Genetic and Evolutionary Computation Conference 2019

Conference Program

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Prague, Czech Republic
July 13-17, 2019

Association for Computing Machinery

Advancing Computing as a Science & Profession

GECCO is sponsored by the Association for Computing Machinery Special Interest Group for Genetic and Evolutionary Computation (SIGEVO). SIG Services: 2 Penn Plaza, Suite 701, New York, NY, 10121, USA, 1-800-342-6626 (USA and Canada) or +212-626-0500 (global).

Welcome

Dear GECCO attendees,

Welcome to the Genetic and Evolutionary Computation Conference (GECCO). After the tremendously successful GECCO 2018 in Kyoto, Japan, GECCO returns this year to Europe, at the heart of one of its most beautiful capitals, Prague.

GECCO is the largest selective conference in the field of Evolutionary Computation, and the main conference of the Special Interest Group on Genetic and Evolutionary Computation (SIGEVO) of the Association for Computing Machinery (ACM). GECCO implements a rigorous and selective reviewing process to identify important and technically sound papers to publish. The technical program is divided into thirteen tracks reflecting all aspects of our field and chaired by experts who make the decisions on accepted papers.

This year, we received 501 papers and accepted 173 of them, which results in a 35% acceptance rate. Those papers are presented by authors orally during the conference. We additionally accepted 168 posters that will be presented during the poster session on Monday evening.

Besides the technical tracks, GECCO includes 33 tutorials selected among 63 proposals and 25 workshops reflecting important topics in our field. They take place during the first two days together with competitions.

The Evolutionary Computation community can be proud that their research is strongly connected to practical problems. At GECCO, research or discussions on applications is present, in particular through the Real World Applications track, the Humies, and the Evolutionary Computation in Practice session.

We are thrilled to welcome as keynote speakers Raia Hadsell from Google Deep Mind and Robert Babuska from TU Delft. We feel greatly honored that Ingo Rechenberg, one of the pioneers of the field of Evolutionary Computation, accepted to give the SIGEVO keynote this year.

We would like to thank all authors for submitting their work to GECCO 2019 as well as tutorial speakers and workshop organizers.

The organization of a conference like GECCO is a tremendous task relying on many people. We are humble and very thankful for their work. We would like to mention first the different chairs: track, tutorial, workshop, student affairs, publicity, competition, late breaking abstracts, student workshop, hot off the press chairs, and the program committee.

We would like to specifically mention and thank deeply Manuel López-Ibáñez, Editor-in-Chief, and Petr Pošík, local chair, for their dedicated work and kindness. Personal thanks go also to Leslie Pérez Cáceres, proceedings chair, who did not hesitate to spend several nights working on the proceedings, program and schedule. We would also like to mention Roxane Rose and Brenda Ramirez, from Executive Events, who handled logistics and registrations, and Franz Rothlauf, Marc Schoenauer, Enrique Alba and Darrell Whitley from SIGEVO for their advice and guidance to organize GECCO.

On behalf of GECCO, we would also like to thank our sponsors and supporters, whose support allowed us to fund additional student travel grants.

Enjoy the conference !

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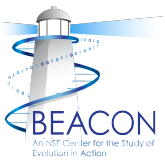

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Ales Zamuda, *University of Maribor*
Saúl Zapotecas-Martínez, *Universidad Autónoma Metropolitana (UAM)*
Christine Zarges, *Aberystwyth University*
Zhu Zexuan, *Shenzhen University*
Zhi-Hui Zhan, *South China University of Technology*
Mengjie Zhang, *Victoria University of Wellington*
Qingfu Zhang, *City University of Hong Kong, City University of Hong Kong Shenzhen Research Institute*
Xingyi Zhang, *Anhui Unversity*
Weijie Zheng, *Southern University of Science and Technology*
Aimin Zhou, *Department of Computer Science and Technology, East China Normal University*
Yan Zhou, *Northeastern University*
Hangyu Zhu, *University of Surrey*
Heiner Zille, *Otto-von-Guericke University Magdeburg*
Nur Zincir-Heywood, *Dalhousie University*
Joseph Zipkin, *Massachusetts Institute of Technology*

Proceedings

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User:	gecco2019
Password:	prague

Schedule and Floor Plans

Schedule at a Glance

Saturday, July 13	Sunday, July 14	Monday, July 15	Tuesday, July 16	Wednesday, July 17
Tutorials and Workshops 08:30-10:20	Tutorials and Workshops 08:30-10:20	Opening Session *Forum Hall (2F)* 8:30		
		Invited Keynote **Raia Hadsell** *Forum Hall (2F)* 09:00-10:10	*Invited Keynote* **Robert Babuska** *Forum Hall (2F)* 09:00-10:10	Paper Sessions and HOP 09:00-10:40
Coffee break	Coffee break	Coffee break	Coffee break	
Tutorials and Workshops 10:40-12:30	Tutorials and Workshops 10:40-12:30	Paper Sessions and ECiP 10:40-12:20	Paper Sessions and HOP 10:40-12:20	Coffee break
				SIGEVO Keynote **Ingo Rechenberg** *Forum Hall (2F)* 11:10-12:20
Lunch on your own	Lunch on your own	Job Market *South Hall 1A (1F)* 12:20-13:00	Lunch on your own	SIGEVO Meeting, Awards and Closing *Forum Hall (2F)* 12:20-13:50
		Lunch on your own		
Tutorials and Workshops 14:00-15:50	Tutorials, Workshops, and Competitions 14:00-15:50	Paper Sessions, ECiP and HUMIES 14:00-15:40	Paper Sessions and HOP 14:00-15:40	
Coffee break	Coffee break	Coffee break	Coffee break	
Tutorials, Workshops, and LBA 16:10-18:00	Tutorials, Workshops, and Competitions 16:10-18:00	Paper Sessions and ECiP 16:10-17:50	Paper Sessions and HOP 16:10-17:50	
Research Funding Opportunities in the EU: FET and ERC *Club A (1F)* 18:00-20:00	Women@GECCO *South Hall 1B (1F)* 18:00-20:00	Poster Session and Reception *Panorama Hall (1F)* 17:50-20:00	Social Event *Letenský zámeček* 19:00-22:00	

Registration desk hours: Saturday, July 13th, 7:45 – 16:10
Sunday, July 14th, 8:00 – 16:10
Monday, July 15th, 8:00 – 16:10
Tuesday, July 16th, 8:00 – 18:15
Wednesday, July 17th, 8:30 – 11:10
(closed during lunch)

Coffee breaks: Foyers

Keynotes and SIGEVO meeting: Forum Hall (2F)

Job market: South Hall 1A (1F)

Poster session and reception: Panorama Hall (1F)

Social event: Tuesday, July 16th, 19:00-22.00 at Letenský zámeček.

The social event of GECCO 2019 will be held on Tuesday, July 16th, starting at 19:00 until approximately 22.00. The event will take place at **Letenský zámeček** located in a park above the old town with a scenic view of Prague.

There is no organized transportation to the event, however, the site is easily reachable by public transport (see next page). Registration to the conference includes a free public transport pass for the duration of the conference.

Dinner will be served in a barbecue buffet style including appetizers and salads, grilled specialties, desserts, and free drinks. We will have the opportunity to enjoy music from a live band!

Transportation from Prague Congress Center to Letenský zámeček (Social Event)

Letenský zámeček is located in a park above the old town. The site is easily reachable by public transport. We suggest the following route to Letenský zámeček (ca 30 minutes):

1. Take metro line C (red) from Vyšehrad to Vltavská (5 stations, ca 10 minutes).
2. Take any tram nr. 1, 8, 12, 25, 26 to station Kamenická (2 stops, ca 5 minutes).
3. The rest (ca 650 m, ca 12 minutes) on foot:
   (a) Continue ca 100 m in the direction of the tram.
   (b) Turn left to Kamenická street, and go south until you hit the park.
   (c) Turn right, and continue ca 100 m along the park.
   (d) Turn left, enter the park and continue ca 150 m to Letenský zámeček.

The detail of the route after you get out of Metro at Vltavská is shown in the following map:

- Blue line: tram Vltavská - Kamenická
- Black dashed line: on foot from Kamenická to Letenský zámeček

Workshop and Tutorial Sessions, Saturday, July 13

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
South Hall 1A	**Learning Classifier Systems: From Principles to Modern Systems** Stein	**IWLCS — International Workshop on Learning Classifier Systems** p. 48		
South Hall 1B	**EvoSoft — Evolutionary Computation Software Systems** p. 44	**IAM/SmartEA — Industrial Applications of Metaheuristics / Evolutionary Algorithms for Smart Grids** p. 46	**Neuroevolution for Deep Reinforcement Learning Problems** Ha	**LBA – Late-Breaking Abstracts** p. 51
Club A	**BBOB — Blackbox Optimization Benchmarking** p. 45		**A Practical Guide to Experimentation (and Benchmarking)** Hansen	**Evolutionary Computation for Digital Art** Neumann, Neumann
Club B	**ECMCDM/DTEO — EC+Multi-Criteria Decision Making / Decomposition Techniques in Evo. Opt.** p. 44	**Recent Advances in Fitness Landscape Analysis** Ochoa, Malan	**SecDef — Genetic and Evolutionary Computation in Defense, Security and Risk Management** p. 50	
Club C	**ECPERM — Evolutionary Computation for Permutation Problems** p. 45		**SAEOpt — Surrogate-Assisted Evolutionary Optimization** p. 49	
Club D	**Hyper-heuristics** Woodward, Tauritz	**Student Workshop** p. 47		
Club E	**Evolutionary Computation: A Unified Approach** De Jong	**Representations for Evolutionary Algorithms** Rothlauf	**Tutorial on Evolutionary Multiobjective Optimization** Brockhoff	**Evolutionary Many-Objective Optimization** Ishibuchi, Sato
Club H	**Constraint-Handling Techniques used with Evolutionary Algorithms** Coello Coello	**Genetic Programming: A Tutorial Introduction** O'Reilly, Hemberg	**GI — Genetic Improvement** p. 48	**NSBECR — New Standards for Benchmarking in EC Research** p. 52
Meeting room 1.1	**Introductory Tutorial: Theory for Non-Theoreticians** Doerr	**Runtime Analysis of Population-based Evolutionary Algorithms** Lehre, Oliveto	**HCNURS — Evolutionary Comp. in Health care and Nursing System** p. 50	

Tutorials Workshops LBA session Student Workshop

Workshop and Tutorial Sessions, Sunday, July 14

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
South Hall 1A	**iGECCO — Interactive Methods @ GECCO** p. 54	**VizGEC — Visualisation Methods in Genetic and Evolutionary Computation** p. 56	**RWACMO — Real-world Applications of Continuous and Mixed-integer Optimization** p. 56	**GBEA — Game-Benchmark for Evolutionary Algorithms** p. 57
South Hall 1B	**Evolutionary Robotics Tutorial** Bredeche, Doncieux, Mouret	**Recent Advances in Particle Swarm Optimization Analysis and Understanding** Engelbrecht, Cleghorn	**Next Generation Genetic Algorithms** Whitley	**Evolution of Neural Networks** Miikkulainen
Club A	**BB-DOB — Black Box Discrete Optimization Benchmarking** p. 54		**Dynamic Parameter Choices in Evolutionary Computation** Doerr	**MedGEC — Workshop on Medical Applications of Genetic and Evolutionary Computation** p. 58
Club B	**CIASE — Computational Intelligence in Aerospace Science and Engineering** p. 53	**Exploratory Landscape Analysis** Kerschke, Preuss	**Model-Based Evolutionary Algorithms** Thierens, Bosman	**Simulation Optimization** Branke
Club C	**EAPU — Evolutionary Algorithms for Problems with Uncertainty** p. 54	**ECADA — Evolutionary Computation for the Automated Design of Algorithms** p. 55	**Solving Complex Problems with Coevolutionary Algorithms** Krawiec, Heywood	**Concurrency in evolutionary algorithms** Merelo
Club D	**CMA-ES and Advanced Adaptation Mechanisms** Akimoto, Hansen	**EVOGRAPH — Evolutionary Data Mining and Optimization over Graphs** p. 56	**Competitions** p. 61	
Club E	**Visualization in Multiobjective Optimization** Filipic, Tusar	**Decomposition Multi-Objective Opt.: Current Developments and Future Opportunities** Li	**EC and Evo. Deep Learning for Image Analysis, Signal Processing and Pattern Recognition** Zhang, Cagnoni	**Creative Evolutionary Computation** Liapis, Yannakakis
Club H	**UMLOP — Understanding Machine Learning Optimization Problems** p. 53	**Semantic Genetic Programming** Moraglio, Krawiec	**Sequential Experimentation by Evolutionary Algorithms** Shir, Bäck	**Push** Spector, McPhee
Meeting room 1.1		**Theory of Estimation-of-Distribution Algorithms** Witt	**LAHS — Landscape-Aware Heuristic Search** p. 57	

Tutorials Workshops Competitions

Parallel Sessions, Monday, July 15 through Wednesday, July 17

	Monday July 15 10:40-12:20	Monday July 15 14:00-15:40	Monday July 15 16:10-17:50	Tuesday July 16 10:40-12:20	Tuesday July 16 14:00-15:40	Tuesday July 16 16:10-17:50	Wednesday July 17 09:00-10:40
South Hall 1A	**EMO1** p. 73	**EMO2** ☆ p. 75	**GA1** ☆ p. 78	**RWA4** ☆ p. 82	**CS3 +GECH3** ☆ p. 83	**EMO4** p. 86	**EMO5** p. 89
South Hall 1B	**EML1** ☆ p. 73	**HUMIES** p. 60	**GP3** ☆ p. 78	**DETA1 +SBSE2 +THEORY2** ☆ p. 80	**ENUM2** ☆ p. 84	**ECOM5** ☆ p. 86	**GP4** p. 90
Club A	**GP1** p. 73	**GP2** p. 75	**ENUM1** p. 77	**GA2** p. 81	**GA3** p. 84	**GA4** p. 87	**GA5** p. 89
Club B	**ECIP1** p. 64	**ECIP2** p. 64	**ECIP3** p. 64	**HOP1** p. 81	**HOP2** p. 84	**HOP3** p. 87	**HOP4** p. 90
Club C	**ACO-SI1** p. 72	**THEORY1** p. 76	**GECH1** p. 78	**ACO-SI2** p. 80	**RWA5** p. 85	**THEORY3** p. 88	
Club D	**ECOM1** p. 72	**ECOM2** p. 75	**EMO3** p. 77	**ECOM3** p. 81	**ECOM4** p. 83	**RWA7** p. 87	**GECH4** p. 89
Club E	**CS1** p. 72	**SBSE1** p. 76	**EML2** p. 77	**CS2** p. 80	**EML3** p. 83	**EML4** p. 86	**DETA2** p. 89
Club H	**RWA1** p. 74	**RWA2** p. 75	**RWA3** p. 78	**GECH2** p. 81	**RWA6** p. 85	**RWA8** p. 88	**RWA9** p. 90
Panorama Hall			**Authors Poster Setup**				

☆ Sessions with best paper nominees

HUMIES

ECiP

HOP

Track List and Abbreviations

ACO-SI: Ant Colony Optimization and Swarm Intelligence

CS: Complex Systems (Artificial Life / Artificial Immune Systems / Generative and Developmental Systems / Evolutionary Robotics / Evolvable Hardware)

DETA: Digital Entertainment Technologies and Arts

ECiP: Evolutionary Computation in Practice

ECOM: Evolutionary Combinatorial Optimization and Metaheuristics

EML: Evolutionary Machine Learning

EMO: Evolutionary Multiobjective Optimization

ENUM: Evolutionary Numerical Optimization

GA: Genetic Algorithms

GECH: General Evolutionary Computation and Hybrids

GP: Genetic Programming

HUMIES: Annual "Humies" Awards For Human-Competitive Results

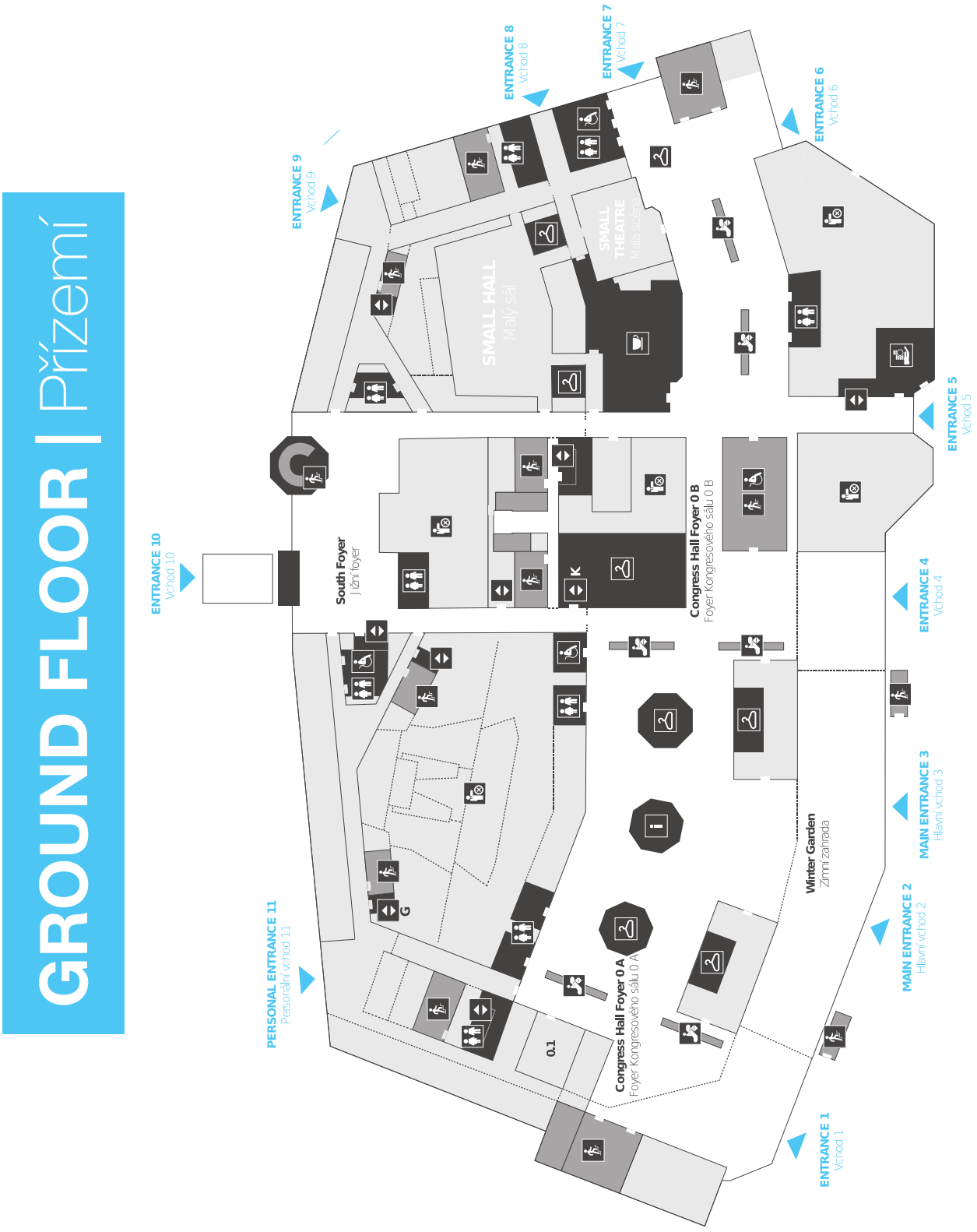
HOP: Hot Off the Press

RWA: Real World Applications

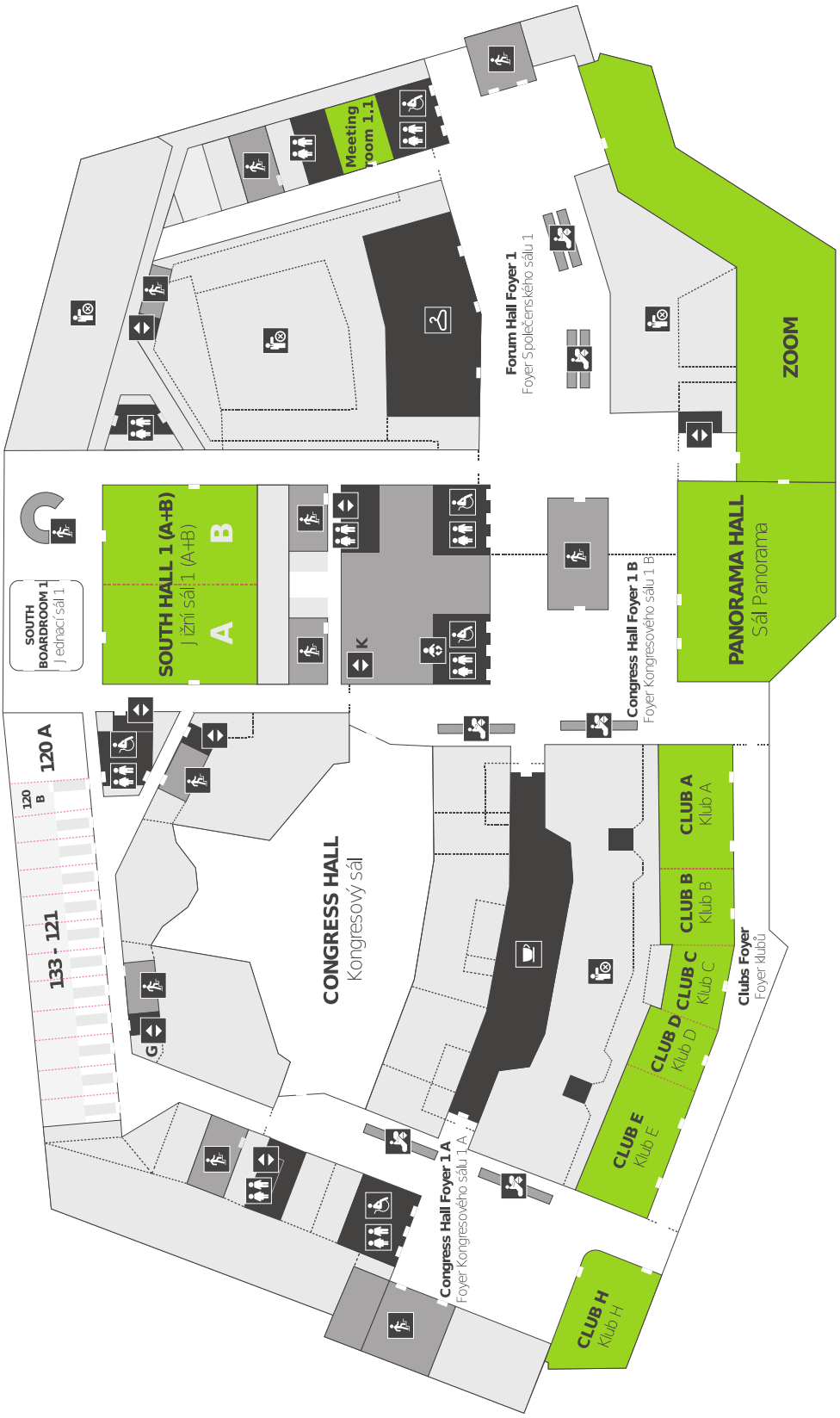
SBSE: Search-Based Software Engineering

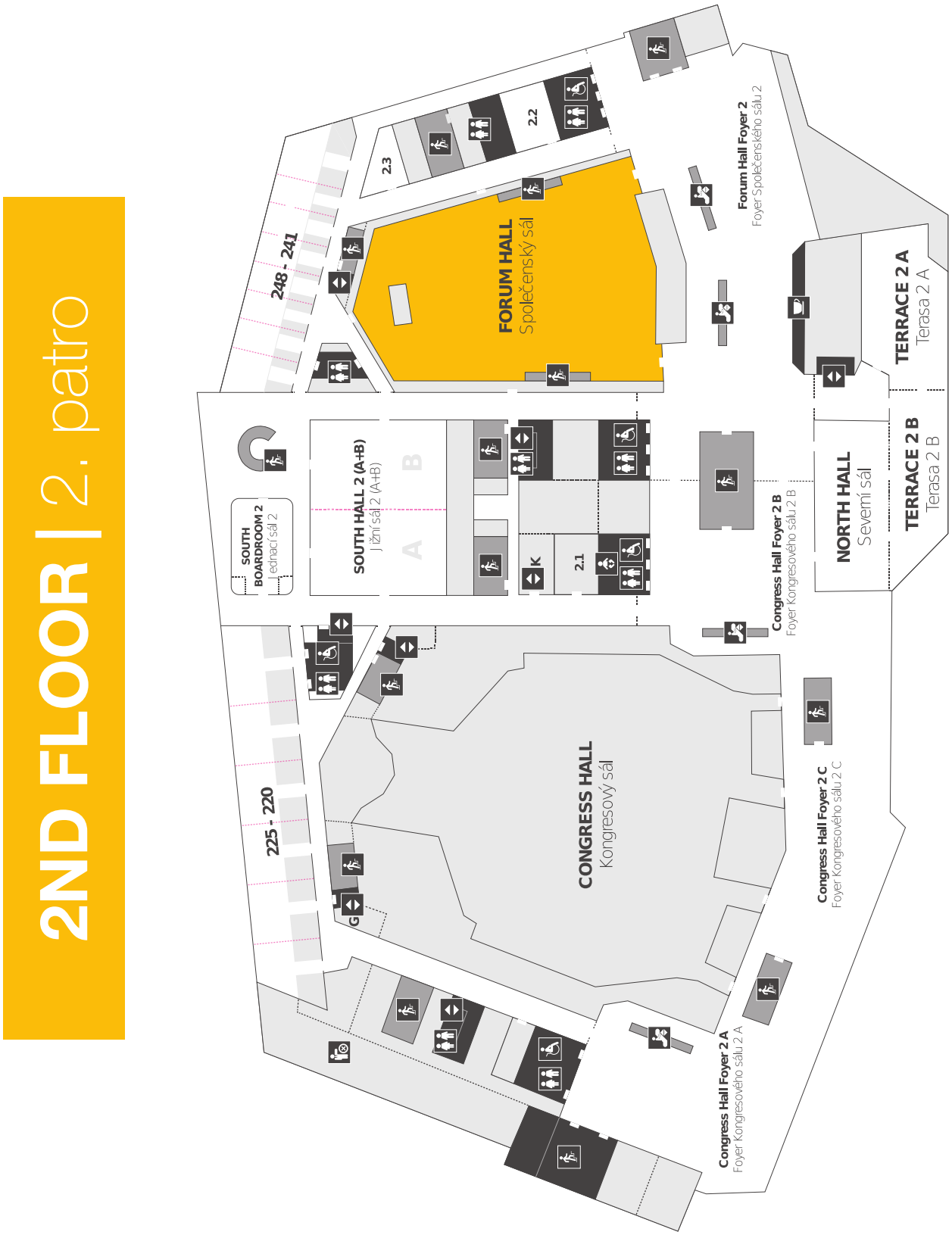
THEORY: Theory

Floor Plans


GROUND FLOOR | Přízemí
ENTRANCE 8
Vchod 8
ENTRANCE 7
Vchod 7
ENTRANCE 6
Vchod 6
ENTRANCE 9
Vchod 9
SMALL THEATRE
Malá scéna
SMALL HALL
Malý sál
ENTRANCE 5
Vchod 5
ENTRANCE 10
Vchod 10
South Foyer
Jižní foyer
Congress Hall Foyer 0 B
Foyer Kongresového sálu 0 B
ENTRANCE 4
Vchod 4
MAIN ENTRANCE 3
Hlavní vchod 3
Winter Garden
Zimní zahrada
MAIN ENTRANCE 2
Hlavní vchod 2
PERSONAL ENTRANCE 11
Personální vchod 11
Congress Hall Foyer 0 A
Foyer Kongresového sálu 0 A
ENTRANCE 1
Vchod 1

1ST FLOOR | 1. patro




2ND FLOOR | 2. patro
FORUM HALL
Společenský sál
Forum Hall Foyer 2
Foyer Společenského sálu 2
TERRACE 2 A
Terasa 2 A
TERRACE 2 B
Terasa 2 B
NORTH HALL
Severní sál
SOUTH HALL 2 (A+B)
Jižní sál 2 (A+B)
SOUTH BOARDROOM 2
Jednací sál 2
Congress Hall Foyer 2 B
Foyer Kongresového sálu 2 B
CONGRESS HALL
Kongresový sál
Congress Hall Foyer 2 C
Foyer Kongresového sálu 2 C
Congress Hall Foyer 2 A
Foyer Kongresového sálu 2 A
248 - 241
225 - 220
2.1
2.2
2.3
A
B
K
G

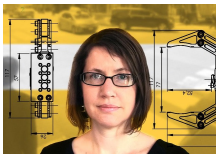
Keynotes

GECCO KEYNOTE

Challenges for Learning in Complex Environments

Monday, July 15, 9:00-10:10
Forum Hall (2F)

Raia Hadsell, *Senior Research Scientist, Google DeepMind, London, UK*



Deep reinforcement learning has rapidly grown as a research field with far-reaching potential for artificial intelligence. Games and simple physical simulations have been used as the main benchmark domains for many fundamental developments. As the field matures, it is important to develop more sophisticated learning systems with the aim of solving more complex real-world tasks, but problems like catastrophic forgetting remain critical, and important capabilities such as skill composition through curriculum learning remain unsolved. Continual learning is an important challenge for reinforcement learning, because RL agents are trained sequentially, in interactive environments, and are especially vulnerable to the phenomena of catastrophic forgetting and catastrophic interference. Successful methods for continual learning have broad potential, because they could enable agents to learn multiple skills, potentially enabling complex behaviors.

In particular, while deep learning has shown excellent progress towards training systems to perform with human or superhuman ability on various tasks (domains like vision, speech, and language as well as games such as Starcraft and Go), the resulting systems are still sluggish to respond to new information, or non-stationarities in the environment, compared to humans. Learning algorithms do exist that can quickly adapt to new data, but these are often at odds with large-scale deep learning systems. Meta-learning is one example of a learning paradigm that may not have this dilemma and thus holds promise as a framework for supporting fast and slow learning in a single learner. In this framework, one could view the learning process as having two levels of optimisation: an outer loop, which might adapt slowly towards a "species" level of optimisation, tailored for an environment, a morphology, and a family of skills or tasks; and an inner loop which allows an individual agent to more quickly adapt and diversify in response to a lifetime of experiences. I would argue that model-free deep reinforcement learning is an effective algorithm for optimising the outer loop of this process, but it may not be as successful as an algorithm for effective lifelong learning - the inner loop of the process.

Biosketch: Raia Hadsell, a senior research scientist at DeepMind, has worked on deep learning and robotics problems for over 10 years.

Her early research developed the approach of learning embeddings using Siamese networks, which has been used extensively for representation learning. After completing a PhD with Yann LeCun, which featured a self-supervised deep learning vision system for a mobile robot, her research continued at Carnegie Mellon's Robotics Institute and SRI International, and in early 2014 she joined DeepMind in London to study artificial general intelligence. Her current research focuses on the challenge of continual learning for AI agents and robots. While deep RL algorithms are capable of attaining superhuman performance on single tasks, they often cannot transfer that performance to additional tasks, especially if experienced sequentially.

She has proposed neural approaches such as policy distillation, progressive nets, and elastic weight consolidation to solve the problem of catastrophic forgetting for agents and robots.

GECCO KEYNOTE

Genetic Programming Methods for Reinforcement Learning

Tuesday, July 16, 9:00-10:10

Robert Babuska, *TU Delft, The Netherlands*

Forum Hall (2F)

Reinforcement Learning (RL) algorithms can be used to optimally solve dynamic decision-making and control problems. With continuous-valued state and input variables, RL algorithms must rely on function approximators to represent the value function and policy mappings. Commonly used numerical approximators, such as neural networks or basis function expansions, have two main drawbacks: they are black-box models offering no insight in the mappings learnt, and they require significant trial and error tuning of their meta-parameters. In addition, results obtained with deep neural networks suffer from the lack of reproducibility.

In this talk, we discuss a family of new approaches to constructing smooth approximators for RL by means of genetic programming and more specifically by symbolic regression. We show how to construct process models and value functions represented by parsimonious analytic expressions using state-of-the-art algorithms, such as Single Node Genetic Programming and Multi-Gene Genetic Programming. We will include examples of nonlinear control problems that can be successfully solved by reinforcement learning with symbolic regression and illustrate some of the challenges this exciting field of research is currently facing.

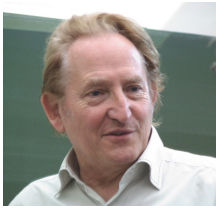
Biosketch: Prof. Dr. Robert Babuska, MSc received the M.Sc. (Hons.) degree in control engineering from the Czech Technical University in Prague, in 1990, and the Ph.D. (cum laude) degree from Delft University of Technology, the Netherlands, in 1997. He has had faculty appointments with the Czech Technical University in Prague and with the Electrical Engineering Faculty, TU Delft. Currently, he is a full professor of Intelligent Control and Robotics at TU Delft, Faculty 3mE, Department of Cognitive Robotics. In the past, he made seminal contributions to the field of nonlinear control and identification with the use of fuzzy modeling techniques. His current research interests include reinforcement learning, adaptive and learning robot control, nonlinear system identification and state-estimation. He has been involved in the applications of these techniques in various fields, ranging from process control to robotics and aerospace.

SIGEVO KEYNOTE

Evolution, Robotics and the Somersaulting Spider

Ingo Rechenberg, *TU Berlin, Germany*

Wednesday, July 17, 11:10-12:20
Forum Hall (2F)



Biological evolution can be really fast. 5000 years ago the Sahara was still green. Now, after the formation of the desert, an ingenious locomotion technique has been invented in an exclave of the Sahara. Like a cyclist, the spider *Cebrennus rechenbergi* moves over the obstacle-free surface of the isolated Moroccan desert Erg Chebbi.

Turboevolution, as known from the Darwin Finches on the Galapagos Islands, implies the question: How fast can evolution be? A short introduction to the theory of the evolution-strategy gives the answer. Comparing with a simple random search the speed of progress increases enormously with the accuracy of the imitation of the rules of biological evolution.

We are bionicists: We have transferred the ingenious leg movements of the cyclist spider to a robot. The result is a machine, perhaps a future Mars rover, that can run and roll in many fashions. Videos from the Moroccan Erg Chebbi desert demonstrate the extraordinary performance of the bionics rover.

Biosketch: Ingo Rechenberg is a German researcher and professor currently in the field of bionics. Rechenberg is a pioneer of the fields of evolutionary computation and artificial evolution. In the 1960s and 1970s he invented a highly influential set of optimization methods known as evolution strategies (from German Evolutionsstrategie). His group successfully applied the new algorithms to challenging problems such as aerodynamic wing design. These were the first serious technical applications of artificial evolution, an important subset of the still growing field of bionics.

Rechenberg was educated at the Technical University of Berlin and at the University of Cambridge. Since 1972 he has been a full professor at the Technical University of Berlin, where he is heading the Department of Bionics and Evolution Techniques.

His awards include the Lifetime Achievement Award of the Evolutionary Programming Society (US, 1995) and the Evolutionary Computation Pioneer Award of the IEEE Neural Networks Society (US, 2002).

The Moroccan flic-flac spider, *Cebrennus rechenbergi*, was named in his honor, as he first collected specimens in the Moroccan desert.

Tutorials

Introductory Tutorials

Constraint-Handling Techniques used with Evolutionary Algorithms
Carlos Artemio Coello Coello, *CINVESTAV-IPN*
Saturday, July 13, 08:30-10:20
Club H (1F)

Introductory Tutorial: Theory for Non-Theoreticians
Benjamin Doerr, *Ecole Polytechnique*
Saturday, July 13, 08:30-10:20
Meeting room 1.1 (1F)

Hyper-heuristics
Daniel R. Tauritz, *Missouri University of Science and Technology*
John R. Woodward, *Queen Mary University of London*
Saturday, July 13, 08:30-10:20
Club D (1F)

Evolutionary Computation: A Unified Approach
Kenneth De Jong, *George Mason University*
Saturday, July 13, 08:30-10:20
Club E (1F)

Learning Classifier Systems: From Principles to Modern Systems
Anthony Stein, *University of Augsburg*
Saturday, July 13, 08:30-10:20
South Hall 1A (1F)

Representations for Evolutionary Algorithms
Franz Rothlauf, *Universität Mainz*
Saturday, July 13, 10:40-12:30
Club E (1F)

Introduction to Genetic Programming
Una-May O'Reilly, *CSAIL, Massachusetts Institute of Technology*
Erik Hemberg, *MIT*
Saturday, July 13, 10:40-12:30
Club H (1F)

Runtime Analysis of Evolutionary Algorithms: Basic Introduction
Per Kristian Lehre, *University of Birmingham*
Pietro Oliveto, *University of Sheffield*
Saturday, July 13, 10:40-12:30
Meeting room 1.1 (1F)

A Practical Guide to Experimentation (and Benchmarking)
Nikolaus Hansen, *Inria*
Saturday, July 13, 14:00-15:50
Club A (1F)

Tutorial on Evolutionary Multiobjective Optimization
Dimo Brockhoff, *Inria*
Saturday, July 13, 14:00-15:50
Club E (1F)

Neuroevolution for Deep Reinforcement Learning Problems
David Ha, *Google Brain*
Saturday, July 13, 14:00-15:50
South Hall 1B (1F)

Evolutionary Many-Objective Optimization
Hisao Ishibuchi, *Southern University of Science Technology (SUSTech)*
Hiroyuki Sato, *The University of Electro-Communications*
Saturday, July 13, 16:10-18:00
Club E (1F)

Evolutionary Robotics Tutorial
Nicolas Bredeche, *Sorbonne Université*
Stéphane Doncieux, *Sorbonne Université*
Jean-Baptiste Mouret, *INRIA*
Sunday, July 14, 08:30-10:20
South Hall 1B (1F)

Model-Based Evolutionary Algorithms
Dirk Thierens, *Utrecht University*
Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*
Sunday, July 14, 14:00-15:50
Club B (1F)

Evolution of Neural Networks — Sunday, July 14, 16:10-18:00
Risto Miikkulainen, *The University of Texas at Austin* — South Hall 1B (1F)

Advanced Tutorials

Recent Advances in Fitness Landscape Analysis — Saturday, July 13, 10:40-12:30
Gabriela Ochoa, *University of Stirling* — Club B (1F)
Katherine Mary Malan, *University of South Africa*

Evolutionary Computation for Digital Art — Saturday, July 13, 16:10-18:00
Aneta Neumann, *The University of Adelaide* — Club A (1F)
Frank Neumann, *The University of Adelaide*

Visualization in Multiobjective Optimization — Sunday, July 14, 08:30-10:20
Bogdan Filipic, *Jozef Stefan Institute* — Club E (1F)
Tea Tusar, *Jozef Stefan Institute*

CMA-ES and Advanced Adaptation Mechanisms — Sunday, July 14, 08:30-10:20
Youhei Akimoto, *University of Tsukuba* — Club D (1F)
Nikolaus Hansen, *Inria*

Recent Advances in Particle Swarm Optimization Analysis and Understanding — Sunday, July 14, 10:40-12:30 — South Hall 1B (1F)
Andries P. Engelbrecht, *University of Stellenbosch*
Christopher W. Cleghorn, *University of Pretoria*

Semantic Genetic Programming — Sunday, July 14, 10:40-12:30
Alberto Moraglio, *University of Exeter* — Club H (1F)
Krzysztof Krawiec, *Poznan University of Technology*

Decomposition Multi-Objective Optimisation: Current Developments and Future Opportunities — Sunday, July 14, 10:40-12:30 — Club E (1F)
Ke Li, *University of Exeter*
Qingfu Zhang, *City University of Hong Kong*

Dynamic Parameter Choices in Evolutionary Computation — Sunday, July 14, 14:00-15:50
Carola Doerr, *CNRS* — Club A (1F)

Next Generation Genetic Algorithms. — Sunday, July 14, 14:00-15:50
Darrell Whitley, *Colorado State University* — South Hall 1B (1F)

Solving Complex Problems with Coevolutionary Algorithms — Sunday, July 14, 14:00-15:50
Krzysztof Krawiec, *Poznan University of Technology* — Club C (1F)
Malcolm Heywood, *Dalhousie University*

Sequential Experimentation by Evolutionary Algorithms — Sunday, July 14, 14:00-15:50
Ofer M. Shir, *Tel-Hai College* — Club H (1F)
Thomas Bäck, *Leiden University*

Simulation Optimization — Sunday, July 14, 16:10-18:00
Juergen Branke, *University of Warwick* — Club B (1F)

Specialized Tutorials

Exploratory Landscape Analysis — Sunday, July 14, 10:40-12:30
Pascal Kerschke, *University of Münster* — Club B (1F)
Mike Preuss, *Leiden University*

Theory of Estimation-of-Distribution Algorithms — Sunday, July 14, 10:40-12:30
Carsten Witt, *Technical University of Denmark* — Meeting room 1.1 (1F)

Evolutionary Computation and Evolutionary Deep Learning for Image Analysis, Signal Processing and Pattern Recognition — Sunday, July 14, 14:00-15:50 — Club E (1F)
Mengjie Zhang, *Victoria University of Wellington*
Stefano Cagnoni, *University of Parma*

Push — Sunday, July 14, 16:10-18:00
Lee Spector, *Hampshire College* — Club H (1F)
Nicholas Freitag McPhee, *University of Minnesota, Morris*

Concurrency in evolutionary algorithms — Sunday, July 14, 16:10-18:00
JJ Merelo, *University of Granada* — Club C (1F)

Creative Evolutionary Computation — Sunday, July 14, 16:10-18:00
Antonios Liapis, *University of Malta* — Club E (1F)
Georgios N. Yannakakis, *University of Malta*

Workshops,
Late Breaking Abstracts,
and Women@GECCO

ECMCDM + DTEO — Evolutionary Computation + Multiple Criteria Decision Making / Decomposition Techniques in Evolutionary Optimization

Organizers: Richard Allmendinger (University of Manchester); Tinkle Chugh (University of Exeter); Bilel Derbel (Univ. Lille, Inria Lille - Nord Europe); Jussi Hakanen (University of Jyvaskyla); Ke Li (University of Exeter); Xiaodong Li (RMIT University); Saul Zapotecas-Martinez (SHINSHU University)

Time and Location: Saturday, July 13, 08:30-10:20, Club B (1F)

Minimum Spanning Tree-based Clustering of Large Pareto Archives
Andrzej Jaszkiewicz

Differential Evolution for Multi-Modal Multi-Objective Problems
Monalisa Pal, Sanghamitra Bandyopadhyay

A Tabu Search-based Memetic Algorithm for the Multi-objective Flexible Job Shop Scheduling Problem
Marios Kefalas, Steffen Limmer, Asteris Apostolidis, Markus Olhofer, Michael Emmerich, Thomas Baeck

Invited talk
Edward Keedwell

EvoSoft — Evolutionary Computation Software Systems

Organizers: Michael Affenzeller (University of Applied Science Upper Austria; Institute for Formal Models and Verification,Johannes Keppler University Linz); Stefan Wagner (University of Applied Sciences Upper Austria)

Time and Location: Saturday, July 13, 08:30-10:20, South Hall 1B (1F)

Evolutionary and Swarm-Intelligence Algorithms through Monadic Composition
Gary Pamparà, Andries P. Engelbrecht

A Symbolic Evolutionary Algorithm Software Platform
Rodolfo Ayala Lopes, Thiago Macedo Gomes, Alan R. R. de Freitas

MABE 2.0: an introduction to MABE and a road map for the future of MABE development
Clifford Bohm, Alexander Lalejini, Jory Schossau, Charles Ofria

Generalized Incremental Orthant Search: Towards Efficient Steady-State Evolutionary Multiobjective Algorithms
Maxim Buzdalov

ECJ at 20: Toward a General Metaheuristics Toolkit
Eric O. Scott, Sean Luke

Automatic Configuration of NSGA-II with jMetal and irace
Antonio J. Nebro, Manuel López-Ibáñez, Cristóbal Barba-González, José García-Nieto

ECPERM — Evolutionary Computation for Permutation Problems

Organizers: Marco Baioletti (University of Perugia); Josu Ceberio (University of the Basque Country); John McCall (Smart Data Technologies Centre); Valentino Santucci (University for Foreigners of Perugia)

Time and Location: Saturday, July 13, 08:30-12:30, Club C (1F)

Opening
Josu Ceberio

Invited talk
Jose A. Lozano

Search moves in the local optima networks of permutation spaces: the QAP case
Marco Baioletti, Alfredo Milani, Valentino Santucci, Marco Tomassini

Evolutionary Search Techniques for the Lyndon Factorization of Biosequences
Amanda Clare, Jacqueline W. Daykin, Thomas Mills, Christine Zarges

An Experimental Comparison of Algebraic Differential Evolution using different Generating Sets
Marco Baioletti, Alfredo Milani, Valentino Santucci, Umberto Bartoccini

On the Definition of Dynamic Permutation Problems under Landscape Rotation
Joan Alza, Mark Bartlett, Josu Ceberio, John McCall

Deriving Knowledge from Local Optima Networks for Evolutionary Optimization in Inventory Routing Problem
Piotr Lipinski, Krzysztof Michalak

Panel
Sébastien Verel, Francisco Chicano, Jose A. Lozano, John McCall

Closing
Valentino Santucci

BBOB — Black Box Optimization Benchmarking

Organizers: Anne Auger (INRIA; CMAP, Ecole Polytechnique); Dimo Brockhoff (INRIA Saclay - Ile-de-France; CMAP, Ecole Polytechnique); Nikolaus Hansen (Inria, Ecole polytechnique); Tea Tusar (Jozef Stefan Institute); Konstantinos Varelas (Inria Saclay Ile-de-France, Thales LAS France SAS)

Time and Location: Saturday, July 13, 08:30-12:30, Club A (1F)

Introduction to BBOB
Dimo Brockhoff

Benchmarking Large Scale Variants of CMA-ES and L-BFGS-B on the bbob-largescale Testbed
Konstantinos Varelas

Benchmarking MO-CMA-ES and COMO-CMA-ES on the Bi-objective bbob-biobj Testbed
Paul Dufossé, Cheikh Touré

Benchmarking Algorithms from the platypus Framework on the Biobjective bbob-biobj Testbed
Dimo Brockhoff, Tea Tušar

Mini-Intro to BBOB
Dimo Brockhoff

Benchmarking the ATM Algorithm on the BBOB 2009 Noiseless Function Testbed
Benjamin Jacob Bodner

The Impact of Sample Volume in Random Search on the bbob Test Suite
Dimo Brockhoff, Nikolaus Hansen

Benchmarking GNN-CMA-ES on the BBOB noiseless testbed
Louis Faury, Clément Calauzènes, Olivier Fercoq

