# Genetic and Evolutionary Computation Conference 2018

**Conference Program** 



Kyoto, Japan July 15-19, 2018



Association for Computing Machinery

Advancing Computing as a Science & Profession



Welcome
Sponsors and Supporters
Organizers and Track Chairs
Program Committee
Proceedings
Schedule and Floor Plans
Schedule at a Glance
Workshop and Tutorial Sessions
Paper Sessions Overview
Track List and Abbreviations
Floor Plans
Keynotes
Tutorials 34
Workshops Late Breaking Abstracts and Women@GECCO
Humies Competitions Evolutionary Computation in Practice Hot off the Press and Job Market
Annual "Humies" Awards for Human-Competitive Results
Competitions
Evolutionary Computation in Practice 5'
SIGE VO Summer School
Best Paper Nominations
Papers and Posters
Tuesday, July 17, 10:40-12:20
Tuesday, July 17, 14:00-15:40
Tuesday, July 17, 16:00-17:40
Wednesday, July 18, 10:40-12:20
Wednesday, July 18, 15:30-17:10
Thursday, July 19, 09:00-10:40
Poster Session
Abstracts by Track
ACO-SI
CS
DETA
ECOM
EML
ЕМО 12
ENUM
GA 132
GECH
GP
НОР
RWA
SBSE
Theory
Instructions for Session Chairs and Presenters

### Author Index

163



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#### Welcome

### Welcome

It is my pleasure to welcome you to the Genetic and Evolutionary Computation Conference (GECCO) 2018 in Kyoto, Japan, July 15-19, on behalf of the entire organization committee. It is a great honor to held GECCO in Asia for the first time, parallel to the splendid Gion festival. GECCO is the main conference of the Special Interest Group on Genetic and Evolutionary Computation (SIGEVO) of the Association for Computing Machinery (ACM). GECCO prides itself in being the top quality conference in the area of genetic and evolutionary computation. This quality is ensured by having a selective and thorough reviewing process. Decisions on the acceptance of papers are made by expert track chairs with strong reputations, covering all the key areas in our field.

This year 514 papers were submitted to 13 different tracks, and 1910 reviews were assigned. Less than 38% of papers have been accepted as full papers, with a further 29% accepted for poster presentation. In addition, 65 poster-only papers were submitted, of which less than 48% were accepted for poster presentation.

I am thrilled that this year we are able to offer an enticing variety of industry invited keynote presentations by Kazuo Yano (Hitachi Ltd.), Tatsuya Okabe (DENSO Co., Ltd.), Naoko Yamazaki (former JAXA astronaut), and, for the SIGEVO Chair plenary lecture, David E. Goldberg (ThreeJoy Associates, Inc. and University of Illinois).

Attending GECCO provides an opportunity to listen to and interact with the leading experts in our field, to establish new collaborations, and to reunite with well-known friends. On top of that, GECCO this year offers an amazing plethora of 21 workshops and 40 tutorials at no extra charge. Furthermore, with the competitions and the annual Humies event sponsored by John Koza, GECCO are sure to present the edge of modern computational possibilities and the latest human competitive results in our field. Following last year initiatives, GECCO 2018 continues this year the Summer School and the Job Market events. GECCO 2018 also brings a few items to the table such as the mobile application, an improved voting system for the best paper awards where attendees can only vote for one best paper session, and an integrated review of workshops and competitions within the same submission system.

I would like to thank all authors for submitting their excellent work to GECCO 2018 and all people who contributed to the organization of the conference. I am very much in debt to the organization committee, the track chairs, and the reviewers for their tremendous works. GECCO could not happen without the joint and tireless effort of the amazing people that make up the GECCO community. In particular, I would like to specifically thank the editor-in-chief Hernan Aguirre for the excellent teamwork, the local chair Hisashi Handa and the local financial chair Hiroyuki Sato for the arrangement of local activities, and the proceedings chair Arnaud Liefooghe for the huge job of getting the proceedings together in time. I would also like to thank Enrique Alba, Kalyanmoy Deb, and Darrell Whitley from the business committee of GECCO, and Franz Rothlauf and Marc Schoenauer from SIGEVO for their in-depth knowledge, experience and advice on how to organize a successful GECCO. In addition, I would like to thank the core event organization team, Roxane Rose, Cara Candler, and Annabel Custer from Executive Events for handling registrations and logistics, and Mark Montague and Leah Glick from Linklings for improving the paper submission system to handle all types of papers including workshop papers, poster papers, and competitions.

On behalf of GECCO, I further want to thank our industry sponsors SparkCognition, Nature Research, Sentient, Uber AI Labs, Springer, Beacon and ACM SIGEVO as well as Japanese sponsors NEC, Fujitsu Limited, Rakuten/Linkshare, NTT DATA Engineering Systems Corporation, DataDirect Networks Japan, HPCTECH Corporation, Intelligent Light, The Japanese Society for Evolutionary Computation, Shinshu University, The University of Electro-Communications (UEC), Artificial Intelligence eXploration (AIX) research center at UEC for their contribution and supports.

Finally, I sincerely wish all of you attending GECCO an excellent conference experience that brings you a lot of new insights, collaborations, ideas and inspiration for future research, and of course, some fun to go with it all.

#### Keiki Takadama

GECCO 2018 General Chair The University of Electro-Communications Tokyo, Japan

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Andries Engelbrecht, University of Pretoria Roderich Gross, University of Sheffield

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

Emma Hart, Edinburgh Napier University Sebastian Risi, IT University of Copenhagen

#### DETA — Digital Entertainment Technologies and Arts

Aniko Ekart, Aston University Julian Togelius, New York University

#### ECOM — Evolutionary Combinatorial Optimization and Metaheuristics

Christian Blum, Artificial Intelligence Research Institute Sébastien Verel, Université du Littoral Côte d'Opale

#### EML — Evolutionary Machine Learning

Will Neil Browne, Victoria University of Wellington Yusuke Nojima, Osaka Prefecture University

#### EMO — Evolutionary Multiobjective Optimization

Tea Tušar, Jozef Stefan Institute Qingfu Zhang, City University of Hong Kong

#### **ENUM** — Evolutionary Numerical Optimization

Nikolaus Hansen, Inria Saclay Jose A. Lozano, University of the Basque Country UPV/EHU

#### GA — Genetic Algorithms

Dirk Thierens, Utrecht University Tian-Li Yu, National Taiwan University

#### GECH — General Evolutionary Computation and Hybrids

Juergen Branke, University of Warwick Yaochu Jin, University of Surrey

#### **GP** — Genetic Programming

Hitoshi Iba, University of Tokyo Sara Silva, BioISI / FCUL

#### **RWA** — Real World Applications

Thomas Bartz-Beielstein, TH Köln - University of Applied Sciences Anna I Esparcia-Alcazar, Universitat Politècnica de València

#### SBSE — Search-Based Software Engineering

Giuliano Antoniol, Polytechnique Montréal Federica Sarro, University College London

#### Theory

Anne Auger, Inria Saclay Per Kristian Lehre, University of Birmingham

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**Schedule and Floor Plans** 



# Schedule at a Glance

Sunday, July 15	Monday, July 16	Tuesday, July 17	Wednesday, July 18	Thursday, July 19	
Tutorials, Workshops, and Competitions	Tutorials and Workshops 09:00-10:40	Opening 09:00 Invited Keynote Kazuo Yano 09:10-10:20	SparkCognition 09:00 Invited Keynote Tatsuya Okabe 09:10-10:20	Paper Sessions and HOP 09:00-10:40	
09:30-11:10	Coffee Break			Coffee Break	
Lunch on Your Own	Tutorials and Workshops 11:00-12:40	Paper Sessions and ECiP 10:40-12:20	Paper Sessions and HOP 10:40-12:20	SIGEVO Keynote David E. Goldberg 11:00-12:10	
Tutorials and Workshops	Lunch on Your Own	Lunch on Your Own (Job Market)	Lunch on Your Own	SIGEVO Meeting/Awards Closing 12:10-13:40	
12:50-14:30 Coffee Break	Tutorials, Workshops, and LBA	Paper Sessions, ECiP and HUMIES	Invited Keynote Naoko Yamazaki 14:00-15:10	SIGEVO Summer School Closing	
Tutorials and Workshops 14:50-16:30	14:00-15:40	14:00-15:40	Coffee Break	13:40-16:30	
	Coffee Break Tutorials, Workshops,	Coffee Break Paper Sessions and ECiP	Paper Sessions and HOP		
	and LBA 16:00-17:40	and ECIP 16:00-17:40	15:30-17:10		
Welcome Party 17:45-20:00	Women @ GECCO 18:00-20:00	Poster Session 18:00-20:00	Social Event 18:00-22:00		

Registration desk hours: 9:00-16:00 (closed during lunch)

Coffee breaks: Foyer of Terrsa Hall (1F and 2F)

Keynotes, job market, poster session, and SIGEVO meeting: Terrsa Hall (1F)

Summer School lunch meetings: Sunday, July 15 and Monday, July 16 - Study Room

Student Workshop lunch meeting: Monday, July 16 - Conference Room No. 9

GPEM meeting: Tuesday, July 17 - Conference Room No. 9

ECJ meeting: Wednesday, July 18 - Conference Room No. 9

Welcome party: Terrsa Hall (1F)

Social event: GECCO 2018 banquet will be held at Shunju Hall, in Rihga Royal Hotel Kyoto, on Wednesday, July 18. Rihga Royal Hotel Kyoto (http://www.rihgaroyalkyoto.com/) is located on the west side of Kyoto Station, at about a 15 minutes walk from the conference venue.

Dinner will be served in buffet style including Japanese traditional food and free drinks. In addition, you can enjoy traditional Japanese culture, geiko/maiko, and Iga ninja show.





Geiko and maiko are traditional Japanese female entertainers, who learn traditional Japanese performing arts, such as dance, song, and playing shamisen (traditional Japanese instrument). You can enjoy dance to song and shamisen music performed by geiko and maiko who ware luxurious kimonos. Iga ninja show is a unique ninja (Iga Hattori school) show centered on the traditional ninjutsu that has been handed down since the Warring States period. You can learn a lot of ninjutsu while enjoying the battle between female and male ninja who make use of numerous ninjutsu.





One suggested route can be checked at this URL. From the Conference Venue to Rihga Royal Hotel Kyoto:

- 1. Go to Hachijo-Dori street from the Conference venue through Nishinotoin-Dori street.
- 2. Turn left and go to Abranokoji-Dori street.
- 3. Cross the intersection (Hachijo Abrakoji) and turn right.
- 4. Go straight to north and go under the track.
- 5. You will see the entrance of Rihga Royal Hotel Kyoto on the left side.



# Workshop and Tutorial Sessions, Sunday, July 15

	09:30-11:10	12:50-14:30	14:50-16:30		
Terrsa Hall (1F)	Shift Your Research & Labo- ratory into Higher Gear with 3 Shift Skills & 4 Smooth Rules	Evolution of Neural Networks	Neuroevolution for Deep Reinforcement Learning Problems		
	Goldberg	Miikkulainen	На		
	BBOB — Black Box	RWACMO — Real-world	<b>GBEA</b> — Game-Benchmark for		
Training	Optimization Benchmarking	<b>Applications of Continuous and</b>	Evolutionary Algorithms		
Room 1 $(2F)$		Mixed-integer Ontimization			
	40	12	14		
	p. 40	p. 42	p. 44		
	Runtime Analysis of	Evolutionary Computation	Hyper-heuristics		
Training	Evolutionary Algorithms:	and Games			
Room 2 $(2F)$	Basic Introduction				
		T 1' D' X 1 1'			
	Lehre, Oliveto	Togelius, Risi, Yannakakis	Woodward, Tauritz		
	VizGEC/SAEOpt —	EvoSoft — Evolutionary Compu	tation Software Systems		
Training	Visualisation Methods in EC /				
Room 3 $(2F)$	Surrogate-Assisted				
1000iii 5 (21)	Englistion and Ontinization				
	Evolutionary Optimisation p. 41		p. 43		
Conference	Introducing	Evolutionary	A Practical Guide to		
D	Learning Classifier Systems:	Reinforcement Learning:	Experimentation		
Room	Rules that Canture Complexity	General Models and Adaptation	<b>I</b>		
Medium (2F)	Kules that Capture Complexity	General Mouels and Adaptation			
	Urbanowicz, Vargas	Vargas	Hansen		
	Evolutionary Robotics	Next Generation	Search-based Test Optimization		
AV Study		Genetic Algorithms	for Software Systems		
Room (2F)		8			
1000111 (21)		TT 71 1 - 1			
	Doncieux, Bredeche, Mouret	Whitley	Ali		
Conference	EABDMCP — Evolutionary	EiC — Evolution in Cognition	EIEHSCoEvo — Exploration		
Boom A	Algorithms for Big Data and		of Inaccessible Environments		
KOOIII A	Massively Complex Problems		through Hardware/Software		
(3F)	p 40	n 41	Co-evolution n 42		
	p. 40	p. 41	p. 45		
	Competitions	Search-Maps: Visualising and	LAHS — Landscape-Aware		
Conference		Exploiting the Global Structure	Heuristic Search		
Room B (3F)		of Computational Search Spaces			
	n 55	Ochoa Veeranen	n 13		
	IOMES Intelligent	FCUNS Evolutionomy Comm	p. 45		
	IOWIES — Intelligent	ECHNS — Evolutionary Comp	utation in Health Care and		
Conference	Operations Management in the	Nursing System			
Room C (3F)	Energy Sector				
	n 40		n 42		
	Introduction to	Representations for	p. 12		
Conference	Carat's Dragman in				
Room D	Geneuc Programming	Evolutionary Algorithms			
(3F)					
(31)	O'Reilly	Rothlauf			
	Introductory Mathematical	Introductory Statistics for EC.	Theory for Non-Theoreticians		
Conforma	Decomposition for EC	A Vienal Ammune 1	Theory for Non-Theoreticians		
D	rrogramming for EC	A visual Approach			
Room 2 (3F)					
	Shir	Wineberg	Doerr		



Workshops

Competitions

# Workshop and Tutorial Sessions, Monday, July 16

	09:00-10:40	11:00-12:40	14:00-15:40	16:00-17:40		
Terrsa Hall (1F)	Model-Based Evolutionary Algorithms	Evolutionary Multiobjective Optimization	Decomposition Multi- Objective Optimisation	Visualization in Multi- objective Optimization		
	Thierens, Bosman	Brockhoff	Li, Zhang	Filipic, Tusar		
Training Room 1 (2F)			NSBECR — New Stan- dards for Benchmarking in Evolutionary Compu- tation Research p. 47	PDEIM — Parallel and Distributed Evolution- ary Inspired Methods p. 48		
Training Room 2 (2F)	SecDef — Genetic and Ev in Defense, Security and	volutionary Computation Risk Management p. 45	Late-Breaking Abstracts			
Training Room 3 (2F)	BB-DOB — Black Box Benchmarking	Discrete Optimization	GI — Genetic Improvement			
	CMA-FS and Advanced	Particle Swarm	Dynamic Parameter	Automated Offline		
Conference Room	Adaptation Mechanisms	Optimization	Choices in Evolutionary Computation	Design of Algorithms		
Mediulli (2F)	Akimoto, Hansen	Engelbrecht, Cleghorn	Doerr	López-Ibáñez, Stützle		
	Bio-Inspired Ap-	Evolutionary	Cloudy Distributed	Expressive Genetic Pro-		
AV Study	proaches to Anomaly	Computation for	Evolutionary	gramming: Concepts		
Room (2F)	and Intrusion Detection	Digital Art	Computation	and Applications		
	Martí, Schoenauer	Neumann, Neumann	Merelo	Spector, McPhee		
Conforma	IAM/ECADA —	MedGEC — Medical	EAPU — Evolutionary	DTEO — Decomposition		
Room A	Industrial Application /	Applications of Genetic	Algorithms for Problems	<b>Techniques in Evolution-</b>		
(3E)	Automated Design of	and Evolutionary	with Uncertainty	ary Optimization		
(51)	Algorithms p. 44	Computation p. 46	p. 47	p. 48		
Conference Room B (3F)	Promoting Diversity in Evolutionary Optimiza- tion: Why and How Squillero, Tonda	Student Workshop		p. 49		
Conference Room C (3F)	Medical Applications of Evolutionary Computation	IWLCS — Learning Classifier Systems				
	Smith		ECG	p. 46		
Conference	Evolutionary	Simulation Optimization	EU for Easture Selection and	EC/DL for Image Anal-		
Room D	A Unified Approach		Feature Selection and	and Pottorn Pocognition		
(3F)	A Unined Approach	D 1	reature Construction	and Pattern Recognition		
	De Jong	Seguential E	Aue, Znang	Znang, Cagnoni		
Conference	Distribution Algorithms	sequential Experimen-	Techniques used with	Solving Complex Prob-		
Room 2 (3F)	Distribution Algorithms	Algorithms	EAs	ary Algorithms		
100m 2 (01)	Witt	Shir Bäck	Coello Coello	Krawiec Heywood		
	vv111	Jill, Dack				
			-	Women @ GECCO		
	Tutorials	Workshops	LBA session	Conference Room D (3F) 18:00-20:00		

# Parallel Sessions, Tuesday, July 17 through Thursday, July 19

	Tuesda July 1	ay 7	Tuesda July 1	ay 7	Tuesd July	ay 17	Wednes	day 18	Wednes	day 8	Thurso July	lay 19
	10:40-12	2:20	14:00-15	5:40	16:00-1	7:40	10:40-12	2:20	15:30-17	7:10	09:00-1	0:40
Terrsa Hall (1F)	EML1	n 71	Venue Poster Setup		Authors Poster Setup		ECOM4	n 81	GA4	n 86	EMO7	n 89
Training Room 1 (2F)	ENUM1	p. 71	HUMIES	p. 54	ENUM2	p. 78	ENUM3	p. 82	Σ	<b>p. 00</b>	Σ	p. 07
Training Room 2 (2F)	GECH1	p. 72	EML2	p. 74	EML3	p. 77	EML4	p. 81	EML5	p. 86	EML6	p. 89
Training Room 3 (2F)	RWA1	p 72	GECH2	p 75	RWA3	p 79	RWA4	n 84	RWA5	n 87	RWA6	n 91
Conference Room Medium (2F)	DETA1	70	RWA2	<u>p. 15</u>	CS2	<u>p. 77</u>	GP3	<u>p. 01</u>	DETA2 + THEOR + GECH4	Y3	ENUM4	0.0
AV Study Room (2F)	CS1	<u>p. 70</u>	GP1	<u>p. 70</u>	GP2	p. //	CS3	p. 83	CS4	p. 85	RWA7	p. 90
Conference Room A (3F)	THEORYI	<u>p. 70</u>	THEORY	<u>p. 75</u>	GECH3	p. 79	SBSE1	p. 81	SBSE2	<u>p. 85</u>	THEORY	<u>p. 91</u> 4
Conference Room B (3F)	GA1	p. 73	ACO-SI1	p. 70	GA2	p. 79	GA3	p. 84	ACO-SI2	p. 85	EML7	p. 91
Conference Room C (3F)	ECiP1	p. 57	ECiP2	p. 57	ECiP3	p. 57	HOP1	p. 83	HOP2	p. 87	НОР3	p. 90
Conference Room D (3F)	EMO1	p. 71	EMO2	р. 75	EMO3	p. 78	EMO4	p. 82	EMO6	р. 86	HOP4	p. 90
Conference Room 2 (3F)	ECOM1		ECOM2		ECOM3		EMO5		ECOM5		DETA3	
		p. /0		p. /4		p. //		p. 82		p. 80		p. 89



### **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**



Keynotes



# GECCO Keynote AI for Happiness of People

Tuesday, July 17, 9:10-10:20 Terrsa Hall (1F)

Kazuo Yano, Fellow, Corporate Officer, Hitachi, Ltd., Tokyo, Japan



There is little discussion on why AI is necessary. The reason for requiring AI is not because technology has been advanced. It is that demand requires flexibility to change and diversity, whereas standardization of work since Taylor cannot meet this. This is called from "ruleoriented" to "outcome-oriented." We have developed AI ("multipurpose AI") which enables flexible action according to circumstances for given outcome. It has already been utilized in more than 60 business cases in areas, such as financial, distribution, energy, and transportation. To enable flexible action, a consistent objective is required. The higher is the level of the objective, the higher its value and consistency. "The happiness" is positioned at the top in any problem. We have discovered a method to quantify the happiness of people from movements

of the body using accelerometer. We also have developed AI that supports enhancement of people's happiness. This paves a way to the new capitalism that judges everything for human happiness. From a society seeking to follow uniform rules in the past, it is possible to realize a society in which flowers are bloomed at the place where the person is located. The whole picture of this new society in introduced.

**Biosketch:** Kazuo Yano received the B. S., M. S., and Ph. D degrees from Waseda University, Japan, in 1982, 1984, 1993, respectively. From 1991 to 1992 he was a Visiting Scientist at the Arizona State University.

He is now a Fellow, Corporate Officer, Hitachi Ltd. He is known for the pioneering works in semiconductor field, such as the world-first room-temperature single-electron memories in 1993. In 2003, he has pioneered the measurement and analysis of social big data. The wearable sensor for this purpose has been introduced in a Harvard Business Review. He has succeeded quantifying the happiness, which has been used in more than 30 companies. His recent work is on the multi-purpose artificial intelligence, which has been applied to over 60 cases. He has applied over 350 patents and his papers are cited by over 2500 papers. His book, *The New Invisible Hand*, is cited as one of top-10 business books in Japan in 2014.

He received 1994 IEEE Paul Rappaport Award, 1996 IEEE Lewis Winner Award, 1998 IEEE Jack Raper Award, Kujin Award from Hitachi Henjinkai in 1995, 2007 MBE Erize Prize, the Best Paper Award of International Conference on ASE/IEEE Social Informatics 2012. He is a Fellow of the IEEE.

#### **GECCO** Keynote

## Exploitation of Bio Signal Data to Understand Human State

Wednesday, July 18, 9:10-10:20 Terrsa Hall (1F)

Tatsuya Okabe, AI R&I Division and Value Innovation Division, DENSO Co., Ltd.



Around 2010, brain machine interface (or brain computer interface), which can control a machine (a computer) by human thought, was one of hot topics in computer science area. The basic technical components of brain machine interface are sensing bio signal, i.e. brain activity, analyzing bio signal data and controlling a machine based on the analyzed data. Many institutes and companies joined competitions to show the results of brain machine interface and its applications. However, a few products were released based on these competitions. The main reasons are insufficient performance against product level and no proper applications. After

these competitions, the progress of exploitation of bio signal data was little bit saturated.

Recently, exploitation of bio signal data to estimate human state is becoming a hot topic again because of technological aspect and social needs. The performance of machine learning including deep learning proposed by Hinton is dramatically improving and the progress of computer resources, ex. GPGPU, allows us to treat huge data and carry out huge calculation. After showing the surprising performance of deep learning in the field of computer vision, the exploitation of bio signal data is revisited from machine learning point of view.

Furthermore, since possibility of autonomous driving and advanced driver assistant system based on AI technology is becoming more realistic, estimation of human state, i.e. a driver, is starting to gather our attention because except for

L4/L5 autonomous driving, transfer of responsibility for control of car from a car to a driver or vise versa, so called 'takeover' or 'handover', should be considered. In order to transfer the right properly, we have to consider several strategies according to a human (human) state, ex. normal transfer, warning, or emergency stop without transfer.

In my presentation, the history of exploitation of bio signal data including brain machine interface will be explained and several hot topics around bio signal exploitation, ex. combination of AI and brain machine interface, will be shown. Finally, we would like to discuss the future topics around bio signal exploitation.

**Biosketch:** Tatsuya Okabe was born in Osaka in 1970 and learned material science in Osaka university and the graduated school of Osaka university with master thesis. In 1995, I joined West Japan Railway co., Ltd. and developed a total train planning system as a leader. After releasing the system, I started to work for Honda R&D as a fundamental researcher in 1999. I researched for optimization, parallel computing, machine learning, brain machine interface, robotics and signal processing. From 2000 to 2004, I worked for Honda Research Institute Europe in Germany and received doctor degree from Bielefeld university supervised by Prof. Ritter, Prof. Koerner and Prof. Sendhoff in 2004. From 2006 to 2009, I was sent to Advanced Telecommunications Research Institute International in Kyoto to develop a brain machine interface and reached highest performance of brain machine interface and succeeded to control a humanoid robot by human thought. From 2016 to 2017, I was assigned as a responsible manager to establish Honda Innovation Lab. Tokyo. In 2017, I joined DENSO to research for IoT and human state estimation in more attractive environment. Now, I am working in DENSO as a general manager of AI R&I div. and Value Innovation div. in Tokyo.

#### GECCO Keynote

# Connecting Human and Technologies in Space

Naoko Yamazaki, The University of Tokyo, former JAXA astronaut



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Based on the experience onboard the International Space Station (ISS) and Space Shuttle Discovery, the way we are trained on the ground and we live in space will be introduced.

In recent space vehicles, human-machine interfaces have been developing. A validity of robots has been already researched and verified in some cases, such as, becoming a conversation partner in spaceship, supporting to take a video, doing extravehicular activity, and robots will eventually play more important roles.

To make robots cooperate with humans on an equal basis or to replace humans for robots, considering sharing responsibilities, what we need is not only an improvement, but also an innovation. When trying to make an innovation, it is important to look ahead beyond a few generations. Even the technologies that seem to be absurd dreams may cause breakthroughs.

Since I serve as an Executive Committee Member of "World Robot Summit" held in Japan in 2020, I would like to introduce its challenges as well.

I would like to emphasize the importance of wide "teamwork" including human beings, robots and computers and their interfaces.

**Biosketch:** Naoko Yamazaki was born in Chiba, Japan and earned a Master of Science degree majored in Aerospace Engineering from the University of Tokyo in 1996, and then started working for Japan Aerospace Exploration Agency (JAXA). In 1999, she was selected as an astronaut candidate and was qualified as a Soyuz-TMA Flight Engineer in 2004 and NASA Mission Specialist in 2006.

