predictors of certain flight parameters (10% over a baseline prediction for airspeed and 70% for altitude), given the four input parameters of airspeed, altitude, pitch and roll. Mean average error ranged between 0.08% for altitude to 2% for roll. Cross validation of the best neural networks indicate that the trained neural networks have predictive power. Further, they have potential to act as overall descriptors of the flights and can potentially be used to detect anomalous flights, even determining which flight parameters are causing the anomaly. These initial results provide a step towards providing effective predictors of general aviation flight behavior, which can be used to develop warning and predictive maintenance systems, reducing accident rates and saving lives.

Proc. p. 782 Random Partial Neighborhood Search for University Course Timetabling Problem
S4.11
Yuichi Nagata and Isao Ono

We propose an tabu search algorithm using an candidate list stratety with random sampling for the university course timetabling problem, where the neighborhood size can be adjusted by a parameter *ratio*. With this framework, we can control the trade-off between exploration and exploitation by adjusting the neighborhood size. Experimental results show that the proposed algorithm outperforms state-of-the-art algorithms when the neighborhood size is set properly.

Proc. p. 792 Balancing Bicycle Sharing Systems: An Analysis of Path Relinking and Recombination within a GRASP Hybrid
S5.11
Petrina Papazek, Christian Kloimüllner, Bin Hu, and Günther Raidl

In bike sharing systems, a vehicle fleet rebalances the system by continuously moving bikes among stations in order to avoid rental stations to run entirely empty or full. We address the static problem variant assuming initial fill levels for each station and seek vehicle tours with corresponding loading instructions to reach given target fill levels as far as possible. Our primary objective is to minimize the absolute deviation between target and final fill levels for all rental stations. Building upon a previously suggested GRASP hybrid, we investigate different approaches for hybridizing them with Path Relinking (PR) and simpler recombination operators. Computational tests on benchmark instances derived from a real world scenario in Vienna give insight on the impacts of the PR and recombination techniques and manifest that certain PR extension improve the results significantly. Ultimately, a hybrid exclusively searching a partial PR path in the neighborhood of the guiding solutions turns out to be most fruitful.

Proc. p. 802 Multiobjective Selection of Input Sensors for SVR Applied to Road Traffic Prediction
S6.12
Jiri Petrlik, Otto Fucik, and Lukas Sekanina

Modern traffic sensors can measure various road traffic variables such as the traffic flow and average speed. However, some measurements can lead to incorrect data which cannot further be used in subsequent processing tasks such as traffic prediction or intelligent control. In this paper, we propose a method selecting a subset of input sensors for a support vector regression (SVR) model which is used for traffic prediction. The method is based on a multimodal and multiobjective NSGA-II algorithm. The multiobjective approach allowed us to find a good trade-off between the prediction error and the number of sensors in real-world situations when many traffic data measurements are unavailable.

Proc. p. 812 Evolving DPA-Resistant Boolean Functions
S5.12
Stjepan Picek, Lejla Batina, and Domagoj Jakobovic

Boolean functions are important primitives in cryptography. Accordingly, there exist numerous works on the methods of constructions of Boolean functions. However, the property specifying the resistance of Boolean functions against Differential Power Analysis (DPA) attacks was until now scarcely investigated and only for S-boxes. Here, we evolve Boolean functions that have higher resistance to DPA attacks than others published before by using two well-known evolutionary computation methods where genetic programming shows best performance.

Proc. p. 822 Combining Evolutionary Computation and Algebraic Constructions to Find Cryptography-Relevant Boolean Functions
S1.11
Stjepan Picek, Elena Marchiori, Lejla Batina, and Domagoj Jakobovic

Boolean functions play a central role in security applications because they constitute one of the basic primitives for modern cryptographic services. In the last decades, research on Boolean functions has been boosted due to the importance of security in many diverse public systems relying on such technology. A main focus is to find Boolean functions with specific properties. An open problem in this context is to find a balanced Boolean function with an 8-bit input and nonlinearity 118. Theoretically, such a function has been shown to exist, but it has not been found yet. In this work we focus on specific classes of Boolean functions, and analyze the landscape of results obtained by integrating algebraic and evolutionary computation (EC) based approaches. Results indicate that combinations of these approaches give better results although not reaching 118 nonlinearity.