Benchmarking Multivariate Solvers of SciPy on the Noiseless Testbed
Konstantinos Varelas, Marie-Ange Dahito

The COCO data archive and This Year's Results
Nikolaus Hansen

IAM + SmartEA — Industrial Application of Metaheuristics / Workshop on Evolutionary Algorithms for Smart Grids

Organizers: Silvino Fernandez Alzueta (ArcelorMittal); Fernando Lezama (GECAD, Polytechnic of Porto); Joao Soares (GECAD, Polytechnic of Porto); Thomas Stützle (Université Libre de Bruxelles); Zita Vale (Polytechnic of Porto); Pablo Valledor (ArcelorMittal)

Time and Location: Saturday, July 13, 10:40-12:30, South Hall 1B (1F)

Welcome and Introduction
Silvino Fernandez

What Textbooks Don't Say about Applying Metaheuristics in Industry
Bogdan Filipic

Increasing Trust in Meta-Heuristics by Using MAP-Elites
Neil Urquhart, Michael Guckert, Simon Powers

A Memetic Algorithm to Optimize Bus Timetable with Unequal Time Intervals
Pengfei Gao, Xingquan Zuo, Qiang Bian, Xinchao Zhao

Industry 4.0 & Next Future challenges of Evolutionary Computation
Pablo Valledor

Business Models for Flexibility of Electric Vehicles: Evolutionary Computation for a Successful Implementation
Fernando Lezama, Joao Soares, Ricardo Faia, ZIta Vale, Leonardo H. Macedo, Ruben Romero

Student Workshop

Organizers: Youhei Akimoto (University of Tsukuba); Christine Zarges (Aberystwyth University)

Time and Location: Saturday, July 13, 10:40-18:00, Club D (1F)

(Best Paper nominees are marked with a star)

Limited Memory, Limited Arity Unbiased Black-Box Complexity: First Insights
Nina Bulanova, Maxim Buzdalov

Fixed-Target Runtime Analysis of the (1+1) EA with Resampling
Dmitry Vinokurov, Maxim Buzdalov, Arina Buzdalova, Benjamin Doerr, Carola Doerr

Knowledge-Driven Reference-Point Based Multi-Objective Optimization: First Results
Henrik Smedberg

Adaptive Landscape Analysis
Anja Jankovic, Carola Doerr

Expressiveness and Robustness of Landscape Features
Quentin Renau, Johann Dreo, Carola Doerr, Benjamin Doerr

Lunch break — 12:30 - 14:00

Theoretical and Empirical Study of the $(1 + (\lambda, \lambda))$ **EA on the LeadingOnes Problem** ☆
Vitalii Karavaev, Denis Antipov, Benjamin Doerr

On the Construction of Pareto-compliant Quality Indicators ☆
Jesús Guillermo Falcón-Cardona, Michael T. M. Emmerich, Carlos A. Coello Coello

Ensemble-Based Constraint Handling in Multiobjective Optimization ☆
Aljosa Vodopija, Akira Oyama, Bogdan Filipic

Dynamic Compartmental Models for Algorithm Analysis and Population Size Estimation ☆
Hugo Monzón, Hernán Aguirre, Sébastien Verel, Arnaud Liefooghe, Bilel Derbel, Kiyoshi Tanaka

Optimization of a Demand Responsive Transport Service Using Multi-objective Evolutionary Algorithms
Renan José dos Santos Viana, André Gustavo dos Santos, Flávio Vinícius Cruzeiro Martins, Elizabeth Fialho Wanner

Coffee break — 15:50 - 16:10

Random subsampling improves performance in lexicase selection
Jose Guadalupe Hernandez, Alexander Michael Lalejini, Emily Dolson, Charles Ofria

Meta-Genetic Programming For Static Quantum Circuits
Kenton M. Barnes, Michael B. Gale

Modularity Metrics for Genetic Programming
Anil Kumar Saini, Lee Spector

A Biased Random Key Genetic Algorithm for the Weighted Independent Domination Problem
Guillem Rodríguez Corominas, Christian Blum, Maria J. Blesa

Evolution and Self-teaching in Neural Networks: Another comparison when the agent is more primitively conscious
Nam Le

IWLCS — International Workshop on Learning Classifier Systems

Organizers: Masaya Nakata (Yokohama National University); Anthony Stein (University of Augsburg); Takato Tatsumi (The University of Electro-Communications)

Time and Location: Saturday, July 13, 10:40-18:00, South Hall 1A (1F)

Welcome Note from the organizers and workshop organization
Takato Tatsumi, Anthony Stein, Masaya Nakata

NEW: Review of "Past Year Research" in the field of LCS
Takato Tatsumi, Masaya Nakata, Anthony Stein

Invited talk
Martin V. Butz

A Survey of Formal Theoretical Advances Regarding XCS
David Pätzel, Anthony Stein, Jörg Hähner

XCS-CR for Handling Input, Output, and Reward Noise
Takato Tatsumi, Keiki Takadama

Preliminary tests of a real-valued Anticipatory Classifier System
Norbert Kozlowski, Olgierd Unold

LCS-Based Automatic Configuration of Approximate Computing Parameters for FPGA System Designs
Simon Conrady, Manu Manuel, Arne Kreddig, Walter Stechele

Real-Time Detection of Internet Addiction Using Reinforcement Learning System
Hong-Ming Ji, Liang-Yu Chen, Tzu-Chien Hsiao

Predicting the Remaining Useful Life of Plasma Equipment through XCSR
Liang-Yu Chen, Jia-Hua Lee, Ya-Liang Yang, Ming-Tsung Yeh, Tzu-Chien Hsiao

Demo: Presentation of ExSTraCTs and BioHEL
Ryan Urbanowicz, Jaume Bacardit

Round table discussion
Anthony Stein

Closing
Anthony Stein

GI — Genetic Improvement

Organizers: Brad Alexander (University of Adelaide); Saemundur Haraldsson (Lancaster University); Markus Wagner (School of Computer Science, The University of Adelaide); John Woodward (Queen Mary University of London)

Time and Location: Saturday, July 13, 14:00-15:50, Club H (1F)

Toward Human-Like Summaries Generated from Heterogeneous Software Artefacts
Mahfouth Alghamdi, Christoph Treude, Markus Wagner

Genetic Improvement of Data gives double precision invsqrt
W. Langdon

On Adaptive Specialisation in Genetic Improvement
Aymeric Blot, Justyna Petke

Genetic Algorithms for Affine Transformations to Existential t-Restrictions
Ryan E. Dougherty, Erin Lanus, Charles J. Colbourn, Stephanie Forrest

A Survey of Genetic Improvement Search Spaces
Justyna Petke, Brad Alexander, Earl T. Barr, Alexander E.I. Brownlee, Markus Wagner, David R. White

The Quest for Non-Functional Property Optimisation in Heterogeneous and Fragmented Ecosystems: a Distributed Approach
Mahmoud Bokhari, Markus Wagner, Brad Alexander

SAEOpt — Surrogate-Assisted Evolutionary Optimisation

Organizers: Richard Everson (University of Exeter); Jonathan Edward Fieldsend (University of Exeter); Yaochu Jin (University of Surrey); Alma A. M. Rahat (University of Plymouth); Handing Wang (Xidian University)

Time and Location: Saturday, July 13, 14:00-18:00, Club C (1F)

On The Use of Surrogate Models in Engineering Design Optimization and Exploration: The Key Issues
Pramudita Satria Palar, Rhea Patricia Liem, Lavi Rizki Zuhal, Koji Shimoyama

Benchmarking Surrogate-Assisted Genetic Recommender Systems
Thomas Gabor, Philipp Altmann

Prediction of neural network performance by phenotypic modeling
Alexander Hagg, Martin Zaefferer, Jörg Stork, Adam Gaier

Multi-Point Infill Sampling Strategies Exploiting Multiple Surrogate Models
Paul Beaucaire, Charlotte Beauthier, Caroline Sainvitu

Deadline-Driven Approach for Multi-Fidelity Surrogate-Assisted Environmental Model Calibration
Nikolay Nikitin, Pavel Vychuzhanin, Alexander Hvatov, Irina Deeva, Anna Kalyuzhnaya, Sergey Kovalchuk

On Benchmarking Surrogate-Assisted Evolutionary Algorithms
Vanessa Volz, Boris Naujoks

Keynote Speech
Boris Naujoks

HCNURS — Evolutionary Computation in Health care and Nursing System

Organizers: Koichi Nakayama (Saga University); Chika Oshima (Saga University)

Time and Location: Saturday, July 13, 14:00-18:00, Meeting room 1.1 (1F)

Computing Rational Border Curves of Melanoma and Other Skin Lesions from Medical Images with Bat Algorithm
Akemi Galvez, Iztok Fister Jr., Eneko Osaba, Iztok Fister, Javier Del Ser, Andres Iglesias

An Entirely Self-Administrated Genetic Algorithm Implemented Using Blockchain Technology
Koichi Nakayama, Kanta Nanri, Yutaka Moriyama, Chika Oshima

Discovering dependencies among mined association rules with population-based metaheuristics
Iztok Fister Jr., Akemi Galvez, Eneko Osaba, Javier Del Ser, Andres Iglesias, Iztok Fister

Drone Monitoring System for Disaster Areas
Patrick Hock, Koki Wakiyama, Koichi Nakayama, Chika Oshima

A Deep Learning System that Learns a Discriminative Model Autonomously Using Difference Images
Ryodai Hamasaki, Koichi Nakayama

Intention Inference from 2D Poses of Preliminary Action Using OpenPose
Ryuji Tanaka, Chika Oshima, Koichi Nakayama

SecDef — Genetic and Evolutionary Computation in Defense, Security and Risk Management

Organizers: Riyad Alshammari (King Saud bin Abdulaziz University for Health Sciences); Anna Isabel Esparcia-Alcazar (Universitat Politècnica de València); Erik Hemberg (MIT CSAIL); Tokunbo Makanju (New York Institute of Technology)

Time and Location: Saturday, July 13, 14:00-18:00, Club B (1F)

A New approach for Malware Detection Based on Evolutionary Algorithm
Farnoush Manavi, Ali Hamzeh

Vulnerability Assessment of Machine Learning Based Malware Classification Models
Yasir Malik, Adetokunbo Makanju, Godwin Raju, Pavol Zavarsky

Investigating Algorithms for Finding Nash Equilibria in Cybersecurity Problems
Linda Zhang, Erik Hemberg

A Role-Base Approach and a Genetic Algorithm for VLAN Design in Large Critical Infrastructures
Igor Saenko, Igor Kotenko

C^3PO**: Cipher Construction with Cartesian genetic PrOgramming**
Stjepan Picek, Karlo Knezevic, Domagoj Jakobovic, Ante Derek

A Mixed Framework to Support Heterogeneous Collection Asset Scheduling
Jean Berger, Moufid Harb, Ibrahim Abualhaol, Alexander Tekse, Rami Abielmona, Emil Petriu

Darwinian Malware Detectors: A Comparison of Evolutionary Solutions to Android Malware
Zachary Wilkins, Nur Zincir-Heywood

Automated Design of Tailored Link Prediction Heuristics for Applications in Enterprise Network Security
Aaron Scott Pope, Daniel R. Tauritz, Melissa Turcotte

LBA — Late Breaking Abstracts

Organizers: Carola Doerr (CNRS, Sorbonne University)

Time and Location: Saturday, July 13, 16:10-18:00, South Hall 1B (1F)

Skill Emergence and Transfer in Multi-Agent Environments
Ingmar Kanitscheider, Bowen Baker, Todor Markov, Igor Mordatch

Multidimensional Time Series Feature Engineering by Hybrid Evolutionary Approach
Piotr Lipinski, Krzysztof Michalak

Predictability on Performance of Surrogate-assisted Evolutionary Algorithm According to Problem Dimension
Dong Pil Yu, yong hyuk kim

On the automatic planning of healthy and balanced menus
Alejandro Marrero, Eduardo Segredo, Coromoto Leon

Modelling and Solving the Combined Inventory Routing Problem with Risk Consideration
Ahmed Kheiri, Konstantinos Zografos

Stabilize Training Generative Adversarial Networks by Genetic Algorithms
Hwi-Yeon Cho, Yong-Hyuk Kim

Application of Estimation of Distribution Algorithm for Feature Selection
Mayowa Ayodele

Integrating Agent Actions with Genetic Action Sequence Method
Man-Je Kim, Jun Suk Kim, Donghyeon Lee, Sungjin James Kim, Min-jung Kim, Chang Wook Ahn

Determination of microscopic residual stresses using diffraction methods, EBSD maps, and evolutionary algorithms
J. Ignacio Hidalgo, Ricardo Fernández Fernández, Oscar Garnica, J. Manuel Colmenar, Juan Lanchrares, Gaspar Gónzalez-Docel

Parallel GPQUICK
W. Langdon

A Honeybee Mating Optimization Algorithm For Solving The Static Bike Rebalancing Problem
Mariem Sebai, Ezzeddine Fatnassi, Lilia Rejeb

CE+EPSO: a Merged Approach to Solve SCOPF Problem
Carolina Gil Marcelino, Leonel Magalhães Carvalho, Vladimiro Miranda, Armando da Silva, Carlos Eduardo Pedreira, Elizabeth Fialho Wanner

OINNIONN - Outward Inward Neural Network and Inward Outward Neural Network Evolution
Aviv Segev, Rituparna Datta, Ryan Benton, Dorothy Curtis

Towards Solving Neural Networks with Optimization Trajectory Search
Lia Tamaziyevna Parsenadze, Danilo Vasconcellos Vargas, Toshiyuki Fujita

Transfer of Evolutionary Computation Techniques to Synthetic Biology: Tests in Silico
Alexander V. Spirov, Myasnikova Ekaterina

EDA with Hamming Distance for Consumption-Loan Planning in Experimental Economics
Yukiko Orito, Tomoko Kashima

Beyond Coreset Discovery: Evolutionary Archetypes
Pietro Barbiero, Giovanni Squillero, Alberto Tonda

Identifying Variable Interaction Using Mutual Information of Multiple Local Optima
Yapei Wu, Xingguang Peng, Demin Xu

A New Hybrid Ant Colony Algorithms for The Traveling Thief Problem
Wiem Zouari, Ines Alaya, Moncef Tagina

Hybrid Estimation of Distribution Algorithm for solving a Resource Level Allocation Problem in a Legal Business
Mayowa Ayodele, K.Nadia Papamichail, Darren Buckley, Geraldine Gallagher

A Two-Phase Genetic Algorithm for Incorporating Environmental Considerations with Production, Inventory and Routing Decisions in Supply Chain Networks
Adel Aazami, Ali Papi, Nader Azad, Armin Jabbarzadeh

Predictive Model for Epistasis-based Basis Evaluation on Pseudo-Boolean Function Using Deep Neural Networks
Yong-Hoon Kim, Junghwan Lee, Yong-Hyuk Kim

Probabilistic Grammar-based Deep Neuroevolution
Pak-Kan Wong, Man-Leung Wong, Kwong-Sak Leung

Selective Pressure in Constrained Differential Evolution
Vladimir Vadimovich Stanovov, Shakhnaz Agasuvar kyzy Akhmedova, Eugene Stanislavovich Semenkin

Bi-objective optimal planning for emergency resource allocation in the maritime oil spill accident response phase under uncertainty
Guohai Zhu, Kewei Yang, Qingsong Zhao, Zhiwei Yang

Genetic Algorithm-based Feature Selection for Depression Scale Prediction
SeungJu Lee, Hyunji Moon, Dajung Kim, Yourim Yoon

Trajectory Optimization for Car Races using Genetic Algorithms
Dana Vrajitoru

Genetic Algorithms are Very Good Solved Sudoku Generators
Amit Benbassat

NSBECR — New Standards for Benchmarking in Evolutionary Computation Research

Organizers: William LaCava (University of Massachusetts Amherst)

Time and Location: Saturday, July 13, 16:10-18:00, Club H (1F)

HIBACHI: A heuristic method for simulating data of arbitrary complexity to benchmark machine learning methods
Jason Moore

Exploring the MLDA Benchmark on the Nevergrad Platform
Jeremy Rapin, Marcus Gallagher, Pascal Kerschke, Mike Preuss, Olivier Teytaud

Comparison of Contemporary Evolutionary Algorithms on the Rotated Klee-Minty Problem
Michael Hellwig, Patrick Spettel, Hans-Georg Beyer

A living benchmark of symbolic regression and machine learning methods
William LaCava, Patryk Orzechowski

UMLOP — Understanding Machine Learning Optimization Problems

Organizers: Marcus Gallagher (Univ. Queensland); Pascal Kerschke (University of Münster); Mike Preuss (Universiteit Leiden); Olivier Teytaud (TAO, Inria)

Time and Location: Sunday, July 14, 08:30-10:20, Club H (1F)

Evolutionary Discovery of Coresets for Classification
Pietro Barbiero, Giovanni Squillero, Alberto Tonda

Global structure of policy search spaces for reinforcement learning
Belinda Stapelberg, Katherine Mary Malan

Automatic Surrogate Modelling Technique Selection based on Features of Optimization Problems
Bhupinder Singh Saini, Manuel López-Ibáñez, Kaisa Miettinen

Making a Case for (Hyper-)Parameter Tuning as Benchmark Problems
Carola Doerr, Johann Dreo, Pascal Kerschke

CIASE — Computational Intelligence in Aerospace Science and Engineering

Organizers: David Camacho (Universidad Autónoma de Madrid)

Time and Location: Sunday, July 14, 08:30-10:20, Club B (1F)

Solving Multi-objective Dynamic Travelling Salesman Problems by Relaxation
Lorenzo Angelo Ricciardi, Massimiliano Vasile

Structured-Chromosome GA Optimisation For Satellite Tracking
Lorenzo Gentile, Cristian Greco, Edmondo Minisci, Thomas Bartz-Beielstein, Massimiliano Vasile

Hybridizing Differential Evolution and Novelty Search for Multimodal Optimization Problems
Aritz D. Martinez, Eneko Osaba, Izaskun Oregi, Iztok Fister Jr., Iztok Fister, Javier Del Ser

Determination of Microscopic Residual Stresses using Evolutionary Algorithms
J. Ignacio Hidalgo, Ricardo Fernández, J. Manuel Colmenar, Oscar Garnica, Juan Lanchares, Gaspar González-Doncel

Benchmarking Constrained Surrogate-based Optimization on Low Speed Airfoil Design Problems
Pramudita Satria Palar, Yohanes Bimo Dwianto, Rommel Regis, Akira Oyama, Lavi Rizki Zuhal

Interplanetary Transfers via Deep Representations of the Optimal Policy and/or of the Value Function
Dario Izzo, Ekin Öztürk, Marcus Märtens

Immune and Genetic Hybrid Optimization Algorithm for Data Relay Satellite with Microwave and Laser Links
Weihu Zhao, Guijin Xia, Cheng Dong, Wei Li, Shuai Ren, Yinghui Xue, Shuwen Chen, Xiya Chen

iGECCO — Interactive Methods @ GECCO

Organizers: Matthew Barrie Johns (University of Exeter); Ed Keedwell (University of Exeter); Nick Ross (University of Exeter); David Walker (University of Plymouth)

Time and Location: Sunday, July 14, 08:30-10:20, South Hall 1A (1F)

Human-Evolutionary Problem Solving through Gamification of a Bin-Packing Problem
Nicholas David Fitzhavering Ross, Edward Keedwell, Dragan Savic, Matthew Barrie Johns

An Intuitive and Traceable Human-based Evolutionary Computation System for Solving Problems in Human Organizations
Kei Ohnishi, Tomohiro Yoshikawa, Tian-Li Yu

Keynote Talk
Jim Smith

EAPU — Evolutionary Algorithms for Problems with Uncertainty

Organizers: Ozgur Akman (University of Exeter); Khulood Alyahya (Exeter University); Juergen Branke (University of Warwick); Jonathan Edward Fieldsend (University of Exeter)

Time and Location: Sunday, July 14, 08:30-10:20, Club C (1F)

A Generator for Dynamically Constrained Optimization Problems
Gary Pamparà, Andries P. Engelbrecht

Hybrid Techniques for Detecting Changes in Less Detectable Dynamic Multiobjective Optimization Problems
Shaaban Sahmoud, Haluk Rahmi Topcuoglu

Uncertainty in Real-World Steel Stacking Problems
Andreas Beham, Sebastian Raggl, Stefan Wagner, Michael Affenzeller

Cost-aware robust optimisation over time
Yaochu Jin

BB-DOB — Black Box Discrete Optimization Benchmarking

Organizers: Carola Doerr (CNRS, Sorbonne University); Pietro S. Oliveto (The University of Sheffield); Thomas Weise (University of Science and Technology of China (USTC), School of Computer Science and Technology); Ales Zamuda (University of Maribor)

Time and Location: Sunday, July 14, 08:30-12:30, Club A (1F)

Introduction to the workshop
Pietro Oliveto

Illustrating the Trade-Off between Time, Quality, and Success Probability in Heuristic Search
Ivan Ignashov, Arina Buzdalova, Maxim Buzdalov, Carola Doerr

Bayesian Performance Analysis for Black-Box Optimization Benchmarking
Borja Calvo, Ofer M. Shir, Josu Ceberio, Carola Doerr, Hao Wang, Thomas Bäck, Jose A. Lozano

Towards Better Estimation of Statistical Significance When Comparing Evolutionary Algorithms
Maxim Buzdalov

Binary 100-Digit Challenge using IEEE-754 Coded Numerical Optimization Scenarios (100b-Digit) and V-shape Binary Distance-based Success History Differential Evolution (DISHv)
Ales Zamuda

Coffee break — 10:20 - 10:40

Kinder Surprise's Debut in Discrete Optimisation – A Real-World Toy Problem that can be Subadditive
Markus Wagner

Benchmarking Discrete Optimization Heuristics with IOHprofiler
Carola Doerr, Furong Ye, Naama Horesh, Hao Wang, Ofer M. Shir, Thomas Bäck

Panel Discussion
Carola Doerr

ECADA — Evolutionary Computation for the Automated Design of Algorithms

Organizers: Emma Hart (Edinburgh Napier University); Daniel R. Tauritz (Missouri University of Science and Technology); John Woodward (Queen Mary University of London)

Time and Location: Sunday, July 14, 10:40-12:30, Club C (1F)

Toward Self-Learning Model-Based EAs
Erik Andreas Meulman, Peter Alexander Nicolaas Bosman

SAPIAS: Towards an independent Self-Adaptive Per-Instance Algorithm Selection for Metaheuristics
Mohamed Amine EL Majdouli

Instruction-Level Design of Local Optimisers using Push GP
Michael Adam Lones

Empirical Evidence of the Effectiveness of Primitive Granularity Control for Hyper-Heuristics
Adam Harter, Aaron Scott Pope, Daniel R. Tauritz, Chris Rawlings

Automated Design of Random Dynamic Graph Models
Aaron Scott Pope, Daniel R. Tauritz, Chris Rawlings

Evolving Mean-Update Selection Methods for CMA-ES
Samuel N. Richter, Michael G. Schoen, Daniel R. Tauritz

VizGEC — Visualisation Methods in Genetic and Evolutionary Computation

Organizers: Richard Everson (University of Exeter); Jonathan Edward Fieldsend (University of Exeter); David Walker (University of Plymouth)

Time and Location: Sunday, July 14, 10:40-12:30, South Hall 1A (1F)

The Cartography of Computational Search Spaces
Gabriela Ochoa

An Analysis of Dimensionality Reduction Techniques for Visualizing Evolution
Andrea De Lorenzo, Eric Medvet, Tea Tušar, Alberto Bartoli

Visualisation demos and discussion
David Walker

EVOGRAPH — Evolutionary Data Mining and Optimization over Graphs

Organizers: David Camacho (Universidad Autonoma de Madrid); Javier Del Ser Lorente (University of the Basque Country (UPV/EHU), TECNALIA); Eneko Osaba (Tecnalia Research & Innovation)

Time and Location: Sunday, July 14, 10:40-12:30, Club D (1F)

Combining Bio-inspired Meta-Heuristics and Novelty Search for Community Detection over Evolving Graph Streams
Eneko Osaba, Javier Ser, Angel Panizo, David Camacho, Akemi Galvez, Andres Iglesias

Solving the Parameterless Firefighter Problem using Multiobjective Evolutionary Algorithms
Krzysztof Michalak

Nature-Inspired Metaheuristics for optimizing Information Dissemination in Vehicular Networks
Antonio David Masegosa, Eneko Osaba, Juan S. Angarita-Zapata, Ibai Laña, Javier Del Ser

RWACMO — Real-world Applications of Continuous and Mixed-integer Optimization

Organizers: Kazuhisa Chiba (The University of Electro-Communications); Akira Oyama (Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency); Pramudita Satria Palar (Institut Teknologi Bandung); Koji Shimoyama (Tohoku University); Hemant Kumar Singh (University of New South Wales at Australian Defence Force Academy (UNSW@ADFA), Canberra ACT, Australia)

Time and Location: Sunday, July 14, 14:00-15:50, South Hall 1A (1F)

Implementing Evolutionary Optimization to Model Neural Functional Connectivity
Kaitlin M. Maile, Manish Saggar, Risto Miikkulainen

Worst Case Search over a Set of Forecasting Scenarios Applied to Financial Stress-Testing
Steffen Finck

Identifying Solutions of Interest for Practical Many-objective Problems using Recursive Expected Marginal Utility
Hemant Kumar Singh, Tapabrata Ray, Tobias Rodemann, Markus Olhofer

Offline Data-driven Evolutionary Optimization
Yaochu Jin

Many Criteria Optimisation and decision support for automotive systems design
Markus Olhofer

LAHS — Landscape-Aware Heuristic Search

Organizers: Arnaud Liefooghe (Univ. Lille, Inria Lille - Nord Europe); Gabriela Ochoa (University of Stirling); Nadarajen Veerapen (Université de Lille); Sebastien Verel (Université du Littoral Côte d'Opale)

Time and Location: Sunday, July 14, 14:00-18:00, Meeting room 1.1 (1F)

Visualising the Landscape of Multi-Objective Problems using Local Optima Networks
Jonathan Edward Fieldsend, Khulood Alyahya

Landscape Analysis Under Measurement Error
Khulood Alyahya, Ozgur E. Akman, Jonathan E. Fieldsend

Local Optima Network Analysis for MAX-SAT
Gabriela Ochoa, Francisco Chicano

Local Optima Networks for Continuous Fitness Landscapes
Jason Adair, Gabriela Ochoa, Katherine Mary Malan

Coupling the Design of Benchmark with Algorithm in Landscape-Aware Solver Design
Johann Dreo, Carola Doerr, Yann Semet

GBEA — Game-Benchmark for Evolutionary Algorithms

Organizers: Pascal Kerschke (University of Münster); Boris Naujoks (TH Köln - University of Applied Sciences); Tea Tusar (Jozef Stefan Institute); Vanessa Volz (Queen Mary University of London)

Time and Location: Sunday, July 14, 16:10-18:00, South Hall 1A (1F)

Game Benchmark for Evolutionary Algorithms: An Overview
Vanessa Volz, Tea Tusar, Boris Naujoks, Pascal Kerschke

Game AI Hyperparameter Tuning in Rinascimento
Ivan Bravi, Vanessa Volz, Simon Lucas

Panel: How can EC and games researchers learn from game benchmarking results?
Dimo Brockhoff, Jonathan Fieldsend, Mike Preuss, Simon Lucas

General discussion on (real-world) benchmarking
Vanessa Volz, Tea Tusar, Pascal Kerschke, Boris Naujoks

MedGEC — Medical Applications of Genetic and Evolutionary Computation

Organizers: Stefano Cagnoni (University of Parma); Robert M. Patton (Oak Ridge National Laboratory); Stephen L. Smith (University of York)

Time and Location: Sunday, July 14, 16:10-18:00, Club A (1F)

A New Evolutionary Rough Fuzzy Integrated Machine Learning Technique for microRNA selection using Next-Generation Sequencing data of Breast Cancer

Jnanendra Prasad Sarkar, Indrajit Saha, Somnath Rakshit, Monalisa Pal, Michal Wlasnowolski, Anasua Sarkar, Ujjwal Maulik, Dariusz Plewczynski

Semantic Learning Machine Improves the CNN-Based Detection of Prostate Cancer in Non-Contrast-Enhanced MRI

Paulo Lapa, Ivo Gonçalves, Leonardo Rundo, Mauro Castelli

Can Clustering Improve Glucose Forecasting with Genetic Programming Models?

Sergio Contador, J. Ignacio Hidalgo, Oscar Garnica, J. Manuel Velasco, Juan Lanchares

Application of Classification for Figure Copying Test in Parkinson's Disease Diagnosis by Using Cartesian Genetic Programming

Tian Xia, Jeremy Cosgrove, Jane Alty, Stuart Jamieson, Stephen Smith

Women@GECCO

Organizers: Elizabeth Wanner (Aston University); Christine Zarges (Aberystwyth University)

Time and Location: Sunday, July 14, 18:00-20:00, South Hall 1B (1F)

Women@GECCO meets pub quiz

Learning in complex environments
Raia Hadsell, *Google DeepMind*

Planning & scheduling for your life
Hana Rudová, *Masaryk University*

Towards a set of heuristics for approaching the academic career: Ideas from Patagonia, Go, Algorithm Configuration, and Academy
Leslie Pérez Cáceres, *Pontificia Universidad Católica de Valparaíso*

Open discussion

Humies, Competitions, Evolutionary Computation in Practice, Hot off the Press, and Job Market

16th Annual Humies Awards for Human Competitive Results

Presentations: Monday, July 15, 14:00-15:40
South Hall 1B (1F)

Announcement of Awards: Wednesday, July 17, 12:00-13:50
Forum Hall (2F)

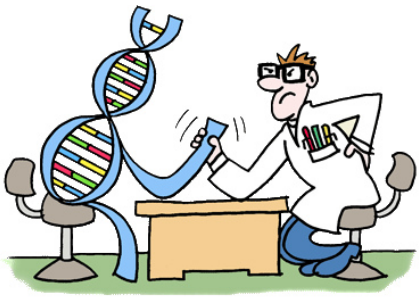
On-location chair: Erik D. Goodman

Judging Panel: Erik D. Goodman, Una-May O'Reilly, Wolfgang Banzhaf, Darrell D. Whitley, Lee Spector

Publicity Chair: William Langdon

Prizes: prizes totaling $10,000 to be awarded

Detailed Information: *www.human-competitive.org*



Techniques of genetic and evolutionary computation are being increasingly applied to difficult real-world problems — often yielding results that are not merely academically interesting, but competitive with the work done by creative and inventive humans. Starting at the *Genetic and Evolutionary Computation Conference* (GECCO) in 2004, cash prizes have been awarded for human competitive results that had been produced by some form of genetic and evolutionary computation in the previous year.

The total prize money for the Humies awards is $10,000 US dollars. As a result of detailed consideration of the entries in this year's Humies competition, the selected finalists will each be invited to give a short presentation to the Humies judges at GECCO. Each presentation will be 10 minutes. This presentation session is open to all GECCO attendees. After the session the judges will confer and select winners for Bronze (either one prize of $2,000 or two prizes of $1,000) Silver ($3,000) and Gold ($5,000) awards. The awards will be announced and presented to their winners during the GECCO closing ceremony on Wednesday.

Competitions

Competition on Niching Methods for Multimodal Optimization

Organizers: Mike Preuss, Michael Epitropakis, Xiaodong Li, Andries Engelbrecht

Time and Location: Sunday, July 14, 14:05-14:30, Club D (1F)

The aim of the competition is to provide a common platform that encourages fair and easy comparisons across different niching algorithms. The competition allows participants to run their own niching algorithms on 20 benchmark multimodal functions with different characteristics and levels of difficulty.

Evolutionary Computation in Uncertain Environments: A Smart Grid Application

Organizers: Fernando Lezama, Joao Soares, Zita Vale, José Rueda Torres

Time and Location: Sunday, July 14, 14:30-14:55, Club D (1F)

This competition proposes the optimization of a centralized day-ahead energy resource management problem in smart grids under environments with uncertainty. This year we increased the difficulty by proving a more challenging case study, namely with higher degree of uncertainty. The GECCO 2019 competition on "Evolutionary Computation in Uncertain Environments: A Smart Grid Application" has the purpose of bringing together and testing the more advanced Computational Intelligence (CI) techniques applied to an energy domain problem, namely the energy resource management problem under uncertain environments. The competition provides a coherent framework where participants and practitioners of CI can test their algorithms to solve a real-world optimization problem in the energy domain with uncertainty consideration, which makes the problem more challenging and worth to explore.

Internet of Things: Online Anomaly Detection for Drinking Water Quality

Organizers: Frederik Rehbach, Margarita Rebolledo, Steffen Moritz, Sowmya Chandrasekaran, Thomas Bartz-Beielstein

Time and Location: Sunday, July 14, 14:55-15:20, Club D (1F)

For the 8th time in GECCO history, the SPOTSeven Lab is hosting an industrial challenge in cooperation with various industry partners. This year's challenge, based on the 2018 challenge, is held in cooperation with "Thüringer Fernwasserversorgung" that provides their real-world data set. The task of this years competition is to develop an anomaly detection algorithm for the water- and environmental data set. Early identification of anomalies in water quality data is a challenging task. It is important to identify true undesirable variations in the water quality. At the same time, false alarm rates have to be very low.

Virtual Creatures Competition

Organizers: Sam Kriegman, Nick Cheney, Sebastian Risi, Joel Lehman

Time and Location: Sunday, July 14, 15:20-15:45, Club D (1F)

The Virtual Creatures Competition will be held in the competition session at the Genetic and Evolutionary Computation Conference. The contest's purpose is to highlight progress in virtual creatures research and showcase evolutionary computation's ability to craft interesting well-adapted creatures with evolved morphologies and controllers. Video entries demonstrating evolved virtual creatures are judged by technical achievement, aesthetic appeal, innovation, and perceptual animacy (perceived aliveness).

100-Digit Challenge, and Four Other Numerical Optimization Competitions

Organizers: Kenneth Price, Noor Awad, Mostafa Ali, Kalyanmoy Deb, Ponnuthurai Suganthan

Time and Location: Sunday, July 14, 16:10-16:35, Club D (1F)

Research on single objective optimization algorithms often forms the foundation for more complex methods, such as niching algorithms and both multi-objective and constrained optimization algorithms. Traditionally, single objective benchmark problems are also the first test for new evolutionary and swarm algorithms. Additionally, single objective benchmark problems can be transformed into dynamic, niching composition, computationally expensive and many other classes of problems. It is with the goal of better understanding the behavior of evolutionary algorithms as single objective optimizers that we are introducing the 100-Digit Challenge.
The original SIAM 100-Digit Challenge was developed in 2002 by Oxford's Nick Trefethen in conjunction with the Society for Industrial and Applied Mathematics (SIAM) as a test for high-accuracy computing. Specifically, the challenge was to solve 10 hard problems to 10 digits of accuracy. One point was awarded for each correct digit, making the maximum score 100, hence the name. Contestants were allowed to apply any method to any problem and take as long as needed to solve it. Out of the 94 teams that entered, 20 scored 100 points and 5 others scored 99. Like the SIAM version, our competition has 10 problems, which in our case are 10 functions to optimize, and the goal is to compute each function's minimum value to 10 digits of accuracy without being limited by time. In contrast to the SIAM version, however, our 100-Digit Challenge asks contestants to solve all ten problems with one algorithm, although limited control parameter "tuning" for each function will be permitted to restore some of the original contest's flexibility. Another difference is that the score for a given function is the average number of correct digits in the best 25 out of 50 trials (still a maximum of 10 points per function).

AI Competition for the Legends of the Three Kingdoms Game

Organizers: Xingguo Chen, Duofeng Wu, Binghui Xie

Time and Location: Sunday, July 14, 16:35-17:00, Club D (1F)

LTK (Legends of the Three Kingdoms) is a popular board game worldwide. Its online version was first developed in 2008. Since then, there have been many versions, including PC, Mac, Android, iOS. There exceeds 64.9 million downloads for mobile versions. In previous competitions, including Simulated Car Racing Championship (GECCO 2015), MicroRTS AI Competition (GECCO 2017), World Computer Chess Championships (IJCAI 2018), the relationships of competition or cooperation between the players are deterministic. The LTK game is a multi-agent, incomplete information game. Of particular interest is that players in LTK should learn the dynamics of competition and/or cooperation. This is a key feature we think for AI in multi-agent systems. In this competition, we offer a programming-language-free competition system, where agent receive and send data according to the JSON format. Thus, competition teams can develop AI algorithms via any programming language with a JSON parser support.

Bi-Objective Optimisation for the Travelling Thief Problem

Organizers: Julian Blank, Markus Wagner

Time and Location: Sunday, July 14, 17:00-17:25, Club D (1F)

Real-world optimization problems often consist of several NP-hard combinatorial optimization problems that interact with each other. Such multi-component optimization problems are difficult to solve not only because of the contained hard optimization problems, but in particular, because of the interdependencies between the different components. Interdependence complicates a decision making by forcing each sub-problem to influence the quality and feasibility of solutions of the other sub-problems. This influence might be even stronger when one sub-problem changes the data used by another one through a solution construction process. Examples of multi-component problems are vehicle routing problems under loading constraints, the maximizing material utilization while respecting a production schedule, and the relocation of containers in a port while minimizing idle times of ships.

The goal of this competition is to provide a platform for researchers in computational intelligence working on multi-component optimization problems. The main focus of this competition is on the combination of TSP and Knapsack problems. However, we plan to extend this competition format to more complex combinations of problems (that have typically been dealt with individually in the past decades) in the upcoming years.

Black Box Optimization Competition (BBComp)

Organizers: Tobias Glasmachers

Time and Location: Sunday, July 14, 17:25-17:50, Club D (1F)

The Black Box Optimization Competition is the first competition platform in the continuous domain where test problems are truly black boxes to participants. The only information known to optimizer and participant is the dimension of the problem, bounds on all variables, and a budget of black box queries. The competition covers single- and multi-objective optimization.

Evolutionary Computation in Practice

Organizers: Thomas Bartz-Beielstein, *Institute for Data Science, Engineering, and Analytics, TH Köln*
Bogdan Filipic, *Jozef Stefan Institute*
Jörg Stork, *Institute for Data Science, Engineering, and Analytics, TH Köln*
Erik Goodman, *BEACON Center for the Study of Evolution in Action, Michigan State University*

In the Evolutionary Computation in Practice (ECiP) track, well-known speakers with outstanding reputation in academia and industry present background and insider information on how to establish reliable cooperation with industrial partners. They actually run companies or are involved in cooperations between academia and industry. If you attend, you will learn multiple ways to extend EC practice beyond the approaches found in textbooks. Experts in real-world optimization with decades of experience share their approaches to creating successful projects for real-world clients. Some of what they do is based on sound project management principles, and some is specific to our type of optimization projects. A panel of experts describes a range of techniques you can use to identify, design, manage, and successfully complete an EA project for a client. If you are working in academia and are interested in managing industrial projects, you will receive valuable hints for your own research projects.

Session 1: Bridging the Gap between Academia and Industry Monday, July 15, 10:40-12:20, Club B (1F)

Chair: Bogdan Filipic, *Jozef Stefan Institute*

The Chameleon Researcher: Succeeding in Academia and Industry
Emma Hart, *Nature-Inspired Intelligent Systems Group, Edinburgh Napier University*

Gaining Insights from Optimising Wave Energy Converters
Markus Wagner, *School of Computer Science, University of Adelaide*

Publishing Your Research Work
Ronan Nugent, *Springer*

Session 2: "Real" Real-World Optimization Monday, July 15, 14:00-15:40, Club B (1F)

Chair: Jörg Stork, *Institute for Data Science, Engineering, and Analytics, TH Köln*

Easy to Use and Efficient Optimization Tools in Industrial Engineering: A Strong Market Requirement
Carlos Kavka, *ESTECO SpA*

From Laboratory Development to Steelmaking Facility Scheduling: Defeating Skepticism
Silvino Fernández Alzueta, *Global R&D Division, ArcelorMittal*

Interpretable Control for Industrial Systems by Genetic Programming
Daniel Hein, *Siemens Corporate Technology*

Session 3: Ask the Experts / Getting a Job Monday, July 15, 16:10-17:50, Club B (1F)

Chair: Erik D. Goodman, *BEACON Center for the Study of Evolution in Action, Michigan State University*

On Evolutionary Algorithms for Industrial Optimization
Thomas Bäck, *Leiden Institute of Advanced Computer Science, Leiden University*

Evolutionary Computation Based Methods as Enabling Technologies for Prescriptive Analytics
Michael Affenzeller, *Heuristic and Evolutionary Algorithms Lab, University of Applied Sciences Upper Austria*

Panel Discussion

Hot off the Press

Organizer: Julia Handl, *University of Manchester*

Time and Location:
– **HOP1**: Tuesday, July 16, 10:40-12:20, Club B (1F)
– **HOP2**: Tuesday, July 16, 14:00-15:40, Club B (1F)
– **HOP3**: Tuesday, July 16, 16:10-17:50, Club B (1F)
– **HOP4**: Wednesday, July 17, 09:00-10:40, Club B (1F)

The HOP (Hot Off the Press) track offers authors of recent papers the opportunity to present their work to the GECCO community, both by giving a talk on one of the three main days of the conference and by having a 2-page abstract appear in the Proceedings Companion, in which also the workshop papers, late-breaking abstracts, and tutorials appear. We invite researchers to submit summaries of their own work recently published in top-tier conferences and journals. Contributions are selected based on their scientific quality and their relevance to the GECCO community. Typical contributions include (but are not limited to) evolutionary computation papers appeared at venues different from GECCO, papers comparing different heuristics and optimization methods that appeared at a general heuristics or optimization venue, papers describing applications of evolutionary methods that appeared at venues of this application domain, or papers describing methods with relevance to the GECCO community that appeared at a venue centered around this methods domain. In any case, it is the authors responsibility to make clear why this work is relevant for the GECCO community, and to present the results in a language accessible to the GECCO community.

Job Market

Organizers: Boris Naujoks, *TH Köln - Cologne University of Applied Sciences*
Tea Tušar, *Jozef Stefan Institute*

Time and Location: Monday, July 15, 12:20-13:00, South Hall 1A (1F)

At the GECCO Job Market people offering jobs in Evolutionary Computation can advertise open positions and meet with potential candidates. Any kind of positions are of interest (PhD, Postdoc, Professor, Engineer, etc.) — from academia as well as industry. After brief presentations of the available jobs participants have the possibility to set up face-to-face meetings for further discussions.

The collection of positions on offer can be found at the SIGEVO web site:
`https://sig.sigevo.org/index.html/tiki-index.php?page=Job+Ads+Listing`

Research funding opportunities in the EU: FET and ERC

Organizers: Antonio Loredan, *Future and Emerging Technologies (FET), European Commission*
Endika Bengoetxea, *European Research Council (ERC), European Commission*

Time and Location: Saturday, July 13, 18:00-20:00, Club A (1F)

This session will present two EU programmes that offer funding opportunities for researchers, some of which are also available for non-EU nationals.

Firstly, 2019 FET-related funding opportunities will be introduced, both from FET-Open and FET-Proactive and within the new European Innovation Council (EIC) pilot. Secondly, the ERC and its calls for research grants will be presented.

In both presentation there will also be a FET and ERC research grantee explaining their experience and advising on the FET and ERC programs respectively.

The European Research Council (ERC) is a public body of the European Union which offers funding for research. Top researchers from any scientific or technological domain and from all over the world, i.e., also outside the European union) are eligible for funding. See `https://erc.europa.eu/` for more details.

Best Paper Nominations

Voting Instructions

Beware: Each GECCO attendee has only one vote and can only vote for a single best paper session. The best paper session for which to vote can be decided after attending several best paper sessions (see below).

Procedure: Each track has nominated one or more papers for a best paper award (see the list below). There will be one award per "Best Paper" session. Papers competing for the same award are presented in the same "Best Paper" session (see the schedule of sessions). Nominees from small tracks are grouped together into the same session. The votes are nominative and cannot be delegated to another attendee.

To be allowed to vote, a GECCO attendee must:

1. Collect their nominative voting voucher distributed with the registration material at the registration desk;
2. Attend the corresponding "Best Paper" session and collect the voting ballot that will be distributed to the audience by the session chair;
3. Complete the voting ballot with their choice for best paper award;
4. Hand the ballot together with their nominative voting voucher, either to the session chair at the end of the session or to the registration desk during opening hours (before 18:15 on *Tuesday, July 16*). The voucher will be verified against the badge of the voter.