In April, 2010, Yamazaki was onboard Space Shuttle Discovery on the crew of STS-131, an assembly & resupply mission to the International Space Station (ISS) and operated remote manipulator systems for both of Space Shuttle and ISS. She retired from JAXA in 2011 and has been serving as a member of Japan Space Policy Committee and an adviser of Young Astronaut Club (YAC), a visiting professor at Ritsumeikan University and Joshibi University of Art and Design, etc.

Wednesday, July 18, 14:00-15:10

Terrsa Hall (1F)

# SIGEVO Plenary Lecture On Becoming a Reflective Practitioner

Thursday, July 19, 11:00-12:10 Terrsa Hall (1F)

David E. Goldberg, ThreeJoy Associates, Inc. and University of Illinois (Emeritus)



The tension between theory, experiment, and practice plays out in genetic and evolutionary computation (GEC) as it plays out in other areas of science and technology. Back in the 80s, 90s, and 00s, I was always compelled to mix theory, experiment, and practical application in vigorous ways to achieve both understanding and effective computation, but my methodology often seemed to irritate more people than it satisfied. Theoreticians didn't think the work was quite "proper theory", and experimentalists/practitioners didn't think the work was sufficiently "real worldly." Although these concerns were always present in my GEC work, I haven't been thinking about them specifically over the last few years. Since resigning my tenure in 2010, I've been on a global quest to improve engineering education, a quest described in the book, *A Whole New Engineer* (www.wholenewengineer.org), and partially as a result of that journey, I think I can now better articulate some of the intuitions that led to the methodology of my earlier GEC career.

I start philosophically by sharing some of Don Schön's thoughts about the epistemology of practice. He asks, how is it, that practitioners, whether they be physicians, architects, engineers, accounts, computer scientists, or even physical scientists, know things in practice? The conventional wisdom, Schön claims, is that practitioners know things by first, mastering a body of well understood and accepted theory, then applying that theory in practice. Schön calls this theory of practical knowing, technical rationality, and he claims that it (1) is the dominant paradigm of epistemology of practice and that (2) it is largely mistaken (or at least, incomplete and misleading). As an alternative, he suggests that practitioners come to know through a process of reflection-in-action, and the talk discusses some of the key ideas behind this model of practice.

Thereafter, I revisit two case studies in early GEC work, the idea and use of deception and the idea and use of approximate little models through the lenses of technical rationality and reflection-in-action. The aim of this examination is to better understand the objections to and the intentions of the work, both. These are found to line up nicely along Schön's lines. Thereafter, I introduce Barry Johnson's notion of a polarity, and frame technical rationality and reflection-inaction. Johnson suggests that polarities are often regarded as solutions, but suggests that the appropriate stance is that poles must be managed. Here I suggest that the complexity of GEC demands the development of a population of reflective practitioners who actively manage the polarities of technical rationality and reflection-inaction, both. The talk discusses some of the key practices, particularly conversational practices, that can help do this.

The talk concludes with some theoretical and practical observations regarding the education of A Whole New Engineer and what these might offer the educators and education of the next generation of genetic algorithmists and evolutionary computationers.

**Biosketch:** David E. Goldberg (Dave) is a trained civil engineer (Michigan, 75, 76, 83) in hydraulics and hydrology, a registered engineer (PA), and a trained leadership coach (Georgetown, 2011). He taught engineering at Michigan, Alabama, and Illinois for 26 years, and as an academic, was known for his work in artificial intelligence, particularly genetic algorithms and evolutionary algorithms, amassing an h-index h=102, including 5 authored texts and a number of edited volumes, including the highly cited Genetic Algorithms in Search, Optimization, and Machine Learning (Addison-Wesley, 1989). During his career he has co-founded a Silicon Valley startup (*www.sharethis.com*), 3 academic conferences, including one combining philosophy & engineering, and an educational transformation incubator (iFoundry at UIUC). He now heads *www.ThreeJoy.com*, a coaching & change leadership firm for higher education, and *www.BigBeacon.org*, a 501(c3) non-profit corporation devoted to transforming higher education.

In 2010, Dave resigned his tenure and distinguished professorship at the University of Illinois to help transform higher education in alignment with the creativity imperative of the 21st century. Specifically, he traveled to Asia, South America, Europe, and back to North America to unlock the keys to authentic transformation and thereby unleash a new generation of students, faculty, and educational leaders. Today, Dave travels the globe to help co-create more transformative educational institutions and organizations. His most recent book, A Whole New Engineer: The Coming Revolution in Engineering Education, is available in hardcover and e-book formats (*www.wholenewengineer.org*).
**Tutorials** 



# Introductory Tutorials

Shift Your Research & Laboratory into Higher Gear with 3 Shift Skills & 4 Smooth Rules	Sunday, July 15, 09:30-11:10
David E. Goldberg, ThreeJoy Associates, Inc.	Terrsa Hall (1F)
Runtime Analysis of Evolutionary Algorithms: Basic Introduction Per Kristian Lehre, University of Birmingham Pietro S. Oliveto, University of Sheffield	Sunday, July 15, 09:30-11:10 Training Room 2 (2F)
Introducing Learning Classifier Systems: Rules that Capture Complexity Ryan Urbanowicz, University of Pennsylvania Danilo Vargas, Kyushu University	Sunday, July 15, 09:30-11:10 Conference Room Medium (2F)
Introduction to Genetic Programming	Sunday, July 15, 09:30-11:10
Una-May O'Reilly, <i>MIT</i>	Conference Room D (3F)
Introductory Mathematical Programming for EC	Sunday, July 15, 09:30-11:10
Ofer M. Shir, Tel-Hai College	Conference Room 2 (3F)
<b>Evolution of Neural Networks</b>	Sunday, July 15, 12:50-14:30
Risto Miikkulainen, <i>The University of Texas at Austin</i>	Terrsa Hall (1F)
<b>Evolutionary Computation and Games</b> Julian Togelius, IT University of Copenhagen Sebastian Risi, IT University of Copenhagen Georgios N. Yannakakis, University of Malta	Sunday, July 15, 12:50-14:30 Training Room 2 (2F)
Search-Maps: Visualising and Exploiting the Global Structure of Compu-	Sunday, July 15, 12:50-14:30
tational Search Spaces Gabriela Ochoa, University of Stirling Nadarajen Veerapen, University of Stirling	Conference Room B (3F)
<b>Representations for Evolutionary Algorithms</b>	Sunday, July 15, 12:50-14:30
Franz Rothlauf, <i>Universität Mainz</i>	Conference Room D (3F)
Introductory Statistics for EC: A Visual Approach	Sunday, July 15, 12:50-14:30
Mark Wineberg, University of Guelph	Conference Room 2 (3F)
Neuroevolution for Deep Reinforcement Learning Problems	Sunday, July 15, 14:50-16:30
David Ha, <i>Google Brain</i>	Terrsa Hall (1F)
<b>Hyper-heuristics</b> John R. Woodward, <i>Queen Mary University of London</i> Daniel R. Tauritz, <i>Missouri University of Science and Technology</i>	Sunday, July 15, 14:50-16:30 Training Room 2 (2F)
A Practical Guide to Experimentation	Sunday, July 15, 14:50-16:30
Nikolaus Hansen, <i>Inria</i>	Conference Room Medium (2F)
Search-based Test Optimization for Software Systems	Sunday, July 15, 14:50-16:30
Shaukat Ali, Simula Research Laboratory	AV Study Room (2F)
Theory for Non-Theoreticians	Sunday, July 15, 14:50-16:30
Benjamin Doerr, <i>Ecole Polytechnique</i>	Conference Room 2 (3F)
Model-Based Evolutionary Algorithms Dirk Thierens, Utrecht University Peter A.N. Bosman, Centrum Wiskunde & Informatica (CWI)	Monday, July 16, 09:00-10:40 Terrsa Hall (1F)

Evolutionary Computation: A Unified Approach Kenneth De Jong, Krasnow Institute	Monday, July 16, 09:00-10:40 Conference Room D (3F)
<b>Evolutionary Multiobjective Optimization</b> Dimo Brockhoff, <i>Inria</i>	Monday, July 16, 11:00-12:40 Terrsa Hall (1F)
Advanced Tutorials	
<b>Evolutionary Reinforcement Learning: General Models and Adaptation</b> Danilo Vasconcellos Vargas, Kyushu University	Sunday, July 15, 12:50-14:30 Conference Room Medium (2F)
<b>Next Generation Genetic Algorithms</b> Darrell D. Whitley, <i>Colorado State University</i>	Sunday, July 15, 12:50-14:30 AV Study Room (2F)
<b>CMA-ES and Advanced Adaptation Mechanisms</b> Youhei Akimoto, <i>University of Tsukuba</i> Nikolaus Hansen, <i>Inria</i>	Monday, July 16, 09:00-10:40 Conference Room Medium (2F)
<b>Promoting Diversity in Evolutionary Optimization: Why and How</b> Giovanni Squillero, <i>Politecnico di Torino</i> Alberto Tonda, <i>INRA</i>	Monday, July 16, 09:00-10:40 Conference Room B (3F)
Particle Swarm Optimization: A Guide to Effective, Misconception Free,	Monday, July 16, 11:00-12:40
Andries Engelbrecht, University of Pretoria Christopher Wesley Cleghorn, University of Pretoria	Conference Room Medium (2F)
<b>Evolutionary Computation for Digital Art</b> Aneta Neumann, <i>The University of Adelaide</i> Frank Neumann, <i>The University of Adelaide</i>	Monday, July 16, 11:00-12:40 AV Study Room (2F)
Simulation Optimization Juergen Branke, University of Warwick	Monday, July 16, 11:00-12:40 Conference Room D (3F)
Sequential Experimentation by Evolutionary Algorithms Ofer M. Shir, Tel-Hai College Thomas Bäck, Leiden University	Monday, July 16, 11:00-12:40 Conference Room 2 (3F)
Decomposition Multi-Objective Optimisation: Current Developments and Future Opportunities	Monday, July 16, 14:00-15:40
Ke Li, University of Exeter Qingfu Zhang, City University of Hong Kong	Terrsa Hall (1F)
<b>Dynamic Parameter Choices in Evolutionary Computation</b> Carola Doerr, CNRS and Sorbonne University	Monday, July 16, 14:00-15:40 Conference Room Medium (2F)
<b>Constraint-Handling Techniques used with Evolutionary Algorithms</b> Carlos A. Coello Coello, <i>CINVESTAV-IPN</i>	Monday, July 16, 14:00-15:40 Conference Room 2 (3F)
<b>Visualization in Multiobjective Optimization</b> Bogdan Filipic, <i>Jozef Stefan Institute</i> Tea Tusar, <i>Jozef Stefan Institute</i>	Monday, July 16, 16:00-17:40 Terrsa Hall (1F)
<b>Expressive Genetic Programming: Concepts and Applications</b> Lee Spector, <i>Hampshire College</i> Nicholas Freitag McPhee, <i>University of Minnesota, Morris</i>	Monday, July 16, 16:00-17:40 AV Study Room (2F)

<b>Solving Complex Problems with Coevolutionary Algorithms</b> Krzysztof Krawiec, <i>Poznan University of Technology</i> Malcolm Heywood, <i>Dalhousie University</i>	Monday, July 16, 16:00-17:40 Conference Room 2 (3F)
Specialized Tutorials	
<b>Evolutionary Robotics</b> Stephane Doncieux, <i>Université Pierre et Marie Curie</i> Nicolas Bredeche, <i>Université Pierre et Marie Curie</i> Jean-Baptiste Mouret, <i>Inria</i>	Sunday, July 15, 09:30-11:10 AV Study Room (2F)
<b>Bio-Inspired Approaches to Anomaly and Intrusion Detection</b> Luis Martí, Universidade Federal Fluminense Marc Schoenauer, Inria	Monday, July 16, 09:00-10:40 AV Study Room (2F)
Medical Applications of Evolutionary Computation Stephen L. Smith, <i>University of York</i>	Monday, July 16, 09:00-10:40 Conference Room C (3F)
<b>Theory of Estimation-of-Distribution Algorithms</b> Carsten Witt, <i>Technical University of Denmark</i>	Monday, July 16, 09:00-10:40 Conference Room 2 (3F)
<b>Cloudy Distributed Evolutionary Computation</b> JJ Merelo, <i>University of Granada</i>	Monday, July 16, 14:00-15:40 AV Study Room (2F)
<b>Evolutionary Computation for Feature Selection and Feature Construction</b> Bing Xue, Victoria University of Wellington Mengjie Zhang, Victoria University of Wellington	Monday, July 16, 14:00-15:40 Conference Room D (3F)
Automated Offline Design of Algorithms Manuel López-Ibáñez, University of Manchester Thomas Stützle, IRIDIA, Université Libre de Bruxelles	Monday, July 16, 16:00-17:40 Conference Room Medium (2F)
Evolutionary Computation and Evolutionary Deep Learning for Image Analysis, Signal Processing and Pattern Recognition	Monday, July 16, 16:00-17:40
Mengjie Zhang, Victoria University of Wellington Stefano Cagnoni, University of Parma	Conference Room D (3F)

Workshops, Late Breaking Abstracts, and Women@GECCO



# **BBOB** — Black Box Optimization Benchmarking

- **Organizers:** Anne Auger (INRIA; CMAP, Ecole Polytechnique); Julien Bect (CentraleSupélec); Dimo Brockhoff (INRIA Saclay - Ile-de-France; CMAP, Ecole Polytechnique); Nikolaus Hansen (Inria, research centre Saclay); Rodolphe Le Riche (Ecole Nationale Supérieure des Mines de Saint–Etienne); Victor Picheny (INRA); Tea Tusar (Jozef Stefan Institute)
- Time and Location: Sunday, July 15, 09:30-11:10, Training Room 1 (2F)

Benchmarking the PSA-CMA-ES on the BBOB Noiseless Testbed Kouhei Nishida, Youhei Akimoto

- **Benchmarking a Variant of the CMAES-APOP on the BBOB Noiseless Testbed** Duc Manh Nguyen
- **Stopping Criteria, Initialization, and Implementations of BFGS and their Effect on the BBOB Test Suite** Aurore Blelly, Matheus Felipe-Gomes, Anne Auger, Dimo Brockhoff
- **Comparing Black-Box Differential Evolution and Classic Differential Evolution** Aljosa Vodopija, Tea Tusar, Bogdan Filipic

# EABDMCP — Evolutionary Algorithms for Big Data and Massively Complex Problems

**Organizers:** David Camacho (Universidad Autonoma de Madrid); Pedro Castillo (UGR); Francisco Chávez (University of Extremadura); Antonio J. Fernández Leiva (University of Málaga); JJ Merelo (University of Granada)

Time and Location: Sunday, July 15, 09:30-11:10, Conference Room A (3F)

#### Multi-objective Feature Selection for EEG Classification with Multi-Level Parallelism on Heterogeneous CPU-GPU Clusters

Juan José Escobar, Julio Ortega, Antonio Francisco Díaz, Jesús González, Miguel Damas

#### Mapping evolutionary algorithms to a reactive, stateless architecture

JJ Merelo, José-Mario García Valdez

# **IOMES** — Intelligent Operations Management in the Energy Sector

Organizers: Luis Martí (Universidade Federal Fluminense); John McCall (Smart Data Technologies Centre); Nayat Sanchez-Pi (Rio de Janeiro State University (UERJ))

Time and Location: Sunday, July 15, 09:30-11:10, Conference Room C (3F)

#### Multiobjective Evolutionary Polygonal Approximation for Identifying Crude Oil Reservoirs José Luis Guerrero, Luis Martí, Nayat Sanchez-Pi, Antonio Berlanga, José Manuel Molina

#### Crude Oil Refinery Scheduling: Addressing a Real-World Multiobjective Problem through Genetic Programming and Dominance-based Approaches

Cristiane Salgado Pereira, Douglas Mota Dias, Marley Rebuzzi Vellasco, Francisco Henrique F. Viana, Luis Martí

#### **Towards Bundling Minimal Trees in Polygonal Maps**

Victor Parque, Tomoyuki Miyashita

# VizGEC/SAEOpt — Visualisation Methods in Genetic and Evolutionary Computation / 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 Exeter); David Walker (University of Exeter); Handing Wang (University of Surrey)

Time and Location: Sunday, July 15, 09:30-11:10, Training Room 3 (2F)

#### VINE: An Open Source Interactive Data Visualization Tool for Neuroevolution

Rui Wang, Jeff Clune, Kenneth O. Stanley

**Visualizing the tape of life: exploring evolutionary history with virtual reality** Emily L. Dolson, Charles Ofria

- Visualising the Search Process for Multi-objective Optimisation Marde Helbig
- Evaluating Surrogate Models for Multi-Objective Influence Maximization in Social Networks

Doina Bucur, Giovanni Iacca, Andrea Marcelli, Giovanni Squillero, Alberto Tonda

#### Asynchronous Surrogate-assisted Optimization Networks

Johannes Karder, Andreas Beham, Bernhard Werth, Stefan Wagner, Michael Affenzeller

#### **EiC** — Evolution in Cognition

**Organizers:** Joshua Auerbach (Champlain College); Harold de Vladar (Konrad Lorenz Institute, Centre for Parmenides Foundation); Stéphane Doncieux (Sorbonne Universite; CNRS, ISIR); Richard Duro (Universidade da Coruña)

Time and Location: Sunday, July 15, 12:50-14:30, Conference Room A (3F)

#### **Invited Talk**

Kenji Doya

Invited Talk

Joel Lehman

Invited Talk

Stephane Doncieux

#### Meta Learning by the Baldwin Effect

Chrisantha Fernando, Jakub Sygnowski, Simon Osindero, Jane Wang, Tom Schaul, Denis Teplyashin, Pablo Sprechmann, Alexander Pritzel, Andrei Rusu

#### The Flouted Naming Game: Contentions and Conventions in Culture

Harold P. de Vladar

# **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; Japan Aerospace Exploration Agency); Pramudita Palar (Tohoku University); 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 15, 12:50-14:30, Training Room 1 (2F)

- **Invited Talk: Algorithms for Optimization Under Budget Constraints, with Application Examples** Thomas Bäck
- Invited Talk: Memetic and Bayesian Perspectives on Transfer Optimization: From Algorithms to Applications Abhishek Gupta

Well Placement Optimization for Carbon dioxide Capture and Storage via CMA-ES with Mixed Integer Support

Atsuhiro Miyagi, Hajime Yamamoto, Youhei Akimoto

On Vehicle Surrogate Learning with Genetic Programming Ensembles

Victor Parque, Tomoyuki Miyashita

#### ECHNS — Evolutionary Computation in Health Care and Nursing System

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

Time and Location: Sunday, July 15, 12:50-16:30, Conference Room C (3F)

**Can evolutionary computing be applied to dementia care?** Taro Sugihara

- Sustainable Sensor Network Architecture for Monitoring Human Activities Ren Ohmura
- CATARO: A Robot that Tells Caregivers a Patient's Current Non-Critical Condition Indirectly Patrick Hock, Chika Oshima, Koichi Nakayama
- **Classifier Generalization for Comprehensive Classifiers Subsumption in XCS** Caili Zhang, Takato Tatsumi, Hiroyuki Sato, Tim Kovacs, Keiki Takadama

**Framework for planning the training sessions in triathlon** Iztok Fister, Janez Brest, Andres Iglesias, Iztok Jr. Fister

**Development of an Evaluation System for Upper Limb Function Using AR Technology** Yunan He, Ikushi Sawada, Osamu Fukuda, Ryusei Shima, Nobuhiko Yamaguchi, Hiroshi Okumura

Envy based Fairness in Hedonic Games Suguru Ueda

# EvoSoft — Evolutionary Computation Software Systems

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

Time and Location: Sunday, July 15, 12:50-16:30, Training Room 3 (2F)

- **Performance Assessment of Multi-Objective Evolutionary Algorithms With the R Package ecr** Jakob Bossek
- **Performance improvements of evolutionary algorithms in Perl 6** JJ Merelo, José-Mario García Valdez
- A Generic Distributed Microservices and Container based Framework for Metaheuristic Optimization Hatem Khalloof, Wilfried Jakob, Jianlei Liu, Eric Braun, Shadi Shahoud, Clemens Duepmeier, Veit Hagenmeyer
- **Evo-ROS: Integrating Evolution and the Robot Operating System** Glen A. Simon, Jared M. Moore, Anthony J. Clark, Philip K. McKinley
- **Review: A Web-Based Simulation Viewer for Sharing Evolutionary Robotics Results** Anthony J. Clark, Jared M. Moore
- **Plushi: An Embeddable, Language Agnostic, Push Interpreter** Edward R. Pantridge, Lee Spector

# EIEHSCoEvo — Exploration of Inaccessible Environments through Hardware/Software Co-evolution

**Organizers:** Gerd Ascheid (RWTH Aachen); Peter Baltus (Eindhoven University of Technology); Ahmed Hallawa (RWTH Aachen); Giovanni Iacca (University of Trento); Anil Yaman (Eindhoven University of Technology)

Time and Location: Sunday, July 15, 14:50-16:30, Conference Room A (3F)

# Invited Talk: Evolutionary Robotics and Collective Behaviours: From Understanding Nature to Designing Robot Swarms

Nicolas Bredeche

#### Evolving Hardware Instinctive Behaviors in Resource-scarce Agent Swarms Exploring Hard-to-reach Environments

Martin Andraud, Ahmed Hallawa, Jaro De Roosa, Eugenio Cantatore, Gerd Ascheid, Marian Verhelst

A Distributed Epigenetic Shape Formation and Regeneration Algorithm for a Swarm of Robots Rahul Shivnarayan Mishra, Tushar Semwal, Shivashankar B. Nair

# LAHS — Landscape-Aware Heuristic Search

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

Time and Location: Sunday, July 15, 14:50-16:30, Conference Room B (3F)

Progressive Gradient Walk for Neural Network Fitness Landscape Analysis

**Computationally Efficient Local Optima Network Construction** Jonathan E. Fieldsend

Filter versus Wrapper Feature Selection based on Problem Landscape Features Werner Mostert, Katherine Malan, Andries Engelbrecht

### **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 (TU Dortmund University)

Time and Location: Sunday, July 15, 14:50-16:30, Training Room 1 (2F)

Short presentation of a new benchmarking suite from game-based problems. Then, extensive discussions on what characteristics benchmarking problems should have and which ones are typical for games.

https://ls11-www.cs.tu-dortmund.de/people/volz/gamesbench\_sched.html

# IAM/ECADA — Industrial Application of Metaheuristics / Evolutionary Computation for the Automated Design of Algorithms

**Organizers:** Silvino Fernandez Alzueta (ArcelorMittal); Manuel López-Ibáñez (Decision and Cognitive Sciences Research Centre, University of Manchester); Thomas Stützle (Université Libre de Bruxelles); Daniel R. Tauritz (Missouri University of Science and Technology); Pablo Valledor (ArcelorMittal); John Woodward (Queen Mary, University of London)

Time and Location: Monday, July 16, 09:00-10:40, Conference Room A (3F)

- **Invited Talk: Optimization when the Evaluation Budget is very Limited: Algorithms and Applications** Thomas Bäck
- Generating Interpretable Fuzzy Controllers using Particle Swarm Optimization and Genetic Programming Daniel Hein, Steffen Udluft, Thomas A. Runkler
- The Automated Design of Probabilistic Selection Methods for Evolutionary Algorithms Samuel N. Richter, Daniel R. Tauritz
- **Invited Talk: Lifelong Learning Methods in Heuristic Optimisation for Continual Problem Solving** Emma Hart

#### **BB-DOB** — Black Box Discrete Optimization Benchmarking

- **Organizers:** Pietro S. Oliveto (The University of Sheffield); Markus Wagner (School of Computer Science, The University of Adelaide); Thomas Weise (University of Science and Technology of China (USTC), School of Computer Science and Technology); Borys Wrobel (Adam Mickiewicz University); Ales Zamuda (University of Maribor)
- Time and Location: Monday, July 16, 09:00-12:40, Training Room 3 (2F)
- **Compiling a Benchmarking Test-Suite for Combinatorial Black-Box Optimization: A Position Paper** Ofer M. Shir, Carola Doerr, Thomas Bäck

#### **Discrete Real-world Problems in a Black-box Optimization Benchmark**

Sebastian Raggl, Andreas Beham, Viktoria Hauder, Stefan Wagner, Michael Affenzeller

# Difficult Features of Combinatorial Optimization Problems and the Tunable W-Model Benchmark Problem for Simulating them

Thomas Weise, Zijun Wu

A Generic Problem Instance Generator for Discrete Optimization Problems Markus Ullrich, Thomas Weise, Abhishek Awasthi, Jörg Lässig

Parameterization of State-of-the-Art Performance Indicators: A Robustness Study Based on Inexact TSP Solvers

Pascal Kerschke, Jakob Bossek, Heike Trautmann

# A Black-Box Discrete Optimization Benchmarking (BB-DOB) Pipeline Survey: Taxonomy, Evaluation, and Ranking

Ales Zamuda, Christine Zarges, Miguel Nicolau

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

Organizers: Riyad Alshammari (King Saud bin Abdulaziz University for Health Sciences); Tokunbo Makanju (KDDI Research)

Time and Location: Monday, July 16, 09:00-12:40, Training Room 2 (2F)

- Invited Talk: GA-Based User Identity Management Dipankar Dasgupta
- Machine Learning Based Detection of Water Contamination in Water Distribution Systems Hadi Mohammed, Ibrahim Abdul Hameed, Razak Seidu

#### Using Evolutionary Dynamic Optimization for Monitor Selection in Highly Dynamic Communication Infrastructures

Robin Mueller-Bady, Martin Kappes, Francisco Palomo-Lozano, Inmaculada Medina-Bulo

- A Genetic Algorithm for Dynamic Controller Placement in Software Defined Networking Samuel Champagne, Tokunbo Makanju, Chengchao Yao, Nur Zincir-Heywood, Malcolm Heywood
- Genetic Algorithms for Role Mining in Critical Infrastructure Data Spaces Igor Saenko, Igor Kotenko
- Adversarial Co-evolution of Attack and Defense in a Segmented Computer Network Environment Erik Hemberg, Joseph R. Zipkin, Richard W. Skowyra, Neal Wagner, Una-May O'Reilly