Proc. p. 832 A Memetic Algorithm for Multi Layer Hierarchical Ring Network Design
S2.11 *Christian Schauer and Günther Raidl*

We address the Multi Layer Hierarchical Ring Network Design Problem. This problem arises in the design of large telecommunication backbones, when high reliability is emphasized. The aim is to connect nodes that are assigned to different layers using a hierarchy of rings of bounded length. We present a memetic algorithm that focuses on clustering the nodes of each layer into disjoint subsets. A decoding procedure is then applied to each genotype for determining a ring connecting all nodes of each cluster. For local improvement we incorporate a previous variable neighborhood search. We experimentally evaluate our memetic algorithm on various graphs and show that it outperforms the sole variable neighborhood search approach in 13 out of 30 instances, while in eight instances they perform on par.

Proc. p. 842 Scheduling the English Football League with a Multi-objective Evolutionary Algorithm
S3.12 *Lyndon While and Graham Kendall*

We describe a multi-objective evolutionary algorithm that derives schedules for the English Football League over the busy New Year period according to seven objectives. The two principal objectives are to minimise travel distances for teams and supporters, and to minimise so-called "pair clashes" where teams which are geographically close play at home simultaneously, which can cause problems for police, and other logistical issues. The other five objectives implement various problem constraints. The schedules derived are often superior both to those used in the relevant years, and to those previously published in the literature, especially for the harder problem instances. In addition, the system returns a set of schedules offering different trade-offs between the main objectives, any of which might be of interest to the authorities.

Proc. p. 852 Coupling Evolution and Information Theory for Autonomous Robotic Exploration
S1.12 *Guohua Zhang and Michèle Sebag*

This paper investigates a hybrid two-phase approach toward exploratory behavior in robotics. In a first phase, controllers are evolved to maximize the quantity of information in the sensori-motor datastream generated by the robot. In a second phase, the data acquired by the evolved controllers is used to support an information theory-based controller, selecting the most informative action in each time step. The approach, referred to as EvITE, is shown to outperform both the evolutionary and the information theory-based approaches standalone, in terms of actual exploration of the arena. Further, the EvITE controller features some generality property, being able to efficiently explore other arenas than the one considered during the first evolutionary phase.

Proc. p. 862 S7.12 Local Optima and Weight Distribution in the Number Partitioning Problem
Khulood Alyahya and Jonathan E. Rowe

This paper investigates the relation between the distribution of the weights and the number of local optima in the Number Partitioning Problem (NPP). The number of local optima in the 1-bit flip landscape was found to be strongly and negatively correlated with the coefficient of variation (CV) of the weights. The average local search cost using the 1-bit flip operator was also found to be strongly and negatively correlated with the CV of the weights. A formula based on the CV of the weights for estimating the average number of local optima in the 1-bit flip landscape is proposed in the paper. The paper also shows that the CV of the weights has a potentially useful application in guiding the choice of heuristic search algorithm.

Proc. p. 872 S6.13 Quasi-Stability of Real Coded Finite Populations
Jarosław Arabas and Rafał Biedrzycki

This contribution analyzes dynamics of mean and variance of real chromosomes in consecutive populations of an Evolutionary Algorithm with selection and mutation. Quasi-stable state is characterized with an area in which population mean and variance will remain roughly unchanged for many generations. Size of the area can be indirectly estimated from the infinite population analysis and is influenced by the population size, selection type and parameter, and the mutation variance. The paper gives formulas that define this influence and illustrates them with numerical examples.

Proc. p. 882 S3.13 On the Use of Evolution Strategies for Optimization on Spherical Manifolds
Dirk V. Arnold

We study the behaviour of evolution strategies applied to a simple class of unimodal optimization problems on spherical manifolds. The techniques used are the same as those commonly employed for the analysis of the behaviour of evolution strategies in Euclidean search spaces. However, we find that there are significant differences in strategy behaviour unless the vicinity of an optimal solution has been reached. Experiments with cumulative step size adaptation reveal the existence of metastable states associated with large step sizes, which can preclude reaching optimal solutions.

Proc. p. 892 S1.13 Unbiased Black-Box Complexity of Parallel Search
Golnaz Badkobeh, Per Kristian Lehre, and Dirk Sudholt

We propose a new black-box complexity model for search algorithms evaluating λ search points in parallel. The parallel unbiased black-box complexity gives lower bounds on the number of function evaluations *every* parallel unbiased black-box algorithm needs to optimise a given problem. It captures the inertia caused by offspring populations in evolutionary algorithms and the total computational effort in parallel metaheuristics. Our model applies to all unary variation operators such as mutation or local search. We present lower bounds for the LeadingOnes function and general lower bound for all functions with a unique optimum that depend on the problem size and the degree of parallelism, λ. The latter is tight for OneMax; we prove that a $(1+\lambda)$ EA with adaptive mutation rates is an optimal parallel unbiased black-box algorithm.