Best Paper Nominations

Complex Systems (CS)

POET: Open-Ended Coevolution of Environments and their Optimized Solutions
Rui Wang, Joel Lehman, Jeff Clune, Kenneth O. Stanley
Tuesday, July 16, 14:00-14:25
South Hall 1A (1F)

Digital Entertainment Technologies and Arts (DETA)

Evolving Dota 2 Shadow Fiend Bots using Genetic Programming with External Memory
Robert Jacob Smith, Malcolm I. Heywood
Tuesday, July 16, 10:40-11:05
South Hall 1B (1F)

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

A generic approach to districting with diameter or center-based objectives
Alex Gliesch, Marcus Ritt
Tuesday, July 16, 16:10-16:35
South Hall 1B (1F)

Algorithm Selection Using Deep Learning Without Feature Extraction
Mohamad Alissa, Kevin Sim, Emma Hart
Tuesday, July 16, 16:35-17:00
South Hall 1B (1F)

Adaptive Large Neighborhood Search for Scheduling of Mobile Robots
Quang-Vinh Dang, Hana Rudová, Cong Thanh Nguyen
Tuesday, July 16, 17:00-17:25
South Hall 1B (1F)

Evolutionary Machine Learning (EML)

Evolving Controllably Difficult Datasets for Clustering
Cameron Shand, Richard Allmendinger, Julia Handl, Andrew Webb, John Keane
Monday, July 15, 10:40-11:05
South Hall 1B (1F)

NSGA-Net: Neural Architecture Search using Multi-Objective Genetic Algorithm
Zhichao Lu, Ian Whalen, Vishnu Boddeti, Yashesh Dhebar, Kalyanmoy Deb, Erik Goodman, Wolfgang Banzhaf
Monday, July 15, 11:05-11:30
South Hall 1B (1F)

Evolutionary Multiobjective Optimization (EMO)

Challenges of Convex Quadratic Bi-objective Benchmark Problems
Tobias Glasmachers
Monday, July 15, 14:00-14:25
South Hall 1A (1F)

Robust indicator-based algorithm for interactive evolutionary multiple objective optimization
Michał Tomczyk, Miłosz Kadziński
Monday, July 15, 14:25-14:50
South Hall 1A (1F)

Evolutionary Numerical Optimization (ENUM)

A Global Surrogate Assisted CMA-ES
Nikolaus Hansen
Tuesday, July 16, 14:00-14:25
South Hall 1B (1F)

Adaptive Ranking Based Constraint Handling for Explicitly Constrained Black-Box Optimization
Naoki Sakamoto, Youhei Akimoto
Tuesday, July 16, 14:25-14:50
South Hall 1B (1F)

Landscape Analysis of Gaussian Process Surrogates for the Covariance Matrix Adaptation Evolution Strategy
Zbyněk Pitra, Jakub Repický, Martin Holeňa
Tuesday, July 16, 14:50-15:15
South Hall 1B (1F)

Genetic Algorithms (GA)

A Benefit-Driven Genetic Algorithm for Balancing Privacy and Utility in Database Fragmentation
Yong-Feng Ge, Jinli Cao, Hua Wang, Jiao Yin, Wei-Jie Yu, Zhi-Hui Zhan, Jun Zhang
Monday, July 15, 16:10-16:35
South Hall 1A (1F)

Multi-heap Constraint Handling in Gray Box Evolutionary Algorithms
Thiago Macedo Gomes, Alan Robert Resende de Freitas, Rodolfo Ayala Lopes
Monday, July 15, 16:35-17:00
South Hall 1A (1F)

Evolutionary Diversity Optimization Using Multi-Objective Indicators
Aneta Neumann, Wanru Gao, Markus Wagner, Frank Neumann
Monday, July 15, 17:00-17:25
South Hall 1A (1F)

General Evolutionary Computation and Hybrids (GECH)

Surrogate Models for Enhancing the Efficiency of Neuroevolution in Reinforcement Learning
Jörg Stork, Martin Zaefferer, Thomas Bartz-Beielstein, A. E. Eiben
Tuesday, July 16, 14:25-14:50
South Hall 1A (1F)

Genetic Programming (GP)

Solving Symbolic Regression Problems with Formal Constraints
Iwo Błądek, Krzysztof Krawiec
Monday, July 15, 16:10-16:35
South Hall 1B (1F)

Semantic variation operators for multidimensional genetic programming
William La Cava, Jason H. Moore
Monday, July 15, 16:35-17:00
South Hall 1B (1F)

Lexicase Selection of Specialists
Thomas Helmuth, Edward Pantridge, Lee Spector
Monday, July 15, 17:00-17:25
South Hall 1B (1F)

Real World Applications (RWA)

A Hybrid Evolutionary Algorithm Framework for Optimising Power Take Off and Placements of Wave Energy Converters
Mehdi Neshat, Bradley Alexander, Nataliia Sergiienko, Markus Wagner
Tuesday, July 16, 10:40-11:05
South Hall 1A (1F)

A Novel Hybrid Scheme Using Genetic Algorithms and Deep Learning for the Reconstruction of Portuguese Tile Panels
Daniel Rika, Dror Sholomon, Eli O. David, Nathan S. Netanyahu
Tuesday, July 16, 11:05-11:30
South Hall 1A (1F)

Multiobjective Shape Design in a Ventilation System with a Preference-driven Surrogate-assisted Evolutionary Algorithm
Tinkle Chugh, Tomas Kratky, Kaisa Miettinen, Yaochu Jin, Pekka Makkonen
Tuesday, July 16, 11:30-11:55
South Hall 1A (1F)

Search-Based Software Engineering (SBSE)

Resource-based Test Case Generation for RESTful Web Services
Man Zhang, Bogdan Marculescu, Andrea Arcuri
Tuesday, July 16, 11:30-11:55
South Hall 1B (1F)

Theory (THEORY)

A Tight Runtime Analysis for the cGA on Jump Functions - EDAs Can Cross Fitness Valleys at No Extra Cost
Benjamin Doerr
Tuesday, July 16, 11:05-11:30
South Hall 1B (1F)

Papers and Posters

ACO-SI1 Monday, July 15, 10:40-12:20, Club C (1F)

Chair: Christopher Cleghorn (University of Pretoria)

Control Parameter Sensitivity Analysis of the Multi-guide Particle Swarm Optimization Algorithm 10:40-11:05
Kyle Harper Erwin, Andries Engelbrecht

On the Selection of the Optimal Topology for Particle Swarm Optimization: A Study of the Tree as the Universal Topology 11:05-11:30
Ángel Arturo Rojas-García, Arturo Hernández-Aguirre, S. Ivvan Valdez

A Stable Hybrid method for Feature Subset Selection using Particle Swarm Optimization with Local Search 11:30-11:55
Hassen Dhrif, Luis G. Sanchez Giraldo, Miroslav Kubat, Stefan Wuchty

A Peek into the Swarm: Analysis of the Gravitational Search Algorithm and Recommendations for Parameter Selection 11:55-12:20
Florian Knauf, Ralf Bruns

CS1 Monday, July 15, 10:40-12:20, Club E (1F)

Chair: Sebastian Risi (IT University of Copenhagen)

Novelty Search: a Theoretical Perspective 10:40-11:05
Stéphane Doncieux, Alban Laflaquière, Alexandre Coninx

Benchmarking Open-Endedness in Minimal Criterion Coevolution 11:05-11:30
Jonathan C. Brant, Kenneth O. Stanley

Autonomous skill discovery with Quality-Diversity and Unsupervised Descriptors 11:30-11:55
Antoine Cully

Modeling User Selection in Quality Diversity 11:55-12:20
Alexander Hagg, Alexander Asteroth, Thomas Bäck

ECOM1 Monday, July 15, 10:40-12:20, Club D (1F)

Chair: Sebastien Verel (Université du Littoral Côte d'Opale)

When Resampling to Cope With Noise, Use Median, Not Mean 10:40-11:05
Benjamin Doerr, Andrew M. Sutton

Fast Re-Optimization via Structural Diversity 11:05-11:30
Benjamin Doerr, Carola Doerr, Frank Neumann

On Inversely Proportional Hypermutations with Mutation Potential 11:30-11:55
Dogan Corus, Pietro S. Oliveto, Donya Yazdani

Characterising the Rankings Produced by Combinatorial Optimisation Problems and Finding their Intersections 11:55-12:20
Leticia Hernando, Alexander Mendiburu, Jose Antonio Lozano

EML1: Best papers Monday, July 15, 10:40-12:20, South Hall 1B (1F)

Chair: Jean-Baptiste Mouret (Inria / CNRS / Univ. Lorraine)
(Best Paper nominees are marked with a star)

Evolving Controllably Difficult Datasets for Clustering ☆ 10:40-11:05
Cameron Shand, Richard Allmendinger, Julia Handl, Andrew Webb, John Keane

NSGA-Net: Neural Architecture Search using Multi-Objective Genetic Algorithm ☆ 11:05-11:30
Zhichao Lu, Ian Whalen, Vishnu Boddeti, Yashesh Dhebar, Kalyanmoy Deb, Erik Goodman, Wolfgang Banzhaf

Efficient Personalized Community Detection via Genetic Evolution 11:30-11:55
Zheng Gao, Chun Guo, Xiaozhong Liu

Population-based Ensemble Classifier Induction for Domain Adaptation 11:55-12:20
Bach Hoai Nguyen, Bing Xue, Mengjie Zhang, Peter Andreae

EMO1 Monday, July 15, 10:40-12:20, South Hall 1A (1F)

Chair: Arnaud Liefooghe (Univ. Lille, Inria Lille - Nord Europe)

A Parameterless Performance Metric for Reference-Point Based Multi-Objective Evolutionary Algorithms 10:40-11:05
Sunith Bandaru, Henrik Smedberg

Convergence and Diversity Analysis of Indicator-based Multi-Objective Evolutionary Algorithms 11:05-11:30
Jesus Guillermo Falcon-Cardona, Carlos Artemio Coello Coello

Efficient Real-Time Hypervolume Estimation with Monotonically Reducing Error 11:30-11:55
Jonathan Edward Fieldsend

Uncrowded Hypervolume Improvement: COMO-CMA-ES and the Sofomore framework 11:55-12:20
Cheikh Toure, Nikolaus Hansen, Anne Auger, Dimo Brockhoff

GP1 Monday, July 15, 10:40-12:20, Club A (1F)

Chair: Erik Hemberg (Massachusetts Institute of Technology)

On Domain Knowledge and Novelty to Improve Program Synthesis Performance with Grammatical Evolution 10:40-11:05
Erik Hemberg, Jonathan Kelly, Una-May O'Reilly

Comparing and Combining Lexicase Selection and Novelty Search 11:05-11:30
Lia Jundt, Thomas Helmuth

Teaching GP to Program Like a Human Software Developer: Using Perplexity Pressure to Guide Program Synthesis Approaches 11:30-11:55
Dominik Sobania, Franz Rothlauf

On the Role of Non-effective Code in Linear Genetic Programming 11:55-12:20
Léo Françoso Dal Piccol Sotto, Franz Rothlauf

RWA1 Monday, July 15, 10:40-12:20, Club H (1F)

Chair: Ekaterina Holdener (Saint Louis University)

ECOM2 Monday, July 15, 14:00-15:40, Club D (1F)

Chair: Gabriela Ochoa (University of Stirling)

Investigation of the Traveling Thief Problem 14:00-14:25
Rogier Hans Wuijts, Dirk Thierens

Predict or Screen Your Expensive Assay? DoE vs. Surrogates in Experimental Combinatorial Optimization 14:25-14:50
Naama Horesh, Thomas Bäck, Ofer M. Shir

Walsh Functions as Surrogate Model for Pseudo-Boolean Optimization Problems 14:50-15:15
Florian Leprêtre, Sébastien Verel, Cyril Fonlupt, Virginie Marion

EMO2: Best papers Monday, July 15, 14:00-15:40, South Hall 1A (1F)

Chair: Jonathan Edward Fieldsend (University of Exeter)
(Best Paper nominees are marked with a star)

Challenges of Convex Quadratic Bi-objective Benchmark Problems ☆ 14:00-14:25
Tobias Glasmachers

Robust indicator-based algorithm for interactive evolutionary multiple objective optimization ☆ 14:25-14:50
Michał Tomczyk, Miłosz Kadziński

Non-elitist Evolutionary Multi-objective Optimizers Revisited 14:50-15:15
Ryoji Tanabe, Hisao Ishibuchi

GP2 Monday, July 15, 14:00-15:40, Club A (1F)

Chair: Krzysztof Krawiec (Poznan University of Technology, Center for Artificial Intelligence and Machine Learning)

Linear Scaling with and within Semantic Backpropagation-based Genetic Programming for Symbolic Regression 14:00-14:25
Marco Virgolin, Tanja Alderliesten, Peter A. N. Bosman

Evolving Graphs with Horizontal Gene Transfer 14:25-14:50
Timothy Atkinson, Detlef Plump, Susan Stepney

Batch Tournament Selection for Genetic Programming: The quality of Lexicase, the speed of Tournament 14:50-15:15
Vinícius Veloso de Melo, Danilo V. Vargas, Wolfgang Banzhaf

Gin: Genetic Improvement Research Made Easy 15:15-15:40
Alexander Edward Ian Brownlee, Justyna Petke, Brad Alexander, Earl T. Barr, Markus Wagner, David Robert White

RWA2 Monday, July 15, 14:00-15:40, Club H (1F)

Chair: Diane P Fraser (University of Exeter)

Classification of EEG Signals using Genetic Programming for Feature Construction 14:00-14:25
Icaro Marcelino Miranda, Claus Aranha, Marcelo Ladeira

Structured Grammatical Evolution for Glucose Prediction in Diabetic Patients 14:25-14:50
Nuno Lourenço, J. Manuel Colmenar, J. Ignacio Hidalgo, Oscar Garnica

EMOCS: Evolutionary Multi-objective Optimisation for Clinical Scorecard Generation 14:50-15:15
Diane P. Fraser, Edward Keedwell, Stephen L. Michell, Ray Sheridan

Relative evolutionary hierarchical analysis for gene expression data classification 15:15-15:40
Marcin Czajkowski, Marek Kretowski

SBSE1 Monday, July 15, 14:00-15:40, Club E (1F)

Chair: Giuliano Antoniol (Ecole Polytechnique de Montreal)

Why Train-and-Select When You Can Use Them All: Ensemble Model for Fault Localisation 14:00-14:25
Jeongju Sohn, Shin Yoo

Improving Search-Based Software Testing by Constraint-Based Genetic Operators 14:25-14:50
Ziming Zhu, Li Jiao

SQL Data Generation to Enhance Search-Based System Testing 14:50-15:15
Andrea Arcuri, Juan Pablo Galeotti

Footprints of Fitness Functions in Search-Based Software Testing 15:15-15:40
Carlos Guimaraes, Aldeida Aleti, Yuan-Fang Li, Mohamed Abdelrazek

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THEORY1 Monday, July 15, 14:00-15:40, Club C (1F)

Chair: Frank Neumann (The University of Adelaide)

Runtime Analysis of the UMDA under Low Selective Pressure and Prior Noise 14:00-14:25
Per Kristian Lehre, Phan Trung Hai Nguyen

Runtime Analysis of Randomized Search Heuristics for Dynamic Graph Coloring 14:25-14:50
Jakob Bossek, Frank Neumann, Pan Peng, Dirk Sudholt

Self-Adjusting Mutation Rates with Provably Optimal Success Rules 14:50-15:15
Benjamin Doerr, Carola Doerr, Johannes Lengler

Improved Runtime Results for Simple Randomised Search Heuristics on Linear Functions with a Uniform Constraint 15:15-15:40
Frank Neumann, Mojgan Pourhassan, Carsten Witt

EML2 Monday, July 15, 16:10-17:50, Club E (1F)

Chair: Risto Miikkulainen (The University of Texas at Austin, University of Texas at Austin)

Evolutionary Neural AutoML for Deep Learning 16:10-16:35
Jason Liang, Elliot Meyerson, Risto Miikkulainen, Babak Hodjat, Dan Fink, Karl Mutch

Evolving Deep Neural Networks by Multi-objective Particle Swarm Optimization for Image Classification 16:35-17:00
Bin Wang, Yanan Sun, Bing Xue, Mengjie Zhang

Investigating Recurrent Neural Network Memory Structures using Neuro-Evolution 17:00-17:25
Alexander Ororbia, AbdElRahman ElSaid, Travis Desell

Deep Neuroevolution of Recurrent and Discrete World Models 17:25-17:50
Sebastian Risi, Kenneth O. Stanley

EMO3 Monday, July 15, 16:10-17:50, Club D (1F)

Chair: Tea Tusar (Jozef Stefan Institute)

Single- and Multi-Objective Game-Benchmark for Evolutionary Algorithms 16:10-16:35
Vanessa Volz, Boris Naujoks, Pascal Kerschke, Tea Tušar

Real-valued Evolutionary Multi-modal Multi-objective Optimization by Hill-valley Clustering 16:35-17:00
Stef C. Maree, Tanja Alderliesten, Peter A. N. Bosman

Surrogate-assisted Multi-objective Optimization based on Decomposition: A Comprehensive Comparative Analysis 17:00-17:25
Nicolas Berveglieri, Bilel Derbel, Arnaud Liefooghe, Hernán Aguirre, Kiyoshi Tanaka

Cooperative based Hyper-heuristic for Many-objective Optimization 17:25-17:50
Gian Fritsche, Aurora Pozo

ENUM1 Monday, July 15, 16:10-17:50, Club A (1F)

Chair: Dirk V. Arnold (Dalhousie University)

Analysis of a Meta-ES on a Conically Constrained Problem 16:10-16:35
Michael Hellwig, Hans-Georg Beyer

Large-Scale Noise-Resilient Evolution-Strategies 16:35-17:00
Oswin Krause

A Surrogate Model Assisted (1+1)-ES with Increased Exploitation of the Model 17:00-17:25
Jingyun Yang, Dirk V. Arnold

Deep Reinforcement Learning Based Parameter Control in Differential Evolution 17:25-17:50
Mudita Sharma, Alexandros Komninos, Manuel López-Ibáñez, Dimitar Kazakov

GA1: Best papers Monday, July 15, 16:10-17:50, South Hall 1A (1F)

Chair: Gabriela Ochoa (University of Stirling)
(Best Paper nominees are marked with a star)

A Benefit-Driven Genetic Algorithm for Balancing Privacy and Utility in Database Fragmentation ☆ 16:10-16:35
Yong-Feng Ge, Jinli Cao, Hua Wang, Jiao Yin, Wei-Jie Yu, Zhi-Hui Zhan, Jun Zhang

Multi-heap Constraint Handling in Gray Box Evolutionary Algorithms ☆ 16:35-17:00
Thiago Macedo Gomes, Alan Robert Resende de Freitas, Rodolfo Ayala Lopes

Evolutionary Diversity Optimization Using Multi-Objective Indicators ☆ 17:00-17:25
Aneta Neumann, Wanru Gao, Markus Wagner, Frank Neumann

On the investigation of population sizing of genetic algorithms using optimal mixing 17:25-17:50
Yi-Yun Liao, Hung-Wei Hsu, Yi-Lin Juang, Tian-Li Yu

GECH1 Monday, July 15, 16:10-17:50, Club C (1F)

Chair: Yaochu Jin (University of Surrey)

Adaptive Simulator Selection for Multi-Fidelity Optimization 16:10-16:35
Youhei Akimoto, Takuma Shimizu, Takahiro Yamaguchi

Surrogates for Hierarchical Search Spaces: The Wedge-Kernel and an Automated Analysis 16:35-17:00
Daniel Horn, Jörg Stork, Nils-Jannik Schüßler, Martin Zaefferer

Algorithm Portfolio for Individual-based Surrogate-Assisted Evolutionary Algorithms 17:00-17:25
Hao Tong, Jialin Liu, Xin Yao

GP3: Best papers Monday, July 15, 16:10-17:50, South Hall 1B (1F)

Chair: Miguel Nicolau (University College Dublin)
(Best Paper nominees are marked with a star)

Solving Symbolic Regression Problems with Formal Constraints ☆ 16:10-16:35
Iwo Błądek, Krzysztof Krawiec

Semantic variation operators for multidimensional genetic programming ☆ 16:35-17:00
William La Cava, Jason H. Moore

Lexicase Selection of Specialists ☆ 17:00-17:25
Thomas Helmuth, Edward Pantridge, Lee Spector

RWA3 Monday, July 15, 16:10-17:50, Club H (1F)

Chair: Carola Doerr (CNRS, Sorbonne University)

Using a Genetic Algorithm with Histogram-Based Feature Selection in Hyperspectral Image Classification 16:10-16:35
Neil S. Walton, John W. Sheppard, Joseph A. Shaw

ACO-SI2 Tuesday, July 16, 10:40-12:20, Club C (1F)

Chair: Andries P. Engelbrecht (Stellenbosch University)

Simultaneous Meta-Data and Meta-Classifier Selection in Multiple Classifier System 10:40-11:05
Thanh Tien Nguyen, Vu Anh Luong, Van Thi Minh Nguyen, Sy Trong Ha, Alan Wee Chung Liew, John McCall

Scaling Techniques for Parallel Ant Colony Optimization on Large Problem Instances 11:05-11:30
Joshua Peake, Martyn Amos, Paraskevas Yiapanis, Huw Lloyd

AMclr - An Improved Ant-Miner to Extract Comprehensible and Diverse Classification Rules 11:30-11:55
Umair Ayub, Asim Ikram, Waseem Shahzad

CS2 Tuesday, July 16, 10:40-12:20, Club E (1F)

Chair: Nicolas Bredeche (Sorbonne Université, CNRS)

When Mating Improves On-line Collective robotics 10:40-11:05
Amine Boumaza

Evolved embodied phase coordination enables robust quadruped robot locomotion 11:05-11:30
Jørgen Halvorsen Nordmoen, Tønnes Frostad Nygaard, Kai Olav Ellefsen, Kyrre Glette

Evolvability ES: Scalable and Direct Optimization of Evolvability 11:30-11:55
Alexander Gajewski, Jeff Clune, Kenneth O. Stanley, Joel Lehman

Effects of environmental conditions on evolved robot morphologies and behavior 11:55-12:20
Karine Miras, A.E. Eiben

DETA1+SBSE2+THEORY2: Best papers Tuesday, July 16, 10:40-12:20, South Hall 1B (1F)

Chair: Giuliano Antoniol (Ecole Polytechnique de Montreal); Johannes Lengler (ETH Zürich); Vanessa Volz (Queen Mary University of London)
(Best Paper nominees are marked with a star)

Evolving Dota 2 Shadow Fiend Bots using Genetic Programming with External Memory ☆ 10:40-11:05
Robert Jacob Smith, Malcolm I. Heywood

A Tight Runtime Analysis for the cGA on Jump Functions - EDAs Can Cross Fitness Valleys at No Extra Cost ☆ 11:05-11:30
Benjamin Doerr

Resource-based Test Case Generation for RESTful Web Services ☆ 11:30-11:55
Man Zhang, Bogdan Marculescu, Andrea Arcuri

A Hybrid Evolutionary System for Automatic Software Repair 11:55-12:20
Yuan Yuan, Wolfgang Banzhaf

ECOM3 Tuesday, July 16, 10:40-12:20, Club D (1F)

Chair: Emma Hart (Edinburgh Napier University)

A Two-stage Genetic Programming Hyper-heuristic Approach with Feature Selection for Dynamic Flexible Job Shop Scheduling 10:40-11:05
Fangfang Zhang, Yi Mei, Mengjie Zhang

Application of CMSA to the Minimum Capacitated Dominating Set Problem 11:05-11:30
Pedro Pinacho-Davidson, Salim Bouamama, Christian Blum

An Improved Merge Search Algorithm For the Constrained Pit Problem in Open-pit Mining 11:30-11:55
Angus Kenny, Xiaodong Li, Andreas Ernst, Yuan Sun

Evolutionary Algorithms for the Chance-Constrained Knapsack Problem 11:55-12:20
Yue Xie, Oscar Harper, Hirad Assimi, Aneta Neumann, Frank Neumann

GA2 Tuesday, July 16, 10:40-12:20, Club A (1F)

Chair: Peter Bosman (Centrum Wiskunde & Informatica (CWI))

Parallelism and Partitioning in Large-Scale GAs using Spark 10:40-11:05
Laila Alterkawi, Matteo Migliavacca

The Massively Parallel Mixing Genetic Algorithm for the Traveling Salesman Problem 11:05-11:30
Swetha Varadarajan, Darrell Whitley

A Genetic Algorithm Hybridisation Scheme for Effective Use of Parallel Workers 11:30-11:55
Simon Bowly

Convolutional Neural Network Surrogate-Assisted GOMEA 11:55-12:20
Arkadiy Dushatskiy, Adriënne M. Mendrik, Tanja Alderliesten, Peter A. N. Bosman

GECH2 Tuesday, July 16, 10:40-12:20, Club H (1F)

Chair: Leslie Pérez Cáceres (Pontificia Universidad Católica de Valparaíso)

On the Impact of the Cutoff Time on the Performance of Algorithm Configurators 10:40-11:05
George T. Hall, Pietro S. Oliveto, Dirk Sudholt

Hyper-Parameter Tuning for the $(1+(\lambda,\lambda))$ **GA** 11:05-11:30
Nguyen Dang, Carola Doerr

Meta-learning on Flowshop using Fitness Landscape Analysis 11:30-11:55
Lucas Marcondes Pavelski, Myriam Regattieri Delgado, Marie-Éléonore Kessaci

HOP1 Tuesday, July 16, 10:40-12:20, Club B (1F)

Chair: Daniel Hein (Siemens AG, Munich; Technical University of Munich)

Generating Interpretable Reinforcement Learning Policies using Genetic Programming 10:40-11:05
Daniel Hein, Steffen Udluft, Thomas A. Runkler

Discovering Test Statistics Using Genetic Programming 11:05-11:30
Jason H. Moore, Randal S. Olson, Yong Chen, Moshe Sipper

Stochastic Program Synthesis via Recursion Schemes 11:30-11:55
Jerry Swan, Krzysztof Krawiec, Zoltan A. Kocsis

EBIC: a scalable biclustering method for large scale data analysis 11:55-12:20
Patryk Orzechowski, Jason H. Moore

RWA4: Best papers Tuesday, July 16, 10:40-12:20, South Hall 1A (1F)

Chair: Thomas Bäck (Leiden University); Robin Purshouse (University of Sheffield)
(Best Paper nominees are marked with a star)

A Hybrid Evolutionary Algorithm Framework for Optimising Power Take Off and Placements of Wave Energy Converters ☆ 10:40-11:05
Mehdi Neshat, Bradley Alexander, Nataliia Sergiienko, Markus Wagner

A Novel Hybrid Scheme Using Genetic Algorithms and Deep Learning for the Reconstruction of Portuguese Tile Panels ☆ 11:05-11:30
Daniel Rika, Dror Sholomon, Eli O. David, Nathan S. Netanyahu

Multiobjective Shape Design in a Ventilation System with a Preference-driven Surrogate-assisted Evolutionary Algorithm ☆ 11:30-11:55
Tinkle Chugh, Tomas Kratky, Kaisa Miettinen, Yaochu Jin, Pekka Makkonen

CS3+GECH3: Best papers Tuesday, July 16, 14:00-15:40, South Hall 1A (1F)

Chair: Stephane Doncieux (Sorbonne University, CNRS)
(Best Paper nominees are marked with a star)

POET: Open-Ended Coevolution of Environments and their Optimized Solutions ☆ 14:00-14:25
Rui Wang, Joel Lehman, Jeff Clune, Kenneth O. Stanley

Surrogate Models for Enhancing the Efficiency of Neuroevolution in Reinforcement Learning ☆ 14:25-14:50
Jörg Stork, Martin Zaefferer, Thomas Bartz-Beielstein, A. E. Eiben

Learning with Delayed Synaptic Plasticity 14:50-15:15
Anil Yaman, Giovanni Iacca, Decebal Constantin Mocanu, George Fletcher, Mykola Pechenizkiy

Selection mechanisms affect volatility in evolving markets 15:15-15:40
David Rushing Dewhurst, Michael V. Arnold, Colin M. Van Oort

ECOM4 Tuesday, July 16, 14:00-15:40, Club D (1F)

Chair: Darrell Whitley (Colorado State University)

Route Planning for Cooperative Air-Ground Robots with Fuel Constraints: An Approach based on CMSA 14:00-14:25
Divansh Arora, Parikshit Maini, Pedro Pinacho-Davidson, Christian Blum

A Memetic Algorithm Approach to Network Alignment : Mapping the Classification of Mental Disorders of DSM-IV with ICD-10 14:25-14:50
Mohammad Nazmul Haque, Luke Mathieson, Pablo Moscato

Fitness Comparison by Statistical Testing in Construction of SAT-Based Guess-and-Determine Cryptographic Attacks 14:50-15:15
Artem Pavlenko, Maxim Buzdalov, Vladimir Ulyantsev

A characterisation of S-box fitness landscape in cryptography 15:15-15:40
Domagoj Jakobovic, Stjepan Picek, Marcella Ribeiro, Markus Wagner

EML3 Tuesday, July 16, 14:00-15:40, Club E (1F)

Chair: Mengjie Zhang (Victoria University of Wellington)

Absumption to Complement Subsumption in Learning Classifier Systems 14:00-14:25
Yi Liu, Will N. Browne, Bing Xue

Improvement of Code Fragment Fitness to Guide Feature Construction in XCS 14:25-14:50
Trung Bao Nguyen, Will Neil Browne, Mengjie Zhang

Lexicase Selection in Learning Classifier Systems 14:50-15:15
Sneha Aenugu, Lee Spector

Auto-CVE: A coevolutionary approach to evolve ensembles in Automated Machine Learning 15:15-15:40
Celio Henrique Nogueira Larcher Junior, Helio J.C. Barbosa

ENUM2: Best papers Tuesday, July 16, 14:00-15:40, South Hall 1B (1F)

Chair: Jose A. Lozano (University of the Basque Country, Basque Center for Applied Mathematics)
(Best Paper nominees are marked with a star)

A Global Surrogate Assisted CMA-ES ☆ 14:00-14:25
Nikolaus Hansen

Adaptive Ranking Based Constraint Handling for Explicitly Constrained Black-Box Optimization ☆ 14:25-14:50
Naoki Sakamoto, Youhei Akimoto

Landscape Analysis of Gaussian Process Surrogates for the Covariance Matrix Adaptation Evolution Strategy ☆ 14:50-15:15
Zbyněk Pitra, Jakub Repický, Martin Holeňa

Mixed-Integer Benchmark Problems for Single- and Bi-Objective Optimization 15:15-15:40
Tea Tušar, Dimo Brockhoff, Nikolaus Hansen

GA3 Tuesday, July 16, 14:00-15:40, Club A (1F)

Chair: Francisco Chicano (University of Malaga)

Offspring Population Size Matters when Comparing Evolutionary Algorithms with Self-Adjusting Mutation Rates 14:00-14:25
Anna Rodionova, Kirill Antonov, Arina Buzdalova, Carola Doerr

Evolutionary Consequences of Learning Strategies in a Dynamic Rugged Landscape 14:25-14:50
Nam Le, Anthony Brabazon, Michael O'Neill

HOP2 Tuesday, July 16, 14:00-15:40, Club B (1F)

Chair: Krzysztof Michalak (University of Wroclaw)

Low-Dimensional Euclidean Embedding for Visualization of Search Spaces in Combinatorial Optimization 14:00-14:25
Krzysztof Michalak

A Suite of Computationally Expensive Shape Optimisation Problems Using Computational Fluid Dynamics 14:25-14:50
Steven Daniels, Alma Rahat, Richard Everson, Gavin Tabor, Jonathan Fieldsend

Understanding Exploration and Exploitation Powers of Meta-heuristic Stochastic Optimization Algorithms through Statistical Analysis 14:50-15:15
Tome Eftimov, Peter Korošec

The (1+1)-EA with mutation rate (1+eps)/n is efficient on monotone functions: an entropy compression argument 15:15-15:40
Johannes Lengler, Anders Martinsson, Angelika Steger

RWA5 Tuesday, July 16, 14:00-15:40, Club C (1F)

Chair: Paolo Arcaini (National Institute of Informatics)

Stability Analysis for Safety of Automotive Multi-Product Lines: A Search-Based Approach 14:00-14:25
Nian-Ze Lee, Paolo Arcaini, Shaukat Ali, Fuyuki Ishikawa

Optimizing Evolutionary CSG Tree Extraction 14:25-14:50
Markus Friedrich, Pierre-Alain Fayolle, Thomas Gabor, Claudia Linnhoff-Popien

Functional Generative Design of Mechanisms with Recurrent Neural Networks and Novelty Search 14:50-15:15
Cameron Ronald Wolfe, Cem C. Tutum, Risto Miikkulainen

RWA6 Tuesday, July 16, 14:00-15:40, Club H (1F)

Chair: Neil Urquhart (Edinburgh Napier University)

An Illumination Algorithm Approach to Solving the Micro-Depot Vehicle Routing Problem 14:00-14:25
Neil Urquhart, Silke höhl, Emma Hart

GA-Guided Task Planning for Multiple-HAPS in Realistic Time-Varying Operation Environments 14:25-14:50
Jane Jean Kiam, Eva Besada-Portas, Valerie Hehtke, Axel Schulte

Toward Real-World Vehicle Placement Optimization in Round-Trip Carsharing 14:50-15:15
Boonyarit Changaival, Grégoire Danoy, Dzmitry Kliazovich, Frédéric Guinand, Matthias Brust, Jedrzej Musial, Kittichai Lavangnananda, Pascal Bouvry

Optimising Bus Routes with Fixed Terminal Nodes: Comparing Hyper-heuristics with NSGAII on Realistic Transportation Networks 15:15-15:40
Leena Ahmed, Philipp Heyken, Christine Mumford, Yong Mao

ECOM5: Best papers Tuesday, July 16, 16:10-17:50, South Hall 1B (1F)

Chair: Francisco Chicano (University of Malaga)
(Best Paper nominees are marked with a star)

A generic approach to districting with diameter or center-based objectives ☆ 16:10-16:35
Alex Gliesch, Marcus Ritt

Algorithm Selection Using Deep Learning Without Feature Extraction ☆ 16:35-17:00
Mohamad Alissa, Kevin Sim, Emma Hart

Adaptive Large Neighborhood Search for Scheduling of Mobile Robots ☆ 17:00-17:25
Quang-Vinh Dang, Hana Rudová, Cong Thanh Nguyen

EML4 Tuesday, July 16, 16:10-17:50, Club E (1F)

Chair: Jeff Clune (University of Wyoming)

Adaptive Multi-Subswarm Optimisation for Feature Selection on High-Dimensional Classification 16:10-16:35
Binh Ngan Tran, Bing Xue, Mengjie Zhang

COEGAN: Evaluating the Coevolution Effect in Generative Adversarial Networks 16:35-17:00
Victor Franco Costa, Nuno Lourenço, João Correia, Penousal Machado

An Automated Ensemble Learning Framework Using Genetic Programming for Image Classification 17:00-17:25
Ying Bi, Bing Xue, Mengjie Zhang

Spatial Evolutionary Generative Adversarial Networks 17:25-17:50
Jamal Toutouh, Erik Hemberg, Una-May O'Reilly

EMO4 Tuesday, July 16, 16:10-17:50, South Hall 1A (1F)

Chair: Hisao Ishibuchi (Osaka Prefecture University, Osaka Prefecture Univeristy)

A Feature Rich Distance-Based Many-Objective Visualisable Test Problem Generator 16:10-16:35
Jonathan Edward Fieldsend, Tinkle Chugh, Richard Allmendinger, Kaisa Miettinen

Constrained Multiobjective Distance Minimization Problems 16:35-17:00
Yusuke Nojima, Takafumi Fukase, Yiping Liu, Naoki Masuyama, Hisao Ishibuchi

Archiver Effects on the Performance of State-of-the-art Multi- and Many-objective Evolutionary Algorithms 17:00-17:25
Leonardo César Teonácio Bezerra, Manuel López-Ibáñez, Thomas Stützle

A Multi-point Mechanism of Expected Hypervolume Improvement for Parallel Multi-objective Bayesian Global Optimization 17:25-17:50
Kaifeng Yang, Pramudita Satria Palar, Michael Emmerich, Koji Shimoyama, Thomas Bäck

GA4 Tuesday, July 16, 16:10-17:50, Club A (1F)

Chair: Tian-Li Yu (Department of Electrical Engineering, National Taiwan University)

On Improving the Constraint-Handling Performance with Modified Multiple Constraint Ranking (MCR-mod) for Engineering Design Optimization Problems Solved by Evolutionary Algorithms 16:10-16:35
Yohanes Bimo Dwianto, Hiroaki Fukumoto, Akira Oyama

Intentional Computational Level Design 16:35-17:00
Ahmed Khalifa, Michael Cerny Green, Gabriella Barros, Julian Togelius

An Empirical Evaluation of Success-Based Parameter Control Mechanisms for Evolutionary Algorithms 17:00-17:25
Mario Alejandro Hevia Fajardo

Parametrizing Convection Selection: Conclusions from the Analysis of Performance in the NKq Model 17:25-17:50
Maciej Komosinski, Konrad Miazga

HOP3 Tuesday, July 16, 16:10-17:50, Club B (1F)

Chair: Kai Olav Ellefsen (University of Oslo)

Guiding Neuroevolution with Structural Objectives 16:10-16:35
Kai Olav Ellefsen, Joost Huizinga, Jim Torresen

Combining Artificial Neural Networks and Evolution to Solve Multiobjective Knapsack Problems 16:35-17:00
Roman Denysiuk, António Gaspar-Cunha, Alexandre C. B. Delbem

Analysing Heuristic Subsequences for Offline Hyper-heuristic Learning 17:00-17:25
William B. Yates, Edward C. Keedwell

Gaussian Process Surrogate Models for the CMA-ES 17:25-17:50
Lukas Bajer, Zbynek Pitra, Jakub Repicky, Martin Holena

RWA7 Tuesday, July 16, 16:10-17:50, Club D (1F)

Chair: Robin Purshouse (University of Sheffield)

Evolving Stellar Models to Find the Origins of Our Galaxy 16:10-16:35
Conrad Chan, Aldeida Aleti, Alexander Heger, Kate Smith-Miles

Sentiment analysis with genetically evolved Gaussian kernels 16:35-17:00
Ibai Roman, Alexander Mendiburu, Roberto Santana, Jose A. Lozano

Inverse generative social science using multi-objective genetic programming 17:00-17:25
Tuong Manh Vu, Charlotte Probst, Joshua M. Epstein, Mark Strong, Alan Brennan, Robin C. Purshouse

Surrogate-based Optimization for Reduction of Contagion Susceptibility in Financial Systems 17:25-17:50
Krzysztof Michalak

RWA8 Tuesday, July 16, 16:10-17:50, Club H (1F)

Chair: Leandro Soares Indrusiak (York University)

A Hybrid Metaheuristic Approach to a Real World Employee Scheduling Problem 16:10-16:35
Kenneth Reid, Jingpeng Li, Alexander Brownlee, Mathias Kern, Nadarajen Veerapen, Jerry Swan, Gilbert Owusu

Cloud-based Dynamic Distributed Optimisation of Integrated Process Planning and Scheduling in Smart Factories 16:35-17:00
Shuai Zhao, Piotr Dziurzanski, Michal Przewozniczek, Marcin Komarnicki, Leandro Soares Indrusiak

Evolutionary approaches to dynamic earth observation satellites mission planning under uncertainty 17:00-17:25
Guillaume Poveda, Olivier Regnier-Coudert, Florent Teichteil-Koenigsbuch, Gerard Dupont, Alexandre Arnold, Jonathan Guerra, Mathieu Picard

THEORY3 Tuesday, July 16, 16:10-17:50, Club C (1F)

Chair: Per Kristian Lehre (University of Birmingham)

On the Benefits of Populations for the Exploitation Speed of Standard Steady-State Genetic Algorithms 16:10-16:35
Dogan Corus, Pietro S. Oliveto

Lower Bounds on the Runtime of Crossover-Based Algorithms via Decoupling and Family Graphs 16:35-17:00
Andrew M. Sutton, Carsten Witt

Multiplicative Up-Drift 17:00-17:25
Benjamin Doerr, Timo Kötzing

The Efficiency Threshold for the Offspring Population Size of the (μ, λ) EA 17:25-17:50
Antipov Denis, Benjamin Doerr, Quentin Yang

DETA2 Wednesday, July 17, 09:00-10:40, Club E (1F)

Chair: Penousal Machado (University of Coimbra)

On the Impact of Domain-specific Knowledge in Evolutionary Music Composition 09:00-09:25
Csaba Sulyok, Christopher Harte, Zalán Bodó

Mapping Hearthstone Deck Spaces through MAP-Elites with Sliding Boundaries 09:25-09:50
Matthew C. Fontaine, Scott Lee, L. B. Soros, Fernando De Mesentier Silva, Julian Togelius, Amy K. Hoover

Tile Pattern KL-Divergence for Analysing and Evolving Game Levels 09:50-10:15
Simon M. Lucas, Vanessa Volz

EMO5 Wednesday, July 17, 09:00-10:40, South Hall 1A (1F)

Chair: Sanaz Mostaghim (University of Magdeburg)

An Adaptive Evolutionary Algorithm based on Non-Euclidean Geometry for Many-objective Optimization 09:00-09:25
Annibale Panichella

On the Benefits of Biased Edge-Exchange Mutation for the Multi-Criteria Spanning Tree Problem 09:25-09:50
Jakob Bossek, Christian Grimme, Frank Neumann

A 'Phylogeny-aware' Multi-objective Optimization Approach for Computing MSA 09:50-10:15
Muhammad Ali Nayeem, Md. Shamsuzzoha Bayzid, Atif Hasan Rahman, Rifat Shahriyar, M. Sohel Rahman

Multiobjective Evolutionary Algorithm for DNA Codeword Design 10:15-10:40
Jeisson Prieto, Jonatan Gomez, Elizabeth Leon

GA5 Wednesday, July 17, 09:00-10:40, Club A (1F)

Chair: Nadarajen Veerapen (Université de Lille)

Resource Optimization for Elective Surgical Procedures Using Quantum-inspired Genetic Algorithms. 09:00-09:25
Rene Gonzalez, Marley Vellasco, Karla Figueiredo

A Lexicographic Genetic Algorithm for Hierarchical Classification Rule Induction 09:25-09:50
Gean Pereira, Paulo Gabriel, Ricardo Cerri

A Combination of Two Simple Decoding Strategies for the No-wait Job Shop Scheduling Problem 09:50-10:15
Víctor Manuel Valenzuela Alcaraz, Carlos Alberto Brizuela Rodríguez, María De los Ángeles Cosío León, Alma Danisa Romero Ocaño

GECH4 Wednesday, July 17, 09:00-10:40, Club D (1F)

Chair: Kenneth De Jong (George Mason University)

Scenario Co-Evolution for Reinforcement Learning on a Grid World Smart Factory Domain 09:00-09:25
Thomas Gabor, Andreas Sedlmeier, Marie Kiermeier, Thomy Phan, Marcel Henrich, Monika Pichlmair, Bernhard Kempter, Cornel Klein, Horst Sauer, Reiner Schmid, Jan Wieghardt

Using Subpopulation EAs to Map Molecular Structure Landscapes 09:25-09:50
Ahmed Bin Zaman, Kenneth A. De Jong, Amarda Shehu

Online Selection of CMA-ES Variants 09:50-10:15
Diederick L. Vermetten, Sander van Rijn, Thomas Bäck, Carola Doerr

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GP4 Wednesday, July 17, 09:00-10:40, South Hall 1B (1F)

Chair: Marc Schoenauer (INRIA Saclay)

Novel Ensemble Genetic Programming Hyper-Heuristics for Uncertain Capacitated Arc Routing Problem 09:00-09:25
Shaolin Wang, Yi Mei, Mengjie Zhang

Promoting Semantic Diversity in Multi-objective Genetic Programming 09:25-09:50
Edgar Galván, Marc Schoenauer

Evolving Boolean Functions with Conjunctions and Disjunctions via Genetic Programming 09:50-10:15
Benjamin Doerr, Andrei Lissovoi, Pietro Simone Oliveto

What's inside the black-box? A genetic programming method for interpreting complex machine learning models 10:15-10:40
Benjamin Patrick Evans, Bing Xue, Mengjie Zhang

HOP4 Wednesday, July 17, 09:00-10:40, Club B (1F)

Chair: Cameron Shand (University of Manchester)

Data-Driven Multi-Objective Optimisation of Coal-Fired Boiler Combustion System 09:00-09:25
Alma Rahat, Chunlin Wang, Richard Everson, Jonathan Fieldsend

Hot Off the Press in Expert Systems on Underwater Robotic Missions: Success History Applied to Differential Evolution for Underwater Glider Path Planning 09:25-09:50
Aleš Zamuda, José Daniel Hernández Sosa

A bi-level hybrid PSO – MIP solver approach to define dynamic tariffs and estimate bounds for an electricity retailer profit 09:50-10:15
Inês Soares, Maria João Alves, Carlos Henggeler Antunes

RWA9 Wednesday, July 17, 09:00-10:40, Club H (1F)

Chair: Emma Hart (Edinburgh Napier University)

Well Placement Optimization under Geological Statistical Uncertainty 09:00-09:25
Atsuhiro Miyagi, Youhei Akimoto, Hajime Yamamoto

Evolving Robust Policies for Community Energy System Management 09:25-09:50
Rui P. Cardoso, Emma Hart, Jeremy V. Pitt

Statistical Learning in Soil Sampling Design Aided by Pareto Optimization 09:50-10:15
Assaf Israeli, Michael Emmerich, Michael (Iggy) Litaor, Ofer M. Shir

A hybrid multi-objective evolutionary algorithm for economic-environmental generation scheduling 10:15-10:40
Vasilios Tsalavoutis, Constantinos Vrionis, Athanasios Tolis

Poster Session
Monday, July 15, 17:50-20:00, Panorama Hall (1F)

Ant Colony Optimization and Swarm Intelligence (ACO-SI)

Scaling ACO to Large-scale Vehicle Fleet Optimisation Via Partial-ACO
Darren M. Chitty, Elizabeth Wanner, Rakhi Parmar, Peter R. Lewis

Collaborative Diversity Control Strategy for Random Drift Particle Swarm Optimization
Chao Li, Jun Sun, Vasile Palade, Qidong Chen, Wei Fang

Inferring Structure and Parameters of Dynamic Systems using Particle Swarm Optimization
Muhammad Usman, Abubakr Awad, Wei Pang, George Macleod Coghill

Complex Systems (CS)

Are Quality Diversity Algorithms Better at Generating Stepping Stones than Objective-based Search?
Adam Gaier, Alexander Asteroth, Jean-Baptiste Mouret

Towards Continual Reinforcement Learning through Evolutionary Meta-Learning
Djordje Grbic, Sebastian Risi

Evolutionary Predator-prey Robot Systems: from simulation to real world
Gongjin Lan, Jiunhan Chen, Agoston Eiben

Evolving Indoor Navigational Strategies Using Gated Recurrent Units In NEAT
James John Butterworth, Rahul Savani, Karl Tuyls

Comparing Encodings for Performance and Phenotypic Exploration in Evolving Modular Robots
Frank Veenstra, Matteo De Carlo, Edgar Buchanan Berumen, Wei Li, Agoston E. Eiben, Emma Hart

Evolution of Cellular Automata Development Using Various Representations
Michal Bidlo

Evaluation of Runtime Bounds for SELEX Procedure with High Selection Pressure
Anton Eremeev, Alexander Spirov

Blending Notions of Diversity for MAP-Elites
Daniele Gravina, Antonios Liapis, Georgios N. Yannakakis

MAP-Elites for Noisy Domains by Adaptive Sampling
Niels Justesen, Sebastian Risi, Jean-Baptiste Mouret

Learning to Select Mates in Artificial Life
Dylan Robert Ashley, Valliappa Chockalingam, Braedy Kuzma, Vadim Bulitko

The Cost of Morphological Complexity
Geoff Nitschke, Danielle Nagar, Alexander Furman

HIT-EE: a Novel Embodied Evolutionary Algorithm for Low Cost Swarm Robotics
Nicolas Bredeche

Positive Impact of Isomorphic Changes in the Environment on Collective Decision-Making
Palina Bartashevich, Sanaz Mostaghim

Digital Entertainment Technologies and Arts (DETA)

Solving Nurikabe with Ant Colony Optimization
Martyn Amos, Matthew Crossley, Huw Lloyd

Evolving Music with Emotional Feedback
Geoff Nitschke, Paul Cohen

Free Form Evolution for Angry Birds Level Structures
Laura Calle Caraballo, Juan Julián Merelo Guervós, Antonio Mora, Mario García Valdez

Crowd-Sourcing the Sounds of Places with a Web-Based Evolutionary Algorithm
Alexander Edward Ian Brownlee, Suk-Jun Kim, Szu-Han Wang, Stella Chan, Jamie Allan Lawson