**Real-Time Strategy Game Micro for Tactical Training Simulations** Sushil J. Louis, Siming Liu, Tianyi Jiang

Automated Design of Network Security Metrics Aaron Scott Pope, Robert Morning, Daniel R. Tauritz, Alexander Kent

#### **Evolution of Network Enumeration Strategies in Emulated Computer Networks**

Sean Harris, Eric Michalak, Kevin Schoonover, Adam Gausmann, Hannah Reinbolt, Joshua Herman, Daniel R. Tauritz, Chris Rawlings, Aaron Scott Pope

### MedGEC — Medical Applications of Genetic and Evolutionary Computation

- **Organizers:** Stefano Cagnoni (University of Parma, Italy); Robert M. Patton (Oak Ridge National Laboratory); Stephen L. Smith (University of York)
- Time and Location: Monday, July 16, 11:00-12:40, Conference Room A (3F)
- Design of HIFU Treatment Plans using an Evolutionary Strategy Marta Cudova, Bradley E. Treeby, Jiri Jaros
- **Coevolving Behavior and Morphology of Simple Agents that Model Small-scale Robots** Milen Georgiev, Ivan Tanev, Katsunori Shimohara
- Solution Exploration using Multi-Objective Genetic Algorithm for Determining Experiment Candidate Lorenzo Perino, Akihiro Fujii, Tsuyoshi Waku, Akira Kobayashi, Satoru Hiwa, Tomoyuki Hiroyasu

### IWLCS — Learning Classifier Systems

**Organizers:** Masaya Nakata (Yokohama National University); Anthony Stein (University of Augsburg); Danilo Vasconcellos Vargas (Kyushu University)

Time and Location: Monday, July 16, 11:00-17:40, Conference Room C (3F)

- Generalizing Rules by Random Forest-based Learning Classifier Systems for High-Dimensional Data Mining Fumito Uwano, Koji Dobashi, Keiki Takadama, Tim Kovacs
- Applying Accuracy-based LCS to Detecting Anomalous Database Access Suin Seo, Sung-Bae Cho
- Invited Talk: How Learning Classifier Systems Can Conquer Important Modern AI Problems Will Neil Browne
- **EvoNN A Customizable Evolutionary Neural Network with Heterogenous Activation Functions** Boris Shabash, Kay Wiese
- XCSR Based on Compressed Input by Deep Neural Network for High Dimensional Data Kazuma Matsumoto, Ryo Takano, Takato Tatsumi, Hiroyuki Sato, Tim Kovacs, Keiki Takadama
- **Optimizing clustering to promote data diversity when generating an ensemble classifier** Zohaib Muhammad Jan, Brijesh Verma, Sam Fletcher

#### An Algebraic Description of XCS David Pätzel, Jörg Hähner

Modulated Clustering Using Integrated Rough Sets and Scatter Search Attribute Reduction Abdel-Rahman Hedar, Abdel-Monem Ibrahim, Alaa Abdel-Hakim, Adel Sewisy

XCS-CR: Determining Accuracy of Classifier by its Collective Reward in Action Set toward Environment with Action Noise

Takato Tatsumi, Tim Kovacs, Keiki Takadama

Model Parameter Adaptive Instance-Based Policy Optimization for Episodic Control Tasks of Nonholonomic Systems

Kyotaro Ohashi, Natsuki Fujiyoshi, Naoki Sakamoto, Youhei Akimoto

Integrating Anticipatory Classifier Systems with OpenAI Gym Norbert Kozłowski, Olgierd Unold

### EAPU — Evolutionary Algorithms for Problems with Uncertainty

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

Time and Location: Monday, July 16, 14:00-15:40, Conference Room A (3F)

Exploration of the Effect of Uncertainty in Homogeneous and Heterogeneous Multi-agent Societies With Regard to their Average Characteristics

Milen Georgiev, Ivan Tanev, Katsunori Shimohara

A Framework for High-Dimensional Robust Evolutionary Multi-Objective Optimization Wei Du, Le Tong, Yang Tang

Robust Multi-Modal Optimisation Khulood Alyahya, Kevin Doherty, Ozgur E. Akman, Jonathan E. Fieldsend

Invited Talk: Enhancing Evolutionary Optimization in Uncertain Environments by Allocating Evaluations via Multi-armed Bandit Algorithms

Xin Qiu, Risto Miikkulainen

Invited Talk: A Hyper-Heuristic Framework for Real-Valued Dynamic Optimization Andries Engelbrecht

# NSBECR — New Standards for Benchmarking in Evolutionary Computation Research

**Organizers:** William LaCava (University of Massachusetts Amherst); Randal S. Olson (University of Pennsylvania); Patryk Orzechowski (University of Pennsylvania); Ryan Urbanowicz (University of Pennsylvania)

Time and Location: Monday, July 16, 14:00-15:40, Training Room 1 (2F)

#### Analysing Symbolic Regression Benchmarks under a Meta-Learning Approach

Luiz Otavio Vilas Boas Oliveira, Joao Francisco Barreto da Silva Martins, Luis Fernando Miranda, Gisele Lobo Pappa

**The Impact of Statistics for Benchmarking in Evolutionary Computation Research** Tome Eftimov, Peter Korošec

Maze Benchmark for Testing Evolutionary Algorithms Camilo Alejandro Alaguna Córdoba, Jonatan Gómez Perdomo

Evolving Benchmark Functions Using Kruskal-Wallis Test Yang Lou, Shiu Yin Yuen, Guanrong Ron Chen

# **GI** — Genetic Improvement

**Organizers:** Brad Alexander (University of Adelaide); Saemundur Haraldsson (University of Stirling); Markus Wagner (School of Computer Science, The University of Adelaide); John Woodward (Queen Mary, University of London); Shin Yoo (Korea Advanced Institute of Science and Technology)

Time and Location: Monday, July 16, 14:00-17:40, Training Room 3 (2F)

Invited Talk: Quantum Genetic Programming

David R. White

- Synthesizing Customized Network Protocols using Genetic Programming Mohammad Roohitavaf, Ling Zhu, Sandeep Kulkarni, Subir Biswas
- **Towards Modular Large-Scale Darwinian Software Improvement** Michael Orlov
- Novelty Search for software improvement of a SLAM system Victor R. López-López, Leonardo Trujillo, Pierrick Legrand
- Genetic Configuration Sampling: Learning a Sampling Strategy for Fault Detection of Configurable Systems Jifeng Xuan, Yongfeng Gu, Zhilei Ren, Xiangyang Jia, Qingna Fan
- Assessing Single-Objective Performance Convergence and Time Complexity for Refactoring Detection David Nader-Palacio, Daniel Rodríguez-Cárdenas, Jonatan Gomez Perdomo
- **Dynamic Fitness Functions for Genetic Improvement in Compilers and Interpreters** Oliver Krauss, Hanspeter Mössenböck, Michael Affenzeller

#### DTEO — Decomposition Techniques in Evolutionary Optimization

**Organizers:** Bilel Derbel (Univ. Lille, Inria Lille - Nord Europe); Hui Li (Xi'an Jiaotong University, China); Ke Li (University of Exeter); Xiaodong Li (RMIT University); Saúl Zapotecas Martínez (CINVESTAV-IPN); Qingfu Zhang (City University of Hong Kong, Hong Kong Shenzhen Research Institute)

Time and Location: Monday, July 16, 16:00-17:40, Conference Room A (3F)

- A Historical Interdependency based Differential Grouping Algorithm for Large Scale Global Optimization An Chen, Zhigang Ren, Yang Yang, Yongsheng Liang, Bei Pang
- A Cooperative Co-evolutionary Algorithm for Large-Scale Multi-Objective Optimization Problems Minghan Li, Jingxuan Wei
- **Decomposition-Based Multiobjective Particle Swarm Optimization for Change Detection in SAR Images** Tao Zhan, Zedong Tang, Maoguo Gong, Xiangming Jiang, Jiao Shi
- Selfish vs. Global Behavior Promotion in Car Controller Evolution Jacopo Talamini, Giovanni Scaini, Eric Medvet, Alberto Bartoli

#### PDEIM — Parallel and Distributed Evolutionary Inspired Methods

- **Organizers:** Ivanoe De Falco (ICAR-CNR); Antonio Della Cioppa (Natural Computation Lab DIEM, University of Salerno); Umberto Scafuri (ICAR-CNR); Ernesto Tarantino (ICAR CNR)
- Time and Location: Monday, July 16, 16:00-17:40, Training Room 1 (2F)
- An Actor Model Implementation of Distributed Factored Evolutionary Algorithms Stephyn G. W. Butcher, John Sheppard
- A Parallel Island Model for Biogeography-Based Classification Rule Mining in Julia Samuel Ebert, Effat Farhana, Steffen Heber
- Vectorized Candidate Set Selection for Parallel Ant Colony Optimization Joshua Peake, Huw Lloyd, Martyn Amos, Paraskevas Yiapanis

Effective Processor Load Balancing using Multi-Objective Parallel Extremal Optimization Ivanoe De Falco, Eryk Laskowski, Richard Olejnik, Umberto Scafuri, Ernesto Tarantino, Marek Tudruj

#### Student Workshop

(Best Student Paper nominees are marked with a star)

Organizers: Youhei Akimoto (University of Tsukuba); Vanessa Volz (TU Dortmund University)

Time and Location: Monday, July 16, 11:00-17:40, Conference Room B (3F)

- **Specialization and Elitism in Lexicase and Tournament Selection** Edward R. Pantridge, Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector
- A Comparison of Semantic-Based Initialization Methods for Genetic Programming Hammad Ahmad, Thomas Helmuth
- Improved Efficiency Of MOPSO With Adaptive Inertia Weight And Dynamic Search Space Lee Ping Pang, Sin Chun Ng
- Using A One-Class Compound Classifier To Detect In-Vehicle Network Attacks Andrew Tomlinson, Jeremy Bryans, Siraj Ahmed Shaikh

From Fitness Landscape Analysis to Designing Evolutionary Algorithms: The Case Study in Automatic Generation of Function Block Applications 🖈 Vladimir Mironovich, Maxim Buzdalov, Valeriy Vyatkin

Runtime Analysis of a Population-based Evolutionary Algorithm with Auxiliary Objectives Selected by Reinforcement Learning

Denis Antipov, Arina Buzdalova, Andrew Stankevich

- Embedded Feature Selection Using Probabilistic Model-Based Optimization 🖈 Shota Saito, Shinichi Shirakawa, Youhei Akimoto
- A Multi-objective Optimization Design Framework for Ensemble Generation 🖈 Victor Henrique Alves Ribeiro, Gilberto Reynoso Meza
- Towards a More General Many-Objective Evolutionary Optimizer using Multi-Indicator Density Estimation 🖈 Jesús Guillermo Falcón-Cardona, Carlos A. Coello Coello

**Diploidy for Evolving Neural Networks** Cara L. Reedy

- Analysis of Evolutionary Multi-Tasking as an Island Model Ryuichi Hashimoto, Hisao Ishibuchi, Naoki Masuyama, Yusuke Nojima
- Incorporation of a decision space diversity maintenance mechanism into MOEA/D for multi-modal multiobjective optimization

Chenxu Hu, Hisao Ishibuchi

Weight Vector Grid with New Archive Update Mechanism for Multi-Objective Optimization Xizi Ni, Hisao Ishibuchi, Kanzhen Wan, Ke Shang, Chukun Zhuang

# LBA — Late-Breaking Abstracts

Organizers: Masaharu Munetomo (Hokkaido University)

- Time and Location: Monday, July 16, 14:00-17:40, Training Room 2 (2F)
- Accelerating Genetic Programming using PyCuda Keiko Ono, Yoshiko Hanada
- Forecasting Soybean Futures Price Using Dynamic Model Averaging and Particle Swarm Optimization Tao Xiong
- A Self-Replication Basis For Designing Complex Agents Thommen Karimpanal George
- Genetically-Trained Deep Neural Networks Krzysztof Pawełczyk, Michal Kawulok, Jakub Nalepa
- The Human-based Evolutionary Computation System Enabling Us to Follow the Solution Evolution Kousuke Fujimoto, Kei Ohnishi, Tomohiro Yoshikawa

# Configuring the Parameters of Artificial Neural Networks using NeuroEvolution and Automatic Algorithm Configuration

Evgenia Papavasileiou, Bart Jansen

- **Optimization Based Adaptive Tagged Visual Cryptography** Pei-Ling Chiu, Kai-Hui Lee
- A Geometric Evolutionary Search for Melody Composition Yong-Wook Nam, Yong-Hyuk Kim
- **Distributed NSGA-II Sharing Extreme Non-dominated Solutions** Yuji Sato, Mikiko Sato, Minami Miyakawa
- Parameter Space Analysis of Genetic Algorithm Using Support Vector Regression Hwi-Yeon Cho, Hye-Jin Kim, Yong-Hyuk Kim
- Evolutionary Algorithm Using Surrogate Assisted Model for Simultaneous Design Optimization Benchmark Problem of Multiple Car Structures
  - Hiro Ohtsuka, Misaki Kaidan, Tomohiro Harada, Ruck Thawonmas
- On the Hardness of Parameter Optimization of Convolution Neural Networks Using Genetic Algorithm and Machine Learning
  - Hyeon-Chang Lee, Dong-Pil Yu, Yong-Hyuk Kim
- Infeasible Solution Repair and MOEA/D Sharing Weight Vectors for Solving Multi-objective Set Packing Problems

Mariko Tanaka, Yuki Yamagishi, Hidetoshi Nagai, Hiroyuki Sato

Is It Worth to Approximate Fitness by Machine Learning?: Investigation on the Extensibility According to Problem Size

Dong-Pil Yu, Yong-Hyuk Kim

**Importance of Finding a Good Basis in Binary Representation** Junghwan Lee, Yong-Hyuk Kim

# Hybrid Swarm of Particle Swarm with Firefly for Complex Function Optimization

Heng Xiao, Toshiharu Hatanaka

Tanja Zerenner, Victor Venema, Petra Friederichs, Clemens Simmer
EBIC: a Next-Generation Evolutionary-Based Parallel Biclustering Method Patryk Orzechowski, Moshe Sipper, Xiuzhen Huang, Jason H. Moore
Digital Investigations on the Evolution of Prokaryote Photosynthesis Regulation Anselmo Pontes, Charles Ofria
Syllabification by Phone Categorization Jacob Krantz, Maxwell Dulin, Paul De Palma, Mark VanDam
Evolving Modular Neural Sequence Architectures with Genetic Programming David Dohan, David So, Quoc Le

Deterministic and Stochastic Precipitation Downscaling using Multi-Objective Genetic Programming

- **Investigation of Kernel Functions in EDA-GK** Ryoichi Hasegawa, Hisashi Handa
- GA and Entropy Objective Function for Solving Sudoku Puzzle Katya Rodriguez-Vazquez
- A Surrogate-assisted Selection Scheme for Genetic Algorithms Employing Multi-layer Neural Networks Masaki Fujiwara, Masaharu Munetomo

# Women@GECCO

Organizers: Khulood Alyahya (Exeter University); Bing Xue (Victoria University of Wellington)

Time and Location: Monday, July 16, 18:00-20:00, Conference Room D (3F)

History of Women@GECCO Gabriela Ochoa, University of Stirling

From a PhD student to an independent researcher: Challenges and Opportunities Minami Miyakawa, *Hosei University* 

**An ongoing pathway to become a leading researcher** Rong Qu, *University of Nottingham* 

Academic career? Dream big, start small and grow gradually Sanaz Mostaghim, Otto von Guericke University Magdeburg

**Speed Dating** 

**Panel Discussion Session** 

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



# 15th Annual Humies Awards for Human Competitive Results

Presentations: Tuesday, July 17, 14:00-15:40 Training Room 1 (2F)

Announcement of Awards: Thursday, July 19, 12:20-13:50 Terrsa Hall (1F)

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 fifteen entries in this year's Humies competition, eight finalists have been invited to each 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 Thursday.

# Competitions

#### **Black Box Optimization Competition**

Organizers: Ilya Loshchilov, Tobias Glasmachers

Time and Location: Sunday, July 15, 09:30-11:10, Conference Room B (3F)

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. We have five competition tracks.

#### **Competition on Niching Methods for Multimodal Optimization**

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

Time and Location: Sunday, July 15, 09:30-11:10, Conference Room B (3F)

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.

#### **General Video Game AI Competition**

Organizers: Diego Perez-Liebana, Julian Togelius, Simon M. Lucas, Ahmed Khalifa, Michael C. Green

Time and Location: Sunday, July 15, 09:30-11:10, Conference Room B (3F)

The GVG-AI Competition explores the problems within general video game playing. How would you create a level generator that can generate a level for any given game? How could you program an AI that creates new rules for existing games or entirely new games altogether? The level generation track explores the ability of level generators to generalize and work on multiple games described in Video Game Description Language (VGDL). Competitors submit level generators that are tasked to generate levels for any set of game rules. The rule generation track explores the ability to generate game rules and winning conditions for a fixed level of a game described in Video Game Description Language (VGDL).

#### 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 15, 09:30-11:10, Conference Room B (3F)

For the 7th 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 2017 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 15, 09:30-11:10, Conference Room B (3F) 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).

# **Evolutionary Computation in Practice**

**Organizers:** Thomas Bartz-Beielstein, Institute for Data Science, Engineering, and Analytics, TH Köln Bogdan Filipic, Jozef Stefan Institute Shigeru Obayashi, Tohoku 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 realworld 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

Tuesday, July 17, 10:40-12:20, Conference Room C (3F) Chair: Bogdan Filipic, *Jozef Stefan Institute* 

#### **Data-Based Modeling and Optimization in Industrial Processes**

Michael Affenzeller, Heuristic and Evolutionary Algorithms Lab, University of Applied Sciences Upper Austria

#### Automated Scheduling of Material Tests in a Chemical Research Lab—Challenges, Pitfalls and Final Implementation

Roland Braune, Department of Business Administration, Faculty of Business, Economics and Statistics, University of Vienna

#### What they Want and What we Can

Akira Oyama, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency

#### Session 2: "Real" Real-World Optimization

Tuesday, July 17, 14:00-15:40, Conference Room C (3F) Chair: Tomoyuki Hiroyasu, *Doshisha University* 

#### Weight Reduction of Car-Body Structure using Evolutionary Computation and Data-mining Takehisa Kohira, Technical Research Center, Mazda Motor Corporation

Takenisa Konira, Technical Research Center, Mazda Motor Corporation

Material Design of Filled Rubbers based on Materials Informatics Koishi Masataka and Naoya Kowatari, Yokohama Rubber Company

#### Design Optimization of the Zao Ski Jumping Hill

Seo Kazuya, Department of Science, Yamagata University

#### Session 3: Ask the Experts / Getting a Job

Tuesday, July 17, 16:00-17:40, Conference Room C (3F) Chair: Thomas Bartz-Beielstein, *Institute for Data Science, Engineering, and Analytics, TH Köln* 

#### From University Know-How to a Commercial Product—a Hazardous Journey

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

Publishing Your Research Work Ronan Nugent, Springer

**Panel Discussion** 

# Hot off the Press

Organizer: Grant Dick, University of Otago

Time and Location: - HOP1: Wednesday, July 18, 10:40-12:20, Conference Room C (3F)

- HOP2: Wednesday, July 18, 15:30-17:10, Conference Room C (3F)
- HOP3: Thursday July 19, 09:00-10:40, Conference Room C (3F)
- HOP4: Thursday, July 19, 09:00-10:40, Conference Room D (3F)

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 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: Tuesday, July 17, 12:20-14:00, Terrsa Hall (1F)

The Job Market is a rather new GECCO event where 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 the academia as well as the 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 presented at the job market can be found at the SIGEVO web site: http://sig.sigevo.org/index.html/tiki-index.php?page=Job+Ads+Listing

SIGEVO Summer School



# SIGEVO Summer School: S3 2018

**Organizer:** JJ Merelo, University of Granada

Participants: S3 students and mentors

**Dates:** July 13-14 (School activities in Osaka) July 15-19 (Soft merged activities with GECCO), with exclusive S3 activities on July 19

Venue: July 13-14: Blossom Cafe building, Kindai University, Osaka

July 15-19: GECCO venue

Mentors: Dr. Anna Esparcia Alcázar

Dr. Juan Julián Merelo Guervós

Dr. Francisco Fernández de la Vega

Dr. José Mario García Valdez

Dr. Marc Schoenauer

SIGEVO is a special interest group of ACM always looking for new ways to enlarge the community of researchers working in different biologically inspired metaheuristics. The second SigEvo Summer School (S3) will be held held in conjunction with GECCO 2018 in Kyoto. The core of the second S3 will take place in Osaka in the days previous to the conference, and will continue in daily interactions during the conference proper in Kyoto, finishing in the same day of the conference later in the afternoon. That way, students will be able to enjoy and learn during the conference proper at the same time they meet researchers and advance in their learning tasks. GECCO tutorials, workshops, and papers will be an integral part of the S3.

During the S3, the students will first decide on a problem to tackle, and then work on it to produce, by the end of the school, an interactive presentation including a report, data, interactive notebooks and free software. This will be done through teamwork and online cooperation, with an open science approach.

After the two initial sessions (in Osaka) where the students will get to meet each other and create work teams, the mentors will design an itinerary for every student through the tutorials, workshops and sessions, which they will then comment on during daily checkpoints.

By the end of the summer school, they will have created an interactive notebook that will be presented and defended in front their peers.

Important comments:

- Mentors will consider at all times the high variety of students in terms of research maturity, culture, and research preferences (i.e., will offer assorted assignments).
- Students will participate in every activity of the school to the extent of their availability.



Blossom Café in Osaka, were the first sessions of S3 will take place

#### Friday, July 13

Presentation, group dynamics and presentation of group tools, scientific programming and visualization tools. Team building and design thinking session for elaboration of projects.

Saturday, July 14

Team presentation and mentoring choice and assignment. Mentors working with teams for on-demand talks and tutorials. Short presentations in the afternoon, and personal tutoring sessions.

Sunday, July 15 — Thursday, July 19

Attending tutorials and workshops. Lunchtime meetings with tutors, after-work meeting for scheduling the next days and choose tracks and papers to attend. Most interaction will take place in the online collaboration tools that will be set up for the participants.

## Thursday, July 19 (Afternoon)

Lunchtime general meeting, and afternoon hackathon, presentation editing and delivery.

# (before GECCO)

(before GECCO)

(during GECCO)

(after GECCO)

**Best Paper Nominations** 



# **Best Paper Nominations**

#### **Voting Instructions**

**Beware:** In contrast to previous years, GECCO attendees can only vote for <u>one best paper session</u> this year. This means that one needs to choose beforehand in which session to vote.

**Procedure:** Each track, or group of small tracks, has designated a few nominees (see the lists below). The papers in competition for the same Award are presented in the same session, and the vote for this Award takes place at the end of the session. The votes are nominative, and cannot be delegated to another attendee.

To be allowed to vote one needs to:

- Attend the entire corresponding best paper session;
- Handle the nominative voting voucher distributed with the registration material.

Voting procedure:

- At the beginning of the session, the voting ballots are distributed in the audience by the session chair;
- At the end of the session, the session chair collects the voting ballots and the nominative voting vouchers, checking the badge/voucher match.