Proc. p. 902 S2.12 A Generalized Markov-Chain Modelling Approach to $(1, \lambda)$-ES Linear Optimization
Alexandre Chotard and Martin Holeňa

Several recent publications investigated Markov-chain modelling of linear optimization by a $(1, \lambda)$-ES, considering both unconstrained and linearly constrained optimization, and both constant and varying step size. All of them assume normality of the involved random steps, and while this is consistent with a black-box scenario, information on the function to be optimized (e.g. separability) may be exploited by the use of another distribution. The objective of our contribution is to complement previous studies realized with normal steps, and to give sufficient conditions on the distribution of the random steps for the success of a constant step-size $(1, \lambda)$-ES on the simple problem of a linear function with a linear constraint. The decomposition of a multidimensional distribution into its marginals and the copula combining them is applied to the new distributional assumptions, particular attention being paid to distributions with Archimedean copulas.

Proc. p. 912 S4.12 Level-Based Analysis of Genetic Algorithms and Other Search Processes
Dogan Corus, Duc-Cuong Dang, Anton V. Eremeev, and Per Kristian Lehre

The fitness-level technique is a simple and old way to derive upper bounds for the expected runtime of simple *elitist* evolutionary algorithms (EAs). Recently, the technique has been adapted to deduce the runtime of algorithms with *non-elitist* populations and *unary* variation operators [2,8]. In this paper, we show that the restriction to unary variation operators can be removed. This gives rise to a much more general analytical tool which is applicable to a wide range of search processes. As introductory examples, we provide simple runtime analyses of many variants of the Genetic Algorithm on well-known benchmark functions, such as OneMax, LeadingOnes, and the sorting problem.

Proc. p. 922 S4.13 Maximizing Submodular Functions under Matroid Constraints by Multi-objective Evolutionary Algorithms
Tobias Friedrich and Frank Neumann

Many combinatorial optimization problems have underlying goal functions that are submodular. The classical goal is to find a good solution for a given submodular function f under a given set of constraints. In this paper, we investigate the runtime of a multi-objective evolutionary algorithm called GSEMO until it has obtained a good approximation for submodular functions. For the case of monotone submodular functions and uniform cardinality constraints we show that GSEMO achieves a $(1 - 1/e)$-approximation in expected time $\mathcal{O}(n^2 (\log n + k))$, where k is the value of the given constraint. For the case of non-monotone submodular functions with k matroid intersection constraints, we show that GSEMO achieves a $1/(k + 2 + 1/k + \epsilon)$-approximation in expected time $\mathcal{O}(n^{k+5} \log(n)/\epsilon)$.

Proc. p. 932 S5.13 On the Runtime Analysis of Fitness Sharing Mechanisms
Pietro S. Oliveto, Dirk Sudholt, and Christine Zarges

Fitness sharing is a popular diversity mechanism implementing the idea that similar individuals in the population have to share resources and thus, share their fitnesses. Previous runtime analyses of fitness sharing studied a variant where selection was based on populations instead of individuals. We use runtime analysis to highlight the benefits and dangers of the original fitness sharing mechanism on the well-known test problem TwoMax, where diversity is crucial for finding both optima. In contrast to population-based sharing, a (2+1) EA in the original setting does not guarantee finding both optima in polynomial time; however, a (μ+1) EA with $\mu \geq 3$ always succeeds in expected polynomial time. We further show theoretically and empirically that large offspring populations in (μ+1) EAs can be detrimental as overpopulation can make clusters of search points go extinct.

Proc. p. 942 S2.13 Runtime Analysis of Evolutionary Algorithms on Randomly Constructed High-Density Satisfiable 3-CNF Formulas
Andrew M. Sutton and Frank Neumann

We show that simple mutation-only evolutionary algorithms find a satisfying assignment on two similar models of random planted 3-CNF Boolean formulas in polynomial time with high probability in the high constraint density regime. We extend the analysis to random formulas conditioned on satisfiability (i.e., the so-called filtered distribution) and conclude that most high-density satisfiable formulas are easy for simple evolutionary algorithms. With this paper, we contribute the first rigorous study of randomized search heuristics from the evolutionary computation community on well-studied distributions of random satisfiability problems.