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

Does Constraining the Search Space of GA Always Help? The Case of Balanced Crossover Operators
Luca Manzoni, Luca Mariot, Eva Tuba

Decentralised Multi-Demic Evolutionary Approach to the Dynamic Multi-Agent Travelling Salesman Problem
Thomas Eliot Kent, Arthur Richards

Ranking-based Discrete Optimization Algorithm for Asymmetric Competitive Facility Location
Algirdas Lancinskas, Julius Zilinskas, Pascual Fernandez, Blas Pelegrin

Approaching the Quadratic Assignment Problem with Kernels of Mallows Models under the Hamming Distance
Etor Arza, Josu Ceberio, Aritz Pérez, Ekhiñe Irurozki

Simulated Annealing for the Single-Vehicle Cyclic Inventory Routing Problem
Aldy Gunawan, Vincent F. Yu, Audrey Tedja Widjaja, Pieter Vansteenwegen

The Quadratic Assignment Problem: Metaheuristic optimization using HC12 Algorithm
Radomil Matousek, Ladislav Dobrovsky, Jakub Kudela

Noisy Combinatorial Optimisation by Evolutionary Algorithms
Aishwaryaprajna, Jonathan E. Rowe

A Memetic Algorithm with Distance-guided Crossover: Distributed Data-intensive Web Service Composition
Soheila Sadeghiram, Hui Ma, Gang Chen

Optimizing Permutation-Based Problems With a Discrete Vine-Copula as a Model for EDA
Abdelhakim Cheriet, Roberto Santana

Towards a Formal Specification of Local Search Neighborhoods from a Constraint Satisfaction Problem Structure
Mateusz Ślażyński, Salvador Abreu, Grzegorz Jacek Nalepa

Evolutionary Machine Learning (EML)

Evolutionary Data Augmentation in Deep Face Detection
João Correia, Tiago Martins, Penousal Machado

Improving Classification Performance of Support Vector Machines via Guided Custom Kernel Search
Kumar Ayush, Abhishek Sinha

Evolutionarily-tuned support vector machines
Wojciech Dudzik, Michal Kawulok, Jakub Nalepa

Novelty Search for Deep Reinforcement Learning Policy Network Weights by Action Sequence Edit Metric Distance
Ethan C. Jackson, Mark Daley

Using Genetic Programming for Combining an Ensemble of Local and Global Outlier Algorithms to Detect New Attacks
Gianluigi Folino, Maryam Amir Haeri, Francesco Sergio Pisani, Luigi Pontieri, Pietro Sabatino

Strategies for improving performance of evolutionary biclustering algorithm EBIC
Patryk Orzechowski, Jason H. Moore

Augmenting neuro-evolutionary adaptation with representations does not incur a speed accuracy trade-off
Douglas Kirkpatrick, Arend Hintze

Multiobjective Multi Unit Type Neuroevolution for Micro in RTS Games
Aavaas Gajurel, Sushil J. Louis

Evolving Convolutional Neural Networks through Grammatical Evolution
Ricardo Henrique Remes Lima, Aurora Trinidad Ramirez Pozo

On the Potential of Evolutionary Algorithms for Replacing Backpropagation for Network Weight Optimization
Hao Wang, Thomas Bäck, Aske Plaat, Michael Emmerich, Mike Preuss

How XCS Can Prevent Misdistinguishing Rule Accuracy: A Preliminary Study
Masaya Nakata, Will Browne

Nested Monte Carlo Search Expression Discovery for the Automated Design of Fuzzy ART Category Choice Functions
Marketa Illetskova, Islam Elnabarawy, Leonardo Enzo Brito da Silva, Daniel R. Tauritz, Donald C. Wunsch II

Identifying Idealised Vectors for Emotion Detection Using CMA-ES
Mohammed Ali A. Alshahrani, Spyridon Samothrakis, Maria Fasli

Differential Evolution for Instance based Transfer Learning in Genetic Programming for Symbolic Regression
Qi Chen, Bing Xue, Mengjie Zhang

Evolving Recurrent Neural Networks for Emergent Communication
Joshua David Sirota, Vadim Bulitko, Matthew R. G. Brown, Sergio Poo Hernandez

Neural Network Architecture Search with Differentiable Cartesian Genetic Programming for Regression
Marcus Märtens, Dario Izzo

Multi-GPU approach for big data mining - global induction of decision trees
Krzysztof Jurczuk, Marcin Czajkowski, Marek Kretowski

Reuse of Program Trees in Genetic Programming with a New Fitness Function in High-Dimensional Unbalanced Classification
Wenbin Pei, Bing Xue, Lin Shang, Mengjie Zhang

Evolutionary Multiobjective Optimization (EMO)

A Physarum-Inspired Competition Algorithm for Solving Discrete Multi-Objective Optimization Problems
Abubakr Awad, Muhammad Usman, David Lusseau, George Coghill, Wei Pang

A New Constrained Multi-objective Optimization Problems Algorithm Based on Group-sorting
Yijun Liu, Xin Li, Qijia Hao

Performance of Dynamic Algorithms on the Dynamic Distance Minimization Problem
Mardé Helbig, Heiner Zille, Mahrokh Javadi, Sanaz Mostaghim

Classical MOEAs for solving a multi-objective problem of supply chain design and operation
Ángel David Téllez Macías, Antonin Ponsich, Roman Anselmo Mora Gutíerrez

Many-View Clustering - An Illustration using Multiple Dissimilarity Measures
Adán José-García, Julia Handl, Wilfrido Gómez-Flores, Mario Garza-Fabre

Studying Compartmental Models Interpolation to Estimate MOEAs Population Size
Hugo Monzón, Hernán Aguirre, Sébastien Verel, Arnaud Liefooghe, Bilel Derbel, Kiyoshi Tanaka

Improved Binary Additive Epsilon Indicator for Obtaining Uniformly Distributed Solutions in Multi-Objective Optimization
Tatsumasa Ishikawa, Hiroaki Fukumoto, Akira Oyama, Hiroyuki Nishida

On Fairness as a Rostering Objective
Anna Lavygina, Kristopher Welsh, Alan Crispin

Optimisation of Crop Configuration using NSGA-III with Categorical Genetic Operators
Oskar Marko, Dejan Pavlović, Vladimir Crnojević, Kalyanmoy Deb

Operational Decomposition for Large Scale Multi-objective Optimization Problems
Luis Miguel Antonio, Carlos A. Coello Coello, Silvia González Brambila, Josué Figueroa González, Guadalupe Castillo Tapia

Generation Techniques and a Novel On-line Adaptation Strategy for Weight Vectors Within Decomposition-Based MOEAs
Alberto Rodríguez Sánchez, Antonin Ponsich, Antonio López Jaimes

Balancing Exploration and Exploitation in Multiobjective Batch Bayesian Optimization
Hongyan Wang, Hua Xu, Yuan Yuan, Xiaomin Sun, Junhui Deng

Evolving Cooperation for the Iterated Prisoner's Dilemma
Jessica J. Finocchiaro, H. David Mathias

A Parametric Investigation of PBI and AASF Scalarizations
Hemant K. Singh, Kalyanmoy Deb

Enhanced Optimization with Composite Objectives and Novelty Pulsation
Hormoz Shahrzad, Babak Hodjat, Camille Dolle, Andrei Denissov, Simon Lau, Donn Goodhew, Justin Dyer, Risto Miikkulainen

Modified Crowding Distance and Mutation for Multimodal Multi-Objective Optimization
Mahrokh Javadi, Heiner Zille, Sanaz Mostaghim

Towards a Novel NSGA-II-based Approach for Multi-objective Scientific Workflow Scheduling on Hybrid Clouds
Haithem Hafsi, Hamza Gharsellaoui, Sadok Bouamama

A Decomposition-based EMOA for Set-based Robustness
Carlos Ignacio Hernández Castellanos, Sina Ober-Blöbaum

Noisy Multiobjective Black-Box Optimization using Byesian Optimization
Hongyan Wang, Hua Xu, Yuan Yuan, Junhui Deng, Xiaomin Sun

Preferences-based Multiobjective Virtual Machine Placement: A Ceteris Paribus Approach
Abdulaziz Saleh Alashaikh, Eisa Alanazi

Reliability-Based MOGA Design Optimization Using Probabilistic Response Surface Method and Bayesian Neural Network
Juhee Lim, Jongsoo Lee

On a restart metaheuristic for real-valued multi-objective evolutionary algorithms
Christina Brester, Ivan Ryzhikov, Eugene Semenkin, Mikko Kolehmainen

Using Diversity as a Priority Function for Resource Allocation on MOEA/D
Yuri Lavinas, Claus Aranha, Tetsuya Sakurai

A Component-wise Study of K-RVEA: Observations and Potential Future Developments
Ahsanul Habib, Hemant Kumar Singh, Tapabrata Ray

An a priori Knee Identification Multi-objective Evolutionary Algorithm Based on α-Dominance
Guo Yu, Yaochu Jin, Markus Olhofer

Evolutionary Numerical Optimization (ENUM)

On the use of Metaheuristics in Hyperparameters Optimization of Gaussian Processes
Pramudita Satria Palar, Lavi Rizki Zuhal, Koji Shimoyama

Benchmarking the region learning-based JADE on noiseless functions
Mingcheng Zuo, Guangming Dai, Lei Peng, Maocai Wang, Pan Peng, Changchun Chen

Comparing reliability of grid-based Quality-Diversity algorithms using artificial landscapes
Leo Cazenille

Extended Stochastic Derivative-Free Optimization on Riemannian manifolds
Robert Simon Fong, Peter Tino

Limitations of benchmark sets and landscape features for algorithm selection and performance prediction
Benjamin Lacroix, John McCall

Solving Optimization Problems with High Conditioning by Means of Online Whitening
Samineh Bagheri, Wolfgang Konen, Thomas Bäck

Investigating the Effects of Population Size and the Number of Subcomponents on the Performance of SHADE Algorithm with Random Adaptive Grouping for LSGO Problems
Evgenii Sopov, Alexey Vakhnin

A new mutation operator with the ability to adjust exploration and exploitation for DE algorithm
Mingcheng Zuo

GECCO Black-Box Optimization Competitions: Progress from 2009 to 2018
Urban Škvorc, Tome Eftimov, Peter Korošec

An Analysis of Control Parameters of Copula-based EDA Algorithm with Model Migration
Martin Hyrš, Josef Schwarz

On the Non-convergence of Differential Evolution: Some Generalized Adversarial Conditions and A Remedy
Debolina Paul, Saptarshi Chakraborty, Swagatam Das, Ivan Zelinka

Exploitation of Multiple Surrogate Models in Multi-Point Infill Sampling Strategies
Paul Beaucaire, Charlotte Beauthier, Caroline Sainvitu

Evaluating MAP-Elites on Constrained Optimization Problems
Stefano Fioravanzo, Giovanni Iacca

Openly Revisiting Derivative-Free Optimization
Jeremy Rapin, Pauline Luc, Jules Pondard, Nicolas Vasilache, Marie-Liesse Cauwet, Camille Couprie, Olivier Teytaud

A New Neighborhood Topology for QUAntum Particle Swarm Optimization (QUAPSO)
Arnaud Flori, Hamouche Oulhadj, Patrick Siarry

On Equivalence of Algorithm's Implementations: The CMA-ES Algorithm and Its Five Implementations
Rafał Biedrzycki

Empirical Evaluation of Contextual Policy Search with a Comparison-based Surrogate Model and Active Covariance Matrix Adaptation
Alexander Fabisch

Genetic Algorithms (GA)

A Study of the Levy Distribution in Generation of BRKGA Random Keys Applied to Global Optimization
Mariana Alves Moura, Ricardo Martins de Abreu Silva

A Parallel Multi-Population Biased Random-Key Genetic Algorithm for Electric Distribution Network Reconfiguration
Haroldo De Faria Jr., Willian Tessaro Lunardi, Holger Voos

Parameter-less Population Pyramid with Automatic Feedback
Adam Mikolaj Zielinski, Marcin Michal Komarnicki, Michal Witold Przewozniczek

Latin Hypercube Initialization Strategy for Design Space Exploration of Deep Neural Network Architectures
Heitor Rapela Medeiros, Diogo Moury Fernandes Izidio, Antonyus Pyetro do Amaral Ferreira, Edna Natividade da Silva Barros

A Probabilistic Bitwise Genetic Algorithm for B-Spline based Image Deformation Estimation
Takumi Nakane, Takuya Akashi, Xuequan Lu, Chao Zhang

A Group Work Inspired Generation Alternation Model of Real-Coded GA
Takatoshi Niwa, Koya Ihara, Shohei Kato

Genealogical Patterns in Evolutionary Algorithms
Carlos Fernandes, Juan Laredo, Juan Julián Merelo, Agostinho Rosa

Mining a massive RNA-seq dataset with biclustering: are evolutionary approaches ready for big data?
Patryk Orzechowski, Jason H. Moore

The 1/5-th Rule with Rollbacks: On Self-Adjustment of the Population Size in the $(1+(\lambda,\lambda))$ **GA**
Anton Bassin, Maxim Buzdalov

A BRKGA for the Integrated Scheduling Problem in FMSs
S. Mahdi Homayouni, Dalila B.M.M. Fontes, Fernando A.C.C. Fontes

Runtime Analysis of Abstract Evolutionary Search with Standard Crossover
Tina Malalanirainy, Alberto Moraglio

Multiple World Genetic Algorithm to Analyze Individually Advantageous Behaviors in Complex Networks
Yutaro Miura, Fujio Toriumi, Toshiharu Sugawara

Comparison of GAs in Black-Box Scenarios: Use-Case Specific Analysis
Cheng Hao Yang, Hou Teng Cheong, Tian-Li Yu

A Change Would Do You Good: GA-based Approach for Hiding Data in Program Executables
Ryan C. Gabrys, Luis Martinez

Island Model for Parallel Evolutionary Optimization of Spiking Neuromorphic Computing
Catherine Schuman, James Plank, Robert Patton, Thomas Potok

Approximate Search in Dissimilarity Spaces using GA
David Bernhauer, Tomáš Skopal

Genetic Algorithms as Shrinkers in Property-Based Testing
Fang-Yi Lo, Chao-Hong Chen, Ying-ping Chen

Evolving to Recognize High-dimensional Relationships in Data: GA Operators and Representation Designed Expressly for Community Detection
Kenneth Smith, Cezary Janikow, Sharlee Climer

Parameter-less, Population-sizing DSMGA-II
Marcin Michal Komarnicki, Michal Witold Przewozniczek

General Evolutionary Computation and Hybrids (GECH)

Textonboost based on Differential Evolution
Keiko Ono, Daisuke Tawara, Yoshiko Hanada

AlphaStar: An Evolutionary Computation Perspective
Kai Arulkumaran, Antoine Cully, Julian Togelius

Improving the algorithmic efficiency and performance of channel-based evolutionary algorithms
JJ Merelo, Juan-Luis Jiménez Laredo, Pedro Castillo-Valdivieso, Mario García-Valdez, Sergio Rojas

A Classification-Based Selection for Evolutionary Optimization
Jinyuan Zhang, Jimmy Xiangji Huang, Qinmin Vivian Hu

A Hybrid Between a Surrogate-Assisted Evolutionary Algorithm and a Trust Region Method for Constrained Optimization
Rommel G. Regis

A Population Entropy Based Adaptation Strategy for Differential Evolution
Yanyun Zhang, Guangming Dai, Mingcheng Zuo, Lei Peng, Maocai Wang, Zhengquan Liu

Evolved Cellular Automata for Edge Detection
Alina Enescu, Anca Andreica, Laura Dioșan

Comparing Terminal Sets for Evolving CMA-ES Mean-Update Selection
Samuel N. Richter, Michael G. Schoen, Daniel R. Tauritz

Can Route Planning be Smarter with Transfer Optimization?
Ray Lim, Yew-Soon Ong, Hanh Thi Hong Phan, Abhishek Gupta, Allan Nengsheng Zhang

Genetic Programming (GP)

Semantic Fitness Function in Genetic Programming Based on Semantics Flow Analysis
Pak-Kan Wong, Man-Leung Wong, Kwong-Sak Leung

Parsimony Measures in Multi-objective Genetic Programming for Symbolic Regression
Bogdan Burlacu, Gabriel Kronberger, Michael Kommenda, Michael Affenzeller

Designing Correlation Immune Boolean Functions With Minimal Hamming Weight Using Various Genetic Programming Methods
Jakub Husa

Investigating the Use of Linear Programming to Solve Implicit Symbolic Regression Problems
Quang Nhat Huynh, Hemant K. Singh, Tapabrata Ray

Tag-accessed Memory for Genetic Programming
Alexander Michael Lalejini, Charles Ofria

A Genetic Programming Approach to Feature Selection and Construction for Ransomware, Phishing and Spam Detection
Harith Al-Sahaf, Ian Welch

Transfer Learning: A Building Block Selection Mechanism in Genetic Programming for Symbolic Regression
Brandon Muller, Harith Al-Sahaf, Bing Xue, Mengjie Zhang

To Adapt or Not to Adapt, or The Beauty of Random Settings
João E. Batista, Nuno M. Rodrigues, Sara Silva

Multimodal Genetic Programming Using Program Similarity Measurement and Its Application to Wall-Following Problem
Shubu Yoshida, Tomohiro Harada, Ruck Thawonmas

Space Partition based Gene Expression Programming for Symbolic Regression
Qiang Lu, Shuo Zhou, Fan Tao, Zhiguang Wang

Increasing Genetic Programming Robustness using Simulated Dunning-Kruger Effect
Thomas David Griffiths

Automated Design of Random Dynamic Graph Models for Enterprise Computer Network Applications
Aaron Scott Pope, Daniel R. Tauritz, Chris Rawlings

Transfer Learning Based on Feature Weighting and Feature Contribution in Genetic Programming Hyper-heuristic for Solving Uncertain Capacitated Arc Routing Problem
Mazhar Ansari Ardeh, Yi Mei, Mengjie Zhang

Real World Applications (RWA)

On the Use of Context Sensitive Grammars in Genetic Programming For Legal Non-Compliance Detection
Carl Im, Erik Hemberg

Neural Network-Based Multiomics Data Integration in Alzheimer's Disease
Pankhuri Singhal, Shefali S. Verma, Scott M. Dudek, Marylyn D. Ritchie

Impact of subcircuit selection on the efficiency of CGP-based optimization of gate-level circuits
Jitka Kocnova, Zdenek Vasicek

Evolving Optimal Sun-Shading Building Façades
Geoff Nitschke, Leon Coetzee

On the Design of S-box Constructions with Genetic Programming
Stjepan Picek, Domagoj Jakobovic

Evolutionary refinement of the 3D structure of multi-domain protein complexes from small angle X-ray scattering data
Olga Rudenko, Aurelien Thureau, Javier Perez

Optimization of chemical structures for seawater desalination
Kyo Migishima, Takahiro Fuji, Hernán Aguirre, Rodolfo Cruz-Silva, Kiyoshi Tanaka

Benchmarking Genetic Programming in Dynamic Insider Threat Detection
Duc C. Le, Malcolm I. Heywood, Nur Zincir-Heywood

Discovery of Robust Protocols for Secure Quantum Cryptography
Walter Oliver Krawec, Sam A. Markelon

Solving the First and Last Mile Problem with Connected and Autonomous Vehicles
Alma A. M. Rahat, Ralph Ledbetter, Alex Dawn, Robert Byrne, Richard Everson

A Genetic Algorithm for Multi-Robot Routing in Automated Bridge Inspection
Nicholas S. Harris, Sushil Louis, Siming Liu, Hung La

Genetic Algorithms for the Network Slice Design Problem Under Uncertainty
Thomas Bauschert, Varun S. Reddy

Phoneme Aware Speech Recognition through Evolutionary Optimisation
Jordan J. Bird, Elizabeth Wanner, Anikó Ekárt, Diego R. Faria

Multi-objective genetic algorithms for reducing mark read-out effort in lithographic tests
Pierluigi Frisco, Timo Bootsma, Thomas Bäck

Evolutionary Optimization of Epidemic Control Strategies for Livestock Disease Prevention
Krzysztof Michalak

Neural-Network Assistance to Calculate Precise Eigenvalue for Fitness Evaluation of Real Product Design
Yukito Tsunoda, Takahiro Notsu, Yasufumi Sakai, Naoki Hamada, Toshihiko Mori, Teruo Ishihara, Atsuki Inoue

Bond Strength Prediction of FRP-bar Reinforced Concrete: A Multi-gene Genetic Programming Approach
Hamed Bolandi, Wolfgang Banzhaf, Nizar Lajnef, Kaveh Barri, Amir. H. Alavi

Evolving Planar Mechanisms for the Conceptual Stage of Mechanical Design
Paul Lapok, Alistair Lawson, Ben Paechter

Multi-Objective Collective Search and Movement-based Metrics in Swarm Robotics
Sebastian Mai, Heiner Zille, Christoph Steup, Sanaz Mostaghim

EvoIsland: Immersive Interactive Evolutionary 3D Modelling
Alexander Ivanov, Christian Jacob

Graph-based Multi-Objective Generation of Customised Wiring Harnesses
Jens Weise, Steven Benkhardt, Sanaz Mostaghim

Efficient Frontiers in Portfolio Optimisation with Minimum Proportion Constraints
Tahani Alotaibi, Matthew Craven

Feature Selection for Surrogate Model-Based Optimization
Frederik Rehbach, Lorenzo Gentile, Thomas Bartz-Beielstein

Enhancing Classification Performance of Convolutional Neural Networks for Prostate Cancer Detection on Magnetic Resonance Images: a Study with the Semantic Learning Machine
Paulo Lapa, Ivo Gonçalves, Leonardo Rundo, Mauro Castelli

A Genetic Algorithm based Column Generation Method for Multi-Depot Electric Bus Vehicle Scheduling
Congcong Guo, Chunlu Wang, Xingquan Zuo

Optimal Equipment Assignment for Oil Spill Response Using a Genetic Algorithm
Hye-Jin Kim, Junghwan Lee, Jong-Hwui Yun, Yong-Hyuk Kim

Study on multi-objective optimization for the allocation of transit aircraft to gateway considering satellite hall
Boyuan Xia, Zhiwei Yang, Qingsong Zhao

Search-Based Software Engineering (SBSE)

Towards Evolutionary Theorem Proving for Isabelle/HOL
Yutaka Nagashima

A Memetic NSGA-II with EDA-Based Local Search for Fully Automated Multiobjective Web Service Composition
chen wang, Hui Ma, Gang Chen, Sven Hartmann

Franken-Swarm: Grammatical Evolution for the Automatic Generation of Swarm-like Meta-heuristics
Anna Bogdanova, Jair Pereira Junior, Claus Aranha

Visualizing Swarm Behavior with a Particle Density Map
Hyeon-Chang Lee, Yong-Hyuk Kim

Security Testing of Web Applications: A Search-Based Approach for Detecting SQL Injection Vulnerabilities
Muyang Liu, Ke Li, Tao Chen

Genetic Improvement of Data gives Binary Logarithm from sqrt
W. Langdon, J. Petke

Theory (Theory)

A mathematical analysis of EDAs with distance-based exponential models
Imanol Unanue, María Merino, Jose Antonio Lozano

Maximizing Drift is Not Optimal for Solving OneMax
Nathan Buskulic, Carola Doerr

Unlimited Budget Analysis
Jun He, Thomas Jansen, Christine Zarges

Black-Box Complexity of the Binary Value Function
Nina Bulanova, Maxim Buzdalov

Abstracts by Track

Ant Colony Optimization and Swarm Intelligence

ACO-SI1

Monday, July 15, 10:40-12:20 Club C (1F)

Control Parameter Sensitivity Analysis of the Multi-guide Particle Swarm Optimization Algorithm

Kyle Harper Erwin, *Allan Gray*, Andries Engelbrecht, *University of Stellenbosh*

This paper conducts a sensitivity analysis of the recently proposed multi-objective optimizing algorithm, namely the multi-guide particle swarm optimization algorithm (MGPSO). The MGPSO uses subswarms to explore the search space, where each subswarm optimises one of the multiple objectives. A bounded archive is used to share previously found non-dominated solutions between subswarms. A third term, the archive guide, is added to the velocity update equation that represents a randomly selected solution from the archive. The influence of the archive guide on a particle is controlled by the archive balance coefficient and is proportional to the social guide. The original implementation of the MGPSO used static values randomly sampled from a uniform distribution in the range [0,1] for the archive balance coefficient. This paper investigates a number of approaches to dynamically adjust this control parameter. These approaches are evaluated on a variety of multi-objective optimization problems. It is shown that a linearly increasing strategy and stochastic strategies outperformed the standard approach to initializing the archive balance coefficient on two-objective and three objective optimization problems.

On the Selection of the Optimal Topology for Particle Swarm Optimization: A Study of the Tree as the Universal Topology

Ángel Arturo Rojas-García, *Center for Research in Mathematics*, Arturo Hernández-Aguirre, *Center for Research in Mathematics*, S. Ivvan Valdez, *CENTROMET-INFOTEC*

In this paper, we deal with the problem of selecting the best topology in Particle Swarm Optimization. Unlike most state-of-the-art papers, where statistical analysis of a large number of topologies is carried out, in this work we formalize mathematically the problem. In this way, the problem is to find the best topology in the set of all simple connected graphs of n nodes. To determine which is the best topology, each graph in this set must be measured with a function that evaluates its quality. We introduce the concepts of equivalent neighborhood and equivalent topology to prove that for any simple connected graph there is an equivalent tree. The equivalence between two topologies means that each particle belonging to these has the same local best in both. Therefore, the problem can be simplified in complexity to find the best tree in the set of all trees with n nodes. Finally, we give some examples of equivalent topologies, as well as the applicability of the obtained result.

A Stable Hybrid method for Feature Subset Selection using Particle Swarm Optimization with Local Search

Hassen Dhrif, *University of Miami, Florida*, Luis G. Sanchez Giraldo, *University of Miami, Florida*, Miroslav Kubat, *University of Miami, Florida*, Stefan Wuchty, *University of Miami, Florida*

The determination of a small set of biomarkers to make a diagnostic call can be formulated as a feature subset selection (FSS) problem to find a small set of genes with high relevance for the underlying classification task and low mutual redundancy. However, repeated application of a heuristic, evolutionary FSS technique usually does not necessarily produce consistent results. Here, we introduce COMB-PSO-LS, a novel hybrid (wrapper-filter) FSS algorithm based on Particle Swarm Optimization (PSO) that uses a local search strategy to select the least dependent and most relevant feature subsets. In particular, we employ a Randomized Dependence Coefficient (RDC)-based filter technique to guide the search process of the particle swarm, allowing the selection of highly relevant and consistent features. Classifying cancer samples through patient gene expression profiles, we found that COMB-PSO-LS provides highly robust and non-redundant gene subsets that are relevant for the classification process, outperforming standard PSO methods.

A Peek into the Swarm: Analysis of the Gravitational Search Algorithm and Recommendations for Parameter Selection

Florian Knauf, *Hochschule Hannover*, Ralf Bruns, *Hochschule Hannover*

The Gravitational Search Algorithm is a swarm-based optimization metaheuristic that has been successfully applied to many problems. However, to date little analytical work has been done on this topic. This paper performs a mathematical analysis of the formulae underlying the Gravitational Search Algorithm. From this analysis, it derives key properties of the algorithm's expected behavior and recommendations for parameter selection. It then confirms through empirical examination that these recommendations are sound.

ACO-SI2

Tuesday, July 16, 10:40-12:20 Club C (1F)

Simultaneous Meta-Data and Meta-Classifier Selection in Multiple Classifier System

Thanh Tien Nguyen, *Robert Gordon University*, Vu Anh Luong, *Griffith University*, Van Thi Minh Nguyen, *Department of Planning and Investment, Ba Ria Vung Tau*, Sy Trong Ha, *Hanoi University of Science and Technology*, Alan Wee Chung Liew, *Griffith University*, John McCall, *Robert Gordon University*

In ensemble systems, the predictions of base classifiers are aggregated by a combining algorithm (meta-classifier) to achieve

better classification accuracy than using a single classifier. Experiments show that the performance of ensembles significantly depends on the choice of meta-classifier. Normally, the classifier selection method applied to an ensemble usually removes all the predictions of a classifier if this classifier is not selected in the final ensemble. Here we present an idea to only remove a subset of each classifier's prediction thereby introducing a simultaneous meta-data and meta-classifier selection method for ensemble systems. Our approach uses Cross Validation on the training set to generate meta-data as the predictions of base classifiers. We then use Ant Colony Optimization to search for the optimal subset of meta-data and meta-classifier for the data. By considering each column of meta-data, we construct the configuration including a subset of these columns and a meta-classifier. Specifically, the columns are selected according to their corresponding pheromones, and the meta-classifier is chosen at random. The classification accuracy of each configuration is computed based on Cross Validation on meta-data. Experiments on UCI datasets show the advantage of proposed method compared to several classifier and feature selection methods for ensemble systems.

Scaling Techniques for Parallel Ant Colony Optimization on Large Problem Instances

Joshua Peake, *Manchester Metropolitan University*, Martyn Amos, *Northumbria University*, Paraskevas Yiapanis, *Manchester Metropolitan University*, Huw Lloyd, *Manchester Metropolitan University*

Ant Colony Optimization (ACO) is a nature-inspired optimization metaheuristic which has been successfully applied to a wide range of different problems. However, a significant limiting factor in terms of its scalability is memory complexity; in many problems, the pheromone matrix which encodes trails left by ants grows quadratically with the instance size. For very large instances, this memory requirement is a limiting factor, making ACO an impractical technique. In this paper we propose a restricted variant of the pheromone matrix with linear memory complexity, which stores pheromone values only for members of a candidate set of next moves. We also evaluate two selection methods for moves outside the candidate set. Using a combination of these techniques we achieve, in a reasonable time, the best solution qualities recorded by ACO on the Art TSP Traveling Salesman Problem instances, and the first evaluation of a parallel implementation of Max-Min Ant System on instances of this scale. We find that, although ACO cannot yet achieve the solutions found by state-of-the-art genetic algorithms, we rapidly find approximate solutions within 1-2% of the best known.

AMclr - An Improved Ant-Miner to Extract Comprehensible and Diverse Classification Rules

Umair Ayub, *National University of Computer and Emerging Sciences*, Asim Ikram, *National University of Computer and Emerging Sciences*, Waseem Shahzad, *National University of Computer and Emerging Sciences*

Ant-Miner, a rule-based classifier, is a powerful algorithm used to extract classification rules. It has the ability to classify the complex data accurately but it has limitations of high selective pressure, and pre-mature convergence or very slow convergence. One of the big limitations is the correct prediction based evaluation of the rules that has not yet been addressed. In this paper, we propose a new ant-miner (named as AMclr) based on a new quality function, rank based term selection and on rule rejection thresholds. The new quality function is based on rule length, coverage and correct prediction. The rule rejection thresholds are based on coverage and quality of the rule. The proposed algorithm has been tested on various benchmark datasets and compared with other state of the art algorithms. The experimental results showed that the proposed approach achieved better results in terms of accuracy, convergence speed, and comprehensibility.

Complex Systems

CS1

Monday, July 15, 10:40-12:20 Club E (1F)

Novelty Search: a Theoretical Perspective

Stéphane Doncieux, *Sorbonne University*, Alban Laflaquière, *SoftBank Robotics EU*, Alexandre Coninx, *Sorbonne University*

Novelty Search is an exploration algorithm driven by the novelty of a behavior. The same individual evaluated at different generations has different fitness values. The corresponding fitness landscape is thus constantly changing and if, at the scale of a single generation, the metaphor of a fitness landscape with peaks and valleys still holds, this is not the case anymore at the scale of the whole evolutionary process. How does this kind of algorithms behave? Is it possible to define a model that would help understand how it works? This understanding is critical to analyse existing Novelty Search variants and design new and potentially more efficient ones. We assert that Novelty Search asymptotically behaves like a uniform random search process in the behavior space. This is an interesting feature, as it is not possible to directly sample in this space: the algorithm has a direct access to the genotype space only, whose relationship to the behavior space is complex. We describe the model and check its consistency on a classical Novelty Search experiment. We also show that it sheds a new light on results of the literature and suggests future research work.

Benchmarking Open-Endedness in Minimal Criterion

Coevolution

Jonathan C. Brant, *University of Central Florida*, Kenneth O. Stanley, *University of Central Florida*

Minimal criterion coevolution (MCC) was recently introduced to show that a very simple criterion can lead to an open-ended expansion of two coevolving populations. Inspired by the simplicity of striving to survive and reproduce in nature, in MCC there are few of the usual mechanisms of quality diversity algorithms: no explicit novelty, no fitness function, and no local competition. While the idea that a simple minimal criterion could produce quality diversity on its own is provocative, its initial demonstration on mazes and maze solvers was limited because the size of the potential mazes was static, effectively capping the potential for complexity to increase. This paper overcomes this limitation to make two significant contributions to the field: (1) By introducing a completely novel maze encoding with higher-quality mazes that allow indefinite expansion in size and complexity, it offers for the first time a viable, computationally cheap domain for benchmarking open-ended algorithms, and (2) it leverages this new domain to show for the first time a succession of mazes that increase in size indefinitely while solutions continue to appear. With this initial result, a baseline is now established that can help researchers to begin to mark progress in the field systematically.

Autonomous skill discovery with Quality-Diversity and Unsupervised Descriptors

Antoine Cully, *Imperial College*

Quality-Diversity optimization is a new family of optimization algorithms that, instead of searching for a single optimal solution to solving a task, searches for a large collection of solutions that all solve the task in a different way. This approach is particularly promising for learning behavioral repertoires in robotics, as such a diversity of behaviors enables robots to be more versatile and resilient. However, these algorithms require the user to manually define behavioral descriptors, which is used to determine whether two solutions are different or similar. The choice of a behavioral descriptor is crucial, as it completely changes the solution types that the algorithm derives. In this paper, we introduce a new method to automatically define this descriptor by combining Quality-Diversity algorithms with unsupervised dimensionality reduction algorithms. This approach enables robots to autonomously discover the range of their capabilities while interacting with their environment. The results from two experimental scenarios demonstrate that robot can autonomously discover a large range of possible behaviors, without any prior knowledge about their morphology and environment. Furthermore, these behaviors are deemed to be similar to handcrafted solutions that uses domain knowledge and significantly more diverse than when using existing unsupervised methods.

Modeling User Selection in Quality Diversity

Alexander Hagg, *Bonn-Rhein-Sieg University of Applied Sciences*, Alexander Asteroth, *Bonn-Rhein-Sieg University of Applied Sciences*, Thomas Bäck, *Leiden Institute of Advanced Computer Science*

The initial phase in real world engineering optimization and design is a process of discovery in which not all requirements can be made in advance, or are hard to formalize. Quality diversity algorithms, which produce a variety of high performing solutions, provide a unique chance to support engineers and designers in the search for what is possible and high performing. In this work we begin to answer the question how a user can interact with quality diversity and turn it into an interactive innovation aid. By modeling a user's selection it can be determined whether the optimization is drifting away from the user's preferences. The optimization is then constrained by adding a penalty to the objective function. We present an interactive quality diversity algorithm that can take into account the user's selection. The approach is evaluated in a new multimodal optimization benchmark that allows various optimization tasks to be performed. The user selection drift of the approach is compared to a state of the art alternative on both a planning and a neuroevolution control task, thereby showing its limits and possibilities.

CS2

Tuesday, July 16, 10:40-12:20 Club E (1F)

When Mating Improves On-line Collective robotics

Amine Boumaza, *University of Lorraine*

It has been long known from the theoretical work on evolution strategies, that recombination improves convergence towards better solution and improves robustness against selection error in noisy environment. We propose to investigate the effect of recombination in online embodied evolutionary robotics, where evolution is decentralized on a swarm of agents. We hypothesize that these properties can also be observed in these algorithms and thus could improve their performance. We introduce the (μ/μ, 1)-On-line EEA which use a recombination operator inspired from evolution strategies and apply it to learn three different collective robotics tasks, locomotion, item collection and item foraging. Different recombination operators are investigated and compared against a purely mutative version of the algorithm. The experiments show that, when correctly designed, recombination improves significantly the adaptation of the swarm in all scenarios.

Evolved embodied phase coordination enables robust quadruped robot locomotion

Jørgen Halvorsen Nordmoen, *University of Oslo*, Tønnes Frostad Nygaard, *University of Oslo*, Kai Olav Ellefsen, *University of Oslo*, Kyrre Glette, *University of Oslo*

Overcoming robotics challenges in the real world requires resilient control systems capable of handling a multitude of environments and unforeseen events. Evolutionary optimization

using simulations is a promising way to automatically design such control systems, however, if the disparity between simulation and the real world becomes too large, the optimization process may result in dysfunctional real-world behaviors. In this paper, we address this challenge by considering embodied phase coordination in the evolutionary optimization of a quadruped robot controller based on central pattern generators. With this method, leg phases, and indirectly also inter-leg coordination, are influenced by sensor feedback. By comparing two very similar control systems we gain insight into how the sensory feedback approach affects the evolved parameters of the control system, and how the performances differ in simulation, in transferal to the real world, and to different real-world environments. We show that evolution enables the design of a control system with embodied phase coordination which is more complex than previously seen approaches, and that this system is capable of controlling a real-world multi-jointed quadruped robot. The approach reduces the performance discrepancy between simulation and the real world, and displays robustness towards new environments.

Evolvability ES: Scalable and Direct Optimization of Evolvability

Alexander Gajewski, *Columbia University*, Jeff Clune, *Uber AI Labs*, Kenneth O. Stanley, *Uber AI Labs*, Joel Lehman, *Uber AI Labs*

Designing algorithms capable of uncovering highly evolvable representations is an open challenge in evolutionary computation; such evolvability is important in practice, because it accelerates evolution and enables fast adaptation to changing circumstances. This paper introduces evolvability ES, an evolutionary algorithm designed to explicitly and efficiently optimize for evolvability, i.e. the ability to further adapt. The insight is that it is possible to derive a novel objective in the spirit of natural evolution strategies that maximizes the diversity of behaviors exhibited when an individual is subject to random mutations, and that efficiently scales with computation. Experiments in 2-D and 3-D locomotion tasks highlight the potential of evolvability ES to generate solutions with tens of thousands of parameters that can quickly be adapted to solve different tasks and that can productively seed further evolution. We further highlight a connection between evolvability in EC and a recent and popular gradient-based meta-learning algorithm called MAML; results show that evolvability ES can perform competitively with MAML and that it discovers solutions with distinct properties. The conclusion is that evolvability ES opens up novel research directions for studying and exploiting the potential of evolvable representations for deep neural networks.

Effects of environmental conditions on evolved robot morphologies and behavior

Karine Miras, *Vrije Universiteit Amsterdam*, A.E. Eiben, *Vrije Universiteit Amsterdam*

This paper studies the effects of different environments on morphological and behavioral properties of evolving populations of modular robots. To assess these properties, a set of morphological and behavioral descriptors was defined and the evolving population mapped in this multi-dimensional space. Surprisingly, the results show that seemingly distinct environments can lead to the same regions of this space, i.e., evolution can produce the same kind of morphologies/behaviors under conditions that humans perceive as quite different. These experiments indicate that demonstrating the 'ground truth' of evolution stating the firm impact of the environment on evolved morphologies is harder in evolutionary robotics than usually assumed.

CS3+GECH3: Best papers

Tuesday, July 16, 14:00-15:40 South Hall 1A (1F)

POET: Open-Ended Coevolution of Environments and their Optimized Solutions ☆

Rui Wang, *Uber AI Labs*, Joel Lehman, *Uber AI Labs*, Jeff Clune, *Uber AI Labs*, Kenneth O. Stanley, *Uber AI Labs*

How can progress in machine learning and reinforcement learning be automated to generate its own never-ending curriculum of challenges without human intervention? The recent emergence of quality diversity (QD) algorithms offers a glimpse of the potential for such continual open-ended invention. For example, novelty search showcases the benefits of explicit novelty pressure, MAP-Elites and Innovation Engines highlight the advantage of explicit elitism within niches in an otherwise divergent process, and minimal criterion coevolution (MCC) reveals that problems and solutions can coevolve divergently. The Paired Open-Ended Trailblazer (POET) algorithm introduced in this paper combines these principles to produce a practical approach to generating an endless progression of diverse and increasingly challenging environments while at the same time explicitly optimizing their solutions. An intriguing implication is the opportunity to transfer solutions among environments, reflecting the view that innovation is a circuitous and unpredictable process. POET is tested in a 2-D obstacles course domain, where it generates diverse and sophisticated behaviors that create and solve a wide range of environmental challenges, many of which cannot be solved by direct optimization, or by a direct-path curriculum-building control algorithm. We hope that POET will inspire a new push towards open-ended discovery across many domains.

Learning with Delayed Synaptic Plasticity

Anil Yaman, *Technical University of Eindhoven*, Giovanni Iacca, *University of Trento*, Decebal Constantin Mocanu, *Technical University of Eindhoven*, George Fletcher, *Technical University of Eindhoven*, Mykola Pechenizkiy, *Technical University of Eindhoven*

The plasticity property of biological neural networks allows them to perform learning and optimize their behavior by changing their configuration. Inspired by biology, plasticity can be modeled in artificial neural networks by using Hebbian learning rules, i.e. rules that update synapses based on the neuron activations and reinforcement signals. However, the distal reward problem arises when the reinforcement signals are not available immediately after each network output to associate the neuron activations that contributed to receiving the reinforcement signal. In this work, we extend Hebbian plasticity rules to allow learning in distal reward cases. We propose the use of neuron activation traces (NATs) to provide additional data storage in each synapse to keep track of the activation of the neurons. Delayed reinforcement signals are provided after each episode relative to the networks' performance during the previous episode. We employ genetic algorithms to evolve delayed synaptic plasticity (DSP) rules and perform synaptic updates based on NATs and delayed reinforcement signals. We compare DSP with an analogous hill climbing algorithm that does not incorporate domain knowledge introduced with the NATs, and show that the synaptic updates performed by the DSP rules demonstrate more effective training performance relative to the HC algorithm.

Selection mechanisms affect volatility in evolving markets

David Rushing Dewhurst, *University of Vermont*, Michael V. Arnold, *University of Vermont*, Colin M. Van Oort, *University of Vermont*

Financial asset markets are sociotechnical systems whose constituent agents are subject to evolutionary pressure as unprofitable agents exit the marketplace and more profitable agents continue to trade assets. Using a population of evolving zero-intelligence agents and a frequent batch auction price-discovery mechanism as substrate, we analyze the role played by evolutionary selection mechanisms in determining macro-observable market statistics. Specifically, we show that selection mechanisms incorporating a local fitness-proportionate component are associated with high correlation between a micro risk-aversion parameter and a commonly-used macro-volatility statistic, while a purely quantile-based selection mechanism shows significantly less correlation and is associated with higher absolute levels of fitness (profit) than other selection mechanisms. These results point the way to a possible restructuring of market incentives toward reduction in market-wide worst performance, leading profit-driven agents to behave in ways that are associated with beneficial macro-level outcomes.

Digital Entertainment Technologies and Arts

DETA1+SBSE2+THEORY2: Best papers

Tuesday, July 16, 10:40-12:20 South Hall 1B (1F)

Evolving Dota 2 Shadow Fiend Bots using Genetic Programming with External Memory ☆

Robert Jacob Smith, *Dalhousie University*, Malcolm I. Heywood, *Dalhousie University*

The capacity of genetic programming (GP) to evolve a 'hero' character in the Dota 2 video game is investigated. A reinforcement learning context is assumed in which the only input is a 320-dimensional state vector and performance is expressed in terms of kills and net worth. Minimal assumptions are made to initialize the GP game playing agents – evolution from a tabula rasa starting point – implying that: 1) the instruction set is not task specific; 2) end of game performance feedback reflects quantitive properties a player experiences; 3) no attempt is made to impart game specific knowledge into GP, such as heuristics for improving navigation, minimizing partial observability, improving team work or prioritizing the protection of specific strategically important structures. In short, GP has to actively develop its own strategies for all aspects of the game. We are able to demonstrate competitive play with the built in game opponents assuming 1-on-1 competitions using the 'Shadow Fiend' hero. The single most important contributing factor to this result is the provision of external memory to GP. Without this, the resulting Dota 2 bots are not able to identify strategies that match those of the built-in game bot.

DETA2

Wednesday, July 17, 09:00-10:40 Club E (1F)

On the Impact of Domain-specific Knowledge in Evolutionary Music Composition

Csaba Sulyok, *Babes-Bolyai University*, Christopher Harte, *Melodient Ltd.*, Zalán Bodó, *Babes-Bolyai University*

In this paper we investigate the effect of embedding different levels of musical knowledge in the virtual machine (VM) architectures and phenotype representations of an algorithmic music composition system. We examine two separate instruction sets for a linear genetic programming framework that differ in their knowledge of musical structure: one a Turing-complete register machine, unaware of the nature of its output; the other a domain-specific language tailored to operations typically employed in the composition process. Our phenotype, the output of the VM, is rendered as a musical model comprising a sequence of notes represented by duration and pitch. We compare three different pitch schemes with differing embedded knowledge of tonal concepts, such as key and mode. To derive a fitness metric, we extract musical features from a corpus of Hungarian folk songs in the form of n-grams and entropy values. Fitness is assessed by extracting those same attributes from the phenotype and finding the maximal similarity with

representative corpus features. With two different VM architectures and three pitch schemes, we present and compare results from a total of six configurations, and analyze whether the domain-specific knowledge impacts the results and the rate of convergence in a beneficial manner.

Mapping Hearthstone Deck Spaces through MAP-Elites with Sliding Boundaries

Matthew C. Fontaine, *Independent*, Scott Lee, *Independent*, L. B. Soros, *Champlain College*, Fernando De Mesentier Silva, *Independent*, Julian Togelius, *New York University*, Amy K. Hoover, *New Jersey Institute of Technology*

Quality diversity (QD) algorithms such as MAP-Elites have emerged as a powerful alternative to traditional single-objective optimization methods. They were initially applied to evolutionary robotics problems such as locomotion and maze navigation, but have yet to see widespread application. We argue that these algorithms are perfectly suited to the rich domain of video games, which contains many relevant problems with a multitude of successful strategies and often also multiple dimensions along which solutions can vary. This paper introduces a novel modification of the MAP-Elites algorithm called MAP-Elites with Sliding Boundaries (MESB) and applies it to the design and rebalancing of Hearthstone, a popular collectible card game chosen for its number of multidimensional behavior features relevant to particular styles of play. To avoid overpopulating cells with conflated behaviors, MESB slides the boundaries of cells based on the distribution of evolved individuals. Experiments in this paper demonstrate the performance of MESB in Hearthstone. Results suggest MESB finds diverse ways of playing the game well along the selected behavioral dimensions. Further analysis of the evolved strategies reveals common patterns that recur across behavioral dimensions and explores how MESB can help rebalance the game.