#### CS — Complex Systems

Safe Mutations for Deep and Recurrent Neural Networks through Output Gradients Joel Lehman, Jay Chen, Jeff Clune, Kenneth O. Stanley *Tuesday, July 17, 16:00-16:25, Conference Room Medium (2F)* 

Data-efficient Neuroevolution with Kernel-Based Surrogate Models Adam Gaier, Alexander Asteroth, Jean-Baptiste Mouret *Tuesday, July 17, 16:25-16:50, Conference Room Medium (2F)* 

**Evolution of a Functionally Diverse Swarm via a Novel Decentralised QD Algorithm** Emma Hart, Andreas Siegfried Wilhelm Steyven, Ben Paechter *Tuesday, July 17, 16:50-17:15, Conference Room Medium (2F)* 

#### DETA — Digital Entertainment Technologies and Arts

Evolving Mario Levels in the Latent Space of a Deep Convolutional Generative Adversarial Network Vanessa Volz, Jacob Schrum, Jialin Liu, Simon M. Lucas, Adam M. Smith, Sebastian Risi Wednesday, July 18, 15:30-15:55, Conference Room Medium (2F)

#### ECOM — Evolutionary Combinatorial Optimization and Metaheuristics

**One-Class Constraint Acquisition with Local Search** Daniel Sroka, Tomasz P. Pawlak *Wednesday, July 18, 11:05-11:30, Terrsa Hall (1F)* 

Enhancing Partition Crossover with Articulation Points Analysis Francisco Chicano, Gabriela Ochoa, Darrell D. Whitley, Renato Tinós *Wednesday, July 18, 10:40-11:05, Terrsa Hall (1F)* 

#### **EML** — Evolutionary Machine Learning

#### **Evolved GANs for generating Pareto set approximations**

Unai Garciarena, Alexander Mendiburu, Roberto Santana *Tuesday, July 17, 10:40-11:05, Terrsa Hall (1F)* 

#### **Evolving Bagging Ensembles Using a Spatially-Structured Niching Method**

Grant Dick, Caitlin A. Owen, Peter A. Whigham *Tuesday, July 17, 11:30-11:55, Terrsa Hall (1F)* 

# What About Interpolation? A Radial Basis Function Approach to Classifier Prediction Modeling in XCSF

Anthony Stein, Simon Menssen, Jörg Hähner Tuesday, July 17, 11:05-11:30, Terrsa Hall (1F)

#### EMO — Evolutionary Multiobjective Optimization

#### Data-Driven Analysis of Pareto Set Topology

Naoki Hamada, Keisuke Goto Thursday, July 19, 10:15-10:40, Terrsa Hall (1F)

#### Multi-Objective Evolutionary Hyper-heuristic based on Multiple Indicator-based Density Estimators

Jesús Guillermo Falcón-Cardona, Carlos A. Coello Coello *Thursday, July 19, 09:25-09:50, Terrsa Hall (1F)* 

#### A new R2 indicator for better hypervolume approximation Ke Shang, Hisao Ishibuchi, Min-Ling Zhang, Yiping Liu

Thursday, July 19, 09:50-10:15, Terrsa Hall (1F)

#### **ENUM** — Evolutionary Numerical Optimization

An Empirical Comparison of Metamodeling Strategies in Noisy Environments Sunith Bandaru, Amos H.C. Ng *Thursday, July 19, 09:25-09:50, Conference Room Medium (2F)* 

**PSA-CMA-ES: CMA-ES with Population Size Adaptation** Kouhei Nishida, Youhei Akimoto *Thursday, July 19, 09:00-09:25, Conference Room Medium (2F)* 

#### GA — Genetic Algorithms

#### Runtime Analysis of Probabilistic Crowding and Restricted Tournament Selection for Bimodal Optimisation

Edgar Covantes Osuna, Dirk Sudholt Wednesday, July 18, 15:30-15:55, Terrsa Hall (1F)

# Tunneling Between Plateaus: Improving on a State-of-the-Art MAXSAT Solver using Partition Crossover

Wenxiang Chen, Darrell D. Whitley, Francisco Chicano, Renato Tinós Wednesday, July 18, 15:55-16:20, Terrsa Hall (1F)

#### Learning Bayesian Network Structures with GOMEA

Kalia Orphanou, Dirk Thierens, Peter A.N. Bosman

Wednesday, July 18, 16:20-16:45, Terrsa Hall (1F)

#### GECH — General Evolutionary- ,Computation and Hybrids

Working Principles of Binary Differential Evolution

Weijie Zheng, Guangwen Yang, Benjamin Doerr Wednesday, July 18, 16:20-16:45, Conference Room Medium (2F)

#### **GP** — Genetic Programming

Program Synthesis using Uniform Mutation by Addition and Deletion

Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector Wednesday, July 18, 11:30-11:55, Conference Room Medium (2F)

Solving the Exponential Growth of Symbolic Regression Trees in Geometric Semantic Genetic Programming

Joao Francisco Barreto da Silva Martins, Luiz Otavio Vilas Boas Oliveira, Luis Fernando Miranda, Felipe Casadei, Gisele Lobo Pappa

Wednesday, July 18, 10:40-11:05, Conference Room Medium (2F)

Where are we now? A large benchmark study of recent symbolic regression methods Patryk Orzechowski, William La Cava, Jason H. Moore Wednesday, July 18, 11:05-11:30, Conference Room Medium (2F)

#### **RWA** — Real World Applications

Genetic Programming for Tuberculosis Screening from Raw X-ray Images Armand Rashad Burks, William Fitzgerald Punch *Tuesday, July 17, 14:25-14:50, Conference Room Medium (2F)* 

Benchmarking Evolutionary Computation Approaches to Insider Threat Detection Duc C. Le, Sara Khanchi, Nur Zincir-Heywood, Malcolm Heywood *Tuesday, July 17, 14:50-15:15, Conference Room Medium (2F)* 

#### **THEORY** — Theory

**Domino Convergence: Why One Should Hill-Climb on Linear Functions** Carsten Witt *Wednesday, July 18, 15:55-16:20, Conference Room Medium (2F)*  Papers and Posters



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Tuesday, July 17, 10:40-12:20, AV Study Room (2F) Chair: Joel Lehman (Uber Technologies Inc.)

Fusing Novelty and Surprise for Evolving Robot Morphologies Daniele Gravina, Antonios Liapis, Georgios N. Yannakakis	10:40-11:05
<b>Real-World Evolution Adapts Robot Morphology and Control to Hardware Limitations</b> Tønnes F. Nygaard, Charles Patrick Martin, Eivind Samuelsen, Jim Torresen, Kyrre Glette	11:05-11:30
Interoceptive robustness through environment-mediated morphological development Sam Kriegman, Nick Cheney, Francesco Corucci, Josh C. Bongard	11:30-11:55
Towards the Targeted Environment-Specific Evolution of Robot Components Jack Collins, Wade Geles, Gerard Howard, Frederic Maire	11:55-12:20
<b>DETA1</b> Tuesday, July 17, 10:40-12:20, Conference Room Medium (2F) Chair: Julian Togelius (IT University of Copenhagen)	
Evolving Indirectly Encoded Convolutional Neural Networks to Play Tetris With Low-Le Jacob Schrum	vel Features 10:40-11:05
Evolving simple programs for playing Atari games Dennis Wilson, Sylvain Cussat-Blanc, Hervé Luga, Julian F. Miller	11:05-11:30
Opponent Modeling and Exploitation in Poker Using Evolved Recurrent Neural Networ Xun Li, Risto Miikkulainen	<b>ks</b> 11:30-11:55
Generating Beginner Heuristics for Simple Texas Hold'em Fernando De Mesentier Silva, Julian Togelius, Frank Lantz, Andy Nealen	11:55-12:20
<b>ECOM1</b> Tuesday, July 17, 10:40-12:20, Conference Room 2 (3F) Chair: Thomas Stützle (Université Libre de Bruxelles)	
A heuristic algorithm based on Tabu Search for the solution of Flexible Job Shop Schellems with Lot Streaming	aduling Prob-
Miguel Ángel Fernández Romero, Eric Alfredo Rincón García, Antonin Ponsich, Roman A Gutiérrez	nselmo Mora 10:40-11:05
Iterated Greedy Algorithms for the Hybrid Flowshop Scheduling with Total Flow Time I Hande Öztop, M. Fatih Tasgetiren, Deniz Türsel Eliiyi, Quan-Ke Pan	<b>/inimization</b> 11:05-11:30

An effective hybrid meta-heuristic for a heterogeneous flow shop scheduling problem Matheus de Freitas Araujo, Jose Elias Claudio Arroyo, Ricardo Goncalves Tavares 11:30-11:55

Min-Conflicts Heuristic for Multi-Mode Resource-Constrained Projects Scheduling	
Arben Ahmeti, Nysret Musliu	11:55-12:20
### EML1: Best Papers

Tuesday, July 17, 10:40-12:20, Terrsa Hall (1F) Chair: Will Neil Browne (Victoria University of Wellington); Yusuke Nojima (Osaka Prefecture University) (Best Paper nominees are marked with a star)

Evolved GANs for generating Pareto set approximations 🖈 Unai Garciarena, Alexander Mendiburu, Roberto Santana	10:40-11:05
What About Interpolation? A Radial Basis Function Approach to Classifier Pr XCSF ☆ Anthony Stein. Simon Menssen. Jörg Hähner	ediction Modeling in 11:05-11:30
Evolving Bagging Ensembles Using a Spatially-Structured Niching Method A Grant Dick, Caitlin A. Owen, Peter A. Whigham	11:30-11:55
Attribute Tracking: Strategies Towards Improved Detection and Characterizatio ciations	on of Complex Asso
Ryan Urbanowicz, Christopher Lo, John Holmes, Jason H. Moore	11:55-12:20

### EMO1

Tuesday, July 17, 10:40-12:20, Conference Room D (3F) Chair: Boris Naujoks (TH Köln - University of Applied Sciences)

An Improved Version of a Reference-Based Multi-Objective Evolutionary Algorithm based on IGD+ Edgar Manoatl Lopez, Carlos A. Coello Coello 10:40-11:05

Two Enhancements for Improving the Convergence Speed of a Robust Multi-Objective Coevolutionary Algorithm

Alexandru-Ciprian Zavoianu, Susanne Saminger-Platz, Edwin Lughofer, Wolfgang Amrhein 11:05-11:30

- Evolutionary Computation plus Dynamic Programming for the Bi-Objective Travelling Thief Problem Junhua Wu, Sergey Polyakovskiy, Markus Wagner, Frank Neumann 11:30-11:55
- Parallel Pareto Local Search Revisited First experimental results on Bi-objective UBQPJialong Shi, Qingfu Zhang, Bilel Derbel, Arnaud Liefooghe, Jianyong Sun11:55-12:20

### ENUM1

Tuesday, July 17, 10:40-12:20, Training Room 1 (2F) Chair: Jose A. Lozano (University of the Basque Country)

Drift Theory in Continuous Search Spaces: Expected Hitting Time of the	(1+1)-ES with 1/5 Success
Rule	
Youhei Akimoto, Anne Auger, Tobias Glasmachers	10:40-11:05

**Real-Valued Evolutionary Multi-Modal Optimization driven by Hill-Valley Clustering** Stef C. Maree, Tanja Alderliesten, Dirk Thierens, Peter A.N. Bosman 11:05-11:30

Adaptive Threshold Parameter Estimation with Recursive Differential Grouping for Problem Decomposition

Yuan Sun, Mohammad Nabi Omidvar, Michael Kirley, Xiaodong Li	11:30-11:55
<b>GA1</b> Tuesday, July 17, 10:40-12:20, Conference Room B (3F) Chair: Darrell Whitley (Colorado State University)	
Analysis of the Use of Genetic Algorithms for Indoor Localisation via Cloud Point Mate Miguel d'Arcangues Boland, Leandro Soares Indrusiak	<b>ching</b> 10:40-11:05
Shaper-GA: Automatic Shape Generation for Modular House Design Ana Maria Carvalho de Almeida, Bruno Taborda, Filipe Santos, Krystian Kwiecinski, Sara El	oy 11:05-11:30
Towards a Theory-Guided Benchmarking Suite for Discrete Black-Box Optimization: Pr EA Variants on OneMax and LeadingOnes Carola Doerr, Furong Ye, Sander van Rijn, Hao Wang, Thomas Bäck	<b>rofiling</b> $(1+\lambda)$ 11:30-11:55
<b>GECH1</b> Tuesday, July 17, 10:40-12:20, Training Room 2 (2F) Chair: Juergen Branke (University of Warwick)	
Adaptive Asynchrony in Semi-Asynchronous Evolutionary Algorithm Based on Performation Using Search History Tomohiro Harada	10:40-11:05
Memetic Algorithms Beat Evolutionary Algorithms on the Class of Hurdle Problems Phan Trung Hai Nguyen, Dirk Sudholt	11:05-11:30
Termination Detection Strategies in Evolutionary Algorithms: A Survey Yanfeng Liu, Aimin Zhou, Hu Zhang	11:30-11:55
<b>RWA1</b> Tuesday, July 17, 10:40-12:20, Training Room 3 (2F) Chair: Una-May O'Reilly (CSAIL, Massachusetts Institute of Technology)	
Multi-Objective Journey Planning Under Uncertainty: A Genetic Approach Mohammad Haqqani, Xiaodong Li, Xinghuo Yu	10:40-11:05
A Genetic Programming based Iterated Local Search for Software Project Scheduling Nasser R. Sabar, Ayad Turky, Andy Song	11:05-11:30
Estimating Cement Compressive Strength from Microstructural Images using GEP with Polarized Similarity Weight Tournament Selection	Probabilistic
Evolving Boolean Functions for Fast and Efficient Randomness Testing Vojtech Mrazek, Marek Sýs, Zdenek Vasicek, Lukas Sekanina, Vashek Matyas	11:55-12:20

### THEORY1

Tuesday, July 17, 10:40-12:20, Conference Room A (3F) Chair: Andrei Lissovoi (University of Sheffield)

### **Runtime Analysis for Self-adaptive Mutation Rates**

Benjamin Doerr, Carsten Witt, Jing Yang

10:40-11:05

The linear hidden subset problem for the (1+1) EA with scheduled and adaptive mutation rates Hafsteinn Einarsson, Marcelo Matheus Gauy, Johannes Lengler, Florian Meier, Asier Mujika, Angelika Steger, Felix Weissenberger 11:05-11:30

### A Tight Runtime Analysis for the $(\mu + \lambda)$ EA

Denis Antipov, Benjamin Doerr, Jiefeng Fang, Tangi Hetet

11:30-11:55

<b>ACO-SI1</b> Tuesday, July 17, 14:00-15:40, Conference Room B (3F) Chair: Andries P. Engelbrecht (University of Pretoria)	
A New Foraging-Based Algorithm for Online Scheduling Koen van der Blom, Thomas Bäck	14:00-14:25
Information Sharing and Conflict Resolution in Distributed Factored Evolutionary Alg Stephyn G. W. Butcher, John Sheppard, Shane Strasser	<b>gorithms</b> 14:25-14:50
Recurrent Neural Network-Predictions for PSO in Dynamic Optimization Almuth Meier, Oliver Kramer	14:50-15:15
A Model of Artificial Emotions for Behavior-Modulation and Implicit Coordination in M tems Jerome Guzzi, Alessandro Giusti, Luca Maria Gambardella, Gianni A. Di Caro	lulti-robot Sys- 15:15-15:40
<b>ECOM2</b> Tuesday, July 17, 14:00-15:40, Conference Room 2 (3F) Chair: Frank Neumann (The University of Adelaide)	
Memetic Multilevel Hypergraph Partitioning Sebastian Schlag, Christian Schulz, Robin Andre	14:00-14:25
Randomized Greedy Algorithms for Covering Problems Wanru Gao, Tobias Friedrich, Frank Neumann, Christian Hercher	14:25-14:50
Evolutionary Multi-Level Acyclic Graph Partitioning Orlando Moreira, Merten Popp, Christian Schulz	14:50-15:15
A Multi-objective Formulation of the Team Formation Problem in Social Networks: F	Preliminary Re-
Carlos Brizuela, Julio Juarez	15:15-15:40
<b>EML2</b> Tuesday, July 17, 14:00-15:40, Training Room 2 (2F) Chair: Jeff Clune (Uber Technologies Inc., University of Wyoming)	
Autostacker: A Compositional Evolutionary Learning System Boyuan Chen, Harvey Wu, Warren Mo, Ishanu Chattopadhyay, Hod Lipson	14:00-14:25
Cooperative Multi-Objective Evolutionary Support Vector Machines for Multiclass Pro Alejandro Rosales-Pérez, Andres Eduardo Gutierrez-Rodríguez, Salvador García, Hugo T Carlos A. Coello Coello, Francisco Herrera	<b>oblems</b> erashima-Marín, 14:25-14:50
Evolutionary Feature Subspaces Generation for Ensemble Classification Boyu Zhang, A. K. Qin, Timos Sellis	14:50-15:15
ES Is More Than Just a Traditional Finite-Difference Approximator Joel Lehman, Jay Chen, Jeff Clune, Kenneth O. Stanley	15:15-15:40

### EMO2

Tuesday, July 17, 14:00-15:40, Conference Room D (3F) Chair: Arnaud Liefooghe (Univ. Lille, Inria Lille - Nord Europe)

A Taxonomy of Methods for Visualizing Pareto Front Approximations Bogdan Filipic, Tea Tusar	14:00-14:25
mQAPViz: A divide-and-conquer multi-objective optimization algorithm to compute larg alizations	e data visu-
Claudio Sanhueza, Francia Jiménez, Regina Berretta, Pablo Moscato	14:25-14:50
Surrogate-assisted Evolutionary Biobjective Optimization for Objectives with Non-uni	form Laten-
cies Tinkle Chugh, Richard Allmendinger, Vesa Ojalehto, Kaisa Miettinen	14:50-15:15
A set-oriented MOEA/D	
Bilel Derbel, Arnaud Liefooghe, Qingfu Zhang, Sébastien Verel, Hernán Aguirre, Kiyoshi Tar	naka 15:15-15:40
<b>GECH2</b> Tuesday, July 17, 14:00-15:40, Training Room 3 (2F) Chair: Yaochu Jin (University of Surrey)	
Expected Improvement of Constraint Violation for Expensive Constrained Optimization Ruwang Jiao, Sanyou Zeng, Changhe Li, Yuhong Jiang, Junchen Wang	14:00-14:25
Talakat: Bullet Hell Generation through Constrained Map-ElitesAhmed Khalifa, Scott Lee, Andy Nealen, Julian Togelius	14:25-14:50
Neural Estimation of Interaction Outcomes Paweł Liskowski, Bartosz Wieloch, Krzysztof Krawiec	14:50-15:15
Cooperative Co-evolution with Online Optimizer Selection for Large-Scale Optimization Yuan Sun, Michael Kirley, Xiaodong Li	15:15-15:40
<b>GP1</b> Tuesday, July 17, 14:00-15:40, AV Study Room (2F) Chair: Lee Spector (Hampshire College, University of Massachusetts Amherst)	
Evolving Event-driven Programs with SignalGP Alexander Lalejini, Charles Ofria	14:00-14:25
An Analysis of the Bias of Variation Operators of Estimation of Distribution Programmin Dirk Schweim, Franz Rothlauf	<b>ng</b> 14:25-14:50
Schema-based Diversification in Genetic Programming Bogdan Burlacu, Michael Affenzeller	14:50-15:15
Towards Effective Semantic Operators for Program Synthesis in Genetic Programming Stefan Forstenlechner, David Fagan, Miguel Nicolau, Michael O'Neill	15:15-15:40

<b>RWA2: Best Papers</b> Tuesday, July 17, 14:00-15:40, Conference Room Medium (2F)		
Chair: Anna Isabel Esparcia-Alcazar (Universitat Politècnica de València) marked with a star)	(Best Paper nominees are	
A Detailed Comparison of Meta-Heuristic Methods for Optimising Wave Mehdi Neshat, Bradley Alexander, Markus Wagner, Yuanzhong Xia	Energy Converter Positions 14:00-14:25	
Constin Programming for Tuberculosis Screening from Pour X roy Imag	······	
Armand Rashad Burks, William Fitzgerald Punch	14:25-14:50	
Benchmarking Evolutionary Computation Approaches to Insider Threat Duc C. Le, Sara Khanchi, Nur Zincir-Heywood, Malcolm Heywood	<b>Detection ☆</b> 14:50-15:15	
<b>THEORY2</b> Tuesday, July 17, 14:00-15:40, Conference Room A (3F) Chair: Martin S. Krejca (Hasso Plattner Institute)		
Significance-based Estimation-of-Distribution Algorithms Benjamin Doerr, Martin S. Krejca	14:00-14:25	
Medium Step Sizes are Harmful for the Compact Genetic Algorithm Johannes Lengler, Dirk Sudholt, Carsten Witt	14:25-14:50	
Crossover Can Simulate Bounded Tree Search on a Fixed-Parameter Trad Andrew M. Sutton	ctable Optimization Problem 14:50-15:15	

CS2: Best Papers Tuesday, July 17, 16:00-17:40, Conference Room Medium (2F) Chair: Sebastian Risi (IT University of Copenhagen) (Best Paper nominees are marked	d with a star)
Safe Mutations for Deep and Recurrent Neural Networks through Output Gradients 🖈 Joel Lehman, Jay Chen, Jeff Clune, Kenneth O. Stanley	16:00-16:25
Data-efficient Neuroevolution with Kernel-Based Surrogate Models 🖈 Adam Gaier, Alexander Asteroth, Jean-Baptiste Mouret	16:25-16:50
Evolution of a Functionally Diverse Swarm via a Novel Decentralised QD Algorithm 🖈 Emma Hart, Andreas Siegfried Wilhelm Steyven, Ben Paechter	16:50-17:15
<b>ECOM3</b> Tuesday, July 17, 16:00-17:40, Conference Room 2 (3F) Chair: Bilel Derbel (Univ. Lille, Inria Lille - Nord Europe)	
Escaping Large Deceptive Basins of Attraction with Heavy-Tailed Mutation Operators Tobias Friedrich, Francesco Quinzan, Markus Wagner	16:00-16:25
Improving the Run Time of the (1+1) Evolutionary Algorithm with Luby Sequences Tobias Friedrich, Timo Kötzing, Francesco Quinzan, Andrew M. Sutton	16:25-16:50
Dominance, Epsilon, and Hypervolume Local Optimal Sets in Multi-objective Optimizat to Tell the Difference	ion, and How
Arnaud Liefooghe, Manuel López-Ibáñez, Luís Paquete, Sébastien Verel	16:50-17:15
A two-level diploid genetic based algorithm for solving the family traveling salesman p Petrica Claudiu Pop, Oliviu Matei, Camelia Pintea	roblem 17:15-17:40
<b>EML3</b> Tuesday, July 17, 16:00-17:40, Training Room 2 (2F) Chair: Ryan Urbanowicz (University of Pennsylvania)	
Theoretical Adaptation of Multiple Rule-Generation in XCS Masaya Nakata, Will Neil Browne, Tomoki Hamagami	16:00-16:25
Divide and Conquer: Neuroevolution for Multiclass Classification Tyler McDonnell, Sari Andoni, Elmira Bonab, Sheila Cheng, Jun-Hwan Choi, Jimmie Goode Gavin Sellers, Jacob Schrum	, Keith Moore, 16:25-16:50
Towards an Adaptive Encoding for Evolutionary Data Clustering Cameron Shand, Richard Allmendinger, Julia Handl, John Keane	16:50-17:15
A Genetic Algorithm for Finding an Optimal Curing Strategy for Epidemic Spreading Networks Clara Pizzuti, Annalisa Socievole	in Weighted 17:15-17:40

77

### EMO3

Tuesday, July 17, 16:00-17:40, Conference Room D (3F) Chair: Qingfu Zhang (City University of Hong Kong, Shenzhen Research Institute)

MOEA/D with Uniformly Randomly Adaptive Weights Lucas Rodolfo Celestino Farias, Pedro Henrique Magalhães Braga, Hansenclever França Bas Fausto Ribeiro Araújo	ssani, Aluizio 16:00-16:25
Dual-Grid Model of MOEA/D for Evolutionary Constrained Multiobjective Optimization Hisao Ishibuchi, Takafumi Fukase, Naoki Masuyama, Yusuke Nojima	16:25-16:50
Directed Mating in Decomposition-based MOEA for Constrained Many-objective Optimi Minami Miyakawa, Hiroyuki Sato, Yuji Sato	<b>zation</b> 16:50-17:15
Component-level study of a decomposition-based multi-objective optimizer on a limited budget	d evaluation
Oliver P. H. Jones, Jeremy E. Oakley, Robin C. Purshouse	17:15-17:40
ENUM2 Tuesday, July 17, 16:00-17:40, Training Room 1 (2F) Chair: Alexander Mendiburu (University of the Basque Country UPV/EHU)	
Learning-Based Topology Variation in Evolutionary Level Set Topology Optimization Mariusz Bujny, Nikola Aulig, Markus Olhofer, Fabian Duddeck	16:00-16:25
Analysis of Evolution Strategies with the Optimal Weighted Recombination Chun-kit Au, Ho-fung Leung	16:25-16:50
A Global Information Based Adaptive Threshold for Grouping Large Scale Global Optimi	zation Prob-
An Chen, Yipeng Zhang, Yang Yang, Zhigang Ren, Yongsheng Liang, Bei Pang	16:50-17:15
<b>GA2</b> Tuesday, July 17, 16:00-17:40, Conference Room B (3F) Chair: Dirk Thierens (Utrecht University)	
Grammatical Evolution Algorithm for Evolution of Swarm Behaviors Aadesh Neupane, Michael A. Goodrich, Eric G. Mercer	16:00-16:25
Learning an Evolvable Genotype-Phenotype Mapping Matthew Andres Moreno, Banzhaf Wolfgang, Charles Ofria	16:25-16:50
Serendipitous Scaffolding to improve a Genetic Algorithm's Speed and Quality Heather J. Goldsby, Rebecca L. Young, Jory Schossau, Hans A. Hofmann, Arend Hintze	16:50-17:15

### GECH3

Tuesday, July 17, 16:00-17:40, Conference Room A (3F) Chair: Jonathan Edward Fieldsend (University of Exeter)

Quasi-Bistability of Walk-Based Landscape Measures in Stochastic Fitness Landscapes Bernhard Werth, Erik Pitzer, Gerald Ostermayer, Michael Affenzeller	<b>s</b> 16:00-16:25
Changing or Keeping Solutions in Dynamic Optimization Problems with Switching Cost Danial Yazdani, Juergen Branke, Mohammad Nabi Omidvar, Trung Thanh Nguyen, Xin Yao	<b>s</b> 16:25-16:50
Sequential Sampling for Noisy Optimisation with CMA-ES	
Matthew Groves, Juergen Branke	16:50-17:15
GP2	
Tuesday, July 17, 16:00-17:40, AV Study Room (2F) Chair: Wolfgang Banzhaf (Memorial University of Newfoundland, NSF Beacon Center for Evolution in Action)	the Study of
Genetic Programming Approach to Learning Multi-pass Heuristics for Resource Cons Scheduling Su Nouven, Dhananiay Thiruyady, Andreas T Ernst, Damminda Alabakoon	trained Job
Adaptive Charting Genetic Programming for Dynamic Flexible Job Shop Scheduling Su Nguyen, Mengjie Zhang, Kay Chen Tan, Damminda Alahakoon	16:25-16:50
Measuring Evolvability and Accessibility using the Hyperlink-Induced Topic Search Algo Kyle Nickerson, Yuanzhu Chen, Feng Wang, Ting Hu	<b>orithm</b> 16:50-17:15
Neuro-Guided Genetic Programming: Prioritizing Evolutionary Search with Neural Netw Paweł Liskowski, Iwo Błądek, Krzysztof Krawiec	<b>orks</b> 17:15-17:40
<b>RWA3</b> Tuesday, July 17, 16:00-17:40, Training Room 3 (2F)	
Chair: Peter Bosman (Centrum Wiskunde & Informatica (CWI)) Informed Mutation Operator using Machine Learning for Optimization in Epidemics Prev	vention
Krzysztot iviichaiak	16:00-16:25

Symbolic Regression and Feature Construction with GP-GOMEA applied to Radiotherapy Dose Reconstruction of Childhood Cancer Survivors

Marco Virgolin, Tanja Alderliesten, Arjan Bel, Cees Witteveen, Peter A.N. Bosman 16:25-16:50

Better and Faster Catheter Position Optimization in HDR Brachytherapy for Prostate Cancer using Multi-Objective Real-Valued GOMEA

Marjolein C. van der Meer, Bradley R. Pieters, Yury Niatsetski, Tanja Alderliesten, Arjan Bel, Peter A.N. Bosman 16:50-17:15

Large-Scale Parallelization of Partial Evaluations in Evolutionary Algorithms for Real-World Problems Anton Bouter, Tanja Alderliesten, Arjan Bel, Cees Witteveen, Peter A.N. Bosman 17:15-17:40

Shawn L. Beaulieu, Sam Kriegman, Josh C. Bongard

Neuroevolution of Hierarchical Reservoir Computers

Matthew Dale

<b>CS3</b> Wednesday, July 18, 10:40-12:20, AV Study Room (2F) Chair: Nicolas Bredeche (Sorbonne Université, CNRS)	
Robotic Snake Simulation using Ensembles of Artificial Neural Networks in Evol Grant Warren Woodford, Mathys Cornelius du Plessis	utionary Robotics 10:40-11:05
Discovering the Elite Hypervolume by Leveraging Interspecies Correlation Vassilis Vassiliades, Jean-Baptiste Mouret	11:05-11:30
A Robot to Shape your Natural Plant: The Machine Learning Approach to Mode Hybrid Systems Mostafa Wahby, Mary Katherine Heinrich, Daniel Nicolas Hofstadler, Payam Zaha Phil Avres, Thomas Schmickl, Heiko Hamann	el and Control Bio- dat, Sebastian Risi,
Evolution of Fin Undulation on a Physical Knifefish-inspired Soft Robot Frank Veenstra, Jonas Jørgensen, Sebastian Risi	11:55-12:20
<b>ECOM4: Best Papers</b> Wednesday, July 18, 10:40-12:20, Terrsa Hall (1F) Chair: Sebastien Verel (Université du Littoral Côte d'Opale) <i>(Best Paper nominees are</i>	marked with a star)
Enhancing Partition Crossover with Articulation Points Analysis 🖈 Francisco Chicano, Gabriela Ochoa, Darrell D. Whitley, Renato Tinós	10:40-11:05
<b>One-Class Constraint Acquisition with Local Search </b>	11:05-11:30
A Merge Search Algorithm and its Application to the Constrained Pit Problem in Angus Kenny, Xiaodong Li, Andreas T. Ernst	Mining 11:30-11:55
<b>EML4</b> Wednesday, July 18, 10:40-12:20, Training Room 2 (2F) Chair: Kenneth Stanley (Uber Technologies Inc., University of Central Florida)	
NEAT for Large-Scale Reinforcement Learning through Evolutionary Feature Lo Gradient Search	earning and Policy
Yiming Peng, Gang Chen, Harman Singh, Mengjie Zhang	10:40-11:05
Combating catastrophic forgetting with developmental compression.	

81

11:05-11:30

11:30-11:55

EMO4 Wednesday, July 18, 10:40-12:20, Conference Room D (3F) Chair: Dimo Brockhoff (INRIA Saclay - Ile-de-France; CMAP, Ecole Polytechnique)	
Collaborative Multi-Objective Optimization for Distributed Design of Complex Products Joao Antonio Fialho Vilas Boas Duro, Yiming Yan, Robin C. Purshouse, Peter J. Fleming	10:40-11:05
Transfer Strategies from Single- to Multi-objective Grouping Mechanisms Frederick Sander, Heiner Zille, Sanaz Mostaghim	11:05-11:30
Generalized Offline Orthant Search: One Code for Many Problems in Multiobjective Opt Maxim Buzdalov	i <b>mization</b> 11:30-11:55
Improving the Performance of MO-RV-GOMEA on Problems with Many Objectives using Scalarizations Ngoc Hoang Luong, Tanja Alderliesten, Peter A.N. Bosman	Tchebycheff 11:55-12:20
<b>EMO5</b> Wednesday, July 18, 10:40-12:20, Conference Room 2 (3F) Chair: Ke Li (University of Exeter)	
A Differential Prediction Model for Evolutionary Dynamic Multiobjective Optimization Leilei Cao, Lihong Xu, Erik D. Goodman, Shuwei Zhu, Hui Li	10:40-11:05
Less Detectable Environmental Changes in Dynamic Multiobjective Optimisation Shouyong Jiang, Marcus Kaiser, Jinglei Guo, Shengxiang Yang, Natalio Krasnogor	11:05-11:30
A Steady-State NSGA-II based Multi-objective Multicast Routing Algorithm for Optical N Ying Xu, Yan Zhou	letworks 11:30-11:55
Multiobjective Sparse Unmixing Approach with Noise Removal Xiangming Jiang, Maoguo Gong, Tao Zhan, Zedong Tang	11:55-12:20
<b>ENUM3</b> Wednesday, July 18, 10:40-12:20, Training Room 1 (2F) Chair: Anne Auger (INRIA; CMAP, Ecole Polytechnique)	
A Novel Similarity-based Mutant Vector Generation Strategy for Differential Evolution Eduardo Segredo, Eduardo Lalla-Ruiz, Emma Hart	10:40-11:05
Expanding variational autoencoders for learning and exploiting latent representation distributions	is in search
Unai Garciarena, Roberto Santana, Alexander Mendiburu	11:05-11:30
Analysis of Information Geometric Optimization with Isotropic Gaussian Distribution Samples	Under Finite
Kento Uchida, Youhei Akimoto, Shinichi Shirakawa	11:30-11:55
Inheritance-Based Diversity Measures for Explicit Convergence Control in Evolutionary Thomas Gabor, Lenz Belzner, Claudia Linnhoff-Popien	Algorithms 11:55-12:20

<b>GA3</b> Wednesday, July 18, 10:40-12:20, Conference Room B (3F) Chair: Peter Bosman (Centrum Wiskunde & Informatica (CWI))	
Simple On-the-Fly Parameter Selection Mechanisms for Two Classical Discrete Blac tion Benchmark Problems	k-Box Optimiza-
Carola Doerr, Markus Wagner	10:40-11:05
Investigation of the Exponential Population Scheme for Genetic Algorithms Yuen-Jen Lin, Tian-Li Yu	11:05-11:30
On the Runtime Dynamics of the Compact Genetic Algorithm on Jump Functions Václav Hasenöhrl, Andrew M. Sutton	11:30-11:55
Discrepancy-Based Evolutionary Diversity Optimization Aneta Neumann, Wanru Gao, Carola Doerr, Frank Neumann, Markus Wagner	11:55-12:20
GP3: Best Papers Wednesday, July 18, 10:40-12:20, Conference Room Medium (2F) Chair: Hitoshi Iba (University of Tokyo) (Best Paper nominees are ma	arked with a star)
Solving the Exponential Growth of Symbolic Regression Trees in Geometric Semar gramming 🚖 Joao Francisco Barreto da Silva Martins, Luiz Otavio Vilas Boas Oliveira, Luis Fernand Casadei, Gisele Lobo Pappa	n <b>tic Genetic Pro-</b> o Miranda, Felipe 10:40-11:05
Where are we now? A large benchmark study of recent symbolic regression metho Patryk Orzechowski, William La Cava, Jason H. Moore	ods ☆ 11:05-11:30
Program Synthesis using Uniform Mutation by Addition and Deletion 🖈 Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector	11:30-11:55
HOP1 Wednesday, July 18, 10:40-12:20, Conference Room C (3F) Chair: Grant Dick (University of Otago, Information Science Dept.)	
Towards Automation & Augmentation of the Design of Schedulers for Cellular C	Communications
Michael Fenton, David Fagan	10:40-11:05
Parameter-less (Meta)heuristics for Vehicle Routing Problems Jakub Nalepa, Miroslaw Blocho	11:05-11:30

### Summary of Evolutionary Computation for Wind Farm Layout Optimization

Dennis Wilson, Silvio Rodrigues, Carlos Segura, Ilya Loshchilov, Frank Hutter, Guillermo López Buenfil, Ahmed Kheiri, Ed Keedwell, Mario Ocampo Pineda, Ender Ozcan, Sergio Ivvan Valdez Peña, Brian Goldman, Salvador Botello Rionda, Arturo Hernández Aguirre, Kalyan Veeramachaneni, Sylvain Cussat-Blanc 11:30-11:55

### Better Runtime Guarantees Via Stochastic Domination (Hot-off-the-Press Track at GECCO 2018) Benjamin Doerr 11:55-12:20

### RWA4

Wednesday, July 18, 10:40-12:20, Training Room 3 (2F) Chair: Thomas Bartz-Beielstein (TH Köln, SPOTSeven Lab)

A Rolling Window with Genetic Algorithm Approach to Sorting Aircraft for Automated Alexander Edward Ian Brownlee, John R. Woodward, Michal Weiszer, Jun Chen	Taxi Routing 10:40-11:05
Comparison of Parallel Surrogate-Assisted Optimization Approaches Frederik Rehbach, Martin Zaefferer, Jörg Stork, Thomas Bartz-Beielstein	11:05-11:30
Surrogate assisted optimization of particle reinforced metal matrix composites Lorenzo Gentile, Martin Zaefferer, Dario Giugliano, Haofeng Chen, Thomas Bartz-Beielstei	in 11:30-11:55
Rate-Setter : Roadmap for Faster, Safer, and Better Platform Train Interface Design a	nd Operation
David Fletcher, Rob Harrison, Twin Karmakharm, Paul Richmond, Samadhi Nallaperuma	11:55-12:20
<b>SBSE1</b> Wednesday, July 18, 10:40-12:20, Conference Room A (3F) Chair: Houari Sahraoui (DIRO, Univ. de Montreal)	
Multi-Objective Black-Box Test Case Selection for Cost-Effectively Testing Simulation Aitor Arrieta, Shuai Wang, Ainhoa Arruabarrena, Urtzi Markiegi, Goiuria Sagardui, Leire Et	Models xeberria 10:40-11:05
Dependent Input Sampling Strategies: Using Metaheuristics for Generating Parameter Sampling Regimes	ised Random
Kamaan Cuiviaut, Jahn Andrew Clark, Dishard Freeman Daine	11.05 11.00

Komsan Srivisut, John Andrew Clark, Richard Freeman Paige

11:05-11:30

### Test suite minimization for mutation testing of WS-BPEL compositions Francisco Palomo-Lozano, Inmaculada Medina-Bulo, Antonia Estero-Botaro, Manuel Núñez 11:30-11:55

84

### ACO-SI2

Wednesday, July 18, 15:30-17:10, Conference Room B (3F) Chair: Andries P. Engelbrecht (University of Pretoria)

### A Particle Swarm Optimization based Feature Selection Approach to Transfer Learning in Classification

Bach Hoai Nguyen, Bing Xue, Peter Andreae

Using Ant Colony Optimization to Optimize Long Short-Term Memory Recurrent Neural Networks AbdElRahman ElSaid, Fatima El Jamiy, James Higgins, Brandon Wild, Travis Desell 15:55-16:20

Semi-supervised Learning Assisted Particle Swarm Optimization of Computationally Expensive Problems

Chaoli Sun, Yaochu Jin, Ying Tan

### CS4

Wednesday, July 18, 15:30-17:10, AV Study Room (2F) Chair: Emma Hart (Napier University)

Hierarchical Behavioral Repertoires with Unsupervised Descriptors Antoine Cully, Yiannis Demiris	15:30-15:55
How swarm size during evolution impacts the behavior, generalizability, and brain co animats performing a spatial navigation task	omplexity of
Dominik Fischer, Sanaz Mostaghim, Larissa Albantakis	15:55-16:20
Automatic Synthesis of Swarm Behavioural Rules from their Atomic Components Dilini Samarasinghe, Erandi Lakshika, Michael Barlow, Kathryn Kasmarik	16:20-16:45
On an Immuno-inspired Distributed, Embodied Action-Evolution cum Selection Algorith Tushar Semwal, Divya D. Kulkarni, Shivashankar B. Nair	<b>im</b> 16:45-17:10
DETA2+THEORY3+GECH4: Best Papers Wednesday, July 18, 15:30-17:10, Conference Room Medium (2F) Chair: Per Kristian Lehre (University of Birmingham) (Best Paper nominees are marked	l with a star)
Evolving Mario Levels in the Latent Space of a Deep Convolutional Generative Adve work $\bigstar$	ersarial Net-
vanessa voiz, jacod Schrum, jialin Liu, Simon M. Lucas, Adam M. Smith, Sebastian Risi	15:30-15:55
Domino Convergence: Why One Should Hill-Climb on Linear Functions 🛠 Carsten Witt	15:55-16:20
Working Principles of Binary Differential Evolution 🛠 Weijie Zheng, Guangwen Yang, Benjamin Doerr	16:20-16:45
On the Runtime Analysis of Selection Hyper-Heuristics with Adaptive Learning Periods Benjamin Doerr, Andrei Lissovoi, Pietro S. Oliveto, John Alasdair Warwicker	16:45-17:10

15:30-15:55

16:20-16:45

<b>ECOM5</b> Wednesday, July 18, 15:30-17:10, Conference Room 2 (3F) Chair: Gabriela Ochoa (University of Stirling)	
A fitness landscape analysis of the Travelling Thief Problem Mohamed El Yafrani, Marcella Scoczynski Ribeiro Martins, Mehdi El Krari, Markus Wagne gado, Belaïd Ahiod, Ricardo Lüders	er, Myriam Del- 15:30-15:55
Algorithm Selection on Generalized Quadratic Assignment Problem Landscapes Andreas Beham, Stefan Wagner, Michael Affenzeller	15:55-16:20
Fitness Landscape Analysis around the Optimum in Computational Protein Design David Simoncini, Sophie Barbe, Thomas Schiex, Sébastien Verel	16:20-16:45
Multifractality and Dimensional Determinism in Local Optima Networks Sarah Louise Thomson, Sébastien Verel, Gabriela Ochoa, Nadarajen Veerapen, David Cair	ns 16:45-17:10
<b>EML5</b> Wednesday, July 18, 15:30-17:10, Training Room 2 (2F) Chair: Satoshi Ono (Kagoshima University)	
Evolutionary Architecture Search for Deep Multitask Networks Jason Zhi Liang, Elliot Meyerson, Risto Miikkulainen	15:30-15:55
Memetic Evolution of Deep Neural Networks Pablo Ribalta Lorenzo, Jakub Nalepa	15:55-16:20
Optimizing Floating Centroids Method Neural Network Classifier Using Dynamic Mult Swarm Optimization	ilayer Particle
Changwei Cai, Shuangrong Liu, Lin Wang, Bo Yang, Zhenxiang Chen, Jin Zhou	16:20-16:45
<b>EMO6</b> Wednesday, July 18, 15:30-17:10, Conference Room D (3F) Chair: Bogdan Filipic (Jozef Stefan Institute, Jozef Stefan International Postgraduate School	)
Local Search Effects in Bi-Objective Orienteering Jakob Bossek, Christian Grimme, Stephan Meisel, Günter Rudolph, Heike Trautmann	15:30-15:55
Interactive Multiobjective Optimisation: Preference Changes And Algorithm Response Kendall Peter Taylor, Xiaodong Li	<b>iveness</b> 15:55-16:20
Preference-based 3-Dimensional En-route Airspace Sectorization Cheryl Sze Yin Wong, Suresh Sundaram	16:20-16:45

**GA4: Best Papers** Wednesday, July 18, 15:30-17:10, Terrsa Hall (1F) Chair: Tian-Li Yu (Department of Electrical Engineering, National Taiwan University; National Taiwan Uni-

versity)

(Best Paper nominees are marked with a star)

Runtime Analysis of Probabilistic Crowding and Restricted Tournament Selection fo	r Bimodal Opti-
Edgar Covantes Osuna, Dirk Sudholt	15:30-15:55
Tunneling Between Plateaus: Improving on a State-of-the-Art MAXSAT Solver using I over $\bigstar$	Partition Cross-
Wenxiang Chen, Darrell D. Whitley, Francisco Chicano, Renato Tinós	15:55-16:20
Learning Bayesian Network Structures with GOMEA 🛧 Kalia Orphanou, Dirk Thierens, Peter A.N. Bosman	16:20-16:45
Fast Algorithm for Fair Comparison of Genetic Algorithms Chia-Sheng Chen, Hung-Wei Hsu, Tian-Li Yu	16:45-17:10
HOP2 Wednesday, July 18, 15:30-17:10, Conference Room C (3F) Chair: Grant Dick (University of Otago, Information Science Dept.)	
Approximating Complex Arithmetic Circuits with Formal Error Guarantees: 32-bit complished Milan Češka, Jiří Matyáš, Vojtech Mrazek, Lukas Sekanina, Zdenek Vasicek, Tomas Vojr	Multipliers Ac-
Energy-consumption prediction of Genetic Programming Algorithms using a Fuzzy R	ule-Based Sys-
Franciso Chavez de la O, Francisco Fernandez de Vega, Josefa Diaz-Alvarez, Juan A. G J. Rodriguez, Pedro A. Castillo	arcia, Francisco 15:55-16:20
Evolutionary Computation: An Investigation of Parameter Space Moshe Sipper, Weixuan Fu, Karuna Ahuja, Jason H. Moore	16:20-16:45
Deep Statistical Comparison of Meta-heuristic Stochastic Optimization Algorithms Tome Eftimov, Peter Korošec, Barbara Koroušić Seljak	16:45-17:10
RWA5 Wednesday, July 18, 15:30-17:10, Training Room 3 (2F) Chair: Carlos Antunes (DEEC-UC)	
Investigation of the Latent Space of Stock Market Patterns with Genetic Programmir Sungjoo Ha, Sangyeop Lee, Byung-Ro Moon	<b>Ig</b> 15:30-15:55
Value-Based Manufacturing Optimisation in Serverless Clouds for Industry 4.0 Piotr Dziurzanski, Jerry Swan, Leandro Soares Indrusiak	15:55-16:20
Impacts of Constraints and Constraint Handling Strategies for Multi-Objective Mec	hanical Design
Cyril Picard, Jürg Schiffmann	16:20-16:45

# Optimizing Residential Energy Resources with an Improved Multi-Objective Genetic Algorithm based on Greedy Mutations

Ivo Gonçalves, Álvaro Gomes, Carlos Henggeler Antunes

16:45-17:10

### SBSE2

Wednesday, July 18, 15:30-17:10, Conference Room A (3F) Chair: Giuliano Antoniol (Ecole Polytechnique de Montreal)

- On the Effects of Seeding Strategies: A Case for Search-based Multi-Objective Service Composition Tao Chen, Miqing Li, Xin Yao 15:30-15:55
- A Novel Fitness Function for Automated Program Repair Based on Source Code Checkpoints Eduardo Faria de Souza, Celso Gonçalves Camilo-Junior, Claire Le Goues 15:55-16:20

### Towards the Automated Recovery of Complex Temporal API-Usage Patterns Mohamed Aymen Saied, Houari Sahraoui, Edouard Batot, Michalis Famelis, Pierre-Olivier Talbot

16:20-16:45

### DETA3 Thursday, July 19, 09:00-10:40, Conference Room 2 (3F) Chair: Jacob Schrum (Department of Mathematics and Computer Science, Southwestern University) **Querying Across Time to Interactively Evolve Animations** Isabel Tweraser, Lauren E. Gillespie, Jacob Schrum 09:00-09:25 Generating a Melody Based on Symbiotic Evolution for Musicians' Creative Activities Noriko Otani, Daisuke Okabe, Masayuki Numao 09:25-09:50 EML6 Thursday, July 19, 09:00-10:40, Training Room 2 (2F) Chair: Josh Bongard (University of Vermont) **Ensembles of Evolved Nested Dichotomies for Classification** Marcel Wever, Felix Mohr, Eyke Hüllermeier 09:00-09:25 Efficient Sample Reuse in Policy Search by Multiple Importance Sampling 09:25-09:50 Eiji Uchibe Online Meta-Learning by Parallel Algorithm Competition Stefan Elfwing, Eiji Uchibe, Kenji Doya 09:50-10:15 **Evolutionary Expectation Maximization** Enrico Guiraud, Jakob Drefs, Jörg Lücke 10:15-10:40

### EML7

Thursday, July 19, 09:00-10:40, Conference Room B (3F) Chair: Grant Dick (University of Otago, Information Science Dept.)

- Automatically Evolving Difficult Benchmark Feature Selection Datasets with Genetic Programming Andrew Lensen, Bing Xue, Mengjie Zhang 09:00-09:25
- CovSel: A New Approach for Ensemble Selection Applied to Symbolic Regression Problems Dominik Sobania, Franz Rothlauf 09:25-09:50

Limited Evaluation Cooperative Co-evolutionary Differential Evolution for Large-scale Neuroevolution

Anil Yaman, Decebal Constantin Mocanu, Giovanni Iacca, George Fletcher, Mykola Pechenizkiy

09:50-10:15

### EMO7: Best Papers

Thursday, July 19, 09:00-10:40, Terrsa Hall (1F) Chair: Tea Tusar (Jozef Stefan Institute)

(Best Paper nominees are marked with a star)

Efficient Search Techniques Using Adaptive Discretization of Design Variables on Real-Coded Ev Intionary Computations			
Toshiki Kondo, Tomoaki Tatsukawa	09:00-09:25		
Multi-Objective Evolutionary Hyper-heuristic based on Multiple Indicator-based Density E Jesús Guillermo Falcón-Cardona, Carlos A. Coello Coello			
A new R2 indicator for better hypervolume approximation 🖈 Ke Shang, Hisao Ishibuchi, Min-Ling Zhang, Yiping Liu	09:50-10:15		
Data-Driven Analysis of Pareto Set Topology 🖈 Naoki Hamada, Keisuke Goto	10:15-10:40		
<b>ENUM4: Best Papers</b> Thursday, July 19, 09:00-10:40, Conference Room Medium (2F) Chair: Nikolaus Hansen (Inria, research centre Saclay) (Best Paper nominees are mark	ked with a star)		
PSA-CMA-ES: CMA-ES with Population Size Adaptation 🛧 Kouhei Nishida, Youhei Akimoto	09:00-09:25		
An Empirical Comparison of Metamodeling Strategies in Noisy Environments 🖈 Sunith Bandaru, Amos H.C. Ng	09:25-09:50		
Performance Improvements for Evolutionary Strategy-based One-Class Constraint Sy Tomasz P. Pawlak	/ <b>nthesis</b> 09:50-10:15		
НОРЗ			
Thursday, July 19, 09:00-10:40, Conference Room C (3F) Chair: William LaCava (University of Massachusetts Amherst)			
Constraint Handling Guided by Landscape Analysis in Combinatorial and Continuous Katherine Malan, Irene Moser	<b>Search Spaces</b> 09:00-09:25		
A multidimensional genetic programming approach for identifying epsistatic gene int William La Cava, Sara Silva, Kourosh Danai, Leonardo Vanneschi, Jason H. Moore, Lee S	e <b>ractions</b> Spector		

09:25-09:50

### On Botnet Detection with Genetic Programming under Streaming Data, Label Budgets and Class Imbalance

Sara Khanchi, Ali Vahdat, Malcolm Heywood, Nur Zincir-Heywood

### 09:50-10:15

### Standard Steady State Genetic Algorithms Can Hillclimb Faster than Evolutionary Algorithms using **Standard Bit Mutation** 10:15-10:40

Dogan Corus, Pietro S. Oliveto

### HOP4

Thursday, July 19, 09:00-10:40, Conference Room D (3F) Chair: Krzysztof Michalak (Wroclaw University of Economics)

Employing Multi-Objective Search to Enhance Reactive Test Generation and Prioritization for Test- ing Industrial Cyber-Physical Systems		
Aitor Arrieta, Shuai Wang, Urtzi Markiegi, Goiuria Sagardui, Leire Etxeberria	09:00-09:25	
Detection of Minimum Biomarker Features via Bi-level Optimization Framework b Differential Evolution	y Nested Hybrid	
	09.25-09.50	
ED-LS - A Heuristic Local Search for the Firefighter Problem Krzysztof Michalak	09:50-10:15	
RWA6 Thursday, July 19, 09:00-10:40, Training Room 3 (2F) Chair: Risto Miikkulainen (The University of Texas at Austin, University of Texas at Austin	)	
A GA based Network Optimization Tool for Passive In-Building Distributed Antenna Siddhartha Shakya, Kin Poon, Anis Ouali	<b>Systems</b> 09:00-09:25	
Genetic Algorithm to Study Practical Quantum Adversaries Walter O. Krawec, Sam A. Markelon	09:25-09:50	
Functional Generative Design: An Evolutionary Approach to 3D-Printing Cem C. Tutum, Supawit Chockchowwat, Etienne Vouga, Risto Miikkulainen	09:50-10:15	
Estimation of the Heterogeneous Strategies from Action Log Keiichi Namikoshi, Sachiyo Arai	10:15-10:40	

### RWA7

Thursday, July 19, 09:00-10:40, AV Study Room (2F) Chair: Thomas Bäck (Leiden University)

Evolving the Autosteering of a Car Featuring a Realistically Simulated Steering Res	sponse
Vsevolod Nikulin, Albert Podusenko, Ivan Tanev, Katsunori Shimohara	09:00-09:25

Orthogonalization of Linear Representations for Efficient Evolutionary Design Optimization Andreas Richter, Stefan Dresselhaus, Stefan Menzel, Mario Botsch 09:25-09:50

## Predicting Friction System Performance with Symbolic Regression and Genetic Programming with Factor Variables

Gabriel Kronberger, Michael Kommenda, Andreas Promberger, Falk Nickel 09:50-10:15

# Multi-Objective Aerodynamic Design with User Preference using Truncated Expected Hypervolume Improvement

Pramudita Satria Palar, Kaifeng Yang, Koji Shimoyama, Michael Emmerich, Thomas Bäck 10:15-10:40

### **THEORY4**

Thursday, July 19, 09:00-10:40, Conference Room A (3F) Chair: Anne Auger (INRIA; CMAP, Ecole Polytechnique)