Tile Pattern KL-Divergence for Analysing and Evolving Game Levels

Simon M. Lucas, *Queen Mary University of London*, Vanessa Volz, *Queen Mary University of London*

This paper provides a detailed investigation of using the Kullback-Leibler (KL) Divergence as a way to compare and analyse game-levels, and hence to use the measure as the objective function of an evolutionary algorithm to evolve new levels. We describe the benefits of its asymmetry for level analysis and demonstrate how (not surprisingly) the quality of the results depends on the features used. Here we use tile-patterns of various sizes as features. When using the measure for evolution-based level generation, we demonstrate that the choice of variation operator is critical in order to provide an efficient search process, and introduce a novel convolutional mutation operator to facilitate this. We compare the results with alternative generators, including evolving in the latent space of generative adversarial networks, and Wave Function Collapse. The results clearly show the proposed method to provide competitive performance, providing reasonable quality results with very fast training and reasonably fast generation.

Evolutionary Combinatorial Optimization and Metaheuristics

ECOM1

Monday, July 15, 10:40-12:20 Club D (1F)

When Resampling to Cope With Noise, Use Median, Not Mean

Benjamin Doerr, *Ecole Polytechnique*, Andrew M. Sutton, *University of Minnesota Duluth*

Due to their randomized nature, many nature-inspired heuristics are robust to some level of noise in the fitness evaluations. A common strategy to increase the tolerance to noise is to re-evaluate the fitness of a solution candidate several times and to then work with the average of the sampled fitness values. In this work, we propose to use the median instead of the mean. Besides being invariant to rescalings of the fitness, the median in many situations turns out to be much more robust than the mean. We show that when the noisy fitness is ϵ-concentrated, then a logarithmic number of samples suffice to discover the undisturbed fitness (via the median of the samples) with high probability. This gives a simple metaheuristic approach to transform a randomized optimization heuristics into one that is robust to this type of noise and that has a runtime higher than the original one only by a logarithmic factor. We show further that ϵ-concentrated noise occurs frequently in standard situations. We also provide lower bounds showing that in two such situations, even with larger numbers of samples, the average-resample strategy cannot efficiently optimize the problem in polynomial time.

Fast Re-Optimization via Structural Diversity

Benjamin Doerr, *Ecole Polytechnique*, Carola Doerr, *CNRS*, Frank Neumann, *The University of Adelaide*

When a problem instance is perturbed by a small modification, one would hope to find a good solution for the new instance by building on a known good solution for the previous one. Via a rigorous mathematical analysis, we show that evolutionary algorithms, despite usually being robust problem solvers, can have unexpected difficulties to solve such re-optimization problems. When started with a random Hamming neighbor of the optimum, the (1+1) evolutionary algorithm takes $\Omega(n^2)$ time to optimize the LeadingOnes benchmark function, which is the same asymptotic optimization time when started in a randomly chosen solution. We then propose a way to overcome such difficulties. As our mathematical analysis reveals, the reason for this undesired behavior is that during the opti-

mization structurally good solutions can easily be replaced by structurally worse solutions of equal or better fitness. We propose a simple diversity mechanism that prevents this behavior, thereby reducing the re-optimization time for LeadingOnes to $O(\gamma\delta n)$, where γ is the population size used by the diversity mechanism and $\delta \leq \gamma$ the Hamming distance of the new optimum from the previous solution. We show similarly fast re-optimization times for the optimization of linear functions with changing constraints and for the minimum spanning tree problem.

On Inversely Proportional Hypermutations with Mutation Potential

Dogan Corus, *The University of Sheffield*, Pietro S. Oliveto, *The University of Sheffield*, Donya Yazdani, *The University of Sheffield*

Artificial Immune Systems (AIS) employing hypermutations with linear static mutation potential have recently been shown to be very effective at escaping local optima of combinatorial optimisation problems at the expense of being slower during the exploitation phase compared to standard evolutionary algorithms. In this paper, we prove that considerable speed-ups in the exploitation phase may be achieved with dynamic inversely proportional mutation potentials (IPM) and argue that the potential should decrease inversely to the distance to the optimum rather than to the difference in fitness. Afterwards, we define a simple (1+1) Opt-IA that uses IPM hypermutations and ageing for realistic applications where optimal solutions are unknown. The aim of this AIS is to approximate the ideal behaviour of the inversely proportional hypermutations better and better as the search space is explored. We prove that such desired behaviour and related speed-ups occur for a well-studied bimodal benchmark function called TwoMax. Furthermore, we prove that the (1+1) Opt-IA with IPM efficiently optimises a second multimodal function, Cliff, by escaping its local optima while Opt-IA with static mutation potential cannot, thus requires exponential expected runtime in the distance between the local and global optima.

Characterising the Rankings Produced by Combinatorial Optimisation Problems and Finding their Intersections

Leticia Hernando, *University of the Basque Country UPV/EHU*, Alexander Mendiburu, *University of the Basque Country UPV/EHU*, Jose Antonio Lozano, *Basque Center for Applied Mathematics (BCAM)*

The aim of this paper is to introduce the concept of intersection between combinatorial optimisation problems. We take into account that most algorithms, in their machinery, do not consider the exact objective function values of the solutions, but only a comparison between them. In this sense, if the solutions of an instance of a combinatorial optimisation problem are sorted into their objective function values, we can see the instances as (partial) rankings of the solutions of the search space. Working with specific problems, particularly, the linear ordering problem and the symmetric and asymmetric traveling salesman problem, we show that they can not generate the whole set of (partial) rankings of the solutions of the search space, but just a subset. First, we characterise the set of (partial) rankings each problem can generate. Secondly, we study the intersections between these problems: those rankings which can be generated by both the linear ordering problem and the symmetric/asymmetric traveling salesman problem, respectively. The fact of finding large intersections between problems can be useful in order to transfer heuristics from one problem to another, or to define heuristics that can be useful for more than one problem.

ECOM2

Monday, July 15, 14:00-15:40 Club D (1F)

Investigation of the Traveling Thief Problem

Rogier Hans Wuijts, *Utrecht University*, Dirk Thierens, *Utrecht University*

The Traveling Thief Problem (TTP) is a relatively new benchmark problem created to study problems which consist of interdependent subproblems. In this paper we investigate what the fitness landscape characteristics are of some smaller instances of the TTP with commonly used local search operators in the context of metaheuristics that uses local search. The local search operators include: 2-opt, Insertion, Bitflip and Exchange and metaheuristics include: multi-start local search, iterated local search and genetic local search. Fitness landscape analysis shows among other things that TTP instances contain a lot of local optima but their distance to the global optimum is correlated with its fitness. Local optima networks with respect to an iterated local search reveals that TTP has a multi-funnel structure. Other experiments show that a steady state genetic algorithm with edge assembly crossover outperforms multi-start local search, iterated local search and genetic algorithms with different tour crossovers. At last we performed a comparative study using the genetic algorithm with edge assembly crossover on relatively larger instances of the commonly used benchmark suite. As a result we found new best solutions to almost all studied instances.

Predict or Screen Your Expensive Assay? DoE vs. Surrogates in Experimental Combinatorial Optimization

Naama Horesh, *The Galilee Research Institute - Migal*, Thomas Bäck, *Leiden University*, Ofer M. Shir, *Tel-Hai College*

Statistics-based Design of Experiments (DoE) methodologies are considered the gold standard in existing laboratory equipment for screening predefined experimental assays. Thus far, very little is formally known about their effectiveness in light of global optimization, particularly when compared to evolutionary heuristics. The current study, which was ignited by evolution-in-the-loop of functional protein expression, aims to

conduct such a comparison with a focus on Combinatorial Optimization considering a dozen of decision variables, a search-space cardinality of several million combinations, under a budget of a couple of thousands of function evaluations. Due to the limited budget of evaluations, we argue that surrogate-assisted search methods become relevant for this application domain. To this end, we study a specific so-called Categorical Evolution Strategy (CatES). We systematically compare its performance, with and without being assisted by state-of-the-art surrogates, to DoE-based initialization of the search (exploiting the budget partially or entirely). Our empirical findings show that the surrogate-based approach is superior, as it significantly outperforms the DoE techniques and the CatES alone on the majority of the problems subject to the budget constraint. We conclude by projecting the strengths and weaknesses of EAs versus DoE, when run either directly or surrogate-aided.

Walsh Functions as Surrogate Model for Pseudo-Boolean Optimization Problems

Florian Leprêtre, *Université du Littoral Côte d'Opale*, Sébastien Verel, *Université du Littoral Côte d'Opale*, Cyril Fonlupt, *Université du Littoral Côte d'Opale*, Virginie Marion, *Université du Littoral Côte d'Opale*

Surrogate-modeling is about formulating quick-to-evaluate mathematical models, to approximate black-box and time-consuming computations or simulation tasks. Although such models are well-established to solve continuous optimization problems, very few investigations regard the optimization of combinatorial structures. These structures deal for instance with binary variables, allowing each compound in the representation of a solution to be activated or not. Still, this field of research is experiencing a sudden renewed interest, bringing to the community fresh algorithmic ideas for growing these particular surrogate models. This article proposes the first surrogate-assisted optimization algorithm (WSaO) based on the mathematical foundations of discrete Walsh functions, combined with the powerful grey-box optimization techniques in order to solve pseudo-boolean optimization problems. We conduct our experiments on a benchmark of combinatorial structures and demonstrate the accuracy and the optimization efficiency of the proposed model. We finally highlight how Walsh surrogates may outperform the state-of-the-art surrogate models for pseudo-boolean functions.

ECOM3

Tuesday, July 16, 10:40-12:20 Club D (1F)

A Two-stage Genetic Programming Hyper-heuristic Approach with Feature Selection for Dynamic Flexible Job Shop Scheduling

Fangfang Zhang, *Victoria University of Wellington*, Yi Mei, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Dynamic flexible job shop scheduling (DFJSS) is an important and a challenging combinatorial optimisation problem. Genetic programming hyper-heuristic (GPHH) has been widely used for automatically evolving the routing and sequencing rules for DFJSS. The terminal set is the key to the success of GPHH. There are a wide range of features in DFJSS that reflect different characteristics of the job shop state. However, the importance of a feature can vary from one scenario to another, and some features may be redundant or irrelevant under the considered scenario. Feature selection is a promising strategy to remove the unimportant features and reduce the search space of GPHH. However, no work has considered feature selection in GPHH for DFJSS so far. In addition, it is necessary to do feature selection for the two terminal sets simultaneously. In this paper, we propose a new two-stage GPHH approach with feature selection for evolving routing and sequencing rules for DFJSS. The experimental studies show that the best solutions achieved by the proposed approach are better than that of the baseline method in most scenarios. Furthermore, the rules evolved by the proposed approach involve a smaller number of unique features, which are easier to interpret.

Application of CMSA to the Minimum Capacitated Dominating Set Problem

Pedro Pinacho-Davidson, *Universidad de Concepción*, Salim Bouamama, *University of Ferhat Abbas - Sétif 1*, Christian Blum, *Artificial Intelligence Research Institute (IIIA-CSIC)*

This work deals with the so-called minimum capacitated dominating set (CAPMDS) problem, which is an NP-Hard combinatorial optimization problem in graphs. In this paper we describe the application of a recently introduced hybrid algorithm known as Construct, Merge, Solve & Adapt (CMSA) to this problem. Moreover, we evaluate the performance of a standalone ILP solver. The results show that both CMSA and the ILP solver outperform current state-of-the-art algorithms from the literature. Moreover, in contrast to the ILP solver, the performance of CMSA does not degrade for the largest problem instances. The experimental evaluation is based on a benchmark dataset containing two different graph topologies and considering graphs with variable and uniform node capacities.

An Improved Merge Search Algorithm For the Constrained Pit Problem in Open-pit Mining

Angus Kenny, *RMIT University*, Xiaodong Li, *RMIT University*, Andreas Ernst, *Monash University*, Yuan Sun, *RMIT University*

Conventional mixed-integer programming (MIP) solvers can struggle with many large-scale combinatorial problems, as they contain too many variables and constraints. Meta-heuristics can be applied to reduce the size of these problems by removing or aggregating variables or constraints. Merge search algorithms achieve this by generating populations of solutions, either by heuristic construction, or by finding neighbours to an initial solution. This paper presents a merge search algorithm that improves the population generation heuristic for

a previously published merge search algorithm and utilises a variable grouping heuristic that exploits the common information across a population to aggregate groups of variables in order to create a reduced sub-problem. The algorithm is tested on some well known benchmarks for a complex problem called the constrained pit (CPIT) problem and it is compared to results produced by a merge search algorithm previously used on the same problem and the results published on the minelib website.

Evolutionary Algorithms for the Chance-Constrained Knapsack Problem

Yue Xie, *The University of Adelaide*, Oscar Harper, *The University of Adelaide*, Hirad Assimi, *The University of Adelaide*, Aneta Neumann, *The University of Adelaide*, Frank Neumann, *The University of Adelaide*

Evolutionary algorithms have been widely used for a range of stochastic optimization problems. In most studies, the goal is to optimize the expected quality of the solution. Motivated by real-world problems where constraint violations have extremely disruptive effects, we consider a variant of the knapsack problem where the profit is maximized under the constraint that the knapsack capacity bound is violated with a small probability of at most α. This problem is known as chance-constrained knapsack problem and chance-constrained optimization problems have so far gained little attention in the evolutionary computation literature. We show how to use popular deviation inequalities such as Chebyshev's inequality and Chernoff bounds as part of the solution evaluation when tackling these problems by evolutionary algorithms and compare the effectiveness of our algorithms on a wide range of chance-constrained knapsack instances.

ECOM4

Tuesday, July 16, 14:00-15:40 Club D (1F)

Route Planning for Cooperative Air-Ground Robots with Fuel Constraints: An Approach based on CMSA

Divansh Arora, *IIIT-Delhi*, Parikshit Maini, *IIIT-Delhi*, Pedro Pinacho-Davidson, *Universidad de Concepción*, Christian Blum, *Artificial Intelligence Research Institute (IIIA-CSIC)*

Limited payload capacity on small unmanned aerial vehicles (UAVs) results in restricted flight time. In order to increase the operational range of UAVs, recent research has focused on the use of mobile ground charging stations. The cooperative route planning for both aerial and ground vehicles (GVs) is strongly coupled due to fuel constraints of the UAV, terrain constraints of the GV and the speed differential of the two vehicles. This problem is, in general, an NP-hard combinatorial optimization problem. Existing polynomial-time solution approaches make a trade-off in solution quality for large-scale scenarios and generate solutions with large relative gaps (up to 50 %) from known lower bounds. In this work, we employ a hybrid metaheuristic known as Construct, Merge, Solve & Adapt (CMSA) in order to develop a scalable and computationally efficient solution approach. We discuss results for large scale scenarios and provide a comparative analysis with the current state-of-the-art.

A Memetic Algorithm Approach to Network Alignment : Mapping the Classification of Mental Disorders of DSM-IV with ICD-10

Mohammad Nazmul Haque, *The University of Newcastle*, Luke Mathieson, *University of Technology Sydney*, Pablo Moscato, *The University of Newcastle*

Given two graphs modelling related, but possibly distinct, networks, the alignment of the networks can help identify significant structures and substructures which may relate to the functional purpose of the network components. The Network Alignment Problem is the NP-hard computational formalisation of this goal and is a useful technique in a variety of data mining and knowledge discovery domains. In this paper we develop a memetic algorithm to solve the Network Alignment Problem and demonstrate the effectiveness of the approach on a series of biological networks against the existing state of the art alignment tools. We also demonstrate the use of network alignment as a clustering and classification tool on two mental health disorder diagnostic databases.

Fitness Comparison by Statistical Testing in Construction of SAT-Based Guess-and-Determine Cryptographic Attacks

Artem Pavlenko, *ITMO University*, Maxim Buzdalov, *ITMO University*, Vladimir Ulyantsev, *ITMO University*

Algebraic cryptanalysis studies breaking ciphers by solving algebraic equations. Some of the promising approaches use SAT solvers for this purpose. Although the corresponding satisfiability problems are hard, their difficulty can often be lowered by choosing a set of variables to brute force over, and by solving each of the corresponding reduced problems using a SAT solver, which is called the guess-and-determine attack. In many successful cipher breaking attempts this set was chosen analytically, however, the nature of the problem makes evolutionary computation a good choice. We investigate one particular method for constructing guess-and-determine attacks based on evolutionary algorithms. This method estimates the fitness of a particular guessed bit set by Monte-Carlo simulations. We show that using statistical tests within the comparator of fitness values, which can be used to reduce the necessary number of samples, together with a dynamic strategy for the upper limit on the number of samples, speeds up the attack by a factor of 1.5 to 4.3 even on a distributed cluster.

A characterisation of S-box fitness landscape in cryptography

Domagoj Jakobovic, *University of Zagreb*, Stjepan Picek, *Delft University of Technology*, Marcella Ribeiro, *Federal University of Technology - Paraná/Brazil*, Markus Wagner, *University of Adelaide*

Substitution Boxes (S-boxes) are nonlinear objects often used in the design of cryptographic algorithms. The design of high quality S-boxes is an interesting problem that attracts a lot of attention. Many attempts have been made in recent years to use heuristics to design S-boxes, but the results were often far from the previously known best obtained ones. Unfortunately, most of the effort went into exploring different algorithms and fitness functions while little attention has been given to the understanding why this problem is so difficult for heuristics. In this paper, we conduct a fitness landscape analysis to better understand why this problem can be difficult. Among other, we find that almost each initial starting point has its own local optimum, even though the networks are highly interconnected.

ECOM5: Best papers

Tuesday, July 16, 16:10-17:50 South Hall 1B (1F)

A generic approach to districting with diameter or center-based objectives ☆

Alex Gliesch, *Federal University of Rio Grande do Sul*, Marcus Ritt, *Federal University of Rio Grande do Sul*

Districting is the problem of grouping basic geographic units into clusters called districts. Districts are typically required to be geometrically compact, contiguous, and evenly balanced with respect to attributes of the basic units. Though most applications share these core criteria, domain-specific constraints and objective functions are common. This leads to a fragmented literature with different approaches for similar domains and hinders comparisons between these approaches. In this paper we study a unified heuristic approach that can handle three of the most common objective functions concerning compactness: diameter, p-center and p-median, as well as a variable number of balancing attributes. We propose a multi-start method which iteratively constructs greedy randomized solutions followed by an improvement phase which alternates between optimizing compactness and satisfying balancing constraints through a series of tabu searches. Experiments show that the proposed method is competitive when compared to approaches in the literature which are specific to each objective, improving known upper bounds in some cases.

Algorithm Selection Using Deep Learning Without Feature Extraction ☆

Mohamad Alissa, *Edinburgh Napier University*, Kevin Sim, *Edinburgh Napier University*, Emma Hart, *Edinburgh Napier University*

We propose a novel technique for algorithm selection which adopts a deep-learning approach, specifically a Recurrent-Neural Network with Long-Short-Term-Memory (RNN-LSTM). In contrast to the majority of work in algorithm-selection, the approach does not need any features to be extracted from the data but instead relies on the temporal data sequence as input. A large case study in the domain of 1-d bin packing is undertaken in which instances can be solved by one of four heuristics. We first evolve a large set of new problem instances that each have a clear "best solver" in terms of the heuristics considered. An RNN-LSTM is trained directly using the sequence data describing each instance to predict the best-performing heuristic. Experiments conducted on small and large problem instances with item sizes generated from two different probability distributions are shown to achieve between 7% to 11% improvement over the single best solver (SBS) (i.e. the single heuristic that achieves the best performance over the instance set) and 0% to 2% lower than the virtual best solver (VBS), i.e the perfect mapping.

Adaptive Large Neighborhood Search for Scheduling of Mobile Robots ☆

Quang-Vinh Dang, *Masaryk University*, Hana Rudová, *Masaryk University*, Cong Thanh Nguyen, *Ho Chi Minh City University of Technology*

Our work addresses the scheduling of mobile robots for transportation and processing of operations on machines in a flexible manufacturing system. Both mobile robots and automated guided vehicles (AGVs) can transport components among machines in the working space. Nevertheless, the difference is that mobile robots considered in this work can process specific value-added operations, which is not possible for AGVs. This new feature increases complexity as well as computational demands. To summarize, we need to compute a sequence of operations on machines, the robot assignments for transportation, and the robot assignments for processing. The main contribution is the proposal of an adaptive large neighborhood search algorithm with the sets of exploration and exploitation heuristics to solve the problem considering makespan minimization. Experimental evaluation is presented on the existing benchmarks. The quality of our solutions is compared to a heuristic based on genetic algorithm and mixed-integer programming proposed recently. The comparison shows that our approach can achieve comparable results in real time which is in order of magnitude faster than the earlier heuristic.

Evolutionary Machine Learning

EML1: Best papers

Monday, July 15, 10:40-12:20 South Hall 1B (1F)

Evolving Controllably Difficult Datasets for Clustering ☆

Cameron Shand, *University of Manchester*, Richard Allmendinger, *University of Manchester*, Julia Handl, *University of Manchester*, Andrew Webb, *University of Manchester*, John

Keane, *University of Manchester*

Synthetic datasets play an important role in evaluating clustering algorithms, as they can help shed light on consistent biases, strengths, and weaknesses of particular techniques, thereby supporting sound conclusions. Despite this, there is a surprisingly small set of established clustering benchmark data, and many of these are currently handcrafted. Even then, their difficulty is typically not quantified or considered, limiting the ability to interpret algorithmic performance on these datasets. Here, we introduce a new data generator that uses an evolutionary algorithm to evolve cluster structure of a synthetic data set. We demonstrate how such an approach can be used to produce datasets of a pre-specified difficulty, to trade off different aspects of problem difficulty, and how these interventions directly translate into changes in the clustering performance of established algorithms.

NSGA-Net: Neural Architecture Search using Multi-Objective Genetic Algorithm ☆

Zhichao Lu, *Michigan State University*, Ian Whalen, *Michigan State University*, Vishnu Boddeti, *Michigan State University*, Yashesh Dhebar, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*, Erik Goodman, *Michigan State University*, Wolfgang Banzhaf, *Michigan State University*

This paper introduces NSGA-Net – an evolutionary approach for neural architecture search. NSGA-Net is designed with three goals in mind: (1) a procedure considering multiple conflicting objectives, (2) an efficient procedure balancing exploration and exploitation of the space of potential neural network architectures, and (3) a procedure finding a diverse set of trade-off network architectures in a single run. NSGA-Net is a population-based search algorithm that explores a space of potential neural network architectures in three steps, namely, a population initialization step that is based on prior-knowledge from handcrafted architectures, an exploration step comprising crossover and mutation of architectures, and finally an exploitation step that utilizes the hidden useful knowledge stored in the history of evaluated neural architectures in the form of a Bayesian Network. Experimental results suggest that combining the dual objectives of minimizing an error metric and computational complexity allows NSGA-Net to find competitive neural architectures. Moreover, NSGA-Net achieves a comparable error rate on the CIFAR-10 dataset when compared to other state-of-the-art evolution and reinforcement learning based NAS methods while using orders of magnitude less computational resources. These results should be encouraging to EC researchers showing promise to further use of EC methods in various deep learning paradigms.

Efficient Personalized Community Detection via Genetic Evolution

Zheng Gao, *Indiana University Bloomington*, Chun Guo, *Pandora Media LLC*, Xiaozhong Liu, *Indiana University Bloomington*

Personalized community detection aims to generate communities associated with user need on graphs, which benefits many downstream tasks such as node recommendation and link prediction for users, etc. It is of great importance but lack of enough attention in previous studies which are on topics of user-independent, semi-supervised, or top-K user-centric community detection. Meanwhile, most of their models are time consuming due to the complex graph structure. Different from these topics, personalized community detection requires to provide higher-resolution partition on nodes that are more relevant to user need while coarser manner partition on the remaining less relevant nodes. In this paper, to solve this task in an efficient way, we propose a genetic model including an offline and an online step. In the offline step, the user-independent community structure is encoded as a binary tree. And subsequently an online genetic pruning step is applied to partition the tree into communities. To accelerate the speed, we also deploy a distributed version of our model to run under parallel environment. Extensive experiments on multiple datasets show that our model outperforms the state-of-arts with significantly reduced running time.

Population-based Ensemble Classifier Induction for Domain Adaptation

Bach Hoai Nguyen, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*, Peter Andreae, *Victoria University of Wellington*

In classification, the task of domain adaptation is to learn a classifier to classify target data using unlabeled data from the target domain and labeled data from a related, but not identical, source domain. Transfer classifier induction is a common domain adaptation approach that learns an adaptive classifier directly rather than first adapting the source data. However, most existing transfer classifier induction algorithms are gradient-based, so they can easily get stuck at local optima. Moreover, they usually generate only a single classifier which might fit the source data too well, which results in poor target accuracy. In this paper, we propose a population-based algorithm that can address the above two limitations. The proposed algorithm can re-initialize a population member to a promising region when the member is trapped at local optima. The population-based mechanism allows the proposed algorithm to output a set of classifiers which is more reliable than a single classifier. The experimental results show that the proposed algorithm achieves significantly better target accuracy than four state-of-the-art and well-known domain adaptation algorithms on three real-world domain adaptation problems.

EML2

Monday, July 15, 16:10-17:50 Club E (1F)

Evolutionary Neural AutoML for Deep Learning

Jason Liang, *Cognizant Technology Solutions*, Elliot Meyerson,

Cognizant Technology Solutions, Risto Miikkulainen, *Cognizant Technology Solutions*, Babak Hodjat, *Cognizant Technology Solutions*, Dan Fink, *Cognizant Technology Solutions*, Karl Mutch, *Cognizant Technology Solutions*

Deep neural networks (DNNs) have produced state-of-the-art results in many benchmarks and problem domains. However, the success of DNNs depends on the proper configuration of its architecture and hyperparameters. Such a configuration is difficult and as a result, DNNs are often not used to their full potential. In addition, DNNs in commercial applications often need to satisfy real-world design constraints such as size or number of parameters. To make configuration easier, automatic machine learning (AutoML) systems for deep learning have been developed, focusing mostly on optimization of hyperparameters. This paper takes AutoML a step further. It introduces an evolutionary AutoML framework called LEAF that not only optimizes hyperparameters but also network architectures and the size of the network. LEAF makes use of both state-of-the-art evolutionary algorithms (EAs) and distributed computing frameworks. Experimental results on medical image classification and natural language analysis show that the framework can be used to achieve state-of-the-art performance In particular, LEAF demonstrates that architecture optimization provides a significant boost over hyperparameter optimization, and that networks can be minimized at the same time with little drop in performance. LEAF therefore forms a foundation for democratizing and improving AI, as well as making AI practical in future applications.

Evolving Deep Neural Networks by Multi-objective Particle Swarm Optimization for Image Classification

Bin Wang, *Victoria University of Wellington*, Yanan Sun, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

In recent years, convolutional neural networks (CNNs) have become deeper in order to achieve better classification accuracy in image classification. However, it is difficult to deploy the state-of-the-art deep CNNs for industrial use due to the difficulty of manually fine-tuning the hyperparameters and the trade-off between classification accuracy and computational cost. This paper proposes a novel multi-objective optimization method for evolving state-of-the-art deep CNNs in real-life applications, which automatically evolves the non-dominant solutions at the Pareto front. Three major contributions are made: Firstly, a new encoding strategy is designed to encode one of the best state-of-the-art CNNs; With the classification accuracy and the number of floating point operations as the two objectives, a multi-objective particle swarm optimization method is developed to evolve the non-dominant solutions; Last but not least, a new infrastructure is designed to boost the experiments by concurrently running the experiments on multiple GPUs across multiple machines, and a Python library is developed and released to manage the infrastructure. The experimental results demonstrate that the non-dominant solutions found by the proposed method form a clear Pareto front, and the proposed infrastructure is able to almost linearly reduce the running time.

Investigating Recurrent Neural Network Memory Structures using Neuro-Evolution

Alexander Ororbia, *Rochester Institute of Technology*, AbdElRahman ElSaid, *Rochester Institute of Technology*, Travis Desell, *Rochester Institute of Technology*

This paper presents a new algorithm, Evolutionary eXploration of Augmenting Memory Models (EXAMM), which is capable of evolving recurrent neural networks (RNNs) using a wide variety of memory structures, such as Δ-RNN, GRU, LSTM, MGU and UGRNN cells. EXAMM evolved RNNs to perform prediction of large-scale, real world time series data from the aviation and power industries. These data sets consist of very long time series (thousands of readings), each with a large number of potentially correlated and dependent parameters. Four different parameters were selected for prediction and EXAMM runs were performed using each memory cell type alone, each cell type and simple neurons, and with all possible memory cell types and simple neurons. Evolved RNN performance was measured using repeated k-fold cross validation, resulting in 2420 EXAMM runs which evolved 4, 840, 000 RNNs in 24, 200 CPU hours on a high performance computing cluster. Generalization of the evolved RNNs was examined statistically, providing findings that can help refine the design of RNN memory cells as well as inform future neuro-evolution algorithms.

Deep Neuroevolution of Recurrent and Discrete World Models

Sebastian Risi, *Uber AI Labs*, Kenneth O. Stanley, *Uber AI Labs*

Neural architectures inspired by our own human cognitive system, such as the recently introduced world models, have been shown to outperform traditional deep reinforcement learning (RL) methods in a variety of different domains. Instead of the relatively simple architectures employed in most RL experiments, world models rely on multiple different neural components that are responsible for visual information processing, memory, and decision-making. However, so far the components of these models have to be trained separately and through a variety of specialized training methods. This paper demonstrates the surprising finding that models with the same precise parts can be instead efficiently trained end-to-end through a genetic algorithm (GA), reaching a comparable performance to the original world model by solving a challenging car racing task. An analysis of the evolved visual and memory system indicates that they include a similar effective representation to the system trained through gradient descent. Additionally, in contrast to gradient descent methods that struggle with discrete variables, GAs also work directly with such representations, opening up opportunities for classical planning in latent space. This paper adds additional evidence on the effectiveness of deep neuroevolution for tasks that require

the intricate orchestration of multiple components in complex heterogeneous architectures.

EML3

Tuesday, July 16, 14:00-15:40 Club E (1F)

Absumption to Complement Subsumption in Learning Classifier Systems

Yi Liu, *Victoria University of Wellington*, Will N. Browne, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*

Learning Classifier Systems (LCSs), a 40-year-old technique, evolve interrogatable production rules. XCSs are the most popular reinforcement learning based LCSs. It is well established that the subsumption method in XCSs removes overly detailed rules. However, the technique still suffers from overly general rules that reduce accuracy and clarity in the discovered patterns. This adverse impact is especially true for domains that are containing accurate solutions that overlap, i.e. one data instance is covered by two plausible, but competing rules. A novel method, termed absumption, is introduced to counter over-general rules. Complex Boolean problems that contain epistasis, heterogeneity and overlap are used to test the absumption method. Results show that absumption successfully improves the training performance of XCSs by counteracting over-general rules. Moreover, absumption enables the rule-set to be compacted, such that underlying patterns can be precisely visualized successfully. Additionally, the equations for the optimal size of solutions for a problem domain can now be determined.

Improvement of Code Fragment Fitness to Guide Feature Construction in XCS

Trung Bao Nguyen, *Victoria University of Wellington*, Will Neil Browne, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

In complex classification problems, constructed features with rich discriminative information can simplify decision boundaries. Code Fragments (CFs) produce GP-tree-like constructed features that can represent decision boundaries effectively in Learning Classifier Systems (LCSs). But the search space for useful CFs is vast due to this richness in boundary creation, which is impractical. Online Feature-generation (OF) improves the search of useful CFs by growing promising CFs from a dynamic list of preferable CFs based on the ability to produce accurate and generalised, i.e. high-fitness, classifiers. However, the previous preference for high-numerosity CFs did not encapsulate information about the applicability of CFs directly. Consequently, learning performances of OF with an accuracy-based LCS (termed XOF) struggled to progress in the final learning phase. The hypothesis is that estimating the CF-fitness of CFs based on classifier fitness will aid the search for useful constructed features. This is anticipated to drive the search of decision boundaries efficiently, and thereby improve learning performances. Experiments on large-scale and hierarchical Boolean problems show that the proposed systems learn faster than traditional LCSs regarding the number of generations and time consumption. Tests on real-world datasets demonstrate its capability to find readable and useful features to solve practical problems.

Lexicase Selection in Learning Classifier Systems

Sneha Aenugu, *University of Massachusetts Amherst*, Lee Spector, *Hampshire College*

The lexicase parent selection method selects parents by considering performance on individual data points in random order instead of using a fitness function based on an aggregated data accuracy. While the method has demonstrated promise in genetic programming and more recently in genetic algorithms, its applications in other forms of evolutionary machine learning have not been explored. In this paper, we investigate the use of lexicase parent selection in Learning Classifier Systems (LCS) and study its effect on classification problems in a supervised setting. We further introduce a new variant of lexicase selection, called batch-lexicase selection, which allows for the tuning of selection pressure. We compare the two lexicase selection methods with tournament and fitness proportionate selection methods on binary classification problems. We show that batch-lexicase selection results in the creation of more generic rules which is favorable for generalization on future data. We further show that batch-lexicase selection results in better generalization in situations of partial or missing data.

Auto-CVE: A coevolutionary approach to evolve ensembles in Automated Machine Learning

Celio Henrique Nogueira Larcher Junior, *Laboratório Nacional de Computação Científica*, Helio J.C. Barbosa, *LNCC*

Automated Machine Learning (Auto-ML) is a growing field receiving a lot of attention. Several techniques are being developed to address the question of how to automate the process of defining machine learning pipelines, using diverse types of approaches and with relative success, but still this problem is far from being solved. Ensembles are frequently employed in machine learning given their better performance, when compared to the use of a single model, and higher robustness. However, until now, not much attention has been given to them in the Auto-ML field. In this sense, this work presents Auto-CVE (Automated Coevolutionary Voting Ensemble) a new approach to Auto-ML. Based on a coevolutionary model, it uses two populations (one of ensembles and another for components) to actively search for voting ensembles. When compared to the popular algorithm TPOT, Auto-CVE shows competitive results in both accuracy and computing time.

EML4

Tuesday, July 16, 16:10-17:50 Club E (1F)

Adaptive Multi-Subswarm Optimisation for Feature Selection on High-Dimensional Classification

Binh Ngan Tran, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Feature space is an important factor influencing the performance of any machine learning algorithm including classification methods. Feature selection aims to remove irrelevant and redundant features that may negatively affect the learning process especially on high-dimensional data, which usually suffers from the curse of dimensionality. Feature ranking is one of the most scalable feature selection approaches to high-dimensional problems, but most of them fail to automatically determine the number of selected features as well as detect redundancy between features. Particle swarm optimisation (PSO) is a population-based algorithm which has shown to be effective in addressing these limitations. However, its performance on high-dimensional data is still limited due to the large search space and high computation cost. This study proposes the first adaptive multi-swarm optimisation (AMSO) method for feature selection that can automatically select a feature subset of high-dimensional data more effectively and efficiently than the compared methods. The subswarms are automatically and dynamically changed based on their performance during the evolutionary process. Experiments on ten high-dimensional datasets of varying difficulties have shown that AMSO is more effective and more efficient than the compared PSO-based and traditional feature selection methods in most cases.

COEGAN: Evaluating the Coevolution Effect in Generative Adversarial Networks

Victor Franco Costa, *University of Coimbra*, Nuno Lourenço, *University of Coimbra*, João Correia, *University of Coimbra*, Penousal Machado, *University of Coimbra*

Generative adversarial networks (GAN) present state-of-the-art results in the generation of samples following the distribution of the input dataset. However, GANs are difficult to train, and several aspects of the model should be previously designed by hand. Neuroevolution is a well-known technique used to provide the automatic design of network architectures which was recently expanded to deep neural networks. COEGAN is a model that uses neuroevolution and coevolution in the GAN training algorithm to provide a more stable training method and the automatic design of neural network architectures. COEGAN makes use of the adversarial aspect of the GAN components to implement coevolutionary strategies in the training algorithm. Our proposal was evaluated in the Fashion-MNIST and MNIST dataset. We compare our results with a baseline based on DCGAN and also with results from a random search algorithm. We show that our method is able to discover efficient architectures in the Fashion-MNIST and MNIST datasets. The results also suggest that COEGAN can be used as a training algorithm for GANs to avoid common issues, such as the mode collapse problem.

An Automated Ensemble Learning Framework Using Genetic Programming for Image Classification

Ying Bi, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

An ensemble consists of multiple learners and can achieve a better generalisation performance than a single learner. Genetic programming (GP) has been applied to construct ensembles using different strategies such as bagging and boosting. However, no GP-based ensemble methods focus on dealing with image classification, which is a challenging task in computer vision and machine learning. This paper proposes an automated ensemble learning framework using GP (EGP) for image classification. The new method integrates feature learning, classification function selection, classifier training, and combination into a single program tree. To achieve this, a novel program structure, a new function set and a new terminal set are developed in EGP. The performance of EGP is examined on nine different image classification data sets of varying difficulty and compared with a large number of commonly used methods including recently published methods. The results demonstrate that EGP achieves better performance than most competitive methods. Further analysis reveals that EGP evolves good ensembles simultaneously balancing diversity and accuracy. To the best of our knowledge, this study is the first work using GP to automatically generate ensembles for image classification.

Spatial Evolutionary Generative Adversarial Networks

Jamal Toutouh, *Massachusetts Inst. of Technology*, Erik Hemberg, *Massachusetts Inst. of Technology*, Una-May O'Reilly, *Massachusetts Inst. of Technology*

Generative adversary networks (GANs) suffer from training pathologies such as instability and mode collapse. These pathologies mainly arise from a lack of diversity in their adversarial interactions. Evolutionary generative adversarial networks apply the principles of evolutionary computation to mitigate these problems. We hybridize two of these approaches that promote training diversity. One, E-GAN, at each batch, injects mutation diversity by training the (replicated) generator with three independent objective functions then selecting the resulting best performing generator for the next batch. The other, Lipizzaner, injects population diversity by training a two-dimensional grid of GANs with a distributed evolutionary algorithm that includes neighbor exchanges of additional training adversaries, performance based selection and population-based hyper-parameter tuning. We propose to combine mutation and population approaches to diversity improvement. We contribute a superior evolutionary GANs training method, Mustangs, that eliminates the single loss function used across Lipizzaner 's grid. Instead, each training round, a loss function is selected with equal probability, from among the three E-GAN uses. Experimental analyses on standard benchmarks, MNIST and CelebA, demonstrate that Mustangs provides a statistically faster training method resulting in more accurate networks.

Evolutionary Multiobjective Optimization

EMO1

Monday, July 15, 10:40-12:20 South Hall 1A (1F)

A Parameterless Performance Metric for Reference-Point Based Multi-Objective Evolutionary Algorithms

Sunith Bandaru, *University of Skövde*, Henrik Smedberg, *University of Skövde*

Most preference-based multi-objective evolutionary algorithms use reference points to articulate the decision maker's preferences. Since these algorithms typically converge to a sub-region of the Pareto-optimal front, the use of conventional performance measures (such as hypervolume and inverted generational distance) may lead to misleading results. Therefore, experimental studies in preference-based optimization often resort to using graphical methods to compare various algorithms. Though a few ad-hoc measures have been proposed in the literature, they either fail to generalize or involve parameters that are non-intuitive for a decision maker. In this paper, we propose a performance metric that is simple to implement, inexpensive to compute, and most importantly, does not involve any parameters. The so called expanding hypercube metric has been designed to extend the concepts of convergence and diversity to preference optimization. We demonstrate its effectiveness through constructed preference solution sets in two and three objectives. The proposed metric is then used to compare two popular reference-point based evolutionary algorithms on benchmark optimization problems up to 20 objectives.

Convergence and Diversity Analysis of Indicator-based Multi-Objective Evolutionary Algorithms

Jesus Guillermo Falcon-Cardona, *CINVESTAV-IPN*, Carlos Artemio Coello Coello, *UAM-Azcapotzalco*

In recent years, quality indicators (QIs) have been employed to design selection mechanisms for multi-objective evolutionary algorithms (MOEAs). These indicator-based MOEAs (IB-MOEAs) generate Pareto front approximations that present convergence and diversity characteristics strongly related to the QI that guides the selection mechanism. However, on complex multi-objective optimization problems, the performance of IB-MOEAs is far from being completely understood. In this paper, we empirically analyze the convergence and diversity properties of five steady-state IB-MOEAs based on the hypervolume, $R2$, IGD^+, ϵ^+, and Δ_p. Regarding convergence, we analyze their speed of convergence and the final closeness to the true Pareto front. The IB-MOEAs adopted in our study were tested on problems having different Pareto front shapes, and were taken from six test suites. Our experimental results show general and particular strengths and weaknesses of the adopted IB-MOEAs. We believe that these results are the first step towards a deeper understanding of the behavior of IB-MOEAs.

Efficient Real-Time Hypervolume Estimation with Monotonically Reducing Error

Jonathan Edward Fieldsend, *University of Exeter*

The hypervolume (or S-metric) is a widely used quality measure employed in the assessment of multi- and many-objective evolutionary algorithms. It is also directly integrated as a component in the selection mechanism of some popular optimisers. Exact hypervolume calculation becomes prohibitively expensive in real-time applications as the number of objectives increases and/or the approximation set grows. As such, Monte Carlo (MC) sampling is often used to estimate its value rather than exactly calculating it. This estimation is inevitably subject to error. As standard with Monte Carlo approaches, the standard error decreases with the square root of the number of MC samples. We propose a number of real-time hypervolume estimation methods for unconstrained archives — principally for use in real-time convergence analysis. Furthermore, we show how the number of domination comparisons can be considerably reduced by exploiting incremental properties of the approximated Pareto front. In these methods the estimation error monotonically decreases over time for (i) a capped budget of samples per algorithm generation and (ii) a fixed budget of dedicated computation time per optimiser generation for new MC samples. Results are provided using an illustrative worst-case scenario with rapid archive growth, demonstrating the orders-of-magnitude of speed-up possible.

Uncrowded Hypervolume Improvement: COMO-CMA-ES and the Sofomore framework

Cheikh Toure, *Inria*, Nikolaus Hansen, *Inria*, Anne Auger, *Inria*, Dimo Brockhoff, *Inria*

We present a framework to build a multiobjective algorithm from single-objective ones. This framework addresses the p*n-dimensional problem of finding p solutions in an n-dimensional search space, maximizing an indicator by dynamic subspace optimization. Each single-objective algorithm optimizes the indicator function given p-1 fixed solutions. Crucially, dominated solutions minimize their distance to the empirical Pareto front defined by these p-1 solutions. We instantiate the framework with CMA-ES as single-objective optimizer. The new algorithm, COMO-CMA-ES, is empirically shown to converge linearly on bi-objective convex-quadratic problems and is compared to MO-CMA-ES, NSGA-II and SMS-EMOA.

EMO2: Best papers

Monday, July 15, 14:00-15:40 South Hall 1A (1F)

Challenges of Convex Quadratic Bi-objective Benchmark Problems ☆

Tobias Glasmachers, *Ruhr-University Bochum*

Convex quadratic objective functions are an important base case in state-of-the-art benchmark collections for single-objective optimization on continuous domains. Although often considered rather simple, they represent the highly relevant challenges of non-separability and ill-conditioning. In the multi-objective case, quadratic benchmark problems are under-represented. In this paper we analyze the specific challenges that can be posed by quadratic functions in the bi-objective case. Our construction yields a full factorial design of 54 different problem classes. We perform experiments with well-established algorithms to demonstrate the insights that can be supported by this function class. We find huge performance differences, which can be clearly attributed to two root causes: non-separability and alignment of the Pareto set with the coordinate system.

Robust indicator-based algorithm for interactive evolutionary multiple objective optimization ☆

Michał Tomczyk, *Poznan University of Technology*, Miłosz Kadziński, *Poznan University of Technology*

We propose a novel robust indicator-based algorithm, called IEMO/I, for interactive evolutionary multiple objective optimization. During the optimization run, IEMO/I selects at regular intervals a pair of solutions from the current population to be compared by the Decision Maker. The successively provided holistic judgements are employed to divide the population into fronts of potential optimality. These fronts are, in turn, used to bias the evolutionary search toward a subset of Pareto-optimal solutions being most relevant to the Decision Maker. To ensure a fine approximation of such a subset, IEMO/I employs a hypervolume metric within a steady-state indicator-based evolutionary framework. The extensive experimental evaluation involving a number of benchmark problems confirms that IEMO/I is able to construct solutions being highly preferred by the Decision Maker after a reasonable number of interactions. We also compare IEMO/I with some selected state-of-the-art interactive evolutionary hybrids incorporating preference information in form of pairwise comparisons, proving its competitiveness.

Non-elitist Evolutionary Multi-objective Optimizers Revisited

Ryoji Tanabe, *Southern University of Science and Technology*, Hisao Ishibuchi, *Southern University of Science and Technology*

Since around 2000, it has been considered that elitist evolutionary multi-objective optimization algorithms (EMOAs) always outperform non-elitist EMOAs. This paper revisits the performance of non-elitist EMOAs for bi-objective continuous optimization when using an unbounded external archive. This paper examines the performance of EMOAs with two elitist and one non-elitist environmental selections. The performance of EMOAs is evaluated on the bi-objective BBOB problem suite provided by the COCO platform. In contrast to conventional wisdom, results show that non-elitist EMOAs with particular crossover methods perform significantly well on the bi-objective BBOB problems with many decision variables when using the unbounded external archive. This paper also analyzes the properties of the non-elitist selection.

EMO3

Monday, July 15, 16:10-17:50 Club D (1F)

Single- and Multi-Objective Game-Benchmark for Evolutionary Algorithms

Vanessa Volz, *Queen Mary University of London*, Boris Naujoks, *TH Köln - University of Applied Sciences*, Pascal Kerschke, *University of Münster*, Tea Tušar, *Jožef Stefan Institute*

Despite a large interest in real-world problems from the research field of evolutionary optimisation, established benchmarks in the field are mostly artificial. We propose to use game optimisation problems in order to form a benchmark and implement function suites designed to work with the established COCO benchmarking framework. Game optimisation problems are real-world problems that are safe, reasonably complex and at the same time practical, as they are relatively fast to compute. We have created four function suites based on two optimisation problems previously published in the literature (TopTrumps and MarioGAN). For each of the applications, we implemented multiple instances of several scalable single- and multi-objective functions with different characteristics and fitness landscapes. Our results prove that game optimisation problems are interesting and challenging for evolutionary algorithms.