### Analysis of Noisy Evolutionary Optimization When Sampling Fails

Chao Qian, Chao Bian, Yang Yu, Ke Tang, Xin Yao

09:00-09:25

### On the Robustness of Evolutionary Algorithms to Noise: Refined Results and an Example Where Noise Helps Dirk Sudholt

09:25-09:50

- Runtime Analysis of Randomized Search Heuristics for the Dynamic Weighted Vertex Cover Problem Feng Shi, Frank Neumann, Jianxin Wang 09:50-10:15
- A New Analysis Method for Evolutionary Optimization of Dynamic and Noisy Objective Functions Raphaël Dang-Nhu, Thibault Dardinier, Benjamin Doerr, Gautier Izacard, Dorian Nogneng 10:15-10:40

#### **Poster Session**

Tuesday, July 17, 18:00-20:00, Terrsa Hall (1F)

### ACO-SI — Ant Colony Optimization and Swarm Intelligence

### Multiple Swarm Intelligence Methods based on Multiple Population with Sharing Best Solution for Drastic Environmental Change

Yuta Umenai, Fumito Uwano, Hiroyuki Sato, Keiki Takadama

#### **Particle Swarm and Population Structure**

Carlos M. Fernandes, Nuno Fachada, Juan L.J. Laredo, Agostinho C. Rosa, JJ Merelo

# Artificial Bee Colony Algorithm based on Adaptive Local Information Sharing: Approach for several dynamic changes

Ryo Takano, Hiroyuki Sato, Keiki Takadama

Comparative Performance and Scaling for the Pareto Improving Particle Swarm Algorithm Stephyn G. W. Butcher, John Sheppard, Brian Haberman

# Improving the Accuracy of 2D-3D Registration of Femur Bone for Bone Fracture Reduction Robot using Particle Swarm Optimization

Asaduz Zaman, Seong Young Ko

### Gaussian Bare-bones Cuckoo Search Algorithm

Hu Peng, Changshou Deng, Hui Wang, Wenjun Wang, Xinyu Zhou, Zhijian Wu

### Scouting Strategy for Biasing Fireworks Algorithm Search to Promising Directions Jun Yu, Ying Tan, Hideyuki Takagi

- Multimodal Optimization of Traveling Salesman Problem: A Niching Ant Colony System Xing-Chi Han, Hao-Wen Ke, Yue-Jiao Gong, Ying Lin, Wei-Li Liu, Jun Zhang
- Comparative Study on Discrete SI Approaches to the Graph Coloring Problem Claus Aranha, Jair Pereira Junior, Hitoshi Kanoh
- An Efficient Ant Colony System For Coverage Based Test Case Prioritization Chengyu Lu, Jinghui Zhong

### Inverted Ant Colony Optimization for Search and Rescue in an Unknown Maze-like Indoor Environment

Zainab Husain, Dymitr Ruta, Fabrice Saffre, Yousof Al-Hammadi, Abdel F. Isakovic

### **ComploT** — Competition Entries

Anomaly Detection for Drinking Water Quality via Deep BiLSTM Ensemble Xingguo Chen, Fan Feng, Jikai Wu, Wenyu Liu

### Online Anomaly Detection for Drinking Water Quality Using a Multi-objective Machine Learning Approach

Victor Henrique Alves Ribeiro, Gilberto Reynoso Meza

### Automatic vs. Manual Feature Engineering for Anomaly Detection of Drinking-Water Quality

Valerie Aenne Nicola Fehst, Huu Chuong La, Tri-Duc Nghiem, Ben E. Mayer, Paul Englert, Karl-Heinz Fiebig

### CS — Complex Systems

- **Open-Ended Evolution with Multi-Containers QD** Stephane Doncieux, Alexandre Coninx
- The Dynamics of Cooperation versus Competition Geoff Nitschke, Olaf Witkowski
- Toward Learning Neural Network Encodings for Continuous Optimization Problems Eric O. Scott, Kenneth De Jong
- Evolutionary Hexapod Robot Gait Control Using A New Recurrent Neural Network Learned Through Group-based Hybrid Metaheuristic Algorithm

Chia-Feng Juang, Yu-Cheng Chang, I-Fang Chung

Policy Transfer Methods in RoboCup Keep-Away Geoff Nitschke

### Meta-Learning by the Baldwin Effect

Chrisantha Fernando, Jakub Sygnowski, Simon Osindero, Jane Wang, Tom Schaul, Denis Teplyashin, Pablo Sprechmann, Alexander Pritzel, Andrei Rusu

### Embodiment can combat catastrophic forgetting

Joshua P. Powers, Josh C. Bongard, Sam Kriegman

- A Distributed Dendritic Cell Algorithm for Big Data Zaineb Chelly Dagdia
- Bend and Flex: Passive Flexibility or Active Control in a Quadruped Animat Jared M. Moore, Anthony J. Clark
- Ecological Theory Provides Insights about Evolutionary Computation Emily L. Dolson, Charles Ofria

Why Don't the Modules Dominate? Zhenyue Qin, Robert McKay, Tom Gedeon

### DETA — Digital Entertainment Technologies and Arts

### Silhouette-based Three Dimensional Image Registration Using CMA-ES with Joint Scheme of Partial Restart and Variable Fixing

Takuto Shigenobu, Takuya Ushinohama, Hiroshi Kawasaki, Satoshi Ono

### Hybrid Fighting Game Al using Genetic Algorithm and Monte Carlo Tree Search Man-Je Kim, Chang Wook Ahn

### A Proposal for Distributed Interactive Differential Evolution -In A Case of Creating Sign Sounds for Multiple Users

Makoto Fukumoto, Kota Nomura

### **Collaborative Interactive Evolution in Minecraft**

Pablo González de Prado Salas, Sebastian Risi

### Towards an experiment on perception of affective music generation using MetaCompose

Marco Scirea, Sebastian Risi, Julian Togelius, Peter Eklund

### ECOM — Evolutionary Combinatorial Optimization and Metaheuristics

### EDA-Based Approach to Comprehensive Quality-Aware Automated Semantic Web Service Composition

Chen Wang, Hui Ma, Gang Chen

Genetic Programming Hyper-Heuristic for Multi-Vehicle Uncertain Capacitated Arc Routing Problem Yi Mei, Mengjie Zhang

### An Energy-Efficient Single Machine Scheduling with Release Dates and Sequence-Dependent Setup Times

M. Fatih Tasgetiren, Ugur Eliiyi, Hande Öztop, Damla Kizilay, Quan-Ke Pan

### Distance-based Exponential Probability Models on Constrained Combinatorial Optimization Problems

Josu Ceberio, Alexander Mendiburu, Jose Antonio Lozano

- Relating Training Instances to Automatic Design of Algorithms for Bin Packing via Features Alexander Edward Ian Brownlee, John R. Woodward, Nadarajen Veerapen
- Local Intensity in Memetic Algorithm: Case Study in CARP Zhi-Wei Zeng, Xiao-Min Hu, Min Li, Yu Luo
- A Histogram Estimation of Distribution Algorithm for Resource Scheduling Li-Tao Tan, Wei-Neng Chen, Jun Zhang
- An Efficient Approximation to the Barrier Tree Using the Great Deluge Algorithm Hansang Yun, Byung-Ro Moon

### Feature Construction in Genetic Programming Hyper-heuristics for Dynamic Flexible Job Shop Scheduling

Daniel Yska, Yi Mei, Mengjie Zhang

A Network Design Problem with Location, Inventory and Routing Decisions Onur Kaya, Dogus Ozkok

### EML — Evolutionary Machine Learning

- Reinforcement Learning for Evolutionary Distance Metric Learning Systems Improvement Bassel Ali, Wasin Kalintha, Koichi Moriyama, Masayuki Numao, Ken-ichi Fukui
- A Neuroevolution Strategy Using Multi-agent Incorporated Hierarchical Ensemble Model Kuan-Wu Su, Min-Chieh Yu, Jenq-Shiou Leu

Neuroevolution under Unimodal Error Landscapes: An Exploration of the Semantic Learning Machine Algorithm

Jan-Benedikt Jagusch, Ivo Gonçalves, Mauro Castelli

Clustering sensory inputs using NeuroEvolution of Augmenting Topologies David Kadish

Learning How to Flock: Deriving Individual Behaviour from Collective Behaviour with Multi-Agent Reinforcement Learning and Natural Evolution Strategies

Koki Shimada, Peter Bentley

Building Boosted Classification Tree Ensemble with Genetic Programming Sašo Karakatič, Vili Podgorelec

Confidence-Based Ensemble Modeling in Medical Data Mining

Lukas Kammerer, Michael Affenzeller

Accelerating the Evolution of Convolutional Neural Networks with Node-Level Mutations and Epigenetic Weight Initialization

Travis Desell

- Multiobjective Optimization based Subspace Clustering using Evolvable Genome structure Dipanjyoti Paul, Sriparna Saha, Jimson Mathew
- A Study of Automatic Clustering Based on Evolutionary Many-objective Optimization Shuwei Zhu, Lihong Xu, Leilei Cao

### EMO — Evolutionary Multiobjective Optimization

- Proposal of Benchmark Problem Based on Real-World Car Structure Design Optimization Takehisa Kohira, Hiromasa Kemmotsu, Oyama Akira, Tomoaki Tatsukawa
- Modeling dependencies between decision variables and objectives with copula models Abdelhakim Cheriet, Roberto Santana

Introducing a Linkage Identification Considering non-Monotonicity to Multi-objective Evolutionary Optimization with Decomposition for Real-valued Functions Kousuke Izumiya, Masaharu Munetomo

An Efficient Nondominated Sorting Algorithm

Junchen Wang, Changhe Li, Yiya Diao, Sanyou Zeng, Hui Wang

- An analysis of epsilon-lexicase selection for large-scale many-objective optimization William La Cava, Jason H. Moore
- Studying the Effect of Techniques to Generate Reference Vectors in Many-objective Optimization Miriam Pescador-Rojas, Carlos A. Coello Coello
- Trust-region based Algorithms with Low-budget for Multi-objective Optimization Proteek Chandan Roy, Julian Blank, Rayan Hussein, Kalyanmoy Deb
- Visualization of The Boundary Solutions of High Dimensional Pareto Front from A Decision Maker's Perspective

AKM Khaled Ahsan Talukder, Kalyanmoy Deb, Julian Blank

Accelerating a multi-objective memetic algorithm for feature selection using hierarchical k-means indexes

Francia Jiménez, Claudio Sanhueza, Regina Berretta, Pablo Moscato

Balancing Exploration and Exploitation in Multiobjective Evolutionary Optimization Jianyong Sun, Hu Zhang, Qingfu Zhang, Huanhuan Chen

### Preference-based Evolutionary Algorithms for Many-Objective Mission Planning of Agile Earth Observation Satellites

Longmei Li, Hao Chen, Jing Wu, Jun Li, Ning Jing, Michael Emmerich

Bilevel Innovization: Knowledge Discovery in Scheduling Systems using Evolutionary Bilevel Optimization and Visual Analytics

Julian Schulte, Niclas Feldkamp, Sören Bergmann, Volker Nissen

Studying MOEAs Dynamics and their Performance using a Three Compartmental Model Hugo Monzón, Hernán Aguirre, Sébastien Verel, Arnaud Liefooghe, Bilel Derbel, Kiyoshi Tanaka

On Asynchronous Non-Dominated Sorting for Steady-State Multiobjective Evolutionary Algorithms

Ilya Yakupov, Maxim Buzdalov

#### Pareto dominance-based MOEAs on Problems with Difficult Pareto Set Topologies

Yuri Marca, Hernán Aguirre, Saúl Zapotecas, Arnaud Liefooghe, Bilel Derbel, Sébastien Verel, Kiyoshi Tanaka

### Benchmarking Multiobjective Evolutionary Algorithms and Constraint Handling Techniques on a Real-World Car Structure Design Optimization Benchmark Problem

Hiroaki Fukumoto, Akira Oyama

### **ENUM** — Evolutionary Numerical Optimization

Niching an Archive-based Gaussian Estimation of Distribution Algorithm via Adaptive Clustering Yongsheng Liang, Zhigang Ren, Bei Pang, An Chen

### Enhancing Cooperative Coevolution for Large Scale Optimization by Adaptively Constructing Surrogate Models

Bei Pang, Zhigang Ren, Yongsheng Liang, An Chen

- Investigating Benchmarks for Comparing Algorithms with Parameter Tuning Lee Ashley Christie, Alexander Edward Ian Brownlee, John R. Woodward
- An adapting population size approach in the CMA-ES for multimodal functions Duc Manh Nguyen
- A study of similarity measure between tasks for multifactorial evolutionary algorithm Lei Zhou, Liang Feng, Jinghui Zhong, Zexuan Zhu, Bingshui Da, Zhou Wu
- A Note on the CMA-ES for Functions with Periodic Variables Takahiro Yamaguchi, Youhei Akimoto
- Accelerating Differential Evolution Using Multiple Exponential Cauchy Mutation Tae Jong Choi, Chang Wook Ahn

### Dynamic Constrained Multi-objective Evolutionary Algorithms with A Novel Selection Strategy for Constrained Optimization

Ruwang Jiao, Sanyou Zeng, Changhe Li, Yuhong Jiang

- Multi-Fidelity Surrogate Model Approach to Optimization Sander van Rijn, Sebastian Schmitt, Markus Olhofer, Matthijs van Leeuwen, Thomas Bäck
- Exploratory Landscape Analysis Using Algorithm Based Sampling Yaodong He, Shiu Yin Yuen, Yang Lou

# Extension of Weighted Empirical Distribution and Group-based Adaptive Differential Evolution for Joint Chance Constrained Problems

Kiyoharu Tagawa

Multipopulation Evolution Framework for Multifactorial Optimization Genghui Li, Qingfu Zhang, Weifeng Gao

### **GA** — Genetic Algorithms

A Modern, Event-Based Architecture For Distributed Evolutionary Algorithms Mario García-Valdez, JJ Merelo

Genetic optimisation of BCI systems for identifying games related cognitive states Andrei Iacob, Mihail Morosan, Francisco Sepulveda, Riccardo Poli

### Prediction of Energy Consumption in a NSGA-II-based Evolutionary Algorithm

Salvador Moreno, Julio Ortega, Miguel Damas, Hector Pomares, Jesús González, Antonio Diaz

A Comparative Study on Algorithms for Influence Maximization in Social Networks Yu-Hsiang Chung, Tuan-Fang Fan, Churn-Jung Liau

### NetSynth: A Framework for Synthesizing Customized Network Protocols using Genetic Programming

Mohammad Roohitavaf, Ling Zhu, Sandeep Kulkarni, Subir Biswas

### The influence of fitness caching on modern evolutionary methods and fair computation load measurement

Michal Witold Przewozniczek, Marcin Michal Komarnicki

# Using Genetic Algorithms based on Neighbor List Mechanism to Reduce Handover Latency for IEEE 802.11 WLAN

Lina Hao, Bryan Ng

### GECH — General Evolutionary- ,Computation and Hybrids

### Towards Management of Complex Modeling through a Hybrid Evolutionary Identification

Sergey V. Kovalchuk, Oleg G. Metsker, Anastasia A. Funkner, Ilia O. Kisliakovskii, Nikolai O. Nikitin, Anna V. Kalyuzhnaya, Klavdiya O. Bochenina, Danila A. Vaganov

### A Hybrid Differential Evolution and Estimation of Distribution Algorithm for the Multi-Point Dynamic Aggregation Problem

Rong Hao, Jia Zhang, Bin Xin, Chen Chen, Lihua Dou

### Heterogeneous Island Model with Re-planning of Methods Štěpán Balcar, Martin Pilát

Differential Evolution with Multi-information Guidance Xinyu Zhou, Yunan Liu, Mingwen Wang, Jianyi Wan, Hui Wang, Wenjun Wang, Hu Peng

### Ranking Empirical Cumulative Distribution Functions using Stochastic and Pareto Dominance Hao Wang, Thomas Bäck

### Preselection via One-class Classification for Evolutionary Optimization

Jinyuan Zhang, Aimin Zhou, Guixu Zhang

### An Evolutionary Algorithm with A New Operator and An Adaptive Strategy for Large-Scale Portfolio Problem

Yi Chen, Aimin Zhou, Liang Dou

### Voronoi-Based Archive Sampling for Robust Optimisation

Kevin Doherty, Khulood Alyahya, Jonathan E. Fieldsend, Ozgur E. Akman

### Crowding Distance based Promising Solution Selection in Surrogate Assisted Asynchronous Multi-Objective Evolutionary Algorithm

Tomohiro Harada, Misaki Kaidan, Ruck Thawonmas

### **GP** — Genetic Programming

### Analyzing Effects of Various Trust in Product Recalls Using a Social Simulation with a Co-Evolution Model

Tetsuroh Watanabe, Taro Kanno, Kazuo Furuta

### Generating Term Weighting Schemes through Genetic Programming Ahmad Mazyad, Fabien Teytaud, Cyril Fonlupt

### Classification of Resting-State fMRI for Olfactory Dysfunction in Parkinson's Disease using Evolutionary Algorithms

Amir Dehsarvi, Stephen L. Smith

- Exploring the Application of GOMEA to Bit-string GE Eric Medvet, Alberto Bartoli, Andrea De Lorenzo
- On the Effect of Function Set to the Generalisation of Symbolic Regression Models Miguel Nicolau, Alexandros Agapitos
- Evolving PSO Algorithm Design in Vector Fields Using Geometric Semantic GP Palina Bartashevich, Illya Bakurov, Sanaz Mostaghim, Leonardo Vanneschi

### Multi-Population Genetic Programming with Adaptively Weighted Building Blocks for Symbolic Regression

Zhixing Huang, Jinghui Zhong, Wei-Li Liu, Zhou Wu

#### **RWA** — Real World Applications

- Estimating Parameters for a Dynamical Dengue Model Using Genetic Algorithms Joshua Uyheng, John Clifford Rosales, Kennedy Espina, Ma. Regina Justina Estuar
- Evolving Imaging Model for Super-Resolution Reconstruction Michal Kawulok, Pawel Benecki, Daniel Kostrzewa, Lukasz Skonieczny
- Massively Parallelized Co-evaluation for Many-Objective Space Trajectory Optimization

Martin Schlueter, Masaharu Munetomo

Towards a Small Diverse Pareto-optimal Solutions Set Generator for Multiobjective Optimization Problems

Courtney Ricardo Powell, Katsunori Miura, Masaharu Munetomo

- Discovering Pareto-optimal Process Models: A Comparison of MOEA Techniques Sonia Kundu, Manoj Agarwal, Shikha Gupta, Naveen Kumar
- Competitive Coevolutionary Algorithm Decision Support Daniel Prado Sánchez, Marcos A. Pertierra, Erik Hemberg, Una-May O'Reilly
- Genetic Algorithm based Sleep Scheduling for Maximizing Lifetime of Wireless Sensor Networks Jingjing Li, Zhipeng Luo
- Using Ensemble Modeling to Determine Causes of Multifactorial Disorders lan Rogers, Ranjan Srivastava
- Evolutionary Multi-objective Air-Conditioning Schedule Optimization for Office Buildings Yoshihiro Ohta, Hiroyuki Sato
- SIALAC Benchmark: On the design of adaptive algorithms for traffic lights problems Florian Leprêtre, Cyril Fonlupt, Sébastien Verel, Virginie Marion
- An Optimization Study of Screw Position and Number of Screws for the Fixation Stability of a Distal Femoral Locking Compression Plate Using Genetic Algorithms

Ching-Chi Hsu, Chian-Her Lee, Sung-Ming Hsu

Performance Assessment of a Modified Multi-objective Cuckoo's Search Algorithm for Microgrid Planning considering uncertainties

Andrés Felipe Acosta León, Sergio Felipe Contreras Paredes, Camilo Andrés Cortés Guerrero

### A sentiment analysis-based machine learning approach for financial market prediction via news disclosures

Raymond Chiong, Zongwen Fan, Zhongyi Hu, Marc T.P. Adam, Bernhard Lutz, Dirk Neumann

### A Novel Genetic Algorithm for Lifetime Maximization of Wireless Sensor Networks with Adjustable Sensing Range

Zihui Wu, Ying Lin, Yue-Jiao Gong, Zhengjia Dai, Jun Zhang

- Total Optimization of Smart City by Global-best Brain Storm Optimization Mayuko Sato, Yoshikazu Fukuyama
- Natural Evolution Tells us How to Best Make Goods Delivery: Use Vans Daniel H. Stolfi, Christian Cintrano, Francisco Chicano, Enrique Alba
- Evolutionary Design of Large Approximate Adders Optimized for Various Error Criteria Vojtech Mrazek, Zdenek Vasicek
- Improving Greenhouse Control Using Crop-Model-Driven Multi-Objective Optimization José R. Llera, Erik D. Goodman, Erik S. Runkle, Lihong Xu

### Autonomous Deployment of Mobile Sensors Network in an Unknown Indoor Environment with Obstacles

Khouloud Eledlebi, Dymitr Ruta, Fabrice Saffre, Yousof Alhammadi, Abdel F. Isakovic

### SBSE — Search-Based Software Engineering

- A Dynamic Fitness Function for Search Based Software Testing Xiong Xu, Li Jiao, Ziming Zhu
- Search-based mutation testing to improve performance tests Ana B. Sánchez, Pedro Delgado-Pérez, Inmaculada Medina-Bulo, Sergio Segura
- Identification of Potential Classes in Procedural Code Using a Genetic Algorithm Farshad Ghassemi Toosi, Asanka Wasala, Goetz Botterweck, Jim Buckley
- Solving Team Making Problem for Crowdsourcing with Hybrid Metaheuristic Algorithm Han Wang, Zhilei Ren, Xiaochen Li, Xin Chen, He Jiang

### Theory — Theory

Bayesian Inference for Algorithm Ranking Analysis Borja Calvo, Josu Ceberio, Jose Antonio Lozano

Better Fixed-Arity Unbiased Black-Box Algorithms Nina Bulanova, Maxim Buzdalov

### A Parameterized Runtime Analysis of Randomized Local Search and Evolutionary Algorithm for Max I-Uncut

Pallavi Jain, Lawqueen Kanesh, Jayakrishnan Madathil, Saket Saurabh

Abstracts by Track



### ACO-SI — Ant Colony Optimization and Swarm Intelligence

#### Session: ACO-SI1

Tuesday, July 17, 14:00-15:40, Conference Room B (3F)

### A Model of Artificial Emotions for Behavior-Modulation and Implicit Coordination in Multi-robot Systems

Jerome Guzzi, IDSIA Dalle Molle Institute for Artificial Intelligence Research, Alessandro Giusti, IDSIA Dalle Molle Institute for Artificial Intelligence Research, Luca Maria Gambardella, IDSIA Dalle Molle Institute for Artificial Intelligence Research, Gianni A. Di Caro, Carnegie Mellon University -Qatar

We propose a model of artificial emotions for adaptation and implicit coordination in multi-robot systems. Artificial emotions play two roles, which resemble their function in animals and humans: modulators of individual behavior, and means of communication for social coordination. Emotions are modeled as compressed representations of the internal state, and are subject to a dynamics depending on internal and external conditions. Being a compressed representation, they can be efficiently exposed to nearby robots, allowing to achieve local group-level communication. The model is instantiated for a navigation task, with the aim of showing how coordination can effectively emerge by adding artificial emotions on top of an existing navigation framework. We show the positive effects of emotion-mediated group behaviors in a few challenging scenarios that would otherwise require ad hoc strategies: preventing deadlocks in crowded conditions: enabling efficient navigation of agents with time-critical tasks; assisting robots with faulty sensors. Two performance measures, throughput and number of collisions, are used to quantify the contribution of emotions for modulation and coordination.

### A New Foraging-Based Algorithm for Online Scheduling

### Koen van der Blom, *Leiden University*, Thomas Bäck, *Leiden University*

While much work exists on scheduling, literature in the subfield of online scheduling remains sparse. As with many problems, online scheduling has parallels with natural phenomena. Specifically, online scheduling can be seen in the division of labour among colony insects, such as ants. Although multiple different biological models exist for division of labour, the only one to have been applied in online scheduling is the reinforced threshold model, for instance in the form of the ant task allocation (ATA) algorithm. However, it is neither known how it compares to other models, nor in which applications any of them excel. This paper studies the foraging for work (FFW) model as a possible alternative. To do so, an algorithmic description of the FFW model is introduced, and it is compared with the ATA algorithm on the truck painting problem. For this problem, tasks of various types are scheduled in a flowshop with multiple identical machines in an online fashion. FFW is shown to be very effective at minimising setup time, which is incurred when switching to tasks of different types. Furthermore, this allows FFW to outperform the threshold based approaches when the scheduling environment is placed under heavy load.

#### Information Sharing and Conflict Resolution in Distributed Factored Evolutionary Algorithms

Stephyn G. W. Butcher, *Johns Hopkins University*, John Sheppard, *Montana State University*, Shane Strasser, *Montana State University* 

Competition and cooperation are powerful metaphors that have informed improvements in multi-population algorithms such as the Cooperative Coevolutionary Genetic Algorithm, Cooperative Particle Swarm Optimization, and Factored Evolutionary Algorithms. However, we suggest a different perspective can give a finer grained understanding of how multi-population algorithms come together to avoid problems like hitchhiking and pseudo-minima. In this paper, we apply the concepts of information sharing and conflict resolution through Pareto improvements to analyze the distributed version of FEA. As a result, we find the original DFEA failed to implement FEA with complete fidelity. We then revise DFEA and examine the differences between it and FEA and the new implications for relaxing consensus in the distributed algorithm.

### Recurrent Neural Network-Predictions for PSO in Dynamic Optimization

Almuth Meier, University of Oldenburg, Oldenburg, Germany, Oliver Kramer, University of Oldenburg, Oldenburg, Germany

In order to improve particle swarm optimization (PSO) to tackle dynamic optimization problems, various strategies have been introduced, e.g., random restart, memory, and multi-swarm approaches. However, literature lacks approaches based on prediction. In this paper we propose three different PSO variants employing a prediction approach based on recurrent neural networks to adapt the swarm behavior after a change of the objective function. We compare the variants in an experimental study to a PSO algorithm that is solely based on rerandomization. The experimental study comprises the moving peaks benchmark and dynamic extensions of the Sphere, Rastrigin, and Rosenbrock functions for showing the strengths of the prediction-based PSO variants regarding convergence.