Real-valued Evolutionary Multi-modal Multi-objective Optimization by Hill-valley Clustering

Stef C. Maree, *Amsterdam UMC*, Tanja Alderliesten, *Amsterdam UMC*, Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*

In model-based evolutionary algorithms (EAs), the underlying search distribution is adapted to the problem at hand, for example based on dependencies between decision variables. Hill-valley clustering is an adaptive niching method in which a set of solutions is clustered such that each cluster corresponds to a single mode in the fitness landscape. This can be used to adapt the search distribution of an EA to the number of modes, exploring each mode separately. Especially in a black-box setting, where the number of modes is a priori unknown, an adaptive approach is essential for good performance. In this work, we introduce multi-objective hill-valley clustering and combine it with MAMaLGaM, a multi-objective EA, into the multi-objective hill-valley EA (MO-HillVallEA). We empirically show that MO-HillVallEA outperforms MAMaLGaM and other well-known multi-objective optimization algorithms on a set of benchmark functions. Furthermore, and perhaps most important, we show that MO-HillVallEA is capable of obtaining

and maintaining multiple approximation sets simultaneously over time.

Surrogate-assisted Multi-objective Optimization based on Decomposition: A Comprehensive Comparative Analysis

Nicolas Berveglieri, *Univ. Lille*, Bilel Derbel, *Univ. Lille*, Arnaud Liefooghe, *Univ. Lille*, Hernán Aguirre, *Shinshu University*, Kiyoshi Tanaka, *Shinshu University*

A number of surrogate-assisted evolutionary algorithms are being developed for tackling expensive multiobjective optimization problems. On the one hand, a relatively broad range of techniques from both machine learning and multiobjective optimization can be combined for this purpose. Different taxonomies exist in order to better delimit the design choices, advantages and drawbacks of existing approaches. On the other hand, assessing the relative performance of a given approach is a difficult task, since it depends on the characteristics of the problem at hand. In this paper, we focus on surrogate-assisted approaches using objective space decomposition as a core component. We propose a refined and fine-grained classification, ranging from EGO-like approaches to filtering or pre-screening. More importantly, we provide a comprehensive comparative study of a representative selection of state-of-the-art methods, together with simple baseline algorithms. We rely on selected benchmark functions taken from the bbob-biobj benchmarking test suite, that provides a variable range of objective function difficulties. Our empirical analysis highlights the effect of the available budget on the relative performance of each approach, and the impact of the training set and of the machine learning model construction on both solution quality and runtime efficiency

Cooperative based Hyper-heuristic for Many-objective Optimization

Gian Fritsche, *Federal University of Paraná*, Aurora Pozo, *Federal University of Paraná*

Multi-Objective Evolutionary Algorithms (MOEAs) have shown to be effective, addressing Multi-Objective Problems (MOPs) suitably. Nowadays, there is a variety of MOEAs proposed in the literature. However, it is a challenge to select the best MOEA within a specific domain problem, since the MOEAs present different performance depending on the problem characteristics. Moreover, it is difficult to configure the parameter values or to select the operators properly. Considering this, we propose a new hyper-heuristic approach based on the cooperation of MOEAs (HH-CO). The main characteristic of HH-CO is that every MOEA has a population and exchanges information between them. This paper presents experimental results of HH-CO for the benchmark from CEC'18 competition on many-objective optimization. We present two comparisons: the first one, where HH-CO is compared to each MOEA that composes the pool and to a state-of-the-art hyper-heuristic, and the second one, that compares HH-CO to state-of-the-art algorithms winners of CEC'18 competition. The results were evaluated using a set of quality indicators and were statistically analyzed. The conclusion is that HH-CO is a suitable approach mainly for challenging problems, with complicated fitness landscape, including multi-modality, bias and a high number of objectives.

EMO4

Tuesday, July 16, 16:10-17:50 South Hall 1A (1F)

A Feature Rich Distance-Based Many-Objective Visualisable Test Problem Generator

Jonathan Edward Fieldsend, *University of Exeter*, Tinkle Chugh, *University of Exeter*, Richard Allmendinger, *University of Manchester*, Kaisa Miettinen, *University of Jyväskylä*

In optimiser analysis and design it is informative to visualise how a search point/population moves through the design space over time. Visualisable distance-based many-objective optimisation problems have been developed whose design space is in two-dimensions with arbitrarily many objective dimensions. Previous work has shown how disconnected Pareto sets may be formed, how problems can be projected to and from arbitrarily many design dimensions, and how dominance resistant regions of design space may be defined. Most recently, a test suite has been proposed using distances to lines rather than points. However, active use of visualisable problems has been limited. This may be because the type of problem characteristics available has been relatively limited compared to many practical problems (and non-visualisable problem suites). Here we introduce the mechanisms required to embed several widely seen problem characteristics in the existing problem framework. These include variable density of solutions in objective space, landscape discontinuities, varying objective ranges, neutrality, and non-identical disconnected Pareto set regions. Furthermore, we provide an automatic problem generator (as opposed to hand-tuned problem definitions). The flexibility of the problem generator is demonstrated by analysing the performance of popular optimisers on a range of sampled instances.

Constrained Multiobjective Distance Minimization Problems

Yusuke Nojima, *Osaka Prefecture University*, Takafumi Fukase, *Osaka Prefecture University*, Yiping Liu, *Osaka Prefecture University*, Naoki Masuyama, *Osaka Prefecture University*, Hisao Ishibuchi, *Southern University of Science and Technology*

Various distance minimization problems (DMPs) have been proposed to visualize the search behaviors of evolutionary multiobjective optimization (EMO) algorithms in many-objective problems, multiobjective multimodal problems, and dynamic multiobjective problems. Among those DMPs, only the box constraints are considered. In this paper, we propose several constraint DMPs to visualize the behaviors of EMO algorithms with constraint handling techniques. In the proposed constraint DMPs, constraints are simply specified in the two-dimensional

decision space. In the same manner, high-dimensional problems and multimodal problems can be generated. Computational experiments show different behaviors by different algorithms in various constraint DMPs.

Archiver Effects on the Performance of State-of-the-art Multi- and Many-objective Evolutionary Algorithms

Leonardo César Teonácio Bezerra, *Universidade Federal do Rio Grande do Norte*, Manuel López-Ibáñez, *University of Manchester*, Thomas Stützle, *Université Libre de Bruxelles*

Early works on external solution archiving have pointed out the benefits of unbounded archivers and there have been great advances, theoretical and algorithmic, in bounded archiving methods. Moreover, recent work has shown that the populations of most multi- and many-objective evolutionary algorithms (MOEAs) lack the properties that one would desire when trying to find a bounded Pareto-optimal front. Despite all these results, many recent MOEAs are still being proposed, analyzed and compared without considering any kind of archiver assuming their additional computational cost is not justified. In this paper, we investigate the effect of using various kinds of archivers, improving over previous studies in several aspects: (i) the parameters of MOEAs with and without an external archiver are tuned separately using automatic configuration methods; (ii) we consider a comprehensive range of problem scenarios (number of objectives, function evaluations, computation time limit); (iii) we employ multiple, complementary quality metrics; and (iv) we study the effect of unbounded archivers and two state-of-the-art bounded archiving methods. Our results show that both unbounded and bounded archivers are beneficial even for many-objective problems. We conclude that future proposals and comparisons of MOEAs must include archiving as an algorithmic component.

A Multi-point Mechanism of Expected Hypervolume Improvement for Parallel Multi-objective Bayesian Global Optimization

Kaifeng Yang, *Leiden Institute of Computer Science*, Pramudita Satria Palar, *Faculty of Mechanical and Aerospace Engineering Bandung Institute of Technology*, Michael Emmerich, *Leiden University*, Koji Shimoyama, *Institute of Fluid Science, Tohoku University*, Thomas Bäck, *Leiden University*

The technique of parallelization is a trend in the field of Bayesian global optimization (BGO) and is important for real-world applications because it can make full use of CPUs and speed up the execution times. This paper proposes a multi-point mechanism of the expected hypervolume improvement (EHVI) for multi-objective BGO (MOBGO) by the utilization of the truncated EHVI (TEHVI). The basic idea is to divide the objective space into several sub-objective spaces and then search for the optimal solutions in each sub-objective space by using the TEHVI as the infill criterion. We study the performance of the proposed algorithm and performed comparisons with Kriging believer technique (KB) on 5 scientific benchmarks and a real-world application problem (a low-fidelity multi-objective airfoil optimization design). The stochastic experimental results show that the proposed algorithm performs better than the KB with respect to the hypervolume indicator, indicating that the proposed method provides an efficient parallelization technique for MOBGO.

EMO5

Wednesday, July 17, 09:00-10:40 South Hall 1A (1F)

An Adaptive Evolutionary Algorithm based on Non-Euclidean Geometry for Many-objective Optimization

Annibale Panichella, *Delft University of Technology*

In the last decade, several evolutionary algorithms have been proposed in the literature for solving multi- and many-objective optimization problems. The performance of such algorithms depends on their capability to produce a well-diversified front (diversity) that is as closer to the Pareto optimal front as possible (proximity). Diversity and proximity strongly depend on the geometry of the Pareto front, i.e., whether it forms a Euclidean, spherical or hyperbolic hypersurface. However, existing multi- and many-objective evolutionary algorithms show poor versatility on different geometries. To address this issue, we propose a novel evolutionary algorithm that: (1) estimates the geometry of the generated front using a fast procedure with O(M x N) computational complexity (M is the number of objectives and N is the population size); (2) adapts the diversity and proximity metrics accordingly. Therefore, to form the population for the next generation, solutions are selected based on their contribution to the diversity and proximity of the non-dominated front with regards to the estimated geometry. Computational experiments show that the proposed algorithm outperforms state-of-the-art multi and many-objective evolutionary algorithms on benchmark test problems with different geometries and number of objectives (M=3,5, and 10).

On the Benefits of Biased Edge-Exchange Mutation for the Multi-Criteria Spanning Tree Problem

Jakob Bossek, *University of Münster*, Christian Grimme, *University of Münster*, Frank Neumann, *The University of Adelaide*

Research has shown that for many single-objective graph problems where optimum solutions are composed of low weight sub-graphs, such as the minimum spanning tree problem (MST), mutation operators favoring low weight edges show superior performance. Intuitively, similar observations should hold for multi-criteria variants of such problems. In this work, we focus on the multi-criteria MST problem. A thorough experimental study is conducted where we estimate the probability of edges being part of non-dominated spanning trees as a function of the edges' non-domination level or domination count, respectively. Building on gained insights, we propose several biased one-edge-exchange mutation operators that differ in the

used edge-selection probability distribution (biased towards edges of low rank). Our empirical analysis shows that among different graph types (dense and sparse) and edge weight types (both uniformly random and combinations of Euclidean and uniformly random) biased edge-selection strategies perform superior in contrast to the baseline uniform edge-selection. Our findings are in particular strong for dense graphs.

A 'Phylogeny-aware' Multi-objective Optimization Approach for Computing MSA

Muhammad Ali Nayeem, *Bangladesh University of Engineering and Technology*, Md. Shamsuzzoha Bayzid, *Bangladesh University of Engineering and Technology*, Atif Hasan Rahman, *Bangladesh University of Engineering and Technology*, Rifat Shahriyar, *Bangladesh University of Engineering and Technology*, M. Sohel Rahman, *Bangladesh University of Engineering and Technology*

Multiple sequence alignment (MSA) is a basic step in many analyses in bioinformatics, including predicting the structure and function of proteins, orthology prediction and estimating phylogenies. The objective of MSA is to infer the homology among the sequences of chosen species. Commonly, the MSAs are inferred by optimizing a single objective function. The alignments estimated under one criterion may be different to the alignments generated by other criteria, inferring discordant homologies and thus leading to different evolutionary histories relating the sequences. In the recent past, researchers have advocated for the multi-objective formulation of MSA, to address this issue, where multiple conflicting objective functions are being optimized simultaneously to generate a set of alignments. However, no theoretical or empirical justification with respect to a real-life application has been shown for a particular multi-objective formulation. In this study, we investigate the impact of multi-objective formulation in the context of phylogenetic tree estimation. In essence, we ask the question whether a phylogeny-aware metric can guide us in choosing appropriate multi-objective formulations. Employing evolutionary optimization, we demonstrate that trees estimated on the alignments generated by multi-objective formulation are substantially better than the trees estimated by the state-of-the-art MSA tools, including PASTA, T-Coffee, MAFFT etc.

Multiobjective Evolutionary Algorithm for DNA Codeword Design

Jeisson Prieto, *Universidad Nacional de Colombia*, Jonatan Gomez, *Universidad Nacional de Colombia*, Elizabeth Leon, *Universidad Nacional de Colombia*

Finding effective ways to encode data into DNA is not an easy task since the search space grows exponentially respect to the length of the oligonucleotides (single DNA strands) used in the task. In short, the problem of DNA Codeword Design (CD) is the optimization problem of finding large sets of short oligonucleotides which satisfy certain non-crosshybridizing constraints (combinatorial and/or thermodynamic). In this paper, a Multi-objective Evolutionary Algorithm (MoEA-CD) that exploits the structural properties of the DNA space to improve the speed and quality of candidate solutions to the CD problem is proposed. To this purpose, we consider the CD problem as a set covering problem, and we introduce two approximations mechanisms for computing the coverage and overlap of sets in such DNA space. The algorithm is tested in different DNA space dimensions, and our results indicate that MoEA-CD using such approximation mechanism maintains an excellent performance as the dimension of the search space is increased.

Evolutionary Numerical Optimization

ENUM1

Monday, July 15, 16:10-17:50 Club A (1F)

Analysis of a Meta-ES on a Conically Constrained Problem

Michael Hellwig, *FH Vorarlberg University of Applied Sciences*, Hans-Georg Beyer, *FH Vorarlberg University of Applied Sciences*

The paper presents the theoretical performance analysis of a hierarchical Evolution Strategy (meta-ES) variant for mutation strength control on a conically constrained problem. Infeasible offspring are repaired by projection onto the boundary of the feasibility region. Closed-form approximations are used for the one-generation progress of the lower-level evolution strategy. An interval that brackets the expected progress over a single isolation period of the meta-ES is derived. Approximate deterministic evolution equations are obtained that characterize the upper-level strategy dynamics. It is shown that the dynamical behavior of the meta-ES is determined by the choice of the mutation strength control parameter. The obtained theoretical results are compared to experiments for assessing the approximation quality.

Large-Scale Noise-Resilient Evolution-Strategies

Oswin Krause, *University of Copenhagen*

Ranking-based Evolution Strategies (ES) are efficient algorithms for problems where gradient-information is not available or when the gradient is not informative. This makes ES interesting for Reinforcement-Learning (RL). However, in RL the high dimensionality of the search-space, as well as the noise of the simulations make direct adaptation of ES challenging. Noise makes ranking points difficult and a large budget of re-evaluations is needed to maintain a bounded error rate. In this work, the ranked weighting is replaced by a linear weighting function, which results in nearly unbiased stochastic gradient descent (SGD) on the manifold of probability distributions. The approach is theoretically analysed and the algorithm is

adapted based on the results of the analysis. It is shown that in the limit of infinite dimensions, the algorithm becomes invariant to smooth monotonous transformations of the objective function. Further, drawing on the theory of SGD, an adaptation of the learning-rates based on the noise-level is proposed at the cost of a second evaluation for every sampled point. It is shown empirically that the proposed method improves on simple ES using Cumulative Step-size Adaptation and ranking. Further, it is shown that the proposed algorithm is more noise-resilient than a ranking-based approach.

A Surrogate Model Assisted (1+1)-ES with Increased Exploitation of the Model

Jingyun Yang, *Dalhousie University*, Dirk V. Arnold, *Dalhousie University*

Surrogate models in black-box optimization can be exploited to different degrees. At one end of the spectrum, they can be used to provide inexpensive but inaccurate assessments of the quality of candidate solutions generated by the black-box optimization algorithm. At the other end, optimization of the surrogate model function can be used in the process of generating those candidate solutions themselves. The latter approach more fully exploits the model, but may be more susceptible to systematic model error. This paper examines the effect of the degree of exploitation of the surrogate model in the context of a simple (1+1)-ES. First, we analytically derive the potential gain from more fully exploiting surrogate models by using a spherically symmetric test function and a simple model for the error resulting from the use of surrogate models. We then observe the effects of increased exploitation in an evolution strategy employing Gaussian process surrogate models applied to a range of test problems. We find that the gain resulting from more fully exploiting surrogate models can be considerable.

Deep Reinforcement Learning Based Parameter Control in Differential Evolution

Mudita Sharma, *University of York*, Alexandros Komninos, *University of York*, Manuel López-Ibáñez, *University of Manchester*, Dimitar Kazakov, *University of York*

Adaptive Operator Selection(AOS) controls discrete parameters of Evolutionary Algorithm(EA) during the run. We propose an AOS method based on Double Deep Q-Learning(DDQN), a Deep Reinforcement Learning method, to control mutation strategies of Differential Evolution(DE). It requires two phases. First, a neural network is trained offline by collecting data about the DE state and the reward of applying each mutation strategy over multiple runs of DE applied to train benchmark functions. We define the DE state as combination of 99 different features and we analyze three alternative reward functions. Second, when DDQN is applied as parameter controller within DE to a different test set of benchmark functions, DDQN uses the trained neural network to predict which mutation strategy should be applied to each parent according to the DE state. Benchmark functions for training and testing are taken from the CEC2005 with dimensions 10 and 30. We compare the results of the proposed DE-DDQN algorithm to several non-AOS DE algorithms baseline, random selection and AOS methods, and also to the two winners of the CEC2005 competition. The results show that DE-DDQN outperforms the non-adaptive methods for all functions in the test set; while its results are comparable with the last two algorithms.

ENUM2: Best papers

Tuesday, July 16, 14:00-15:40 South Hall 1B (1F)

A Global Surrogate Assisted CMA-ES ☆

Nikolaus Hansen, *Inria*

We explore the arguably simplest way to build an effective surrogate fitness model in continuous search spaces. The model complexity is linear or diagonal-quadratic or full quadratic, depending on the number of available data. The model parameters are computed from the Moore-Penrose pseudoinverse. The model is used as a surrogate fitness for CMA-ES if the rank correlation between true fitness and surrogate value of recently sampled data points is high. Otherwise, further samples from the current population are successively added as data to the model. We empirically compare the IPOP scheme of the new model assisted lq-CMA-ES with a variety of previously proposed methods and with a simple portfolio algorithm using SLSQP and CMA-ES. We conclude that a global quadratic model and a simple portfolio algorithm are viable options to enhance CMA-ES. The model building code is available as part of the pycma Python module on Github and PyPI.

Adaptive Ranking Based Constraint Handling for Explicitly Constrained Black-Box Optimization ☆

Naoki Sakamoto, *University of Tsukuba*, Youhei Akimoto, *University of Tsukuba*

A novel explicit constraint handling technique for the covariance matrix adaptation evolution strategy (CMA-ES) is proposed. The proposed constraint handling exhibits two invariance properties. One is the invariance to arbitrary element-wise increasing transformation of the objective and constraint functions. The other is the invariance to arbitrary affine transformation of the search space. The proposed technique virtually transforms a constrained optimization problem into an unconstrained optimization problem by considering an adaptive weighted sum of the ranking of the objective function values and the ranking of the constraint violations that are measured by the Mahalanobis distance between each candidate solution to its projection onto the boundary of the constraints. Simulation results are presented and show that the CMA-ES with the proposed constraint handling exhibits the affine invariance and performs similarly to the CMA-ES on unconstrained counterparts.

Landscape Analysis of Gaussian Process Surrogates for the Covariance Matrix Adaptation Evolution Strategy ☆

Zbyněk Pitra, *Faculty of Nuclear Sciences and Physical Engineering of the Czech Technical University*, Jakub Repický, *Institute of Computer Science, Academy of Sciences of the Czech Republic*, Martin Holeňa, *Institute of Computer Science, Academy of Sciences of the Czech Republic*

Gaussian processes modeling technique has been shown as a valuable surrogate model for the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) in continuous single-objective black-box optimization tasks, where the optimized function is expensive. In this paper, we investigate how different Gaussian process settings influence the error between the predicted and genuine population ordering in connection with features representing the fitness landscape. Apart from using features for landscape analysis known from the literature, we propose a new set of features based on CMA-ES state variables. We perform the landscape analysis of a large set of data generated using runs of a surrogate-assisted version of the CMA-ES on the noiseless part of the Comparing Continuous Optimisers benchmark function testbed.

Mixed-Integer Benchmark Problems for Single- and Bi-Objective Optimization

Tea Tušar, *Jožef Stefan Institute*, Dimo Brockhoff, *Inria*, Nikolaus Hansen, *Inria*

We introduce two suites of mixed-integer benchmark problems to be used for analyzing and comparing black-box optimization algorithms. They contain problems of diverse difficulties that are scalable in the number of decision variables. The bbob-mixint suite is designed by partially discretizing the established BBOB (Black-Box Optimization Benchmarking) problems. The bi-objective problems from the bbob-biobj-mixint suite are, on the other hand, constructed by using the bbob-mixint functions as their separate objectives. We explain the rationale behind our design decisions and show how to use the suites within the COCO (Comparing Continuous Optimizers) platform. Analyzing two chosen functions in more detail, we also provide some unexpected findings about their properties.

Genetic Algorithms

GA1: Best papers

Monday, July 15, 16:10-17:50 South Hall 1A (1F)

A Benefit-Driven Genetic Algorithm for Balancing Privacy and Utility in Database Fragmentation ☆

Yong-Feng Ge, *La Trobe University*, Jinli Cao, *La Trobe University*, Hua Wang, *Victoria University*, Jiao Yin, *La Trobe University*, Wei-Jie Yu, *Sun Yat-sen University*, Zhi-Hui Zhan, *South China University of Technology*, Jun Zhang, *South China University of Technology*

In outsourcing data storage, privacy and utility are significant concerns. Techniques such as data encryption can protect the privacy of sensitive information but affect the efficiency of data usage accordingly. By splitting attributes of sensitive associations, database fragmentation can protect data privacy. In the meantime, data utility can be improved through grouping data of high affinity. In this paper, a benefit-driven genetic algorithm is proposed to achieve a better balance between privacy and utility for database fragmentation. To integrate useful fragmentation information in different solutions, a matching strategy is designed. Two benefit-driven operators for mutation and improvement are proposed to construct valuable fragments and rearrange elements. The experimental results show that the proposed benefit-driven genetic algorithm is competitive when compared with existing approaches in database fragmentation.

Multi-heap Constraint Handling in Gray Box Evolutionary Algorithms ☆

Thiago Macedo Gomes, *Universidade Federal de Ouro Preto*, Alan Robert Resende de Freitas, *Universidade Federal de Ouro Preto*, Rodolfo Ayala Lopes, *Universidade Federal de Ouro Preto*

Many optimization problems provide access to the partial or total explicit algebraic representation of the problem, including subfunctions and variable interaction graphs. This extra information allows the development of efficient solvers through new appropriate operators. Besides distinctive reproduction operators for a variety of problem categories, Gray Box algorithms have been proposed as a form to explore this additional information during the search. Considering recent evolutionary operators in the literature, we propose adaptations to Gray Box evolutionary reproduction operators and local search algorithms to deal with constrained problems, a field still little explored in gray box evolutionary optimization. The results show that the proposed methods achieve better solutions than traditional algorithms in a set of constrained binary and integer problems and reach optimal solutions in the literature for some instances.

Evolutionary Diversity Optimization Using Multi-Objective Indicators ☆

Aneta Neumann, *The University of Adelaide*, Wanru Gao, *The University of Adelaide*, Markus Wagner, *The University of Adelaide*, Frank Neumann, *The University of Adelaide*

Evolutionary diversity optimization aims to compute a set of solutions that are diverse in the search space or instance feature space, and where all solutions meet a given quality criterion. With this paper, we bridge the areas of evolutionary diversity optimization and evolutionary multi-objective optimization.

We show how popular indicators frequently used in the area of multi-objective optimization can be used for evolutionary diversity optimization. Our experimental investigations for evolving diverse sets of TSP instances and images according to various features show that two of the most prominent multi-objective indicators, namely the hypervolume indicator and the inverted generational distance, provide excellent results in terms of visualization and various diversity indicators.

On the investigation of population sizing of genetic algorithms using optimal mixing

Yi-Yun Liao, *National Taiwan University*, Hung-Wei Hsu, *National Taiwan University*, Yi-Lin Juang, *National Taiwan University*, Tian-Li Yu, *National Taiwan University*

Genetic algorithms using optimal mixing have shown promising results, while lack of theoretical supports. This paper investigates population sizing from the supply aspect under the optimal mixing scenario. Specifically, more precise analyses on supply, including the expectation and the lower bound, are made. In addition, considering recombining one randomly generated chromosome with the rest of the population to achieve the global optimum, the tight bounds of the size of the population providing proper fragments chosen by restricted oracles are derived. Tight bounds on problems with ring topologies where a subfunction overlaps two other subfunctions are also derived. Finally, experiments are conducted and well match the derivations.

GA2

Tuesday, July 16, 10:40-12:20 Club A (1F)

Parallelism and Partitioning in Large-Scale GAs using Spark

Laila Alterkawi, *University of Kent*, Matteo Migliavacca, *University of Kent*

Big Data promises new scientific discovery and economic value. Genetic algorithms (GAs) have proven their flexibility in many application areas and substantial research effort has been dedicated to improving their performance through parallelisation. In contrast with most previous efforts, we reject approaches that are based on the centralisation of data in the main memory of a single node or that require remote access to shared/distributed memory. We focus instead on scenarios where data is partitioned across machines. In this partitioned scenario, we explore two parallelisation models: PDMS, inspired by the traditional master-slave model, and PDMD, based on island models; we compare their performance in large-scale classification problems. We implement two distributed versions of Bio-HEL, a popular large-scale single-node GA classifier, using the Spark distributed data processing platform. In contrast to existing GA based on MapReduce, Spark allows a more efficient implementation of parallel GAs thanks to its simple, efficient iterative processing of partitioned datasets. We study the accuracy, efficiency, and scalability of the proposed models. Our results show that PDMS provides the same accuracy of traditional BioHEL and exhibit good scalability up to 64 cores, while PDMD provides substantial reduction of execution time at a minor loss of accuracy.

The Massively Parallel Mixing Genetic Algorithm for the Traveling Salesman Problem

Swetha Varadarajan, *Colorado State University*, Darrell Whitley, *Colorado State University*

A new evolutionary algorithm called the Mixing Genetic Algorithm is introduced for the Travelling Salesman Problem. The Mixing Genetic Algorithm does not use selection or mutation, and the offspring replace the parents every generation. By using partition crossover, which is respectful and transmits alleles (edges), it possible to generate two offspring, the best possible offspring and the worst possible offspring, such that no edges are lost during recombination. The Mixing Genetic Algorithm organizes the population so that better solutions are recombined with other good solutions. Because no edges are lost or created during recombination, there is no need to access the evaluation function after the first generation. This dramatically reduces communication costs; this makes it possible to implement the Mixing Genetic Algorithm on massively parallel SIMD machines. The Mixing Genetic Algorithm never loses diversity and cannot prematurely converge. For the Mixing Genetic Algorithm to find the global optimum, the edges found in the global optimum must be in the initial population. We compare the Mixing Genetic Algorithm to EAX, one of the best inexact solvers for the Travelling Salesman Problem. The Mixing Genetic Algorithm often finds optimal solutions much faster than EAX.

A Genetic Algorithm Hybridisation Scheme for Effective Use of Parallel Workers

Simon Bowly, *The University of Melbourne*

Genetic algorithms are simple to accelerate by evaluating the fitness of individuals in parallel. However, when fitness evaluation is expensive and time to evaluate each individual is highly variable, workers can be left idle while waiting for long-running tasks to complete. This paper proposes a local search hybridisation scheme which guarantees 100% utilisation of parallel workers. Separate work queues are maintained for individuals produced by genetic crossover and local search neighbourhood operators, and a priority rule determines which queue should be used to distribute work at each step. Hill-climbing local search and a conventional genetic algorithm can both be derived as special cases of the algorithm. The general case balances allocation of computing time between progressing the genetic algorithm and improving individuals through local search. Through evaluation on a simulated expensive optimisation problem we show that the search performance of the algorithm in terms of number of function evaluations does not vary significantly with the number of workers used, while

still achieving linear speedup through parallelisation. Comparisons with an asynchronous genetic algorithm show that this method of using idle worker capacity for local search can improve performance when the computation budget is limited.

Convolutional Neural Network Surrogate-Assisted GOMEA

Arkadiy Dushatskiy, *Centrum Wiskunde & Informatica (CWI)*, Adriënne M. Mendrik, *Netherlands eScience Center*, Tanja Alderliesten, *Amsterdam UMC*, Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*

We introduce a novel surrogate-assisted Genetic Algorithm (GA) for expensive optimization of problems with discrete categorical variables. Specifically, we leverage the strengths of the Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA), a state-of-the-art GA, and, for the first time, propose to use a convolutional neural network (CNN) as a surrogate model. We propose to train the model on pairwise fitness differences to decrease the number of evaluated solutions that is required to achieve adequate surrogate model training. In providing a proof of principle, we consider relatively standard CNNs, and demonstrate that their capacity is already sufficient to accurately learn fitness landscapes of various well-known benchmark functions. The proposed CS-GOMEA is compared with GOMEA and the widely-used Bayesian-optimization-based expensive optimization frameworks SMAC and Hyperopt, in terms of the number of evaluations that is required to achieve the optimum. In our experiments on binary problems with dimensionalities up to 400 variables, CS-GOMEA always found the optimum, whereas SMAC and Hyperopt failed for problem sizes over 16 variables. Moreover, the number of evaluated solutions required by CS-GOMEA to find the optimum was found to scale much better than GOMEA.

GA3

Tuesday, July 16, 14:00-15:40 Club A (1F)

Offspring Population Size Matters when Comparing Evolutionary Algorithms with Self-Adjusting Mutation Rates

Anna Rodionova, *ITMO University*, Kirill Antonov, *ITMO University*, Arina Buzdalova, *ITMO University*, Carola Doerr, *CNRS*

We analyze the performance of the 2-rate $(1+\lambda)$ Evolutionary Algorithm (EA) with self-adjusting mutation rate control, its 3-rate counterpart, and a $(1+\lambda)$ EA variant using multiplicative update rules on the OneMax problem. We compare their efficiency for offspring population sizes ranging up to $\lambda = 3,200$ and problem sizes up to $n = 100,000$. Our empirical results show that the ranking of the algorithms is very consistent across all tested dimensions, but strongly depends on the population size. While for small values of λ the 2-rate EA performs best, the multiplicative updates become superior for starting for some threshold value of λ between 50 and 100. Interestingly, for population sizes around 50, the $(1+\lambda)$ EA with static mutation rates performs on par with the best of the self-adjusting algorithms. We also consider how the lower bound $p_{\min}$ for the mutation rate influences the efficiency of the algorithms. We observe that for the 2-rate EA and the EA with multiplicative update rules the more generous bound $p_{\min} = 1/n^2$ gives better results than $p_{\min} = 1/n$ when λ is small. For both algorithms the situation reverses for large λ.

Evolutionary Consequences of Learning Strategies in a Dynamic Rugged Landscape

Nam Le, *University College Dublin*, Anthony Brabazon, *University College Dublin*, Michael O'Neill, *University College Dublin*

Learning has been shown to be beneficial to an evolutionary process through the Baldwin Effect. Moreover, learning can be classified into two categories: asocial learning, e.g. trial-and-error; and social learning, e.g. imitation learning. A learning strategy, or learning rule – a combination of individual and social learning – has been suggested by recent research can be more adaptive than both social and individual learning alone. However, this also leaves open an important question as to how best to combine these forms of learning in different environments. This paper investigates this question under a dynamic rugged landscape (i.e. dynamic NK-landscape). Experimental results show that a learning strategy is able to promote an evolving population better, resulting in higher average fitness, over a series of changing environments than asocial learning alone. The results also show that the population of strategic learners maintains a higher proportion of plasticity – the ability to change the phenotype in response to environmental challenges – than the population of individual learners alone.

GA4

Tuesday, July 16, 16:10-17:50 Club A (1F)

On Improving the Constraint-Handling Performance with Modified Multiple Constraint Ranking (MCR-mod) for Engineering Design Optimization Problems Solved by Evolutionary Algorithms

Yohanes Bimo Dwianto, *The University of Tokyo*, Hiroaki Fukumoto, *Japan Aerospace Exploration Agency*, Akira Oyama, *Japan Aerospace Exploration Agency*

This work presents a new rank-based constraint handling technique (CHT) by implementing a modification on Multiple Constraint Ranking (MCR), a recently proposed rank-based constraint handling technique (CHT) for real-world engineering design optimization problems solved by evolutionary algorithms. The new technique, namely MCR-mod, not only maintains MCR's superior feature, i.e. balanced assessment of constraints with different orders of magnitude and/or different units, but also adds some more good features, such as more proper rank definition that the best feasible solution in the population always has better rank than the best infeasible

solution, involvement of good infeasible solution, and easier way of implementation. Numerical experiments on benchmark problems from IEEE-CEC 2006 competition and engineering design are conducted to assess the accuracy and robustness of MCR-mod. From 25 independent runs on each problem, MCR-mod has proven its robustness compared to MCR, by its ability to produce better feasible optimal solution in most problems. Based on nonparametric statistical tests, there are indications that MCR-mod yields significant superiority in terms of accuracy compared with MCR on problems whose most constraints are inequality and active constraints, indicating that all added features of MCR-mod produce some improvements on the constraint-handling performance.

Intentional Computational Level Design

Ahmed Khalifa, *New York University*, Michael Cerny Green, *New York University*, Gabriella Barros, *Modl.ai*, Julian Togelius, *New York University*

The procedural generation of levels and content in video games is a challenging AI problem. Often such generation relies on an intelligent way of evaluating the content being generated so that constraints are satisfied and/or objectives maximized. In this work, we address the problem of creating levels that are not only playable but also revolve around specific mechanics in the game. We use constrained evolutionary algorithms and quality-diversity algorithms to generate small sections of Super Mario Bros levels called scenes, using three different simulation approaches: Limited Agents, Punishing Model, and Mechanics Dimensions. All three approaches are able to create scenes that give opportunity for a player to encounter or use targeted mechanics with different properties. We conclude by discussing the advantages and disadvantages of each approach and compare them to each other.

An Empirical Evaluation of Success-Based Parameter Control Mechanisms for Evolutionary Algorithms

Mario Alejandro Hevia Fajardo, *The University of Sheffield*

Success-based parameter control mechanisms for Evolutionary Algorithms (EA) change the parameters every generation based on the success of the previous generation and the current parameter value. In the last years there have been proposed several mechanisms of success-based parameter control in the literature. The purpose of this paper is to evaluate and compare their sequential optimisation time and parallelisation on different types of problems. The geometric mean of the sequential and parallel optimisation times is used as a new metric to evaluate the parallelisation of the EAs capturing the trade off between both optimisation times. We perform an empirical study comprising of 9 different algorithms on four benchmark functions. From the 9 algorithms eight algorithms were taken from the literature and one is a modification proposed here. We show that the modified algorithms has a 20% faster sequential optimisation time than the fastest known GA on ONEMAX. Additionally we show the benefits of success-based parameter control mechanisms for NP-hard problems and using the proposed metric we also show that success-based offspring population size mechanisms are outperformed by static choices in parallel EAs.

Parametrizing Convection Selection: Conclusions from the Analysis of Performance in the NKq Model

Maciej Komosinski, *Poznan University of Technology*, Konrad Miazga, *Poznan University of Technology*

Convection selection in evolutionary algorithms is a method of splitting the population into subpopulations based on the fitness values of solutions. Convection selection was previously found to be successful when applied to difficult tasks of evolutionary design. However, reaching its full potential requires tuning of a number of parameters that affect the performance of the evolutionary search process. Performing experiments on arbitrary or benchmark fitness functions does not provide general knowledge required for such tuning. Therefore, in order to gain an insight into the link between the characteristics of the fitness landscape, parameters of the algorithm, and quality of the best found solutions, we perform an analysis based on the NKq model of rugged fitness landscapes with neutrality. As a result, we identify several rules that will help researchers and practitioners of evolutionary algorithms adjust the values of convection selection parameters based of the knowledge of the properties of a given optimization problem.

GA5

Wednesday, July 17, 09:00-10:40 Club A (1F)

Resource Optimization for Elective Surgical Procedures Using Quantum-inspired Genetic Algorithms.

Rene Gonzalez, *PUC-Rio*, Marley Vellasco, *PUC-Rio*, Karla Figueiredo, *UERJ*

Currently, Health Units in a large number of countries in the world present service demand that exceed their real capacities. For this reason, is inevitable the emergence of the waiting lists. To prepare the planning of this in an optimized manner results in a substantial challenge due to the number of resources that should be considered. This paper proposes the use of a model based on evolutionary algorithms with quantum inspiration for the automation and optimization of the planning of elective chirurgical procedures. The model denominated Evolutionary Algorithm with Quantum Inspiration for the Health Field (AEIQ-AS), beyond patients and necessary resources for the successful completion of the chirurgical procedure allocation, pursue the reduction of the total time of realization of all the surgeries like so the number of operations out of time. For the validation of the proposed model, a waiting list of 2000 surgeries was created artificially and using a simulation tool also developed in this work. The model achieved a reduction in the time of all surgeries of up to 16.25% and the number of surgeries out of date of up to 13.04%.

A Lexicographic Genetic Algorithm for Hierarchical Classification Rule Induction

Gean Pereira, *Federal University of São Carlos*, Paulo Gabriel, *Federal University of Uberlândia*, Ricardo Cerri, *Federal University of São Carlos*

Hierarchical Classification (HC) consists of assigning an instance to multiple classes simultaneously in a hierarchical structure containing dozens or even hundreds of classes. A field that greatly benefits from HC is Bioinformatics, in which interpretable methods that make predictions automatically are still scarce. In this context, a topic that has gained attention is the classification of Transposable Elements (TEs), which are DNA fragments capable of moving inside the genome of their hosts, affecting the genes' functionalities in many species. Thus, in this paper, we propose a method called Hierarchical Classification with a Lexicographic Genetic Algorithm (HC-LGA), which evolves rules towards the HC of TEs. Our proposed method follows a Multi-Objective Lexicographic approach in order to better deal with the still relevant problem of accuracy-interpretability trade-off. Besides, to the best of our knowledge, this is the first work to combine HC with such an approach. Experiments with two popular TEs datasets showed that HC-LGA achieved competitive results compared with most of the state-of-the-art HC methods in the literature, having the advantage of generating an interpretable model. Furthermore, HC-LGA obtained a comparable performance against its simpler optimization version, however generating a more interpretable list of rules.

A Combination of Two Simple Decoding Strategies for the No-wait Job Shop Scheduling Problem

Víctor Manuel Valenzuela Alcaraz, *Universidad Autónoma de Baja California*, Carlos Alberto Brizuela Rodríguez, *Centro de Investigación Científica y de Educación Superior de Ensenada*, María De los Ángeles Cosío León, *Universidad Politécnica de Pachuca*, Alma Danisa Romero Ocaño, *Universidad Autónoma de Baja California*

This paper deals with the makespan-minimization job shop scheduling problem (JSSP) with no wait precedence constraints. The no-wait JSSP is an extension of the well-known JSSP subject to the constraint that once initiated, the operations for any job have to be processed immediately, one after another, until the job's completion. A genetic algorithm with a new decoding strategy to find good quality solutions is proposed. The proposed decoding named as Reverse Decoding (RD) is a simple variant of the standard job-permutationbased representation for this problem. We show, through numerical examples, that by using simultaneously RD with the standard decoding better solutions than when using the direct or the reverse decoding separately are achieved, even under the same computational effort as the combined version. The proposed variant is compared with state-of-the-art approaches on a set of benchmarks. Experimental results on these benchmarks show that the proposed combination also produces competitive results.

General Evolutionary Computation and Hybrids

GECH1

Monday, July 15, 16:10-17:50 Club C (1F)

Adaptive Simulator Selection for Multi-Fidelity Optimization

Youhei Akimoto, *University of Tsukuba*, Takuma Shimizu, *Shinshu University*, Takahiro Yamaguchi, *Shinshu University*

In simulation-based optimization we often have access to multiple simulators or surrogate models that approximate a computationally expensive or intractable objective function with different trade-off between the fidelity and computational time. Such a setting is called multi-fidelity optimization. In this paper, we propose a novel strategy to adaptively select which simulator to use during optimization of comparison-based evolutionary algorithms. Our adaptive switching strategy works as a wrapper of multiple simulators: optimization algorithms optimize the wrapper function and the adaptive switching strategy selects a simulator inside the wrapper, implying wide applicability of the proposed approach. We empirically investigate how efficiently the adaptive switching strategy manages simulator selection on test problems and theoretically investigate how it changes the fidelity level during optimization.

Surrogates for Hierarchical Search Spaces: The Wedge-Kernel and an Automated Analysis

Daniel Horn, *TU Dortmund*, Jörg Stork, *TH Köln*, Nils-Jannik Schüßler, *TU Dortmund*, Martin Zaefferer, *TH Köln*

Optimization in hierarchical search spaces deals with variables that only have an influence on the objective function if other variables fulfill certain conditions. These types of conditions complicate the optimization process. If the objective function is expensive to evaluate, these complications are further compounded. Especially, if surrogate models are learned to replace the objective function, they have to be able to respect the hierarchical dependencies in the data. In this work a new kernel is introduced, that allows Kriging models (Gaussian process regression) to handle hierarchical search spaces. This new kernel is compared to existing kernels based on an artificial benchmark function. Thereby, we face a typical algorithm design problem: The statistical analysis of benchmark results. Instead of just identifying the best algorithm, it is often desirable to compute algorithm rankings that depend on additional experimental parameters. We propose a method for the automated analysis of such algorithm comparisons. Instead of investigating all parameter constellations of our artificial test function

at once, we apply a cluster algorithm and analyze rankings of the algorithms within each cluster. This new method is used to analyze the above mentioned benchmark of kernels for hierarchical search spaces.

Algorithm Portfolio for Individual-based Surrogate-Assisted Evolutionary Algorithms

Hao Tong, *Southern University of Science and Technology*, Jialin Liu, *Southern University of Science and Technology*, Xin Yao, *Southern University of Science and Technology*

Surrogate-assisted evolutionary algorithms (SAEAs) are powerful optimisation tools for computationally expensive problems (CEPs). However, a randomly selected algorithm may fail in solving unknown problems due to no free lunch theorems, and it will cause more computational resource if we re-run the algorithm or try other algorithms to get a much solution, which is more serious in CEPs. In this paper, we consider an algorithm portfolio for SAEAs to reduce the risk of choosing an inappropriate algorithm for CEPs. We propose two portfolio frameworks for very expensive problems in which the maximal number of fitness evaluations is only 5 times of the problem's dimension. One framework named Par-IBSAEA runs all algorithm candidates in parallel and a more sophisticated framework named UCB-IBSAEA employs the Upper Confidence Bound (UCB) policy from reinforcement learning to help select the most appropriate algorithm at each iteration. An effective reward definition is proposed for the UCB policy. We consider three state-of-the-art individual-based SAEAs on different problems and compare them to the portfolios built from their instances on several benchmark problems given limited computation budgets. Our experimental studies demonstrate that our proposed portfolio frameworks significantly outperform any single algorithm on the set of benchmark problems.

GECH2

Tuesday, July 16, 10:40-12:20 Club H (1F)

On the Impact of the Cutoff Time on the Performance of Algorithm Configurators

George T. Hall, *The University of Sheffield*, Pietro S. Oliveto, *The University of Sheffield*, Dirk Sudholt, *The University of Sheffield*

Algorithm configurators are automated methods to optimise the parameters of an algorithm for a class of problems. We evaluate the performance of a simple random local search configurator (ParamRLS) for tuning the neighbourhood size k of the RLSk algorithm. We measure performance as the expected number of configuration evaluations required to identify the optimal value for the parameter. We analyse the impact of the cutoff time $\varkappa$ (the time spent evaluating a configuration for a problem instance) on the expected number of configuration evaluations required to find the optimal parameter value, where we compare configurations using either best found fitness values (ParamRLS-F) or optimisation times (ParamRLS-T). We consider tuning RLSk for a variant of the Ridge function class (Ridge*), where the performance of each parameter value does not change during the run, and for the OneMax function class, where longer runs favour smaller k. We rigorously prove that ParamRLS-F efficiently tunes RLSk for Ridge* for any $\varkappa$ while ParamRLS-T requires at least quadratic $\varkappa$. For OneMax ParamRLS-F identifies k=1 as optimal with linear $\varkappa$ while ParamRLS-T requires a $\varkappa$ of at least $\Omega(n\log n)$. For smaller $\varkappa$ ParamRLS-F identifies that k>1 performs better while ParamRLS-T returns k chosen uniformly at random.

Hyper-Parameter Tuning for the $(1+(\lambda,\lambda))$ GA

Nguyen Dang, *University of St Andrews*, Carola Doerr, *CNRS*

It is known that the $(1+(\lambda,\lambda))$ Genetic Algorithm (GA) with self-adjusting parameter choices achieves a linear expected optimization time on OneMax if its hyper-parameters are suitably chosen. However, it is not very well understood how the hyper-parameter settings influences the overall performance of the $(1+(\lambda,\lambda))$ GA. Analyzing such multi-dimensional dependencies precisely is at the edge of what running time analysis can offer. To make a step forward on this question, we present an in-depth empirical study of the self-adjusting $(1+(\lambda,\lambda))$ GA and its hyper-parameters. We show, among many other results, that a 15% reduction of the average running time is possible by a slightly different setup, which allows non-identical offspring population sizes of mutation and crossover phase, and more flexibility in the choice of mutation rate and crossover bias – a generalization which may be of independent interest. We also show indication that the parametrization of mutation rate and crossover bias derived by theoretical means for the static variant of the $(1+(\lambda,\lambda))$ GA extends to the non-static case.

Meta-learning on Flowshop using Fitness Landscape Analysis

Lucas Marcondes Pavelski, *Federal University of Technology of Paraná*, Myriam Regattieri Delgado, *Federal University of Technology of Paraná*, Marie-Éléonore Kessaci, *Université de Lille*

In the context of recommendation methods, meta-learning considers the use of previous knowledge regarding problems solution and performance to indicate the best strategy, whenever it faces a new similar problem. This paper studies the use of meta-learning to recommend local search strategies to solve several instances of permutation flowshop problems. The method proposed to conceive the meta-learning model is described considering three main phases: (i) extracting the problem features, (ii) building the performance database and (iii) training the recommendation model. In this work, we extract instances features mainly through fitness landscape analysis; build the performance data using the Irace parameter tuning algorithm and train neural networks models for recommendation. The paper also analyzes two mechanisms that support the

recommendation: one using classification as its basis and another considering ranking processes. Experiments conducted on a wide range of different flowshop instances show that it is possible to recommend not only the best algorithms, but also some of their suitable configurations.