Session: ACO-SI2

Wednesday, July 18, 15:30-17:10, Conference Room B (3F)

#### A Particle Swarm Optimization based Feature Selection Approach to Transfer Learning in Classification

Bach Hoai Nguyen, Victoria University of Wellington, Bing Xue, Victoria University of Wellington, Peter Andreae, Victoria University of Wellington

Transfer learning aims to use acquired knowledge from existing (source) domains to improve learning performance on a different but similar (target) domains. Feature-based transfer learning builds a common feature space, which can minimize differences between source and target domains. However, most existing feature-based approaches usually build a common feature space with certain assumptions about the differences between domains. The number of common features needs to be predefined. In this work, we propose a new feature-based transfer learning method using particle swarm optimization (PSO), where a new fitness function is developed to guide PSO to automatically select a number of original features and shift source and target domains to be closer. Classification performance is used in the proposed fitness function to maintain the discriminative ability of selected features in both domains. The use of classification accuracy leads to a minimum number of model assumptions. The proposed algorithm is compared with four state-of-the-art featurebased transfer learning approaches on three well-known real-world problems. The results show that the proposed algorithm is able to extract less than half of the original features with better performance than using all features and outperforms the four benchmark semi-supervised and unsupervised algorithms.

#### Using Ant Colony Optimization to Optimize Long Short-Term Memory Recurrent Neural Networks

AbdElRahman ElSaid, University of North Dakota, Fatima El Jamiy, University of North Dakota, James Higgins, University of North Dakota, Brandon Wild, University of North Dakota, Travis Desell, University of North Dakota

This work examines the use of ant colony optimization (ACO) to improve long short-term memory (LSTM) re-

current neural networks (RNNs) by refining their cellular structure. The evolved networks were trained on a large database of flight data records obtained from an airline containing flights that suffered from excessive vibration. Results were obtained using MPI (Message Passing Interface) on a high performance computing (HPC) cluster. which evolved 1000 different LSTM cell structures using 208 cores over 5 days. The new evolved LSTM cells showed an improvement in prediction accuracy of 1.37%, reducing the mean prediction error from 6.38% to 5.01% when predicting excessive engine vibrations 10 seconds in the future, while at the same time dramatically reducing the number of trainable weights from 21,170 to 11,650. The ACO optimized LSTM also performed significantly better than traditional Nonlinear Output Error (NOE), Nonlinear AutoRegression with eXogenous (NARX) inputs, and Nonlinear Box-Jenkins (NBJ) models, which only reached error rates of 11.45%, 8.47% and 9.77%, respectively. The ACO algorithm employed could be utilized to optimize LSTM RNNs for any time series data prediction task.

#### Semi-supervised Learning Assisted Particle Swarm Optimization of Computationally Expensive Problems

Chaoli Sun, Taiyuan University of Science and Technology, Yaochu Jin, University of Surrey, Ying Tan, Taiyuan University of Science and Technology

In many real-world optimization problems, it is very timeconsuming to evaluate the performance of candidate solutions because the evaluations involve computationally intensive numerical simulations or costly physical experiments. Therefore, standard population based metaheuristic search algorithms are not best suited for solving such expensive problems because they typically require a large number of performance evaluations. To address this issue, many surrogate-assisted meta-heuristic algorithms have been proposed and shown to be promising in achieving acceptable solutions with a small computation budget. While most research focuses on reducing the reguired number of expensive fitness evaluations, not much attention has been paid to take advantage of the large amount of unlabelled data, i.e., the solutions that have not been evaluated using the expensive fitness functions, generated during the optimization. This paper aims to make use of semi-supervised learning techniques that are able to enhance the training of surrogate models using the unlabelled data together with the labelled data in a surrogateassisted particle swarm optimization algorithm. Empirical studies on five 30-dimensional benchmark problems show that the proposed algorithm is able to find high-quality solutions for computationally expensive problems on a limited computational budget.

### CS — Complex Systems

#### Session: CS1

Tuesday, July 17, 10:40-12:20, AV Study Room (2F)

#### Real-World Evolution Adapts Robot Morphology and Control to Hardware Limitations

Tønnes F. Nygaard, University of Oslo, Charles Patrick Martin, University of Oslo, Eivind Samuelsen, University of Oslo, Jim Torresen, University of Oslo, Kyrre Glette, University of Oslo

For robots to handle the numerous factors that can affect them in the real world, they must adapt to changes and unexpected events. Evolutionary robotics tries to solve some of these issues by automatically optimizing a robot for a specific environment. Most of the research in this field, however, uses simplified representations of the robotic system in software simulations. The large gap between performance in simulation and the real world makes it challenging to transfer the resulting robots to the real world. In this paper, we apply real world multi-objective evolutionary optimization to optimize both control and morphology of a four-leaged mammal-inspired robot. We change the supply voltage of the system, reducing the available torgue and speed of all joints, and study how this affects both the fitness, as well as the morphology and control of the solutions. In addition to demonstrating that this real-world evolutionary scheme for morphology and control is indeed feasible with relatively few evaluations, we show that evolution under the different hardware limitations results in comparable performance for low and moderate speeds, and that the search achieves this by adapting both the control and the morphology of the robot.

#### Towards the Targeted Environment-Specific Evolution of Robot Components

Jack Collins, *CSIRO*, Wade Geles, *CSIRO*, Gerard Howard, *CSIRO*, Frederic Maire, *Queensland University of Technol*ogy

This research considers the task of evolving the physical structure of a robot to enhance its performance in various environments, which is a significant problem in the field of Evolutionary Robotics. Inspired by the fields of evolutionary art and sculpture, we evolve only targeted parts of a robot, which simplifies the optimisation problem compared to traditional approaches that must simultaneously evolve both (actuated) body and brain. Exploration fidelity is emphasised in areas of the robot most likely to benefit from shape optimisation, whilst exploiting existing robot structure and control. Our approach uses a Genetic Algorithm to optimise collections of Bezier splines that together define the shape of a legged robot's Tibia, and

leg performance is evaluated in parallel in a high-fidelity simulator. The leg is represented in the simulator as 3Dprintable file, and as such can be readily instantiated in reality. Provisional experiments in three different environments; results show the evolution of environment-specific leg structures that are both high-performing and notably different to those evolved in the other environments. This proof-of-concept represents an important step towards the environment-dependent optimisation of performancecritical components for a range of ubiquitous, standard, and already-capable robots that can carry out a wide variety of tasks.

#### Interoceptive robustness through environmentmediated morphological development

Sam Kriegman, University of Vermont, Nick Cheney, University of Wyoming, Francesco Corucci, 3DNextech s.r.l., Josh C. Bongard, University of Vermont

Typically, AI researchers and roboticists try to realize intelligent behavior in machines by tuning parameters of a predefined structure (body plan and/or neural network architecture) using evolutionary or learning algorithms. Another but not unrelated longstanding property of these systems is their brittleness to slight aberrations, as highlighted by the growing deep learning literature on adversarial examples. Here we show robustness can be achieved by evolving the geometry of soft robots, their control systems, and how their material properties develop in response to one particular interoceptive stimulus (engineering stress) during their lifetimes. By doing so we realized robots that were equally fit but more robust to extreme material defects (such as might occur during fabrication or by damage thereafter) than robots that did not develop during their lifetimes, or developed in response to a different interoceptive stimulus (pressure). This suggests that the interplay between changes in the containing systems of agents (body plan and/or neural architecture) at different temporal scales (evolutionary and developmental) along different modalities (geometry, material properties, synaptic weights) and in response to different signals (interoceptive and external perception) all dictate those agents' abilities to evolve or learn capable and robust strategies.

### Fusing Novelty and Surprise for Evolving Robot Morphologies

Daniele Gravina, University of Malta, Antonios Liapis, University of Malta, Georgios N. Yannakakis, University of Malta

Traditional evolutionary algorithms tend to converge to a single good solution, which can limit their chance of discovering more diverse and creative outcomes. Divergent search, on the other hand, aims to counter convergence to local optima by avoiding selection pressure towards the objective. Forms of divergent search such as novelty or surprise search have proven to be beneficial for both the efficiency and the variety of the solutions obtained in deceptive tasks. Importantly for this paper, early results in maze navigation have shown that combining novelty and surprise search yields an even more effective search strategy due to their orthogonal nature. Motivated by the largely unexplored potential of coupling novelty and surprise as a search strategy, in this paper we investigate how fusing the two can affect the evolution of soft robot morphologies. We test the capacity of the combined search strategy against objective, novelty, and surprise search, by comparing their efficiency and robustness, and the variety of robots they evolve. Our key results demonstrate that novelty-surprise search is generally more efficient and robust across eight different resolutions. Further, surprise search explores the space of robot morphologies more broadly than any other algorithm examined.

Session: CS2: Best Papers Tuesday, July 17, 16:00-17:40, Conference Room Medium (2F)

#### Safe Mutations for Deep and Recurrent Neural Networks through Output Gradients

Joel Lehman, *Uber AI Labs*, Jay Chen, *Uber AI Labs*, Jeff Clune, *Uber AI Labs*, Kenneth O. Stanley, *Uber AI Labs* 

While neuroevolution (evolving neural networks) has been successful across a variety of domains from reinforcement learning, to artificial life, to evolutionary robotics, it is rarely applied to large, deep neural networks. A central reason is that while random mutation generally works in low dimensions, a random perturbation of thousands or millions of weights will likely break existing functionality. This paper proposes a solution: a family of safe mutation (SM) operators that facilitate exploration without dramatically altering network behavior or requiring additional interaction with the environment. The most effective SM variant scales the degree of mutation of each individual weight according to the sensitivity of the network's outputs to that weight, which requires computing the gradient of outputs with respect to the weights (instead of the gradient of error, as in conventional deep learning). This safe mutation through gradients (SM-G) operator dramatically increases the ability of a simple genetic algorithm-based neuroevolution method to find solutions in high-dimensional domains that require deep and/or recurrent neural networks, including domains that require processing raw pixels. By improving our ability to evolve deep neural networks, this new safer approach to mutation expands the scope of domains amenable to neuroevolution.

### Data-efficient Neuroevolution with Kernel-Based Surrogate Models

Adam Gaier, Bonn-Rhein-Sieg University of Applied Sciences, Alexander Asteroth, Bonn-Rhein-Sieg University of Applied Sciences, Jean-Baptiste Mouret, Inria

Surrogate-assistance approaches have long been used in computationally expensive domains to improve the dataefficiency of optimization algorithms. Neuroevolution, however, has so far resisted the application of these techniques because it requires the surrogate model to make fitness predictions based on variable topologies, instead of a vector of parameters. Our main insight is that we can sidestep this problem by using kernel-based surrogate models, which require only the definition of a distance measure between individuals. Our second insight is that the well-established Neuroevolution of Augmenting Topologies (NEAT) algorithm provides a computationally efficient distance measure between dissimilar networks in the form of "compatibility distance", initially designed to maintain topological diversity. Combining these two ideas, we introduce a surrogate-assisted neuroevolution algorithm that combines NEAT and a surrogate model built using a compatibility distance kernel. We demonstrate the data-efficiency of this new algorithm on the low dimensional cart-pole swing-up problem, as well as the higher dimensional half-cheetah running task. In both tasks the surrogate-assisted variant achieves the same or better results with several times fewer function evaluations as the original NEAT.

### Evolution of a Functionally Diverse Swarm via a Novel Decentralised QD Algorithm

Emma Hart, Edinburgh Napier University, Andreas Siegfried Wilhelm Steyven, Edinburgh Napier University, Ben Paechter, Edinburgh Napier University

The presence of functional diversity within a group has been demonstrated to lead to greater robustness, higher performance and increased problem-solving ability in a broad range of studies that includes insect groups, human groups and swarm robotics. Evolving group diversity however has proved challenging within Evolutionary Robotics, requiring reproductive isolation and careful attention to population size and selection mechanisms. To tackle this issue, we introduce a novel, decentralised, variant of the MAP-Elites illumination algorithm which is hybridised with a well-known distributed evolutionary algorithm (mEDEA). The algorithm simultaneously evolves multiple diverse behaviours for multiple robots, with respect to a simple tokengathering task. Each robot in the swarm maintains a local archive defined by two pre-specified functional traits which is shared with robots it come into contact with. We investigate four different strategies for sharing, exploiting and combining local archives and compare results to mEDEA. Experimental results show that in contrast to pre-

#### Session: CS3

Wednesday, July 18, 10:40-12:20, AV Study Room (2F)

#### Robotic Snake Simulation using Ensembles of Artificial Neural Networks in Evolutionary Robotics

Grant Warren Woodford, *Nelson Mandela University*, Mathys Cornelius du Plessis, *Nelson Mandela University* 

The Evolutionary Robotics process requires the evaluation of large numbers of robot controllers in order to determine their relative fitnesses. The evaluation of many controllers is typically performed in simulation instead of real-world hardware in order to speed up the evolutionary process and avoid damage to robot hardware. Physics-based simulators are traditionally used in robotics for evaluating controllers. Effective traditional simulators may require a high level of accuracy and their creation requires specialised knowledge of the dynamics of the robotic system. Alternatively, Artificial Neural Network based simulators are relatively simple to construct, are highly accurate, efficient and assume little specialised knowledge of the dynamics involved. This paper proposes a novel controller evolution method that integrates uncertainty information from an ensemble of Artificial Neural Network based simulators. By estimating the accuracy of simulator predictions during the controller evolution process, robot behaviours that are not accurately simulated are likely to be avoided. A performance comparison of a single versus ensembles configuration of Artificial Neural Network based simulators is investigated. The ensemble approach developed in this work has so far outperformed all prior controller evolution methods investigated for the presented problem.

#### Discovering the Elite Hypervolume by Leveraging Interspecies Correlation

#### Vassilis Vassiliades, Inria, Jean-Baptiste Mouret, Inria

Evolution has produced an astonishing diversity of species, each filling a different niche. Algorithms like MAP-Elites mimic this divergent evolutionary process to find a set of behaviorally diverse but high-performing solutions, called the elites. Our key insight is that species in nature often share a surprisingly large part of their genome, in spite of occupying very different niches; similarly, the elites are likely to be concentrated in a specific "elite hypervolume" whose shape is defined by their common features. In this paper, we first introduce the elite hypervolume concept and propose two metrics to characterize it: the genotypic spread and the genotypic similarity. We then introduce a new variation operator, called "directional variation", that exploits interspecies (or inter-elites) correlations to accelerate the MAP-Elites algorithm. We demonstrate the effectiveness of this operator in three problems (a toy function, a redundant robotic arm, and a hexapod robot).

#### Evolution of Fin Undulation on a Physical Knifefishinspired Soft Robot

Frank Veenstra, *IT University of Copenhagen*, Jonas Jørgensen, *IT University of Copenhagen*, Sebastian Risi, *IT University of Copenhagen* 

Soft robotics is a growing field of research but a still outstanding challenge is how to efficiently design the controller for a soft morphology. Inspired by the ghost knifefish, this paper presents a marine soft robot that can swim on the surface of the water using an undulating fin underneath its body. We investigate how evolving the control using a propagating wave function affects the swimming performance of the robotic fish and compare the evolved controllers for their similarity to the actual knifefish. The fin and body of the robot are constructed from silicone and six wooden fin rays inside the fin are actuated by servo motors. In order to bypass the reality gap, which would necessitate a complex simulation of the fish, we implemented an Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES) directly on the physical robot to optimize its controller for travel speed. Our results suggest that evolving a simple sine wave or a fourier series can generate robust controllers. The results additionally demonstrate that the best controllers exhibit patterns that are similar to the movements of actual knifefish. Based on these results we believe embodied evolution on physical robots yields promise for future applications to evolving soft robots.

### A Robot to Shape your Natural Plant: The Machine Learning Approach to Model and Control Bio-Hybrid Systems

Mostafa Wahby, University of Lübeck, Mary Katherine Heinrich, Royal Danish Academy, Daniel Nicolas Hofstadler, University of Graz, Payam Zahadat, University of Graz, Sebastian Risi, IT University of Copenhagen, Phil Ayres, Royal Danish Academy, Thomas Schmickl, University of Graz, Heiko Hamann, University of Lübeck

Bio-hybrid systems—close couplings of natural organisms with technology—are high potential and still underexplored. In existing work, robots have mostly influenced group behaviors of animals. We explore the possibilities of mixing robots with natural plants, merging useful attributes. Significant synergies arise by combining the plants' ability to efficiently produce shaped material and the robots' ability to extend sensing and decision-making behaviors. However, programming robots to control plant
motion and shape requires good knowledge of complex plant behaviors. Therefore, we use machine learning to create a holistic plant model and evolve robot controllers. As a benchmark task we choose obstacle avoidance. We use computer vision to construct a model of plant stem stiffening and motion dynamics by training an LSTM network. The LSTM network acts as a forward model predicting change in the plant, driving the evolution of neural network robot controllers. The evolved controllers augment the plants' natural light-finding and tissue-stiffening behaviors to avoid obstacles and grow desired shapes. We successfully verify the robot controllers and bio-hybrid behavior in reality, with a physical setup and actual plants.

Session: CS4 Wednesday, July 18, 15:30-17:10, AV Study Room (2F)

#### How swarm size during evolution impacts the behavior, generalizability, and brain complexity of animats performing a spatial navigation task

Dominik Fischer, Technische Universität München, Sanaz Mostaghim, University of Magdeburg, Larissa Albantakis, University of Madison-Wisconsin

While it is relatively easy to imitate and evolve natural swarm behavior in simulations, less is known about the social characteristics of simulated, evolved swarms, such as the optimal (evolutionary) group size, why individuals in a swarm perform certain actions, and how behavior would change in swarms of different sizes. To address these questions, we used a genetic algorithm to evolve animats equipped with Markov Brains in a spatial navigation task that facilitates swarm behavior. The animats' goal was to frequently cross between two rooms without colliding with other animats. Animats were evolved in swarms of various sizes. We then evaluated the task performance and social behavior of the final generation from each evolution when placed with swarms of different sizes in order to evaluate their generalizability across conditions. According to our experiments, we find that swarm size during evolution matters: animats evolved in a balanced swarm developed more flexible behavior, higher fitness across conditions, and, in addition, higher brain complexity.

# On an Immuno-inspired Distributed, Embodied Action-Evolution cum Selection Algorithm

Tushar Semwal, Indian Institute of Technology Guwahati, Divya D. Kulkarni, Indian Institute of Technology Guwahati, Shivashankar B. Nair, Indian Institute of Technology Guwahati

Traditional Evolutionary Robotics (ER) employs evolutionary techniques to search for a single monolithic controller which can aid a robot to learn a desired task. These techniques suffer from bootstrap and deception issues when the tasks are complex for a single controller to learn. Behaviour-decomposition techniques have been used to divide a task into multiple subtasks and evolve separate subcontrollers for each subtask. However, these subcontrollers and the associated subcontroller arbitrator(s) are all evolved off-line. A distributed, fully embodied and evolutionary version of such approaches will greatly aid online learning and help reduce the reality gap. In this paper, we propose an immunology-inspired embodied action-evolution cum selection algorithm that can cater to distributed ER. This algorithm evolves different subcontrollers for different portions of the search space in a distributed manner just as antibodies are evolved and primed for different antigens in the antigenic space. Experimentation on a collective of real robots embodied with the algorithm showed that a repertoire of antibody-like subcontrollers was created, evolved and shared on-the-fly to cope up with different environmental conditions. In addition, instead of the conventionally used approach of broadcasting for sharing, we present an Intelligent Packet Migration (IPM) scheme that reduces energy consumption.

# Automatic Synthesis of Swarm Behavioural Rules from their Atomic Components

Dilini Samarasinghe, *The University of New South Wales*, Erandi Lakshika, *The University of New South Wales*, Michael Barlow, *The University of New South Wales*, Kathryn Kasmarik, *The University of New South Wales* 

This paper presents an evolutionary computing based approach to automatically synthesise swarm behavioural rules from their atomic components, thus making a step forward in trying to mitigate human bias from the rule generation process, and leverage the full potential of swarm systems in the real world by modelling more complex behaviours. We identify four components that make-up the structure of a rule: control structures, parameters, logical/relational connectives and preliminary actions, which form the rule space for the proposed approach. A boids simulation system is employed to evaluate the approach with grammatical evolution and genetic programming techniques using the rule space determined. While statistical analysis of the results demonstrates that both methods successfully evolve desired complex behaviours from their atomic components, the grammatical evolution model shows more potential in generating complex behaviours in a modularised approach. Furthermore, an analysis of the structure of the evolved rules implies that the genetic programming approach only derives non-reusable rules composed of a group of actions that is combined to result in emergent behaviour. In contrast, the grammatical evolution approach synthesises sound and stable behavioural rules which can be extracted and reused, hence making it

applicable in complex application domains where manual design is infeasible.

# Hierarchical Behavioral Repertoires with Unsupervised Descriptors

# Antoine Cully, *Imperial College*, Yiannis Demiris, *Imperial College*

Enabling artificial agents to automatically learn complex, versatile and high-performing behaviors is a long-lasting challenge. This paper presents a step in this direction with hierarchical behavioral repertoires that stack several behavioral repertoires to generate sophisticated behaviors. Each repertoire of this architecture uses the lower repertoires to create complex behaviors as sequences of simpler ones, while only the lowest repertoire directly controls the agent's movements. This paper also introduces a novel approach to automatically define behavioral descriptors thanks to an unsupervised neural network that organizes the produced high-level behaviors. The experiments show that the proposed architecture enables a robot to learn how to draw digits in an unsupervised manner after having learned to draw lines and arcs. Compared to traditional behavioral repertoires, the proposed architecture reduces the dimensionality of the optimization problems by orders of magnitude and provides behaviors with a twice better fitness. More importantly, it enables the transfer of knowledge between robots: a hierarchical repertoire evolved for a robotic arm to draw digits can be transferred to a humanoid robot by simply changing the lowest layer of the hierarchy. This enables the humanoid to draw digits although it has never been trained for this task.

# DETA — Digital Entertainment Technologies and Arts

Session: DETA1

Tuesday, July 17, 10:40-12:20, Conference Room Medium (2F)

# Generating Beginner Heuristics for Simple Texas Hold'em

Fernando De Mesentier Silva, *New York University*, Julian Togelius, *New York University*, Frank Lantz, *New York University*, Andy Nealen, *New York University* 

Beginner heuristics for a game are simple rules that allow for effective playing. A chain of beginner heuristics of length N is the list of N rules that play the game best. Finding beginner heuristics is useful both for teaching a novice to play the game well and for understanding the dynamics of the game. We present and compare methods for finding beginner heuristics in a simple version of Poker: Pre-Flop Heads-Up Limit Texas Hold'em. We find that genetic programming outperforms greedy-exhaustive search and axis-aligned search in terms of finding well-playing heuristic chains of given length. We also find that there is a limited amount of non-transitivity when playing beginner heuristics of different lengths against each other, suggesting that while simpler heuristics are somewhat general, the more complex seem to overfit their training set.

#### Opponent Modeling and Exploitation in Poker Using Evolved Recurrent Neural Networks

Xun Li, *The University of Texas at Austin*, Risto Miikkulainen, *The University of Texas at Austin* 

As a classic example of imperfect information games,

Heads-Up No-limit Texas Holdem (HUNL) has been studied extensively in recent years. While state-of-the-art approaches based on Nash equilibrium have been successful, they lack the ability to model and exploit opponents effectively. This paper presents an evolutionary approach to discover opponent models based on recurrent neural networks (LSTM) and Pattern Recognition Trees. Experimental results showed that poker agents built in this method can adapt to opponents they have never seen in training and exploit weak strategies far more effectively than Slumbot 2017, one of the cutting-edge Nash-equilibrium-based poker agents. In addition, agents evolved through playing against relatively weak rule-based opponents tied statistically with Slumbot in heads-up matches. Thus, the proposed approach is a promising new direction for building high-performance adaptive agents in HUNL and other imperfect information games.

# Evolving Indirectly Encoded Convolutional Neural Networks to Play Tetris With Low-Level Features

Jacob Schrum, Department of Mathematics and Computer Science, Southwestern University

Tetris is a challenging puzzle game that has received much attention from the AI community, but much of this work relies on intelligent high-level features. Recently, agents played the game using low-level features (10 X 20 board) as input to fully connected neural networks evolved with the indirect encoding HyperNEAT. However, research in deep learning indicates that convolutional neural networks (CNNs) are superior to fully connected networks in processing visuospatial inputs. Therefore, this paper uses HyperNEAT to evolve CNNs. The results indicate that CNNs are indeed superior to fully connected neural networks in Tetris, and identify several factors that influence the successful evolution of indirectly encoded CNNs.

# Evolving simple programs for playing Atari games

Dennis Wilson, *University of Toulouse*, Sylvain Cussat-Blanc, *University of Toulouse*, Hervé Luga, *University of Toulouse*, Julian F. Miller, *University of York* 

Cartesian Genetic Programming (CGP) has previously shown capabilities in image processing tasks by evolving programs with a function set specialized for computer vision. A similar approach can be applied to Atari playing. Programs are evolved using mixed type CGP with a function set suited for matrix operations, including image processing, but allowing for controller behavior to emerge. While the programs are relatively small, many controllers are competitive with state of the art methods for the Atari benchmark set and require less training time. By evaluating the programs of the best evolved individuals, simple but effective strategies can be found.