CS3+GECH3: Best papers

Tuesday, July 16, 14:00-15:40 South Hall 1A (1F)

Surrogate Models for Enhancing the Efficiency of Neuroevolution in Reinforcement Learning ☆

Jörg Stork, *TH Köln - University of Applied Sciences*, Martin Zaefferer, *TH Köln - University of Applied Sciences*, Thomas Bartz-Beielstein, *TH Köln - University of Applied Sciences*, A. E. Eiben, *Vrije Universiteit Amsterdam*

In the last years, reinforcement learning received a lot of attention. One method to solve reinforcement learning tasks is Neuroevolution, where neural networks are optimized by evolutionary algorithms. A disadvantage of Neuroevolution is that it can require numerous function evaluations, while not fully utilizing the available information from each fitness evaluation. This is especially problematic when fitness evaluations become expensive. To reduce the cost of fitness evaluations, surrogate models can be employed to partially replace the fitness function. The difficulty of surrogate modeling for Neuroevolution is the complex search space and how to compare different networks. To that end, recent studies showed that a kernel based approach, particular with phenotypic distance measures, works well. These kernels compare different networks via their behavior (phenotype) rather than their topology or encoding (genotype). In this work, we discuss the use of surrogate model-based Neuroevolution (SMB-NE) using a phenotypic distance for reinforcement learning. In detail, we investigate a) the potential of SMB-NE with respect to evaluation efficiency and b) how to select adequate input sets for the phenotypic distance measure in a reinforcement learning problem. The results indicate that we are able to considerably increase the evaluation efficiency using dynamic input sets.

GECH4

Wednesday, July 17, 09:00-10:40 Club D (1F)

Scenario Co-Evolution for Reinforcement Learning on a Grid World Smart Factory Domain

Thomas Gabor, *LMU Munich*, Andreas Sedlmeier, *LMU Munich*, Marie Kiermeier, *LMU Munich*, Thomy Phan, *LMU Munich*, Marcel Henrich, *University of Augsburg*, Monika Pichlmair, *University of Augsburg*, Bernhard Kempter, *Siemens AG*, Cornel Klein, *Siemens AG*, Horst Sauer, *Siemens AG*, Reiner Schmid, *Siemens AG*, Jan Wieghardt, *Siemens AG*

Adversarial learning has been established as a successful paradigm in reinforcement learning. We propose a hybrid adversarial learner where a reinforcement learning agent tries to solve a problem while an evolutionary algorithm tries to find problem instances that are hard to solve for the current expertise of the agent, causing the intelligent agent to co-evolve with a set of test instances or scenarios. We apply this setup, called scenario co-evolution, to a simulated smart factory problem that combines task scheduling with navigation of a grid world. We show that the so trained agent outperforms conventional reinforcement learning. We also show that the scenarios evolved this way can provide useful test cases for the evaluation of any (however trained) agent.

Using Subpopulation EAs to Map Molecular Structure Landscapes

Ahmed Bin Zaman, *George Mason University*, Kenneth A. De Jong, *George Mason University*, Amarda Shehu, *George Mason University*

The emerging view in molecular biology is that molecules are intrinsically dynamic systems rearranging themselves into different structures to interact with molecules in the cell. Such rearrangements take place on energy landscapes that are vast and multimodal, with minima housing alternative structures. The multiplicity of biologically-active structures is prompting researchers to expand their treatment of classic computational biology problems, such as the template-free protein structure prediction problem (PSP), beyond the quest for the global optimum. In this paper, we revisit subpopulation-oriented EAs as vehicles to switch the objective from classic optimization to landscape mapping. Specifically, we present two EAs, one of which makes use of subpopulation competition to allocate more computational resources to fitter subpopulations, and another of which additionally utilizes a niche preservation technique to maintain stable and diverse subpopulations. Initial assessment on benchmark optimization problems confirms that stabler subpopulations are achieved by the niche-preserving EA. Evaluation on unknown energy landscapes in the context of PSP demonstrates superior mapping performance by both algorithms over a popular Monte Carlo-based method, with the niche-preserving EA achieving superior exploration of lower-energy regions. These results suggest that subpopulation EAs hold much promise for solving important mapping problems in computational structural biology.

Online Selection of CMA-ES Variants

Diederick L. Vermetten, *Leiden University*, Sander van Rijn, *Leiden University*, Thomas Bäck, *Leiden University*, Carola Doerr, *CNRS*

In the field of evolutionary computation, one of the most challenging topics is algorithm selection. Knowing which heuristics to use for which optimization problem is key to obtaining high-quality solutions. We aim to extend this research topic by taking a first step towards a selection method for adaptive CMA-ES algorithms. We build upon the theoretical work done by van Rijn *et al.* [PPSN'18], in which the potential of switching between different CMA-ES variants was quantified in the context

of a modular CMA-ES framework. We demonstrate in this work that their proposed approach is not very reliable, in that implementing the suggested adaptive configurations does not yield the predicted performance gains. We propose a revised approach, which results in a more robust fit between predicted and actual performance. The adaptive CMA-ES approach obtains performance gains on 18 out of 24 tested functions of the BBOB benchmark, with stable advantages of up to 23%. An analysis of module activation indicates which modules are most crucial for the different phases of optimizing each of the 24 benchmark problems. The module activation also suggests that additional gains are possible when including the (B)IPOP modules, which we have excluded for this present work.

Genetic Programming

GP1

Monday, July 15, 10:40-12:20 Club A (1F)

On Domain Knowledge and Novelty to Improve Program Synthesis Performance with Grammatical Evolution

Erik Hemberg, *Massachusetts Institute of Technology*, Jonathan Kelly, *Massachusetts Institute of Technology*, Una-May O'Reilly, *Massachusetts Institute of Technology*

Programmers solve coding problems with the support of both programming and problem specific knowledge. They integrate this domain knowledge to reason by computational abstraction. Correct and readable code arises from sound abstractions and problem solving. We attempt to transfer insights from such human expertise to genetic programming (GP) for solving automatic program synthesis. We draw upon manual and non-GP Artificial Intelligence methods to extract knowledge from synthesis problem definitions to guide the construction of the grammar that Grammatical Evolution uses and to supplement its fitness function. We examine the impact of using such knowledge on 21 problems from the GP program synthesis benchmark suite. Additionally, we investigate the compounding impact of this knowledge and novelty search. The resulting approaches exhibit improvements in accuracy on a majority of problems in the field's benchmark suite of program synthesis problems.

Comparing and Combining Lexicase Selection and Novelty Search

Lia Jundt, *Hamilton College*, Thomas Helmuth, *Hamilton College*

Lexicase selection and novelty search, two parent selection methods used in evolutionary computation, emphasize exploring widely in the search space more than traditional methods such as tournament selection. However, lexicase selection is not explicitly driven to select for novelty in the population, and novelty search suffers from lack of direction toward a goal, especially in unconstrained, highly-dimensional spaces. We combine the strengths of lexicase selection and novelty search by creating a novelty score for each test case, and adding those novelty scores to the normal error values used in lexicase selection. We use this new novelty-lexicase selection to solve automatic program synthesis problems, and find it significantly outperforms both novelty search and lexicase selection. Additionally, we find that novelty search has very little success in the problem domain of program synthesis. We explore the effects of each of these methods on population diversity and long-term problem solving performance, and give evidence to support the hypothesis that novelty-lexicase selection resists converging to local optima better than lexicase selection.

Teaching GP to Program Like a Human Software Developer: Using Perplexity Pressure to Guide Program Synthesis Approaches

Dominik Sobania, *Johannes Gutenberg University Mainz*, Franz Rothlauf, *Johannes Gutenberg University Mainz*

Program synthesis is one of the relevant applications of GP with a strong impact on new fields such as genetic improvement. In order for synthesized code to be used in real-world software, the structure of the programs created by GP must be maintainable. We can teach GP how real-world software is built by learning the relevant properties of mined human-coded software – which can be easily accessed through repository hosting services such as GitHub. So combining program synthesis and repository mining is a logical step. In this paper, we analyze if GP can write programs with properties similar to code produced by human software developers. First, we compare the structure of functions generated by different GP initialization methods to a mined corpus containing real-world software. The results show that the studied GP initialization methods produce a totally different combination of programming language elements in comparison to real-world software. Second, we propose perplexity pressure and analyze how its use changes the properties of code produced by GP. The results are very promising and show that we can guide the search to the desired program structure. Thus, we recommend using perplexity pressure as it can be easily integrated in various search-based algorithms.

On the Role of Non-effective Code in Linear Genetic Programming

Léo Françoso Dal Piccol Sotto, *Federal University of São Paulo*, Franz Rothlauf, *Johannes Gutenberg University*

In linear variants of Genetic Programming (GP) like linear genetic programming (LGP), structural introns can emerge, which are nodes that are not connected to the final output and do not

contribute to the output of a program. There are claims that such non-effective code is beneficial for search, as it can store relevant and important evolved information that can be reactivated in later search phases. Furthermore, introns can increase diversity, which leads to higher GP performance. This paper studies the role of non-effective code by comparing the performance of LGP variants that deal differently with non-effective code for standard symbolic regression problems. As we find no decrease in performance when removing or randomizing structural introns in each generation of a LGP run, we have to reject the hypothesis that structural introns increase LGP performance by preserving meaningful sub-structures. Our results indicate that there is no important information stored in structural introns. In contrast, we find evidence that the increase of diversity due to structural introns positively affects LGP performance.

GP2

Monday, July 15, 14:00-15:40 Club A (1F)

Linear Scaling with and within Semantic Backpropagation-based Genetic Programming for Symbolic Regression

Marco Virgolin, *Centrum Wiskunde & Informatica*, Tanja Alderliesten, *Amsterdam UMC*, Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*

Semantic Backpropagation (SB) is a recent technique that promotes effective variation in tree-based genetic programming. The basic idea of SB is to provide information on what output is desirable for a specified tree node, by propagating the desired root-node output back to the specified node using inversions of functions encountered along the way. Variation operators then replace the subtree located at the specified node with a tree for which the output is closest to the desired output, by searching in a pre-computed library. In this paper, we propose two contributions to enhance SB specifically for symbolic regression, by incorporating the principles of Keijzer's Linear Scaling (LS). In particular, we show how SB can be used in synergy with the scaled mean squared error, and we show how LS can be adopted within library search. We test our adaptations using the well-known variation operator Random Desired Operator (RDO), comparing to its baseline implementation, and to traditional crossover and mutation. Our experimental results on real-world datasets show that SB enhanced with LS substantially improves the performance of RDO, resulting in overall the best performance among all tested GP algorithms.

Evolving Graphs with Horizontal Gene Transfer

Timothy Atkinson, *University of York*, Detlef Plump, *University of York*, Susan Stepney, *University of York*

We introduce a form of neutral Horizontal Gene Transfer (HGT) to the approach Evolving Graphs by Graph Programming (EGGP). We introduce the $\mu\times\lambda$ evolutionary algorithm where μ surviving parents each produce λ children who compete with only their own parents. HGT events then copy the entire active component of one surviving parent into the inactive component of another parent, exchanging genetic information without reproduction. Experimental results from 14 symbolic regression benchmark problems show that the introduction of the $\mu\times\lambda$ EA and HGT events improve the performance of EGGP. Comparisons with Genetic Programming and Cartesian Genetic Programming strongly favour our proposed approach.

Batch Tournament Selection for Genetic Programming: The quality of Lexicase, the speed of Tournament

Vinícius Veloso de Melo, *SkipTheDishes*, Danilo V. Vargas, *Kyushu University*, Wolfgang Banzhaf, *BEACON Center*

Lexicase selection achieves very good solution quality by introducing ordered test cases. However, the computational complexity of lexicase selection can prohibit its use in many applications. In this paper, we introduce Batch Tournament Selection (BTS), a hybrid of tournament and lexicase selection which is approximately one order of magnitude faster than lexicase selection while achieving a competitive quality of solutions. Tests on a number of regression datasets show that BTS compares well with lexicase selection in terms of mean absolute error while having a speed-up of up to 25 times. Surprisingly, BTS and lexicase selection have almost no difference in both diversity and performance. This reveals that batches and ordered test cases are completely different mechanisms which share the same general principle fostering the specialization of individuals. This work introduces an efficient algorithm that sheds light onto the main principles behind the success of lexicase, potentially opening up a new range of possibilities for algorithms to come.

Gin: Genetic Improvement Research Made Easy

Alexander Edward Ian Brownlee, *University of Stirling*, Justyna Petke, *University College London*, Brad Alexander, *University of Adelaide*, Earl T. Barr, *University College London*, Markus Wagner, *University of Adelaide*, David Robert White, *The University of Sheffield*

Genetic improvement (GI) is a young field of research on the cusp of transforming software development. GI uses search to improve existing software. Researchers have already shown that GI can improve human-written code, ranging from program repair to optimising run-time, from reducing energy-consumption to the transplantation of new functionality. Much remains to be done. The cost of re-implementing GI to investigate new approaches is hindering progress. Therefore, we present Gin, an extensible and modifiable toolbox for GI experimentation, with a novel combination of features. Instantiated in Java and targeting the Java ecosystem, Gin automatically transforms, builds, and tests Java projects. Out of the box, Gin supports automated test-generation and source code profiling. We show, through examples and a case study, how Gin facilitates experimentation and will speed innovation in GI.

GP3: Best papers

Monday, July 15, 16:10-17:50 South Hall 1B (1F)

Solving Symbolic Regression Problems with Formal Constraints ☆

Iwo Błądek, *Poznan University of Technology*, Krzysztof Krawiec, *Poznan University of Technology*

In many applications of symbolic regression, domain knowledge constrains the space of admissible models by requiring them to have certain properties, like monotonicity, convexity, or symmetry. As only a handful of variants of genetic programming methods proposed to date can take such properties into account, we introduce a principled approach capable of synthesizing models that simultaneously match the provided training data (tests) and meet user-specified formal properties. To this end, we formalize the task of symbolic regression with formal constraints and present a range of formal properties that are common in practice. We also conduct a comparative experiment that confirms the feasibility of the proposed approach on a suite of realistic symbolic regression benchmarks extended with various formal properties. The study is summarized with discussion of results, properties of the method, and implications for symbolic regression.

Semantic variation operators for multidimensional genetic programming ☆

William La Cava, *University of Pennsylvania*, Jason H. Moore, *University of Pennsylvania*

Multidimensional genetic programming represents candidate solutions as sets of programs, and thereby provides an interesting framework for exploiting building block identification. Towards this goal, we investigate the use of machine learning as a way to bias which components of programs are promoted, and propose two semantic operators to choose where useful building blocks are placed during crossover. A forward stagewise crossover operator we propose leads to significant improvements on a set of regression problems, and produces state-of-the-art results in a large benchmark study. We discuss this architecture and others in terms of their propensity for allowing heuristic search to utilize information during the evolutionary process. Finally, we look at the collinearity and complexity of the data representations that result from these architectures, with a view towards disentangling factors of variation in application.

Lexicase Selection of Specialists ☆

Thomas Helmuth, *Hamilton College*, Edward Pantridge, *Swoop, Inc.*, Lee Spector, *Hampshire College*

Lexicase parent selection filters the population by considering one random training case at a time, eliminating any individuals with errors for the current case that are worse than the best error in the selection pool, until a single individual remains. This process often stops before considering all training cases, meaning that it will ignore the error values on any cases that were not yet considered. Lexicase selection can therefore select specialist individuals that have poor errors on some training cases, if they have great errors on others and those errors come near the start of the random list of cases used for the parent selection event in question. We hypothesize here that selecting these specialists, which may have poor total error, plays an important role in lexicase selection's observed performance advantages over error-aggregating parent selection methods such as tournament selection, which select specialists much less frequently. We conduct experiments examining this hypothesis, and find that lexicase selection's performance and diversity maintenance degrade when we deprive it of the ability of selecting specialists. These findings help explain the improved performance of lexicase selection compared to tournament selection, and suggest that specialists help drive evolution under lexicase selection toward global solutions.

GP4

Wednesday, July 17, 09:00-10:40 South Hall 1B (1F)

Novel Ensemble Genetic Programming Hyper-Heuristics for Uncertain Capacitated Arc Routing Problem

Shaolin Wang, *Victoria University of Wellington*, Yi Mei, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

The Uncertain Capacitated Arc Routing Problem (UCARP) is an important problem with many real-world applications. A major challenge in UCARP is to handle the uncertain environment effectively and reduce the recourse cost upon route failures. Genetic Programming Hyper-heuristic (GPHH) has been successfully applied to automatically evolve effective routing policies to make real-time decisions in the routing process. However, most existing studies obtain a single complex routing policy which is hard to interpret. In this paper, we aim to evolve an ensemble of simpler and more interpretable routing policies than a single complex policy. By considering the two critical properties of ensemble learning, i.e., the effectiveness of each ensemble element and the diversity between them, we propose two novel ensemble GP approaches namely DivBaggingGP and DivNichGP. DivBaggingGP evolves the ensemble elements sequentially, while DivNichGP evolves them simultaneously. The experimental results showed that both DivBaggingGP and DivNichGP could obtain more interpretable routing policies than the single complex routing policy. DivNichGP can achieve better test performance than DivBaggingGP as well as the single routing policy evolved by the current state-of-the-art GPHH. This demonstrates the effectiveness of evolving both effective and interpretable routing policies using ensemble learning.

Promoting Semantic Diversity in Multi-objective Genetic Programming

Edgar Galván, *Department of Computer Science, Maynooth University, Ireland*, Marc Schoenauer, *Inria*

The study of semantics in Genetic Programming (GP) has increased dramatically over the last years due to the fact that researchers tend to report a performance increase in GP when semantic di- versity is promoted. However, the adoption of semantics in Evolu- tionary Multi-objective Optimisation (EMO), at large, and in Multi- objective GP (MOGP), in particular, has been very limited and this paper intends to fill this challenging research area. We propose a mechanism wherein a semantic-based distance is used instead of the widely known crowding distance and is also used as an objec- tive to be optimised. To this end, we use two well-known EMO algorithms: NSGA-II and SPEA2. Results on highly unbalanced bi- nary classification tasks indicate that the proposed approach pro- duces more and better results than the rest of the three other ap- proaches used in this work, including the canonical aforementioned EMO algorithms.

Evolving Boolean Functions with Conjunctions and Disjunctions via Genetic Programming

Benjamin Doerr, *École Polytechnique*, Andrei Lissovoi, *The University of Sheffield*, Pietro Simone Oliveto, *The University of Sheffield*

Recently it has been proved that simple GP systems can efficiently evolve the conjunction of n variables if they are equipped with the minimal required components. In this paper, we make a considerable step forward by analysing the behaviour and performance of a GP system for evolving a Boolean function with unknown components, i.e. the target function may consist of both conjunctions and disjunctions. We rigorously prove that if the target function is the conjunction of n variables, then a GP system using the complete truth table to evaluate program quality evolves the exact target function in $O(\ell n \log^2 n)$ iterations in expectation, where $\ell \geq n$ is a limit on the size of any accepted tree. Additionally, we show that when a polynomial sample of possible inputs is used to evaluate solution quality, conjunctions with any polynomially small generalisation error can be evolved with probability $1 - O(\log^2(n)/n)$. To produce our results we introduce a super-multiplicative drift theorem that gives significantly stronger runtime bounds when the expected progress is only slightly super-linear in the distance from the optimum.

What's inside the black-box? A genetic programming method for interpreting complex machine learning models

Benjamin Patrick Evans, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Interpreting state-of-the-art machine learning algorithms can be difficult. For example, why does a complex ensemble predict a particular class? Existing approaches to interpretable machine learning tend to be either local in their explanations, apply only to a particular algorithm, or overly complex in their global explanations. In this work, we propose a global model extraction method which uses multi-objective genetic programming to construct accurate, simplistic and model-agnostic representations of complex black-box estimators. We found the resulting representations are far simpler than existing approaches while providing comparable reconstructive performance. This is demonstrated on a range of datasets, by approximating the knowledge of complex black-box models such as 200 layer neural networks and ensembles of 500 trees, with a single tree.

Hot Off the Press

HOP1

Tuesday, July 16, 10:40-12:20 Club B (1F)

Generating Interpretable Reinforcement Learning Policies using Genetic Programming

Daniel Hein, *Siemens AG*, Steffen Udluft, *Siemens AG*, Thomas A. Runkler, *Siemens AG*

The search for interpretable reinforcement learning policies is of high academic and industrial interest. Especially for industrial systems, domain experts are more likely to deploy autonomously learned controllers if they are understandable and convenient to evaluate. Basic algebraic equations are supposed to meet these requirements, as long as they are restricted to an adequate complexity. In our recent work "Interpretable policies for reinforcement learning by genetic programming" published in Engineering Applications of Artificial Intelligence 76 (2018), we introduced the genetic programming for reinforcement learning (GPRL) approach. GPRL uses model-based batch reinforcement learning and genetic programming and autonomously learns policy equations from pre-existing default state-action trajectory samples. Experiments on three reinforcement learning benchmarks demonstrate that GPRL can produce human-interpretable policies of high control performance.

Discovering Test Statistics Using Genetic Programming

Jason H. Moore, *University of Pennsylvania*, Randal S. Olson, *University of Pennsylvania*, Yong Chen, *University of Pennsylvania*, Moshe Sipper, *University of Pennsylvania*

We describe a genetic programming-based system for the automated discovery of new test statistics. Specifically, our system was able to discover test statistics as powerful as the t-test for comparing sample means from two distributions with equal variances [1].

Stochastic Program Synthesis via Recursion Schemes

Jerry Swan, *University of York*, Krzysztof Krawiec, *Poznan University of Technology*, Zoltan A. Kocsis, *University of Manch-*

ester

Stochastic synthesis of recursive functions has historically proved difficult, not least due to issues of non-termination and the often ad-hoc methods for addressing this. We propose a general method of implicit recursion which operates via an automatically-derivable decomposition of datatype structure by cases, thereby ensuring well-foundedness. The method is applied to recursive functions of long-standing interest and the results outperform recent work which combines two leading approaches and employs "human in the loop" to define the recursion structure. We show that stochastic synthesis with the proposed method on benchmark functions is effective even with random search, motivating a need for more difficult recursive benchmarks in future. This paper summarizes work that appeared in "Genetic Programming and Evolvable Machines (3 2019) 1-24".

EBIC: a scalable biclustering method for large scale data analysis

Patryk Orzechowski, *University of Pennsylvania*, Jason H. Moore, *University of Pennsylvania*

Biclustering is a technique that looks for patterns hidden in some columns and some rows of the input data. Evolutionary search-based biclustering (EBIC) is probably the first biclustering method that combines high accuracy of detection of multiple patterns with support for big data. EBIC has been recently extended to a multi-GPU method and allows to analyze very large datasets. In this short paper, we discuss the scalability of EBIC as well as its suitability for RNA-seq and single cell RNA-seq (scRNA-seq) experiments.

HOP2

Tuesday, July 16, 14:00-15:40 Club B (1F)

Low-Dimensional Euclidean Embedding for Visualization of Search Spaces in Combinatorial Optimization

Krzysztof Michalak, *Wroclaw University of Economics*

This abstract summarizes the results reported in the paper [3]. In this paper a method named Low-Dimensional Euclidean Embedding (LDEE) is proposed, which can be used for visualizing high-dimensional combinatorial spaces, for example search spaces of metaheuristic algorithms solving combinatorial optimization problems. The LDEE method transforms solutions of the optimization problem from the search space Ω to $\mathbb{R}^k$ (where in practice $k = 2$ or 3). Points embedded in $\mathbb{R}^k$ can be used, for example, to visualize populations in an evolutionary algorithm. The paper shows how the assumptions underlying the the t-Distributed Stochastic Neighbor Embedding (t-SNE) method can be generalized to combinatorial (for example permutation) spaces. The LDEE method combines the generalized t-SNE method with a new Vacuum Embedding method proposed in this paper to perform the mapping $\Omega \rightarrow \mathbb{R}^k$.

A Suite of Computationally Expensive Shape Optimisation Problems Using Computational Fluid Dynamics

Steven Daniels, *University of Exeter*, Alma Rahat, *University of Plymouth*, Richard Everson, *University of Exeter*, Gavin Tabor, *University of Exeter*, Jonathan Fieldsend, *University of Exeter*

Computational Fluid Dynamics (CFD) provides a qualitative (and sometimes even quantitative) prediction of fluid flows through a given system, providing insight into flows that are difficult, expensive or impossible to study using traditional (experimental) techniques. On occasions when design optimisation is applied to real-world engineering problems using CFD, the implementation may not be available for examination. As such, in both the CFD and optimisation communities, there is a need for a set of computationally expensive benchmark test problems for design optimisation using CFD. In this paper, we presented a suite of three computationally expensive real-world problems observed in different fields of engineering. We have developed Python software capable of automatically constructing geometries from a given decision vector, running appropriate simulations using the CFD code OpenFOAM, and returning the computed objective values. Thus, users may easily evaluate a decision vector and perform optimisation of these design problems using their optimisation methods without developing custom CFD code. For comparison, we provided the objective values for the base geometries and typical computation times for the test cases presented in the paper. We plan to present further results on solving these problems at GECCO 2019.

Understanding Exploration and Exploitation Powers of Meta-heuristic Stochastic Optimization Algorithms through Statistical Analysis

Tome Eftimov, *Jožef Stefan Institute*, Peter Korošec, *Jožef Stefan Institute*

Understanding of exploration and exploitation powers of metaheuristic stochastic optimization algorithms is very important for algorithm developers. For this reason, we have recently proposed an approach for making a statistical comparison of metaheuristic stochastic optimization algorithms according to the distribution of the solutions in the search space, which is also presented in this paper. Its main contribution is the support to identify exploration and exploitation powers of the compared algorithms. This is especially important when dealing with multimodal search spaces, which consist of many local optima with similar values, and large-scale continuous optimization problems, where it is hard to understand the reasons for the differences in performances. Experimental results showed that our recently proposed approach gives very promising results.

The (1+1)-EA with mutation rate (1+eps)/n is efficient on monotone functions: an entropy compression argument

Johannes Lengler, *ETH Zurich*, Anders Martinsson, *ETH Zurich*, Angelika Steger, *ETH Zurich*

An important benchmark for evolutionary algorithms are (strictly) monotone functions. For the (1+1)-EA with mutation rate c/n, it was known that it can optimize any monotone function on n bits in time $O(n \log n)$ if $c < 1$. However, it was also known that there are monotone functions on which the (1+1)-EA needs exponential time if $c > 2.2$. For $c = 1$ it was known that the runtime is always polynomial, but it was unclear whether it is quasilinear, and it was unclear whether $c = 1$ is the threshold at which the runtime jumps from polynomial to superpolynomial. We show there exists a $c_0 > 1$ such that for all $0 < c < c_0$ the (1+1)-EA with rate c/n finds the optimum in $O(n \log^2 n)$ steps in expectation. The proof is based on an adaptation of Moser's entropy compression argument. That is, we show that a long runtime would allow us to encode the random steps of the algorithm with less bits than their entropy.

HOP3

Tuesday, July 16, 16:10-17:50 Club B (1F)

Guiding Neuroevolution with Structural Objectives

Kai Olav Ellefsen, *University of Oslo*, Joost Huizinga, *Uber AI Labs*, Jim Torresen, *University of Oslo*

By use of evolutionary algorithms, neural network structures optimally adapted to a given task can be explored. Guiding such neuroevolution with additional objectives related to network structure has been shown to improve performance in some cases. However, apart from objectives aiming to make networks more modular, such structural objectives have not been widely explored. We propose two new structural objectives and test their ability to guide evolving neural networks. The first structural objective guides evolution to align neural networks with a user-recommended decomposition pattern. Intuitively, this should be a powerful guiding target for problems where human users can easily identify a structure. The second structural objective guides evolution towards a population with a high diversity in decomposition patterns. This results in exploration of many different ways to decompose a problem, allowing evolution to find good decompositions faster. Tests on our target problems reveal that both methods perform well on a problem with a very clear and decomposable structure. However, on a problem where the optimal decomposition is less obvious, the structural diversity objective is found to outcompete other structural objectives - and this technique can even increase performance on problems without any decomposable structure at all.

Combining Artificial Neural Networks and Evolution to Solve Multiobjective Knapsack Problems

Roman Denysiuk, *CEA, LIST*, António Gaspar-Cunha, *University of Minho*, Alexandre C. B. Delbem, *University of São Paulo*

The multiobjective knapsack problem (MOKP) is a combinatorial problem that arises in various applications, including resource allocation, computer science and finance. Evolutionary multiobjective optimization algorithms (EMOAs) can be effective in solving MOKPs. Though, they often face difficulties due to the loss of solution diversity and poor scalability. To address those issues, our study proposes to generate candidate solutions by artificial neural networks. This is intended to provide intelligence to the search. As gradient-based learning cannot be used when target values are unknown, neuroevolution is adapted to adjust the neural network parameters. The proposal is implemented within a state-of-the-art EMOA and benchmarked against traditional search operators base on a binary crossover. The obtained experimental results indicate a superior performance of the proposed approach. Furthermore, it is advantageous in terms of scalability and can be readily incorporated into different EMOAs.

Analysing Heuristic Subsequences for Offline Hyper-heuristic Learning

William B. Yates, *University of Exeter*, Edward C. Keedwell, *University of Exeter*

A selection hyper-heuristic is used to minimise the objective functions of a well-known set of benchmark problems. The resulting sequences of low level heuristic selections and objective function values are used to generate a database of heuristic selections. The sequences in the database are broken down into subsequences and the mathematical concept of a *logarithmic return* is used to discriminate between "effective" subsequences, which tend to decrease the objective value, and "disruptive" subsequences, which tend to increase the objective value. These subsequences are then employed in a sequenced based hyper-heuristic and evaluated on an unseen set of benchmark problems. Empirical results demonstrate that the "effective" subsequences perform significantly better than the "disruptive" subsequences across a number of problem domains with 99% confidence. The identification of subsequences of heuristic selections that can be shown to be effective across a number of problems or problem domains could have important implications for the design of future sequence based hyper-heuristics.

Gaussian Process Surrogate Models for the CMA-ES

Lukas Bajer, *Cisco Systems*, Zbynek Pitra, *The Czech Academy of Sciences*, Jakub Repicky, *Charles University*, Martin Holena, *The Czech Academy of Sciences*

This extended abstract previews the usage of Gaussian processes in a surrogate-model version of the CMA-ES, a state-of-the-art black-box continuous optimization algorithm. The proposed algorithm DTS-CMA-ES exploits the benefits of Gaussian process uncertainty prediction, especially during the selection of points for the evaluation with the surrogate model. Very brief results are presented here, while much more elaborate description of the methods, parameter settings and detailed experimental results can be found in the original article Gaussian

Process Surrogate Models for the CMA Evolution Strategy, to appear in the Evolutionary Computation.

HOP4

Wednesday, July 17, 09:00-10:40 Club B (1F)

Data-Driven Multi-Objective Optimisation of Coal-Fired Boiler Combustion System

Alma Rahat, *University of Plymouth*, Chunlin Wang, *Hangzhou Dianzi University*, Richard Everson, *University of Exeter*, Jonathan Fieldsend, *University of Exeter*

Coal remains an important energy source. Nonetheless, pollutant emissions – in particular Oxides of Nitrogen (NOx) – as a result of the combustion process in a boiler. Optimising combustion parameters to achieve a lower NOx emission often results in combustion inefficiency measured with the proportion of unburned coal content (UBC). Consequently there is a range of solutions that trade-off efficiency for emissions. Generally, an analytical model for NOx emission or UBC is unavailable, and therefore data-driven models are used to optimise this multi-objective problem. We introduce the use of Gaussian process models to capture the uncertainties in NOx and UBC predictions arising from measurement error and data scarcity. A novel evolutionary multi-objective search algorithm is used to discover the probabilistic trade-off front between NOx and UBC, and we describe a new procedure for selecting parameters yielding the desired performance. We discuss the variation of operating parameters along the trade-off front. We give a novel algorithm for discovering the optimal trade-off for all load demands simultaneously. The methods are demonstrated on data collected from a boiler in Jianbi power plant, China, and we show that a wide range of solutions trading-off NOx and efficiency may be efficiently located.

Hot Off the Press in Expert Systems on Underwater Robotic Missions: Success History Applied to Differential Evolution for Underwater Glider Path Planning

Aleš Zamuda, *University of Maribor*, José Daniel Hernández Sosa, *Universidad de Las Palmas de Gran Canaria*

The real-world implementation of Underwater Glider Path Planning (UGPP) over the dynamic and changing environment in deep ocean waters requires complex mission planning under very high uncertainties. Such a mission is also influenced to a large extent by remote sensing for forecasting weather models outcomes used to predict spatial currents in deep sea, further limiting the available time for accurate run-time decisions by the pilot, who needs to re-test several possible mission scenarios in a short time, usually a few minutes. Hence, this paper presents the recently proposed UGPP mission scenarios' optimization with a recently well performing algorithm for continuous numerical optimization, Success-History Based Adaptive Differential Evolution Algorithm (SHADE) including Linear population size reduction (L-SHADE). An algorithm for path optimization considering the ocean currents' model predictions, vessel dynamics, and limited communication, yields potential way-points for the vessel based on the most probable scenario; this is especially useful for short-term opportunistic missions where no reactive control is possible. The newly obtained results with L-SHADE outperformed existing literature results for the UGPP benchmark scenarios. Thereby, this new application of Evolutionary Algorithms to UGPP contributes significantly to the capacity of the decision-makers when they use the improved UGPP expert system yielding better trajectories.

A bi-level hybrid PSO – MIP solver approach to define dynamic tariffs and estimate bounds for an electricity retailer profit

Inês Soares, *INESC Coimbra*, Maria João Alves, *INESC Coimbra, CeBER and FEUC*, Carlos Henggeler Antunes, *INESC Coimbra and DEEC-UC*

With the implementation of dynamic tariffs, the electricity retailer may define distinct energy prices along the day. These tariff schemes encourage consumers to adopt different patterns of consumption with potential savings and enable the retailer to manage the interplay between wholesale and retail prices. In this work, the interaction between retailer and consumers is hierarchically modelled as a bi-level (BL) programming problem. However, if the lower level (LL) problem, which deals with the optimal operation of the consumer's appliances, is difficult to solve, it may not be possible to obtain its optimal solution, and therefore the solution to the BL problem is not feasible. Considering a computation budget to solve LL problems, a hybrid particle swarm optimization (PSO) – mixed-integer programming (MIP) approach is proposed to estimate good quality bounds for the upper level (UL) objective function. This work is based on [4].

Real World Applications

RWA1

Monday, July 15, 10:40-12:20 Club H (1F)

Towards Better Generalization in WLAN Positioning Systems with Genetic Algorithms and Neural Networks

Diogo Moury Fernandes Izidio, *Federal University of Pernambuco*, Antonyus Pyetro do Amaral Ferreira, *Center for Strategic Technologies of the Northeast*, Edna Natividade da Silva Barros, *Federal University of Pernambuco*

The most widely used positioning system today is the GPS (Global Positioning System), which has many commercial, civil and military applications, being present in most smartphones.

However, this system does not perform well in indoor locations, which poses a constraint for the positioning task on environments like shopping malls, office buildings, and other public places. In this context, WLAN positioning systems based on fingerprinting have attracted a lot of attention as a promising approach for indoor localization while using the existing infrastructure. This paper contributes to this field by presenting a methodology for developing WLAN positioning systems using genetic algorithms and neural networks. The fitness function of the genetic algorithm is based on the generalization capabilities of the network for test points that are not included in the training set. By using this approach, we have achieved state-of-the-art results with few parameters, and our method has shown to be less prone to overfitting than other techniques in the literature, showing better generalization in points that are not recorded on the radio map.

EVA: An Evolutionary Architecture for Network Virtualization

Ekaterina Holdener, *Saint Louis University*, Flavio Esposito, *Saint Louis Univeristy*, Dmitrii Chemodanov, *University of Missouri - Columbia*

Network virtualization has enabled new business models by allowing infrastructure providers to lease or share their physical infrastructure. A fundamental network management problem that infrastructure providers face to support customized virtual network services is the Virtual Network Embedding (VNE). This requires solving the (NP-hard) problem of matching constrained virtual networks onto the physical network. In this paper, we propose EVA, an architecture that solves the virtual network embedding problem with evolutionary algorithms. By tuning the fitness function and several other policies and parameters, EVA adapts to different types of network topologies and virtualization environments. We compared a few representative policies of EVA with recent virtual network embedding and virtual network function chain allocation solutions; our findings show how with EVA we obtain higher acceptance ratio performance as well as quicker convergence time. We release our implementation code to allow researchers to experiment with evolutionary policy programmability.

Evolutionary Learning of Link Allocation Algorithms for 5G Heterogeneous Wireless Communications Networks

David Lynch, *University College Dublin*, Takfarinas Saber, *University College Dublin*, Stepan Kucera, *Bell Laboratories Nokia-Ireland*, Holger Claussen, *Bell Laboratories Nokia-Ireland*, Michael O'Neill, *University College Dublin*

Wireless communications networks are operating at breaking point during an era of relentless traffic growth. Network operators must utilize scarce and expensive wireless spectrum efficiently in order to satisfy demand. Spectrum on the links between cells and user equipments ('users': smartphones, tablets, etc.) frequently becomes congested. Capacity can be increased by transmitting data packets via multiple links. Packets can be routed through multiple Long Term Evolution (LTE) links in existing fourth generation (4G) networks. In future 5G deployments, users will be equipped to receive packets over LTE, WiFi, and millimetre wave links simultaneously. How can we allocate spectrum on links, so that all customers experience an acceptable quality of service? Building effective schedulers for link allocation requires considerable human expertise. We automate the design process through the novel application of evolutionary algorithms. Evolved schedulers boost downlink rates by over 150% for the worst-performing users, relative to a single-link baseline. The proposed techniques significantly outperform a benchmark algorithm from the literature. The experiments illustrate the promise of evolutionary algorithms as a paradigm for managing 5G software-defined wireless communications networks.

Augmented Evolutionary Intelligence: Combining Human and Evolutionary Design for Water Distribution Network Optimisation

Matthew Barrie Johns, *University of Exeter*, Herman Abdulqadir Mahmoud, *University of Exeter*, David John Walker, *University of Plymouth*, Nicholas David Fitzhavering Ross, *University of Exeter*, Edward C. Keedwell, *University of Exeter*, Dragan A. Savic, *University of Exeter*

Evolutionary Algorithms (EAs) have been employed for the optimisation of both theoretical and real-world problems for decades, including in the field of water systems engineering. These methods although capable of producing near-optimal solutions, often fail to meet real-world application requirements due to considerations which are hard to define in an objective function. One solution is to employ an Interactive Evolutionary Algorithm (IEA), involving the human practitioner in the optimisation process to help guide the algorithm to a solution more suited to real-world implementation. This approach requires the practitioner to make thousands of decisions during an optimisation, potentially leading to user fatigue and diminishing the algorithm's search ability. This work proposes a method for capturing engineering expertise through machine learning techniques and integrating the resultant heuristic into an EA through its mutation operator. The human-derived heuristic based mutation is assessed on a range of water distribution network design problems from the literature and shown to often outperform traditional EA approaches. These developments open up the potential for more effective interaction between human expert and evolutionary techniques and with potential application to a much larger and diverse set of problems beyond the field of water systems engineering.

RWA2

Monday, July 15, 14:00-15:40 Club H (1F)

Classification of EEG Signals using Genetic Programming for Feature Construction

Icaro Marcelino Miranda, *University of Brasília*, Claus Aranha,

University of Tsukuba, Marcelo Ladeira, *University of Brasília*

The analysis of electroencephalogram (EEG) waves is of critical importance for the diagnosis of sleep disorders, such as sleep apnea and insomnia, besides that, seizures, epilepsy, head injuries, dizziness, headaches and brain tumors. In this context, one important task is the identification of visible structures in the EEG signal, such as sleep spindles and K-complexes. The identification of these structures is usually performed by visual inspection from human experts, a process that can be error prone and susceptible to biases. Therefore there is interest in developing technologies for the automated analysis of EEG. In this paper, we propose a new Genetic Programming (GP) framework for feature construction and dimensionality reduction from EEG signals. We use these features to automatically identify spindles and K-complexes on data from the DREAMS project. Using 5 different classifiers, the set of attributes produced by GP obtained better AUC scores than those obtained from PCA or the full set of attributes. Also, the results obtained from the proposed framework obtained a better balance of Specificity and Recall than other models recently proposed in the literature. Analysis of the features most used by GP also suggested improvements for data acquisition protocols in future EEG examinations.

Structured Grammatical Evolution for Glucose Prediction in Diabetic Patients

Nuno Lourenço, *CISUC, Department of Informatics Engineering, University of Coimbra*, J. Manuel Colmenar, *Universidad Rey Juan Carlos*, J. Ignacio Hidalgo, *Universidad Complutense de Madrid*, Oscar Garnica, *Universidad Complutense de Madrid*

Structured grammatical evolution (SGE) is a recent grammar-based genetic programming variant that tackles the main drawbacks of Grammatical Evolution, by relying on a one-to-one mapping between each gene and a non-terminal symbol of the grammar. It was applied, with success, in previous works with a set of classical benchmarks problems. However, assessing performance on hard real-world problems is still missing. In this paper, we fill in this gap, by analysing the performance of SGE when generating predictive models for the glucose levels of diabetic patients. Our algorithm uses features that take into account the past glucose values, insulin injections, and the amount of carbohydrate ingested by a patient. The results show that SGE can evolve models that can predict the glucose more accurately when compared with previous grammar-based approaches used for the same problem. Additionally, we also show that the models tend to be more robust, since the behavior in the training and test data is very similar, with a small variance.

EMOCS: Evolutionary Multi-objective Optimisation for Clinical Scorecard Generation

Diane P. Fraser, *University of Exeter*, Edward Keedwell, *University of Exeter*, Stephen L. Michell, *University of Exeter*, Ray Sheridan, *RD&E Hospital*

Clinical scorecards of risk factors associated with disease severity or mortality outcome are used by clinicians to make treatment decisions and optimize resources. This study develops an automated tool or framework based on evolutionary algorithms for the derivation of scorecards from clinical data. The techniques employed are based on the NSGA-II Multi-objective Optimization Genetic Algorithm (GA) which optimizes the pareto-front of two clinically-relevant scorecard objectives, size and accuracy. Three automated methods are presented which improve on previous manually derived scorecards. The first is a hybrid algorithm which uses the GA for feature selection and a decision tree for scorecard generation. In the second, the GA generates the full scorecard. The third is an extended full scoring system in which the GA also generates the scorecard scores. In this system combinations of features and thresholds for each scorecard point are selected by the algorithm and the evolutionary process is used to discover near-optimal Pareto-fronts of scorecards for exploration by expert decision makers. This is shown to produce scorecards that improve upon a human derived example for C.Difficile, an important infection found globally in communities and hospitals, although the methods described are applicable to any disease where the required data is available.

Relative evolutionary hierarchical analysis for gene expression data classification

Marcin Czajkowski, *Bialystok University of Technology, Faculty of Computer Science*, Marek Kretowski, *Bialystok University of Technology, Faculty of Computer Science*

Relative Expression Analysis (RXA) focuses on finding interactions among a small group of genes and studies the relative ordering of their expression rather than their raw values. Algorithms based on that idea play an important role in biomarker discovery and gene expression data classification. We propose a new evolutionary approach and a paradigm shift for RXA applications in data mining as we redefine the inter-gene relations using the concept of a cluster of co-expressed genes. The global hierarchical classification allows finding various sub-groups of genes, unifies the main variants of RXA algorithms and explores a much larger solution space compared to current solutions based on exhaustive search. Finally, the multi-objective fitness function, which includes accuracy, discriminative power of genes and clusters consistency, as well as specialized variants of genetic operators improve evolutionary convergence and reduce model underfitting. Importantly, patterns in predictive structures are kept comprehensible and may have direct applicability. Experiments carried out on 8 cancer-related gene expression datasets show that the proposed approach allows finding interesting patterns and significantly improves the accuracy of predictions.

RWA3

Monday, July 15, 16:10-17:50 Club H (1F)

Using a Genetic Algorithm with Histogram-Based Feature Selection in Hyperspectral Image Classification

Neil S. Walton, *Montana State University*, John W. Sheppard, *Montana State University*, Joseph A. Shaw, *Montana State University*

Optical sensing has the potential to be an important tool in the automated monitoring of food quality. Specifically, hyperspectral imaging has enjoyed success in a variety of tasks ranging from plant species classification to ripeness evaluation in produce. Although effective, hyperspectral imaging is prohibitively expensive to deploy at scale in a retail setting. With this in mind, we develop a method to assist in designing a low-cost multispectral imager for produce monitoring by using a genetic algorithm (GA) that simultaneously selects a subset of informative wavelengths and identifies effective filter bandwidths for such an imager. Instead of selecting the single fittest member of the final population as our solution, we fit a multivariate Gaussian mixture model to the histogram of the overall GA population, selecting the wavelengths associated with the peaks of the distributions as our solution. By evaluating the entire population, rather than a single solution, we are also able to specify filter bandwidths by calculating the standard deviations of the Gaussian distributions and computing the full-width at half-maximum values. In our experiments, we find that this novel histogram-based method for feature selection is effective when compared to both the standard GA and partial least squares discriminant analysis.

GenAttack: Practical Black-box Attacks with Gradient-Free Optimization

Moustafa Alzantot, *UCLA*, Yash Sharma, *Cooper Union*, Supriyo Chakraborty, *IBM Research*, Huan Zhang, *UCLA*, Cho-Jui Hsieh, *UCLA*, Mani Srivastava, *UCLA*

Deep neural networks are vulnerable to adversarial examples, even in the black-box setting, where the attacker is restricted solely to query access. Existing black-box approaches to generating adversarial examples typically require a significant number of queries, either for training a substitute network or performing gradient estimation. We introduce GenAttack, a gradient-free optimization technique that uses genetic algorithms for synthesizing adversarial examples in the black-box setting. Our experiments on different datasets (MNIST, CIFAR-10, and ImageNet) show that GenAttack can successfully generate visually imperceptible adversarial examples against stateof-the-art image recognition models with orders of magnitude fewer queries than previous approaches. Against MNIST and CIFAR-10 models, GenAttack required roughly 2, 126 and 2, 568 times fewer queries respectively, than ZOO, the prior state-of-the-art black-box attack. In order to scale up the attack to large-scale high-dimensional ImageNet models, we perform a series of optimizations that further improves the query efficiency of our attack leading to 237 times fewer queries against the Inception-v3 model than ZOO. Furthermore, we show that GenAttack can successfully attack some state-of-the-art ImageNet defenses, including ensemble adversarial training and nondifferentiable or randomized input transformations. Our results suggest that evolutionary algorithms open up a promising area of research into effective black-box attacks.

Differential Evolution Based Spatial Filter Optimization for Brain-Computer Interface

Gabriel H. de Souza, *Universidade Federal de Juiz de Fora*, Heder S. Bernardino, *Universidade Federal de Juiz de Fora*, Alex B. Vieira, *Universidade Federal de Juiz de Fora*, Helio J.C. Barbosa, *Laboratório Nacional de Computação Científica*

Brain-Computer Interface (BCI) is an emergent technology with a wide range of applications. For instance, it can be used for post-stroke motor rehabilitation in order to restore part of the motor control of someone injured in an accident. The BCI process involves the signal acquisition and preprocessing of data, extraction and selection of features, and classification. Thus, in order to have a correct classification of the movements, several filters are commonly used to handle the signal data. Here we propose the use of Differential Evolution (DE) with cross-entropy as the objective function to find an appropriate filter. Computational experiments are performed using 2 datasets from BCI competitions for motor imagery with signals of Bipolar and Monopolar Electroencephalography. Also, these problems involve two-class and multiclass classifications. The results show that the proposed DE obtained mean results 9.85% better than the well-known approach Filter Bank Common Spatial Pattern for BCIs with 2 classes for bipolar signals, and it allows for the reduction of the number of electrodes for BCIs with 4 classes.

Optimising Trotter-Suzuki Decompositions for Quantum Simulation Using Evolutionary Strategies

Benjamin Jones, *The University of Sheffield*, George O'Brien, *The University of Sheffield*, David White, *The University of Sheffield*, Earl Campbell, *The University of Sheffield*, John Clark, *The University of Sheffield*

One of the most promising applications of near-term quantum computing is the simulation of quantum systems, a classically intractable task. Quantum simulation requires computationally expensive matrix exponentiation; Trotter-Suzuki decomposition of this exponentiation enables efficient simulation to a desired accuracy on a quantum computer. We apply the Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) algorithm to optimise the Trotter-Suzuki decompositions of a canonical quantum system, the Heisenberg Chain; we reduce simulation error by around 60%. We introduce this problem to the computational search community, show that an evolutionary optimisation approach is robust across runs and problem instances, and find that optimisation results generalise to the simulation of larger systems.

RWA4: Best papers

Tuesday, July 16, 10:40-12:20 South Hall 1A (1F)

A Hybrid Evolutionary Algorithm Framework for Optimising Power Take Off and Placements of Wave Energy Converters ☆

Mehdi Neshat, *University of Adelaide*, Bradley Alexander, *University of Adelaide*, Nataliia Sergiienko, *University of Adelaide*, Markus Wagner, *University of Adelaide*

Ocean wave energy is a source of renewable energy that has gained much attention for its potential to contribute significantly to the coverage of the global energy demand and to reduce environmental issues. In this research, the investigated wave energy converter (WEC) are fully submerged three-tether converters (buoy) deployed in arrays. The main contribution of this study is the investigation and proposal of locations in a size-constrained environment while simultaneously optimizing the Power Takeoff (PTO) configurations, with the overall goal of maximizing the total harnessed power output. We suggest a Hybrid Evolutionary framework which consists of a wide variety of heuristic ideas, including cooperative and hybrid methods, for optimizing the converters placement and PTOs. For assessing and comparing the proposed methods performance, we use two real wave scenarios (Sydney and Perth) with two different buoy numbers. We find that a combination of symmetric local search with Nelder-Mead Simplex direct search and a backtracking optimization strategy is able to outperform previous search techniques.

A Novel Hybrid Scheme Using Genetic Algorithms and Deep Learning for the Reconstruction of Portuguese Tile Panels ☆

Daniel Rika, *Bar-Ilan University*, Dror Sholomon, *Bar-Ilan University*, Eli O. David, *Bar-Ilan University*, Nathan S. Netanyahu, *Bar-Ilan University*

This paper presents a novel scheme, based on a unique combination of genetic algorithms (GAs) and deep learning (DL), for the automatic reconstruction of Portuguese tile panels, a challenging real-world variant of the jigsaw puzzle problem (JPP) with important national heritage implications. Specifically, we introduce an enhanced GA-based puzzle solver, whose integration with a novel DL-based compatibility measure (DLCM) yields state-of-the-art performance, regarding the above application. Current compatibility measures consider typically (the chromatic information of) edge pixels (between adjacent tiles), and help achieve high accuracy for the synthetic JPP variant. However, such measures exhibit rather poor performance when applied to the Portuguese tile panels, which are susceptible to various real-world effects, e.g., monochromatic panels, non-squared tiles, edge degradation, etc. To overcome such difficulties, we have developed a novel DLCM to extract high-level texture/color statistics from the entire tile information. Integrating this measure with our enhanced GA-based puzzle solver, we have demonstrated, for the first time, how to deal most effectively with large-scale real-world problems, such as the Portuguese tile problem. The proposed method outperforms even human experts in several cases, correcting their mistakes in the manual tile assembly.

Multiobjective Shape Design in a Ventilation System with a Preference-driven Surrogate-assisted Evolutionary Algorithm ☆

Tinkle Chugh, *Department of Computer Science, University of Exeter*, Tomas Kratky, *Centre of Hydraulic Research*, Kaisa Miettinen, *University of Jyvaskyla, Faculty of Information Technology*, Yaochu Jin, *University of Jyvaskyla, Faculty of Information Technology*, Pekka Makkonen, *Valtra Inc.*

We formulate and solve a real-world shape design optimization problem of an air intake ventilation system in a tractor cabin by using a preference-based surrogate-assisted evolutionary multiobjective optimization algorithm. We are motivated by practical applicability and focus on two main challenges faced by practitioners in industry: 1) meaningful formulation of the optimization problem reflecting the needs of a decision maker and 2) finding a desirable solution based on a decision maker's preferences when solving a problem with computationally expensive function evaluations. For the first challenge, we describe the procedure of modelling a component in the air intake ventilation system with commercial simulation tools. The problem to be solved involves time consuming computational fluid dynamics simulations. Therefore, for the second challenge, we adapt a recently proposed Kriging-assisted evolutionary algorithm K-RVEA to incorporate a decision maker's preferences. Our numerical results indicate efficiency in using the computing resources available and the solutions obtained reflect the decision maker's preferences well. Actually, two of the solutions dominate the baseline design (the design provided by the decision maker before the optimization process). The decision maker was satisfied with the results and eventually selected one as the final solution.

RWA5

Tuesday, July 16, 14:00-15:40 Club C (1F)

Stability Analysis for Safety of Automotive Multi-Product Lines: A Search-Based Approach

Nian-Ze Lee, *National Taiwan University*, Paolo Arcaini, *National Institute of Informatics*, Shaukat Ali, *Simula Research Laboratory*, Fuyuki Ishikawa, *National Institute of Informatics*

Safety assurance for automotive products is crucial and challenging. It becomes even more difficult when the variability in automotive products is considered. Recently, the notion of automotive multi-product lines (multi-PL) is proposed as a unified framework to accommodate different sources of variability in automotive products. In the context of automotive multi-PL, we propose a stability analysis for safety, motivated by our industrial collaboration, where we observed that under certain operation scenarios, safety varies drastically with

small fluctuations in production parameters, environmental conditions, or driving inputs. To characterize instability, we formulate a multi-objective optimization problem, and solve it with a search-based approach. The proposed technique is applied to an industrial automotive multi-PL, and experimental results show its effectiveness to spot instability. Moreover, based on information gathered during the search, we provide some insights on both testing and quality engineering of automotive products.

Optimizing Evolutionary CSG Tree Extraction

Markus Friedrich, *Institute for Computer Science LMU Munich*, Pierre-Alain Fayolle, *The University of Aizu*, Thomas Gabor, *Institute for Computer Science LMU Munich*, Claudia Linnhoff-Popien, *Institute for Computer Science LMU Munich*

The extraction of 3D models represented by Constructive Solid Geometry (CSG) trees from point clouds is a common problem in reverse engineering pipelines as used by Computer Aided Design (CAD) tools. We propose three independent enhancements on state-of-the-art Genetic Algorithms (GAs) for CSG tree extraction: (1) A deterministic point cloud filtering mechanism that significantly reduces the computational effort of objective function evaluations without loss of geometric precision, (2) a graph-based partitioning scheme that divides the problem domain in smaller parts that can be solved separately and thus in parallel and (3) a 2-level improvement procedure that combines a recursive CSG tree redundancy removal technique with a local search heuristic, which significantly improves GA running times. We show in an extensive evaluation that our optimized GA-based approach provides faster running times and scales better with problem size compared to state-of-the-art GA-based approaches.

Functional Generative Design of Mechanisms with Recurrent Neural Networks and Novelty Search

Cameron Ronald Wolfe, *The University of Texas at Austin*, Cem C. Tutum, *The University of Texas at Austin*, Risto Miikkulainen, *The University of Texas at Austin*

Consumer-grade 3D printers have made the fabrication of aesthetic objects and static assemblies easier, opening the door to automate the design of such objects. However, while static designs are easily produced with 3D printing, functional designs, with moving parts, are more difficult to generate: The search space is high-dimensional, the resolution of the 3D-printed parts is not adequate, and it is difficult to predict the physical behavior of imperfect, 3D-printed mechanisms. An example challenge for automating the design of functional, 3D-printed mechanisms is producing a diverse set of reliable and effective gear mechanisms that could be used after production without extensive post-processing. To meet this challenge, an indirect encoding based on a Recurrent Neural Network (RNN) is proposed and evolved using Novelty Search. The elite solutions of each generation are 3D printed to evaluate their functional performance in a physical test platform. The proposed RNN model successfully discovers sequential design rules that are difficult to discover with other methods. Compared to a direct encoding of gear mechanisms evolved with Genetic Algorithms (GAs), the designs produced by the RNN are geometrically more diverse and functionally more effective, thus forming a promising foundation for the generative design of 3D-printed, functional mechanisms.

RWA6

Tuesday, July 16, 14:00-15:40 Club H (1F)

An Illumination Algorithm Approach to Solving the Micro-Depot Vehicle Routing Problem

Neil Urquhart, *Edinburgh Napier University*, Silke höhl, *Frankfurt University of Applied Sciences*, Emma Hart, *Edinburgh Napier University*

An increasing emphasis on reducing pollution and congestion in city centres combined with an increase in online shopping is changing the ways in which logistics companies address vehicle routing problems (VRP). We introduce the *micro-depot*-VRP, in which a single vehicle is used to supply a set of micro-depots distributed across a city; deliveries are then made from the micro-depot using a combination of electric vehicles, bicycles and pedestrian couriers. We present a formal definition of the problem, and propose a representation that can be used with an optimisation algorithm to minimise the total cost associated with delivering packages. Using five instances created from real-data obtained from Frankfurt, we apply an illumination algorithm in order to obtain a set of results that minimise costs but have differing characteristics in terms of emissions, distance travelled and number of vehicles used. Results show that solutions can be obtained that have equivalent costs to the baseline standard VRP solution, but considerably improve on this in terms of minimising the secondary criteria relating to emissions, vehicles and distance.

GA-Guided Task Planning for Multiple-HAPS in Realistic Time-Varying Operation Environments

Jane Jean Kiam, *University of the Bundeswehr, Munich*, Eva Besada-Portas, *Universidad Complutense de Madrid*, Valerie Hehtke, *Universität der Bundeswehr Muenchen*, Axel Schulte, *University of the Bundeswehr, Universitaet der Bundeswehr Muenchen*

High-Altitude Pseudo-Satellites (HAPS) are long-endurance, fixed-wing, lightweight Unmanned Aerial Vehicles (UAVs) that operate in the stratosphere and offer a flexible alternative for ground activity monitoring/imaging at specific time windows. As their missions must be planned ahead (to let them operate in controlled airspace), this paper presents a Genetic Algorithm (GA)-guided Hierarchical Task Network (HTN)-based planner for multiple HAPS. The HTN allows to compute plans that conform with airspace regulations and operation protocols. The GA copes with the exponentially growing complexity (with the number of monitoring locations and involved HAPS)

of the combinatorial problem to search for an optimal task decomposition (that considers the time-dependent mission requirements and the time-varying environment). Besides, the GA offers a flexible way to handle the problem constraints and optimization criteria: the former encodes the airspace regulations, while the latter measures the client satisfaction, the operation efficiency and the normalized expected mission reward (that considers the wind effects in the uncertainty of the arrival-times at the monitoring-locations). Finally, by integrating the GA into the HTN planner, the new approach efficiently finds overall good task decompositions, leading to satisfactory task plans that can be executed reliably (even in tough environments), as the results in the paper show.

Toward Real-World Vehicle Placement Optimization in Round-Trip Carsharing

Boonyarit Changaival, *University of Luxembourg*, Grégoire Danoy, *University of Luxembourg*, Dzmitry Kliazovich, *ExaMotive S.A.*, Frédéric Guinand, *Le Havre University*, Matthias Brust, *University of Luxembourg*, Jedrzej Musial, *Poznan University of Technology*, Kittichai Lavangnananda, *King Mongkut's University of Technology Thonburi*, Pascal Bouvry, *University of Luxembourg*

Carsharing services have successfully established their presence and are now growing steadily in many cities around the globe. Carsharing helps to ease traffic congestion and reduce city pollution. To be efficient, carsharing fleet vehicles need to be located on city streets in high population density areas and considering demographics, parking restrictions, traffic and other relevant information in the area to satisfy travel demand. This work proposes to formulate the initial placement of a fleet of cars for a round-trip carsharing service as a multi-objective optimization problem. The performance of state-of-the-art metaheuristic algorithms, namely, SPEA2, NSGA-II, and NSGA-III, on this problem is evaluated on a novel benchmark composed of synthetic and real-world instances built from real demographic data and street network. Inverted generational distance (IGD), spread and hypervolume metrics are used to compare the algorithms. Our findings demonstrate that NSGA-II yields significantly lower IGD and higher hypervolume than the rest and SPEA2 has a significantly better diversity if compared with NSGA-II and NSGA-III.

Optimising Bus Routes with Fixed Terminal Nodes: Comparing Hyper-heuristics with NSGAII on Realistic Transportation Networks

Leena Ahmed, *Cardiff University*, Philipp Heyken, *University of Nottingham*, Christine Mumford, *Cardiff University*, Yong Mao, *University of Nottingham*

The urban transit routing problem (UTRP) is concerned with finding efficient travelling routes for public transportation systems. This problem is highly complex, and the development of effective algorithms to solve it is very challenging. Furthermore, realistic benchmark data sets are lacking, making it difficult for researchers to compare their problem-solving techniques with those of other researchers. In this paper we contribute a new set of benchmark instances that have been generated by a procedure that scales down a real world transportation network, yet preserves the vital characteristics of the network layout including "terminal nodes" from which buses are restricted to start and end their journeys. In addition, we present a hyper-heuristic solution approach, specially tailored to solving instances with defined terminal nodes. We use our hyper-heuristic technique to optimise the generalised costs for passengers and operators, and compare the results with those produced by an NSGAII implementation on the same data set. We provide a set of competitive results that improve on the current bus routes used by bus operators in Nottingham.

RWA7

Tuesday, July 16, 16:10-17:50 Club D (1F)

Evolving Stellar Models to Find the Origins of Our Galaxy

Conrad Chan, *Monash University*, Aldeida Aleti, *Monash University*, Alexander Heger, *Monash University*, Kate Smith-Miles, *The University of Melbourne*

After the Big Bang, it took about 200 million years before the very first stars would form - now more than 13 billion years ago. Unfortunately, we will not be able to observe these stars directly. Instead, already now we can observe the 'fossil' records that these stars have left behind. When the first stars exploded as supernovae, their ashes were dispersed and the next generation of stars formed, incorporating some of these supernova debris. We can now measure the chemical abundances in those old stars, which allows us to identify the parents. In this paper, we develop a GA for identifying the 'parents' of these old stars in our galaxy. The objective is to study the now 'extinct' first stars in the universe - what their properties where, how they lived and died, how many they were, and even how different or alike they were. The GA is evaluated on its effectiveness in finding the right combination of 'ashes' from theoretical models in a large database containing a wide variety of stellar models and supernova. The solutions found by the GA are compared to observational data. The aim is to find out which theoretical data best matches current observations.

Sentiment analysis with genetically evolved Gaussian kernels

Ibai Roman, *University of the Basque Country (UPV/EHU)*, Alexander Mendiburu, *University of the Basque Country (UPV/EHU)*, Roberto Santana, *University of the Basque Country (UPV/EHU)*, Jose A. Lozano, *University of the Basque Country (UPV/EHU)*

Sentiment analysis consists of evaluating opinions or statements based on text analysis. Among the methods used to estimate the degree to which a text expresses a certain sentiment are those based on Gaussian Processes. However, traditional Gaussian Processes methods use a predefined kernels

with hyperparameters that can be tuned but whose structure can not be adapted. In this paper, we propose the application of Genetic Programming for the evolution of Gaussian Process kernels that are more precise for sentiment analysis. We use use a very flexible representation of kernels combined with a multi-objective approach that considers simultaneously two quality metrics and the computational time required to evaluate those kernels. Our results show that the algorithm can outperform Gaussian Processes with traditional kernels for some of the sentiment analysis tasks considered.

Inverse generative social science using multi-objective genetic programming

Tuong Manh Vu, *University of Sheffield*, Charlotte Probst, *Centre for Addiction and Mental Health*, Joshua M. Epstein, *New York University*, Mark Strong, *University of Sheffield*, Alan Brennan, *University of Sheffield*, Robin C. Purshouse, *University of Sheffield*

Generative mechanism-based models of social systems, such as those represented by agent-based simulations, require that intra-agent equations (or rules) be specified. However there are often many different choices available for specifying these equations, which can still be interpreted as falling within a particular class of mechanisms. Whilst it is important for a generative model to reproduce historically observed dynamics, it is also important for the model to be theoretically enlightening. Genetic programs (our own included) often produce concatenations that are highly predictive but are complex and hard to interpret theoretically. Here, we develop a new method – based on multi-objective genetic programming – for automating the exploration of both objectives simultaneously. We demonstrate the method by evolving the equations for an existing agent-based simulation of alcohol use behaviors based on social norms theory, the initial model structure for which was developed by a team of human modelers. We discover a trade-off between empirical fit and theoretical interpretability that offers insight into the social norms processes that influence the change and stasis in alcohol use behaviors over time.

Surrogate-based Optimization for Reduction of Contagion Susceptibility in Financial Systems

Krzysztof Michalak, *Wroclaw University of Economics*

This paper studies a bi-objective optimization problem in which the goal is to optimize connections between entities in the market in order to make the entire system resilient to shocks of varying magnitudes. As observed in the literature concerning contagion on the inter-bank market, no system structure maximizes resilience to shocks of all sizes. For larger shocks more connections between entities make the crisis worse, and for smaller shocks more connected systems turn out to be more resilient than less connected ones. In order to benefit from the information about the system connectivity, a machine learning model is used to estimate the values of the objectives attained by a given solution. The paper presents a comparison of a multiobjective optimization algorithm using simulations for evaluating solutions with a surrogate-based algorithm using a machine learning model. In the experiments the surrogate-based method outperformed the simulation-based one. This observation along with the analysis of the dependence between system connectivity and the resilience to shocks of different magnitudes presented in the paper allow to conclude that the information on system connectivity can be used for improving the working of optimization methods aimed at making the system less susceptible to financial contagion.

RWA8

Tuesday, July 16, 16:10-17:50 Club H (1F)

A Hybrid Metaheuristic Approach to a Real World Employee Scheduling Problem

Kenneth Reid, *University of Stirling*, Jingpeng Li, *University of Stirling*, Alexander Brownlee, *University of Stirling*, Mathias Kern, *BT Research & Innovation*, Nadarajen Veerapen, *Université de Lille*, Jerry Swan, *University of Stirling*, Gilbert Owusu, *BT Research & Innovation*

Employee scheduling problems are of critical importance to large businesses. These problems are hard to solve due to large numbers of conflicting constraints. While many approaches address a subset of these constraints, there is no single approach for simultaneously addressing all of them. We hybridise 'Evolutionary Ruin & Stochastic Recreate' and 'Variable Neighbourhood Search' metaheuristics to solve a real world instance of the employee scheduling problem to near optimality. We compare this with Simulated Annealing, exploring the algorithm configuration space using the irace software package to ensure fair comparison. The hybrid algorithm generates schedules that reduce unmet demand by over 28% compared to the baseline. All data used, where possible, is either directly from the real world engineer scheduling operation of around 25,000 employees, or synthesised from a related distribution where data is unavailable.

Cloud-based Dynamic Distributed Optimisation of Integrated Process Planning and Scheduling in Smart Factories

Shuai Zhao, *University of York*, Piotr Dziurzanski, *University of York*, Michal Przewozniczek, *University of York*, Marcin Komarnicki, *Wroclaw University of Technology*, Leandro Soares Indrusiak, *University of York*

In smart factories, process planning and scheduling need to be performed every time a new manufacturing order is received or a factory state change has been detected. A new plan and schedule need to be determined quickly to increase the responsiveness of the factory and enlarge its profit. Simultaneous optimisation of manufacturing process planning and scheduling leads to better results than a traditional sequential approach but is computationally more expensive and thus difficult to be

applied to real-world manufacturing scenarios. In this paper, a working approach for cloud-based distributed optimisation of process planning and scheduling is presented. It executes a multi-objective genetic algorithm on multiple subpopulations (islands). The number of islands is automatically decided based on the current optimisation state. A number of test cases based on two real-world manufacturing scenarios are used to show the applicability of the proposed solution.

Evolutionary approaches to dynamic earth observation satellites mission planning under uncertainty

Guillaume Poveda, *Airbus*, Olivier Regnier-Coudert, *Airbus*, Florent Teichteil-Koenigsbuch, *Airbus*, Gerard Dupont, *Airbus*, Alexandre Arnold, *Airbus*, Jonathan Guerra, *Airbus*, Mathieu Picard, *Airbus*

Mission planning for Earth observation satellite operators typically implies dynamically altering how requests from different customers are prioritized to meet expected deadlines. This exercise is challenging for different reasons. First, satellites are constrained by their acquisition and agility capabilities resulting in many requests being in concurrence with each other. When a request priority is boosted, it may incidentally penalize surrounding requests. Second, there are several uncertain factors such as weather (in particular cloud cover) and future incoming requests that can impact the completion progress of the requests. With order books of increasing size and the planned operations of a growing number of satellites in a close future, there is a clear need for a decision support tool. In this paper, we propose several evolutionary approaches to optimize request priorities based on Local Search and Population-Based Incremental Learning (PBIL). Using a certified algorithm to decode request priorities into satellite actions and a simulation framework developed by Airbus, we are able to realistically evaluate the potential of these methods and benchmark them against operators baselines. Experiments on several scenarios and order books show that EAs can outperform baselines and significantly improve operations both in terms of delay reduction and successful image capture.

RWA9

Wednesday, July 17, 09:00-10:40 Club H (1F)

Well Placement Optimization under Geological Statistical Uncertainty

Atsuhiro Miyagi, *Taisei Corporation*, Youhei Akimoto, *University of Tsukuba*, Hajime Yamamoto, *Taisei Corporation*

To control fluid flow in underground geologic formations, the placement of injection/production wells needs to be optimized taking geological characteristics of the reservoir into account. However, the optimum solution might not perform beneficially in the real world as the simulation result indicated because a reservoir model generally contains considerable geological uncertainty due to limited information of deep underground. Optimizing objective function integrating the response values from different models can be considered as an approach to this difficulty. In the previous study, such objective functions were proposed. However, their applicability has not been evaluated deeply. Therefore, their applicability was examined through well placement optimization for Carbon dioxide Capture and Storage (CCS) under geological statistical uncertainty as a case study. In the case study, we considered an optimization of the multiple wells for CO2 injection in a heterogeneous reservoir whose geological uncertainty was represented by 50 statistically independent reservoir models. As a result, the optimum solution with using all models showed the high applicability by comparing with the sensitivity analysis of nominal solutions, which is independently optimized for the single model, against the uncertainty. In addition, one of the proposed objective functions showed the superior result.

Evolving Robust Policies for Community Energy System Management

Rui P. Cardoso, *Imperial College London*, Emma Hart, *Edinburgh Napier University*, Jeremy V. Pitt, *Imperial College London*

Community energy systems (CESs) are shared energy systems in which multiple communities generate and consume energy from renewable resources. At regular time intervals, each participating community decides whether to self-supply, store, trade, or sell their energy to others in the scheme or back to the grid according to a predefined policy which all participants abide by. The objective of the policy is to maximise average satisfaction across the entire CES while minimising the number of unsatisfied participants. We propose a multi-class, multi-tree genetic programming approach to evolve a set of specialist policies that are applicable to specific conditions, relating to abundance of energy, asymmetry of generation, and system volatility. Results show that the evolved policies significantly outperform a default handcrafted policy. Additionally, we evolve a generalist policy and compare its performance to specialist ones, finding that the best generalist policy can equal the performance of specialists in many scenarios. We claim that our approach can be generalised to any multi-agent system solving a common-pool resource allocation problem that requires the design of a suitable operating policy.

Statistical Learning in Soil Sampling Design Aided by Pareto Optimization

Assaf Israeli, *Tel-Hai College*, Michael Emmerich, *Leiden University*, Michael (Iggy) Litaor, *Tel-Hai College*, Ofer M. Shir, *Tel-Hai College*

Effective soil-sampling is essential for the construction of prescription maps used in Precision Agriculture for Variable Rate Application of nutrients. In practice, designing a field sampling plan is subject to hard limitations, merely due to the associated expenses, where only a few sample points are taken for evaluation. The accuracy of constructed maps is affected by

the number of sampling points, their geographical dispersion and their coverage of the feature space. To improve the accuracy, ancillary data in the form of low-cost, high-resolution field scans could be used for inferring statistical measures for devising the high-cost sampling plan. The current study targets algorithmically-guided sampling plans using available ancillary data. We propose possible models for quantifying spatial coverage and diversity concerning the ancillary data. We investigate models as objective functions, devise Pareto optimization problems and solve them using NSGA-II. We analyzed the obtained sampling plans in an agricultural field, and suggest statistical tools for sample-size determination and plans' ranking according to additional information criteria. We argue that our approach is successful in attaining a practical sampling plan, constituting a fine trade-off between objectives, and possessing no discrepancies.

A hybrid multi-objective evolutionary algorithm for economic-environmental generation scheduling

Vasilios Tsalavoutis, *National Technical University of Athens*, Constantinos Vrionis, *National Technical University of Athens*, Athanasios Tolis, *National Technical University of Athens*

In this study, a hybrid Multi-Objective Evolutionary Algorithm (MOEA) is proposed for the Multi-Objective Short-Term Unit Commitment (MO-STUC) problem, considering the minimization of operation cost and emissions as objectives. The proposed algorithm is based on a real-coded Differential Evolution (DE) and a two-step function to simultaneously deal with both the scheduling of the state of the units and the dispatching of the power among the committed units. Moreover, a local search technique, which combines two distinct local search procedures based on Pareto dominance and scalar fitness function, is hybridized with the proposed MOEA. In addition, a heuristic repair mechanism and a problem-specific mutation operator are adopted to enhance the algorithm's performance. The method is tested on two frequently studied test systems comprising 10 and 20 units, respectively. The non-dominated fronts provided by the proposed method adequately approximate the Pareto fronts of the test instances. Simulation results reveal that the proposed algorithm outperforms two standard MOEAs, based on DE and Genetic Algorithm, with respect to the employed quality indicators. Furthermore, the beneficial impact of combining the two local search procedures is demonstrated.

Search-Based Software Engineering

SBSE1

Monday, July 15, 14:00-15:40 Club E (1F)

Why Train-and-Select When You Can Use Them All: Ensemble Model for Fault Localisation

Jeongju Sohn, *Korea Advanced Institute of Science and Technology*, Shin Yoo, *Korea Advanced Institute of Science and Technology*

Learn-to-rank techniques have been successfully applied to fault localisation to produce ranking models that place faulty program elements at or near the top. Genetic Programming has been successfully used as a learning mechanism to produce highly effective ranking models for fault localisation. However, the inherent stochastic nature of GP forces its users to learn multiple ranking models and choose the best performing one for the actual use. This train-and-select approach means that the absolute majority of the computational resources that go into the evolution of ranking models are eventually wasted. We introduce Ensemble Model for Fault Localisation (EMF), which is a learn-to-rank fault localisation technique that utilises all trained models to improve the accuracy of localisation even further. EMF ranks program elements using a lightweight, voting-based ensemble of ranking models. We evaluate EMF using 389 real-world faults in Defects4J benchmark. EMF can place 30.1% more faults at the top when compared to the best performing individual model from the train-and-select approach. We also apply Genetic Algorithm (GA) to construct the best performing ensemble. Compared to naively using all ranking models, GA generated ensembles can localise further 9.2% more faults at the top on average.

Improving Search-Based Software Testing by Constraint-Based Genetic Operators

Ziming Zhu, *State Key Laboratory of Computer Science, Institute of Software Chinese Academy of Sciences*, Li Jiao, *State Key Laboratory of Computer Science, Institute of Software Chinese Academy of Sciences*

Search-based software testing (SBST) has achieved great attention as an effective technique to automate test data generation. The testing problem is converted into a search problem, and a meta-heuristic algorithm is used to search for the test data in SBST. Genetic Algorithm (GA) is the most popular meta-heuristic algorithm used in SBST and the genetic operators are the key parts in GA. Much work has been done to improve SBST while little research has concentrated on the genetic operators. Due to the blindness and randomness of classic genetic operators, SBST is ineffective in many cases. In this paper, we focus on improving the genetic operators by constraint-based software testing. Compared with classic genetic operators, our improved genetic operators are more purposeful. For the selection operator, we use symbolic execution technique to help us select the test cases which have more useful heuristic information. Then, the constraint-based crossover operator recombines the test cases which have more probability to create better offspring individuals. Finally, the constraint-based mutation operator is used to improve the test cases in order to satisfy

some specific constraints. We applied our constraint-based genetic operators in several benchmarks and the experiments reveal the promising results of our proposal.

SQL Data Generation to Enhance Search-Based System Testing

Andrea Arcuri, *Kristiania University College*, Juan Pablo Galeotti, *Universidad de Buenos Aires*

Automated system test generation for web/enterprise systems requires either a sequence of actions on a GUI (e.g., clicking on HTML links), or direct HTTP calls when dealing with web services (e.g., REST and SOAP). However, web/enterprise systems do often interact with a database. To obtain higher coverage and find new faults, the state of the databases needs to be taken into account when generating white-box tests. In this work, we present a novel heuristic to enhance search-based software testing of web/enterprise systems, which takes into account the state of the accessed databases. Furthermore, we enable the generation of SQL data directly from the test cases. This is useful for when it is too difficult or time consuming to generate the right sequence of events to put the database in the right state. And it is also useful when dealing with databases that are "read-only" for the system under test, and the actual data is generated by other services. We implemented our technique as an extension of EvoMaster, where system tests are generated in the JUnit format. Experiments on five RESTful APIs show that our novel technique improves code coverage significantly (up to +18%).

Footprints of Fitness Functions in Search-Based Software Testing

Carlos Guimaraes, *Monash University*, Aldeida Aleti, *Monash University*, Yuan-Fang Li, *Monash University*, Mohamed Abdelrazek, *Monash University*

Testing is technically and economically crucial for ensuring software quality. One of the most challenging testing tasks is to create test suites that will reveal potential defects in software. However, as the size and complexity of software systems increase, the task becomes more labour-intensive and manual test data generation becomes infeasible. To address this issue, researchers have proposed different approaches to automate the process of generating test data using search techniques; an area that is known as Search-Based Software Testing (SBST). SBST methods require a fitness function to guide the search to promising areas of the solution space. Over the years, a plethora of fitness functions have been proposed. Some methods use control information, others focus on goals. Deciding on what fitness function to use is not easy, as it depends on the software system under test. This work investigates the impact of software features on the effectiveness of different fitness functions. We propose the Mapping the Effectiveness of Test Automation (META) Framework which analysis the footprint of different fitness functions and creates a decision tree that enables the selection of the appropriate function based on software features.

DETA1+SBSE2+THEORY2: Best papers

Tuesday, July 16, 10:40-12:20 South Hall 1B (1F)

Resource-based Test Case Generation for RESTful Web Services ☆

Man Zhang, *Kristiania University College*, Bogdan Marculescu, *Kristiania University College*, Andrea Arcuri, *Kristiania University College*

Nowadays, RESTful web services are widely used for building enterprise applications. In this paper, we propose an enhanced search-based method for automated system test generation for RESTful web services. This method exploits domain knowledge on the handling of HTTP resources, and it is integrated in the Many Independent Objectives (MIO) search algorithm. MIO is an evolutionary algorithm specialized for system test case generation with the aim of maximizing code coverage and fault finding. Our approach builds on top of the MIO by implementing a set of effective templates to structure test actions, based on the semantics of HTTP methods, used to manipulate the web services' resources. We propose four novel sampling strategies for the test cases that can use one or more of these test actions. The strategies are further supported with a set of new, specialized mutation operators that take into account the use of these resources in the generated test cases. We implemented our approach as an extension to the EvoMaster tool, and evaluated it on seven open-source RESTful web services. The results of our empirical study show that our novel, resource-based sampling strategies obtain a significant improvement in performance over the baseline MIO (up to +42% coverage).

A Hybrid Evolutionary System for Automatic Software Repair

Yuan Yuan, *Michigan State University*, Wolfgang Banzhaf, *Michigan State University*

This paper presents an automatic software repair system that combines the characteristic components of several typical evolutionary computation based repair approaches into a unified repair framework so as to take advantage of their respective component strengths. We exploit both the redundancy assumption and repair templates to create a search space of candidate repairs. Then we employ a multi-objective evolutionary algorithm with a low-granularity patch representation to explore this search space, in order to find simple patches. In order to further reduce the search space and alleviate patch overfitting we introduce replacement similarity and insertion relevance to select more related statements as promising fix ingredients, and we adopt anti-patterns to customize the available operation types for each likely-buggy statement. We evaluate our system on 224 real bugs from the Defects4J dataset in comparison with the state-of-the-art repair approaches. The evaluation

results show that the proposed system can fix 111 out of those 224 bugs in terms of passing all test cases, achieving substantial performance improvements over the state-of-the-art. Additionally, we demonstrate the ability of ARJA-e to fix multi-location bugs that are unlikely to be addressed by most of existing repair approaches.

Theory

THEORY1

Monday, July 15, 14:00-15:40 Club C (1F)

Runtime Analysis of the UMDA under Low Selective Pressure and Prior Noise

Per Kristian Lehre, *University of Birmingham*, Phan Trung Hai Nguyen, *University of Birmingham*

We perform a rigorous runtime analysis for the Univariate Marginal Distribution Algorithm on the LeadingOnes function, a well-known benchmark function in the theory community of evolutionary computation with a high correlation between decision variables. For a problem instance of size n, the currently best known upper bound on the expected runtime is $O(n\lambda \log \lambda + n^2)$ (Dang and Lehre, GECCO 2015), while a lower bound necessary to understand how the algorithm copes with variable dependencies is still missing. Motivated by this, we show that the algorithm requires a $e^{\Omega(\mu)}$ runtime with high probability and in expectation if the selective pressure is low on the expected runtime. Furthermore, we for the first time consider the algorithm on the function under a prior noise model and obtain an $O(n^2)$ expected runtime for the optimal parameter settings. In the end, our theoretical results are accompanied by empirical findings, not only matching with rigorous analyses but also providing new insights into the behaviour of the algorithm.

Runtime Analysis of Randomized Search Heuristics for Dynamic Graph Coloring

Jakob Bossek, *University of Muenster*, Frank Neumann, *The University of Adelaide*, Pan Peng, *The University of Sheffield*, Dirk Sudholt, *The University of Sheffield*

We contribute to the theoretical understanding of randomized search heuristics for dynamic problems. We consider the classical graph coloring problem and investigate the dynamic setting where edges are added to the current graph. We then analyze the expected time for randomized search heuristics to recompute high quality solutions. This includes the (1+1)EA and RLS in a setting where the number of colors is bounded and we are minimizing the number of conflicts as well as iterated local search algorithms that use an unbounded color palette and aim to use the smallest colors and – as a consequence – the smallest number of colors. We identify classes of bipartite graphs where reoptimization is as hard as or even harder than optimization from scratch, i.e. starting with a random initialization. Even adding a single edge can lead to hard symmetry problems. However, graph classes that are hard for one algorithm turn out to be easy for others. In most cases our bounds show that reoptimization is faster than optimizing from scratch. Furthermore, we show how to speed up computations by using problem specific operators concentrating on parts of the graph where changes have occurred.

Self-Adjusting Mutation Rates with Provably Optimal Success Rules

Benjamin Doerr, *Ecole Polytechnique*, Carola Doerr, *CNRS*, Johannes Lengler, *ETH Zurich*

The one-fifth success rule is one of the best-known and most widely accepted techniques to control the parameters of evolutionary algorithms. While it is often applied in the literal sense, a common interpretation sees the one-fifth success rule as a family of success-based updated rules that are determined by an update strength F and a success rate s. We analyze in this work how the performance of the (1+1) Evolutionary Algorithm (EA) on LeadingOnes depends on these two hyper-parameters. Our main result shows that the best performance is obtained for small update strengths $F = 1 + o(1)$ and success rate $1/e$. We also prove that the runtime obtained by this parameter setting is asymptotically optimal among all dynamic choices of the mutation rate for the (1+1) EA, up to lower order error terms. We show similar results for the resampling variant of the (1+1) EA, which enforces to flip at least one bit per iteration.

Improved Runtime Results for Simple Randomised Search Heuristics on Linear Functions with a Uniform Constraint

Frank Neumann, *University of Adelaide*, Mojgan Pourhassan, *University of Adelaide*, Carsten Witt, *Technical University of Denmark*

In the last decade remarkable progress has been made in development of suitable proof techniques for analysing randomised search heuristics. The theoretical investigation of these algorithms on classes of functions is essential to the understanding of the underlying stochastic process. Recently, linear functions have gained great attention in this area and results have been obtained on the expected optimisation time of simple randomised search algorithms, on constrained and unconstrained versions of this class of problems. In this paper we study the class of linear functions under uniform constraint and investigate the expected optimisation time of Randomised Local Search (RLS) and a simple evolutionary algorithm called (1+1) EA. We prove a tight bound of $\Theta(n^2)$ for RLS and improve the previously best known bound of (1+1) EA from $O(n^2 \log(Bw_{max}))$ to $O(n^2 \log B)$ in expectation, where w_{max} and B are the maximum weight of the linear objective function and the bound of the uniform constraint, respectively.

DETA1+SBSE2+THEORY2: Best papers

Tuesday, July 16, 10:40-12:20 South Hall 1B (1F)

A Tight Runtime Analysis for the cGA on Jump Functions - EDAs Can Cross Fitness Valleys at No Extra Cost ☆

Benjamin Doerr, *Ecole Polytechnique*

We prove that the compact genetic algorithm (cGA) with hypothetical population size $\mu = \Omega(\sqrt{n}\log n) \cap \text{poly}(n)$ with high probability finds the optimum of any n-dimensional jump function with jump size $k < \frac{1}{20}\ln n$ in $O(\mu\sqrt{n})$ iterations. Since it is known that the cGA with high probability needs at least $\Omega(\mu\sqrt{n} + n\log n)$ iterations to optimize the unimodal ONEMAX function, our result shows that the cGA in contrast to most classic evolutionary algorithms here is able to cross moderate-sized valleys of low fitness at no extra cost. Our runtime guarantee improves over the recent upper bound $O(\mu n^{1.5}\log n)$ valid for $\mu = \Omega(n^{3.5+\varepsilon})$ of Hasenöhrl and Sutton (GECCO 2018). For the best choice of the hypothetical population size, this result gives a runtime guarantee of $O(n^{5+\varepsilon})$, whereas ours gives $O(n\log n)$. We also provide a simple general method based on parallel runs that, under mild conditions, (i) overcomes the need to specify a suitable population size, but gives a performance close to the one stemming from the best-possible population size, and (ii) transforms EDAs with high-probability performance guarantees into EDAs with similar bounds on the expected runtime.

THEORY3

Tuesday, July 16, 16:10-17:50 Club C (1F)

On the Benefits of Populations for the Exploitation Speed of Standard Steady-State Genetic Algorithms

Dogan Corus, *The University of Sheffield*, Pietro S. Oliveto, *The University of Sheffield*

It is generally accepted that populations are useful for the global exploration of multi-modal optimisation problems. Indeed, several theoretical results are available showing such advantages over single-trajectory search heuristics. In this paper we provide evidence that evolving populations via crossover and mutation may also benefit the optimisation time for hill-climbing unimodal functions. In particular, we prove bounds on the expected runtime of the standard (μ+1) GA for OneMax that are lower than its unary black box complexity and decrease in the leading constant with the population size up to $mu = O(\sqrt{\log n})$. Our analysis suggests that the optimal mutation strategy is to flip two bits most of the time. To achieve the results we provide two interesting contributions to the theory of randomised search heuristics: 1) A novel application of drift analysis which compares absorption times of different Markov chains without defining an explicit potential function. 2) To calculate the absorption times of the Markov chains we invert their fundamental matrices. Such a strategy was previously proposed in the literature but to the best of our knowledge this is the first time is has been used to show non-trivial bounds on expected runtimes.

Lower Bounds on the Runtime of Crossover-Based Algorithms via Decoupling and Family Graphs

Andrew M. Sutton, *University of Minnesota Duluth*, Carsten Witt, *Technical University Of Denmark*

The runtime analysis of evolutionary algorithms using crossover as search operator has recently produced remarkable results indicating benefits and drawbacks of crossover and illustrating its working principles. Virtually all these results are restricted to upper bounds on the running time of the crossover-based algorithms. This work addresses this lack of lower bounds and rigorously bounds the optimization time of simple algorithms using uniform crossover on the search space $\{0,1\}^n$ from below via two novel techniques called decoupling and family graphs. First, a simple crossover-based algorithm without selection pressure is analyzed and shown that after $O(\mu\log\mu)$ generations, bit positions are sampled almost independently with marginal probabilities corresponding to the fraction of one-bits at the corresponding position in the initial population. Afterwards, a crossover-based algorithm using tournament selection is analyzed by a novel generalization of the family tree technique originally introduced for mutation-only EAs. Using these so-called family graphs, almost tight lower bounds on the optimization time on the OneMax benchmark function are shown.

Multiplicative Up-Drift

Benjamin Doerr, *Ecole Polytechnique*, Timo Kötzing, *Hasso Plattner Institute*

Drift analysis aims at translating the expected progress of an evolutionary algorithm (or more generally, a random process) into a probabilistic guarantee on its run time (hitting time). So far, drift arguments have been successfully employed in the rigorous analysis of evolutionary algorithms, however, only for the situation that the progress is constant or becomes weaker when approaching the target. Motivated by questions like how fast fit individuals take over a population, we analyze random processes exhibiting a multiplicative growth in expectation. We prove a drift theorem translating this expected progress into a hitting time. This drift theorem gives a simple and insightful proof of the level-based theorem first proposed by Lehre (2011). Our version of this theorem has, for the first time, the best-possible linear dependence on the growth factor (the previous-best was quadratic). This gives immediately stronger run time guarantees for a number of applications.

The Efficiency Threshold for the Offspring Population Size of the (μ, λ) EA

Antipov Denis, *ITMO University*, Benjamin Doerr, *École Polytechnique*, Quentin Yang, *École Polytechnique*

Understanding when evolutionary algorithms are efficient or not is one of the central research tasks in evolutionary computation. In this work, we make progress in understanding the interplay between parent and offspring population size of the (μ,λ) EA. Previous works, roughly speaking, indicate that for $\lambda \geq (1+\varepsilon)e\mu$, this EA easily optimizes the OneMax function, whereas an offspring population size $\lambda \leq (1-\varepsilon)e\mu$ leads to an exponential runtime. Motivated also by the observation that in the efficient regime the (μ,λ) EA loses its ability to escape local optima, we take a closer look into this phase transition. Among other results, we show that when $\mu \leq n^{1/2-c}$ for any constant $c > 0$, then for any $\lambda \leq e\mu$ we have a super-polynomial runtime. However, if $\mu \geq n^{2/3+c}$, then for any $\lambda \geq e\mu$, the runtime is polynomial. For the latter result we observe that the (μ,λ) EA profits from better individuals also because these, by creating slightly worse offspring, stabilize slightly sub-optimal sub-populations. While these first results close to the phase transition do not yet give a complete picture, they indicate that the boundary between efficient and super-polynomial is not just the line $\lambda = e\mu$, and that the reasons for efficiency or not are more complex than what was known so far.

Instructions for Session Chairs and Presenters

Instructions for Session Chairs and Presenters

Instructions for Session Chairs

Thank you for agreeing to chair a session. Session chairs are essential to keep sessions on schedule and moderate the question period.

- Arrive at your session early to check the room and the equipment set-up.
- Let the conference organizers at the registration desk know of any problems or if adjustments are needed.
- If you chair a best paper session, please remind the audience that this is a best paper session, distribute the ballots that you will find in the room at the beginning of the session, and collect the voting ballots and voting vouchers at the end of the session by carefully checking the match between the badge and voucher. After the session, bring the ballots and vouchers to the registration desk. The attendees may also vote directly at the registration desk.
- Follow the scheduled order of talks, as well as presentation times.
- In the unlikely event that a speaker is absent, announce a break until the next presentation is due to start. Breathe normally.
- Do not start early, as participants may be moving between sessions/presentations.
- Introduce each speaker.
- Speakers are allocated 25 minutes for a presentation: 20 minutes for set up and presentation, and 5 minutes for questions.
- Make sure the speaker adheres to the maximum time allotted.
- Moderate questions. If there are no questions, ask one yourself (time permitting). Do not start the next presentation early (or late).
- If a session is without a chair, we ask the last scheduled speaker to perform these duties.

Instructions for Paper Presenters

- Projectors and screens will be available for all presentations.
- Presenters are required to bring (or arrange) their own presentation device (such as a laptop).
- The only guaranteed connection to the projector is VGA. If your device doesn't support this, make sure that you have a converter for your device, or ask to use somebody else's presentation device.
- Quickly check that the device you are using for the presentation works with the projector before the start of the session.
- Talks are allocated 25 minutes: 20 minutes for set up and presentation, and 5 minutes for questions.

The above holds for the papers in the main conference sessions and HOP sessions, contact workshop chairs for workshop-specific details.

Instructions for Poster Presenters

- The poster session will be held on Monday, July 15, 17:50-20:00 in Panorama Hall (1F).
- Hang up your poster during the session the precedes the poster session.
- Poster boards and thumb tacks will be available.
- The definitive maximum poster dimensions are 90 cm (width) x 120 cm (height). Note: the ISO paper size A0 (closely) fits this maximum size.

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