Session: DETA2+THEORY3+GECH4: Best Papers Wednesday, July 18, 15:30-17:10, Conference Room Medium (2F)

# Evolving Mario Levels in the Latent Space of a Deep Convolutional Generative Adversarial Network

Vanessa Volz, *TU Dortmund University*, Jacob Schrum, *Southwestern University*, Jialin Liu, *Queen Mary University of London*, Simon M. Lucas, *Queen*, Adam M. Smith, *University of California, Santa Cruz*, Sebastian Risi, *IT University of Copenhagen* 

Generative Adversarial Networks (GANs) are a machine learning approach capable of generating novel example outputs across a space of provided training examples. Procedural Content Generation (PCG) of levels for video games could benefit from such models, especially for games where there is a pre-existing corpus of levels to emulate. This paper trains a GAN to generate levels for Super Mario Bros using a level from the Video Game Level Corpus. The approach successfully generates a variety of levels similar to one in the original corpus, but is further improved by application of the Covariance Matrix Adaptation Evolution Strategy (CMA-ES). Specifically, various fitness functions are used to discover levels within the latent space of the GAN that maximize desired properties. Simple static properties are optimized, such as a given distribution of tile types. Additionally, the champion A\* agent from the 2009 Mario AI competition is used to assess whether a level is playable, and how many jumping actions are required to beat it. These fitness functions allow for the discovery of levels that exist within the space of examples designed by experts, and also guide the search towards levels that fulfill one or more specified objectives.

Session: DETA3

Thursday, July 19, 09:00-10:40, Conference Room 2 (3F)

#### Querying Across Time to Interactively Evolve Animations

Isabel Tweraser, Department of Mathematics and Computer Science, Southwestern University, Lauren E. Gillespie, Department of Mathematics and Computer Science, Southwestern University, Jacob Schrum, Department of Mathematics and Computer Science, Southwestern University

Compositional Pattern Producing Networks (CPPNs) are a generative encoding that has been used to evolve a variety of novel artifacts, such as 2D images, 3D shapes, audio timbres, soft robots, and neural networks. This paper takes systems that generate static 2D images and 3D shapes with CPPNs and introduces a time input, allowing each CPPN to produce a different set of results for each slice of time. Displaying the results in sequence creates smooth animations that can be interactively evolved to suit users' personal aesthetic preferences. A human subject study involving 40 individuals was conducted to demonstrate that people find the dynamic animations more complex than static outputs, and find interactive evolution of animations more enjoyable than evolution of static outputs. The novel idea of indirectly generating artifacts as a function of time could also be useful in other domains.

# Generating a Melody Based on Symbiotic Evolution for Musicians' Creative Activities

Noriko Otani, *Tokyo City University*, Daisuke Okabe, *Tokyo City University*, Masayuki Numao, *Osaka University* 

When musicians are asked to create music with a special theme or for a particular use, it is important that they meet the client's demands while still expressing their original creativity. As this task is a little more difficult than their free creative activities, an automatic music composition system may support them. Requirements for the system are the ease of expressing the musicians' intention and the shortness of the processing time. In this paper, a scene where musicians create a song using an automatic composition system is assumed, and a method of generating a melody for the system is proposed. In the proposed method, two kinds of sensibility models for melody are induced from the existing music. A melody template is generated on the basis of those models using a symbiotic evolution algorithm. A melody is completed by determining pitch of each note in the melody template. The results of the subjective evaluation experiment show the effectiveness of the proposed method. In addition, two case studies of works with professional musicians are also presented. The results of questionnaire surveys show that the composed music reflects the musicians' intentions and is not inferior to music composed by human composers.

# ECOM — Evolutionary Combinatorial Optimization and Metaheuristics

Session: ECOM1

Tuesday, July 17, 10:40-12:20, Conference Room 2 (3F)

# An effective hybrid meta-heuristic for a heterogeneous flow shop scheduling problem

Matheus de Freitas Araujo, *Universidade Federal de Viçosa*, Jose Elias Claudio Arroyo, *Universidade Federal de Viçosa*, Ricardo Goncalves Tavares, *Universidade Federal de Viçosa* 

In this paper, we study an extension of the nonpermutation flow shop scheduling problem, where n jobs have to be scheduled on m machines, and m workers have to be assigned to operate the m machines. The workers are heterogeneous, that is, the processing time of a job processed on a machine depends on the assigned worker. The objective of the problem is to obtain the best worker allocation and the corresponding job schedule in order to minimize the maximum completion time (makespan). Motivated by the computational complexity of the problem, we propose a Variable Neighborhood Search (VNS) heuristic coupled with Iterated Greedy (IG) algorithm to obtain near optimal solutions. The VNS heuristic is responsible for defining the allocation of workers to machines and IG is responsible for obtaining a schedule of jobs on machines. The performance of our meta-heuristic, named VNS-IG, is compared with the state-of-the-art meta-heuristic proposed in the literature for the problem under study. The results show that our heuristic outperforms the existing algorithm by a significant margin.

# Min-Conflicts Heuristic for Multi-Mode Resource-Constrained Projects Scheduling

#### Arben Ahmeti, TU Wien, Nysret Musliu, TU Wien

We investigate solving of Multi-Mode Resource-Constrained Multiple Projects Scheduling Problem by heuristic techniques. A new method based on Min-Conflicts heuristic is proposed and evaluated. The main idea is to efficiently explore the neighborhood of current solution based on conflicts of activities that share the same resources. This technique is further used within the Iterated Local Search framework that additionally includes the perturbation and the acceptance criteria. Furthermore, we propose three novel project-wise neighborhood operators. Our method is evaluated on benchmark instances proposed in the MISTA conference challenge and compared to the state-of-the-art approaches. Our algorithm obtains competitive results to the solver ranked third in the MISTA challenge. We also applied our method on the existing benchmark instances for multiple-mode resource constrained single project scheduling problems. We provide six new upper bounds for well-known instances of the MMLIB library.

# A heuristic algorithm based on Tabu Search for the solution of Flexible Job Shop Scheduling Problems with Lot Streaming

Miguel Ángel Fernández Romero, Universidad Autónoma Metropolitana - Azcapotzalco, Eric Alfredo Rincón García, Universidad Autónoma Metropolitana - Azcapotzalco, Antonin Ponsich, Universidad Autonoma Metropolitana -Unidad Azcapotzalco, Roman Anselmo Mora Gutiérrez, Universidad Autónoma Metropolitana - Azcapotzalco

The Job Shop Scheduling Problem (JSSP) has received a great attention from operation research and metaheuristic communities, because it constitutes a challenging optimization problem with many real-world applications. In this work, an extension of the simple JSSP operating mode is introduced, including flexibility (operations can be processed by several machines) and lot streaming (jobs may be divided into sublots). An integer programming model is developed in this study for tackling the resulting FJSSP-LS. This model was implemented within a a commercial solver, GUROBI and additionally, a Tabu Search (TS) based algorithm is proposed as a solution technique. Compared over a set of 48 instances (adapated for the FJSSP-LS working mode), the TS heuristic clearly outperforms the upper bounds found by GUROBI, which is never able to converge to optimality in the one hour time limit. Moreover, result analysis enables to provide some insights and draw some guidelines regarding the use of flexibility and lot streaming within JSSP.

#### Iterated Greedy Algorithms for the Hybrid Flowshop Scheduling with Total Flow Time Minimization

Hande Öztop, Yasar University, M. Fatih Tasgetiren, Yasar University, Deniz Türsel Eliiyi, Yasar University, Quan-Ke Pan, Huazhong University of Science and Technology The hybrid flowshop scheduling problem (HFSP) has been extensively studied in the literature, due to its complexity and real-life applicability. Various exact and heuristic algorithms have been developed for the HFSP, and most consider makespan as the only criterion. The studies on HFSP with the objective of minimizing total flow time have been rather limited. This paper presents a mathematical model and efficient iterated greedy algorithms, IG and IG ALL, for the HFSP with total flow time criterion. In order to evaluate the performance of the proposed IG algorithms, the well-known HFSP benchmark suite from the literature is used. As the problem is NP-hard, the proposed mathematical model is solved for all 87 instances under a time limit on CPLEX. Optimal results are obtained for some of these instances. The performance of the IG algorithms is measured by comparisons with these time-limited CPLEX results of the mathematical model. Computational results show that the proposed IG algorithms perform very well in terms of solution time and quality. To the best of our knowledge, for the first time in the literature, the results of flow time criterion have been reported for the HFSP benchmark suite.

#### Session: ECOM2

Tuesday, July 17, 14:00-15:40, Conference Room 2 (3F)

#### Memetic Multilevel Hypergraph Partitioning

Sebastian Schlag, Karlsruhe Institute of Technology, Christian Schulz, University of Vienna, Robin Andre, Karlsruhe Institute of Technology

Hypergraph partitioning has a wide range of applications such as VLSI design or scientific computing. With focus on solution quality, we develop the first multilevel memetic algorithm to tackle the problem. Key components of our contribution are new effective multilevel recombination and mutation operations that provide a large amount of diversity. We perform a wide range of experiments on a benchmark set containing instances from application areas such VLSI, SAT solving, social networks, and scientific computing. Compared to the state-of-the-art hypergraph partitioning tools hMetis, PaToH, and KaHyPar, our new algorithm computes the best results on almost all instances of the benchmark set.

# Randomized Greedy Algorithms for Covering Problems

Wanru Gao, *The University of Adelaide*, Tobias Friedrich, *Hasso-Plattner-Institut*, Frank Neumann, *The University of Adelaide*, Christian Hercher, *University of Flensburg* 

Greedy algorithms provide a fast and often also effective solution to many combinatorial optimization problems. However, it is well known that they sometimes lead to low quality solutions on certain instances. In this paper, we explore the use of randomness in greedy algorithms for the minimum vertex cover and dominating set problem and compare the resulting performance against their deterministic counterpart. Our algorithms are based on a parameter  $\gamma$  which allows to explore the spectrum between uniform and deterministic greedy selection in the steps of the algorithm and our theoretical and experimental investigations point out the benefits of incorporating randomness into greedy algorithms for the two considered problems.

#### A Multi-objective Formulation of the Team Formation Problem in Social Networks: Preliminary Results

#### Carlos Brizuela, CICESE, Julio Juarez, CICESE

The Team Formation Problem in Social Networks (TFP-SN) consists of finding a team of experts, from a social network, that better undertake a given task. It is mandatory for the team to meet the skill set required by the task and it is desired that the team members communicate effectively to achieve their goal. This problem was proven to be NPhard for the optimization of different variants of a communication cost function. Even though, real-life instances of this problem involve the simultaneous optimization of two or more conflicting objectives, the studies of the TFP-SN under the multi-objective model has been rather scarce. In this work, we introduce the TFP-SN as a multi-objective optimization problem for the maximization of two conflicting objectives, the collaborative density and the team's ratio of expertise. We tackle this problem employing the NSGA-II framework, for which a proper representation and variation operators are proposed. Experimental results show that the proposed approach generates competitive solutions when compared with well-known heuristics for this problem. Additionally, as a response to the lack of benchmarks and to setup a baseline for future comparisons, we provide a detailed description of the generated instances.

#### **Evolutionary Multi-Level Acyclic Graph Partitioning**

Orlando Moreira, Intel Corporation, Merten Popp, Intel Corporation, Christian Schulz, University of Vienna

Directed graphs are widely used to model data flow and execution dependencies in streaming applications. This enables the utilization of graph partitioning algorithms for the problem of parallelizing execution on multiprocessor architectures under hardware resource constraints. However due to program memory restrictions in embedded multiprocessor systems, applications need to be divided into parts without cyclic dependencies. This can be done by a subsequent second graph partitioning step with an additional acyclicity constraint. We have two main contributions. First, we contribute a multi-level algorithm for the acyclic graph partitioning problem that achieves a 9% reduction of the edge cut compared to the previous singlelevel algorithm. Based on this, we engineer an evolutionary algorithm to further reduce the cut, achieving a 30% reduction on average compared to the state of the art. We show that this can reduce the amount of communication for a real-world imaging application and thereby accelerate it by up to 5% on an embedded multiprocessor architecture. In addition, we demonstrate how a custom fitness function for the evolutionary algorithm can be used to optimize other objectives like load balancing if the communication volume is not predominantly important on a given hardware platform.

Session: ECOM3 Tuesday, July 17, 16:00-17:40, Conference Room 2 (3F)

# A two-level diploid genetic based algorithm for solving the family traveling salesman problem

Petrica Claudiu Pop, *Technical University of Cluj-Napoca*, Oliviu Matei, *Technical University of Cluj-Napoca*, Camelia Pintea, *Technical University of Cluj-Napoca* 

In this paper, we consider the Family Traveling Salesman Problem (FTSP), which is a variant of the classical Traveling Salesman Problem (TSP). Given a partition of the nodes into a predefined number of clusters, called families, the aim of the FTSP is to find a minimum cost tour visiting a given number of nodes from each family. We describe a novel solution approach for solving the FTSP obtained by decomposing the problem into two smaller subproblems: a macro-level subproblem and a micro-level subproblem and solving them separately. The goal of the first subproblem is to provide tours visiting the families using a classical genetic algorithm and a diploid genetic algorithm, while the aim of the second subproblem is to find the minimumcost tour, corresponding to the above mentioned tours, visiting a given number of nodes from each family. The second subproblem is solved by transforming each global tour into a traveling salesman problem (TSP) which then is optimally computed using the Concorde TSP solver. The preliminary computational results on an usually used set of benchmark instances prove that our solution approach provides competitive solutions in comparison to the existing methods for solving the FTSP.

# Dominance, Epsilon, and Hypervolume Local Optimal Sets in Multi-objective Optimization, and How to Tell the Difference

Arnaud Liefooghe, Univ. Lille, Manuel López-Ibáñez, University of Manchester, Luís Paquete, University of Coimbra, Sébastien Verel, Université du Littoral Côte d'Opale

Local search algorithms have shown good performance

for several multi-objective combinatorial optimization problems. These approaches naturally stop at a local optimal set (LO-set) under given definitions of neighborhood and preference relation among subsets of solutions, such as set-based dominance relation, hypervolume or epsilon indicator. It is an open question how LO-sets under different set preference relations relate to each other. This paper reports an in-depth experimental analysis on multiobjective nk-landscapes. Our results reveal that, whatever the preference relation, the number of LO-sets typically increases with the problem non-linearity, and decreases with the number of objectives. We observe that strict LO-sets of bounded cardinality under set-dominance are LO-sets under both epsilon and hypervolume, and that LO-sets under hypervolume are LO-sets under set-dominance, whereas LO-sets under epsilon are not. Nonetheless. LO-sets under set-dominance are more similar to LOsets under epsilon than under hypervolume. These findings have important implications for multi-objective local search. For instance, a dominance-based approach with bounded archive gets more easily trapped and might experience difficulty to identify an LO-set under epsilon or hypervolume. On the contrary, a hypervolume-based approach is expected to perform more steps before converging to better approximations.

# Escaping Large Deceptive Basins of Attraction with Heavy-Tailed Mutation Operators

Tobias Friedrich, *Hasso Plattner Institute*, Francesco Quinzan, *Hasso Plattner Institute*, Markus Wagner, *The University of Adelaide* 

In many Evolutionary Algorithms (EAs), a parameter that needs to be tuned is that of the mutation rate, which determines the probability for each decision variable to be mutated. Typically, this rate is set to 1/n for the duration of the optimization, where n is the number of decision variables. This setting has the appeal that the expected number of mutated variables per iteration is one. In a recent theoretical study, it was proposed to sample the number of mutated variables from a power-law distribution. This results into a significantly higher probability on larger numbers of mutations, so that escaping local optima becomes more probable. In this paper, we propose another class of non-uniform mutation rates. We study the benefits of this operator in terms of average-case black-box complexity analysis and experimental comparison. We consider both pseudo-Boolean artificial landscapes and combinatorial problems (the Minimum Vertex Cover and the Maximum Cut). We observe that our non-uniform mutation rates significantly outperform the standard choices, when dealing with landscapes that exhibit large deceptive basins of attraction.

Improving the Run Time of the (1+1) Evolutionary Al-

#### gorithm with Luby Sequences

Tobias Friedrich, Hasso Plattner Institute, Timo Kötzing, Hasso Plattner Institute, Francesco Quinzan, Hasso Plattner Institute, Andrew M. Sutton, University Minnesota Duluth

In the context of black box optimization, the most common way to handle deceptive attractors is to periodically restart the algorithm. In this paper, we explore the benefits of combining the simple (1+1) Evolutionary Algorithm (EA) with the Luby Universal Strategy - the (1+1)EAu, a restart strategy that does not require parameter tuning. We first consider two artificial pseudo-boolean landscapes, on which the (1+1)EA exhibits exponential run time. We prove that the (1+1)EAu has polynomial run time on both instances. We then consider the Minimum Vertex Cover on two classes of graphs. Again, the (1+1)EA yields exponential run time on those instances, and the (1+1)EAu finds the global optimum in polynomial time. We conclude by studying the Makespan Scheduling. We consider an instance on which the (1+1)EA does not find a  $(4/3-\epsilon)$ -approximation in polynomial time, and we show that the (1+1)EAu reaches a  $(4/3-\epsilon)$ -approximation in polynomial time. We then prove that the (1+1)EAu serves as an Efficient Polynomial-time Approximation Scheme (EPTAS) for the Partition Problem, for a  $(1+\epsilon)$ -approximation with  $\epsilon$ > 4/n.

Session: ECOM4: Best Papers Wednesday, July 18, 10:40-12:20, Terrsa Hall (1F)

#### **One-Class Constraint Acquisition with Local Search**

Daniel Sroka, *Institute of Computing Science*, Tomasz P. Pawlak, *Institute of Computing Science* 

We propose One-Class Constraint Acquisition with Local Search (OCCALS), a novel method for computer-assisted acquisition of Mixed-Integer Linear Programming (MILP) models from examples. OCCALS is designed to help human experts in preparation of MILP models for their systems. OCCALS supports building MILP models from the examples of positive class only, thus requiring relatively cheap to acquire training set, e.g., by observing historical execution of a system. OCCALS effectively handles multimodal distribution of the training set that may happen in practice. We show experimentally the superiority of OC-CALS to a state-of-the-art method.

# Enhancing Partition Crossover with Articulation Points Analysis

Francisco Chicano, *University of Malaga*, Gabriela Ochoa, *University of Stirling*, Darrell D. Whitley, *Colorado State University*, Renato Tinós, *University of Sao Paulo* 

Partition Crossover is a recombination operator for pseudo-Boolean optimization with the ability to explore an

exponential number of solutions in linear or square time. It decomposes the objective function as a sum of subfunctions, each one depending on a different set of variables. The decomposition makes it possible to select the best parent for each subfunction independently, and the operator provides the best out of  $2^q$  solutions, where q is the number of subfunctions in the decomposition. These subfunctions are defined over the connected components of the recombination graph: a subgraph of the objective function variable interaction graph containing only the differing variables in the two parents. In this paper, we advance further and propose a new way to increase the number of linearly independent subfunctions by analyzing the articulation points of the recombination graph. These points correspond to variables that, once flipped, increase the number of connected components. The presence of a connected component with an articulation point increases the number of explored solutions by a factor of, at least, 4. We evaluate the new operator using Iterated Local Search combined with Partition Crossover to solve NK Landscapes and MAX-SAT.

# A Merge Search Algorithm and its Application to the Constrained Pit Problem in Mining

Angus Kenny, *RMIT University*, Xiaodong Li, *RMIT University*, Andreas T. Ernst, *Monash University* 

Many large-scale combinatorial problems contain too many variables and constraints for conventional mixedinteger programming (MIP) solvers to manage. To make the problems easier for the solvers to handle, various meta-heuristic techniques can be applied to reduce the size of the search space, by removing, or aggregating, variables and constraints. A novel meta-heuristic technique is presented in this paper called merge search, which takes an initial solution and uses the information from a large population of neighbouring solutions to determine promising areas of the search space to focus on. The population is merged to produce a restricted sub-problem, with far fewer variables and constraints, which can then be solved by a MIP solver. Merge search is applied to a complex problem from open-pit mining called the constrained pit (CPIT) problem, and compared to current state-of-theart results on well known benchmark problems, minelib, and is shown to give better quality solutions in five of the six instances.

Session: ECOM5 Wednesday, July 18, 15:30-17:10, Conference Room 2 (3F)

Multifractality and Dimensional Determinism in Local Optima Networks

Sarah Louise Thomson, University of Stirling, Sébastien Verel, Université du Littoral Côte d'Opale, Gabriela Ochoa, University of Stirling, Nadarajen Veerapen, University of Stirling, David Cairns, University of Stirling

We conduct a study of local optima networks (LONs) in a search space using fractal dimensions. The fractal dimension (FD) of these networks is a complexity index which assigns a non-integer dimension to an object. We propose a fine-grained approach to obtaining the FD of LONs. using the probabilistic search transitions encoded in LON edge weights. We then apply multi-fractal calculations to LONs for the first time, comparing with mono-fractal analysis. For complex systems such as LONs, the dimensionality may be different between two sub-systems and multifractal analysis is needed. Here we focus on the Quadratic Assignment Problem (QAP), conducting fractal analyses on sampled LONs of reasonable size for the first time. We also include fully enumerated LONs of smaller size. Our results show that local optima spaces can be multi-fractal and that valuable information regarding probabilistic selfsimilarity is encoded in the edge weights of local optima networks. Links are drawn between these phenomena and the performance of two competitive metaheuristic algorithms.

# Algorithm Selection on Generalized Quadratic Assignment Problem Landscapes

Andreas Beham, University of Applied Sciences Upper Austria, Stefan Wagner, University of Applied Sciences Upper Austria, Michael Affenzeller, University of Applied Sciences Upper Austria

Algorithm selection is useful in decision situations where among many alternative algorithm instances one has to be chosen. This is often the case in heuristic optimization and is detailed by the well-known no-free-lunch (NFL) theorem. A consequence of the NFL is that a heuristic algorithm may only gain a performance improvement in a subset of the problems. With the present study we aim to identify correlations between observed differences in performance and problem characteristics obtained from statistical analysis of the problem instance and from fitness landscape analysis (FLA). We compare 12 different algorithm instances including single-solution and population-based ones, open source and commercial solvers based on expected runtime to a certain target. Finally, we evaluate the performance of a recommendation algorithm that uses this information to make an informed choice for selecting a certain algorithm instance. The main contributions of this paper to the state of the art are: \* Fitness landscape analysis of the generalized quadratic assignment problem \* Comparing a range of approaches, including both open source implementations and commercial solvers \* Evaluation of a nearest-neighbor-based algorithm selection approach

# Fitness Landscape Analysis around the Optimum in Computational Protein Design

David Simoncini, *LISBP*, Sophie Barbe, *LISBP*, Thomas Schiex, *INRA*, Sébastien Verel, *Université du Littoral Côte d'Opale* 

The geometry and properties of the fitness landscapes of Computational Protein Design (CPD) are not well understood, due to the difficulty for sampling methods to access the NP-hard optima and explore their neighborhoods. In this paper, we enumerate all solutions within a 2 kcal/mol energy interval of the optimum for two CPD problems. We compute the number of local minima, the size of the attraction basins, and the local optima network. We provide various features in order to characterize the fitness landscapes, in particular the multimodality, and the ruggedness of the fitness landscape. Results show some key differences in the fitness landscapes and help to understand the successes and failures of meta-heuristics on CPD problems. Our analysis gives some previously inaccessible and valuable information on the problem structure related to the optima of the CPD instances (multi-funnel structure), and could lead to the development of more efficient meta-heuristic methods.

# A fitness landscape analysis of the Travelling Thief Problem

Mohamed El Yafrani, Mohammed V University in Rabat, Marcella Scoczynski Ribeiro Martins, Federal University of Technology - Parana UTFPR, Mehdi El Krari, Mohammed V University in Rabat, Markus Wagner, The University of Adelaide, Myriam Delgado, Federal University of Technology - Parana UTFPR, Belaïd Ahiod, Mohammed V University in Rabat, Ricardo Lüders, Federal University of Technology - Parana UTFPR

Local Optima Networks are models proposed to understand the structure and properties of combinatorial landscapes. The fitness landscape is explored as a graph whose nodes represent the local optima (or basins of attraction) and edges represent the connectivity between them. In this paper, we use this representation to study a combinatorial optimisation problem, with two interdepend components, named the Travelling Thief Problem (TTP). The objective is to understand the search space structure of the TTP using basic local search heuristics and to distinguish the most impactful problem features. We create a large set of enumerable TTP instances and generate a Local Optima Network for each instance using two hill climbing variants. Two problem features are investigated, namely the knapsack capacity and profit-weight correlation. Our insights can be useful not only to design landscape-aware local search heuristics, but also to better understand what makes the TTP challenging for specific heuristics.

# EML — Evolutionary Machine Learning

Session: EML1: Best Papers Tuesday, July 17, 10:40-12:20, Terrsa Hall (1F)

# Evolved GANs for generating Pareto set approximations

Unai Garciarena, University of the Basque Country, Alexander Mendiburu, University of the Basque Country, Roberto Santana, University of the Basque Country

In machine learning, generative models are used to create data samples that mimic the characteristics of the training data. Generative adversarial networks (GANs) are neuralnetwork based generator models that have shown their capacity to produce realistic samples in different domains. In this paper we propose a neuro-evolutionary approach for evolving deep GAN architectures together with the loss function and generator-discriminator synchronization parameters. We also propose the problem of Pareto set (PS) approximation as a suitable benchmark to evaluate the quality of neural-network based generators in terms of the accuracy of the solutions they generate. The covering of the Pareto front (PF) by the generated solutions is used as an indicator of the mode-collapsing behavior of GANs. We show that it is possible to evolve GANs that generate good PS approximations. Our method scales to up to 784 variables and that it is capable to create architecture transferable across dimensions and functions.

# Evolving Bagging Ensembles Using a Spatially-Structured Niching Method

# Grant Dick, University of Otago, Caitlin A. Owen, University of Otago, Peter A. Whigham, University of Otago

This paper presents a novel approach to constructing ensembles for prediction using a bootstrap aggregation (bagging) model. The proposed method uses analogies from ecological modelling to view bootstrap samples as a local adaptation resource in a spatially structured population. Through local competition and breeding, adaptation towards specific bootstrap samples takes place and the resulting ensemble emerges from a single global population in a single run. This makes better use of available computational resources, and negates the need for multiple runs typically required by a bagging approach. We examine the robustness of the method with respect to the number of bootstrap samples in the ensemble, and demonstrate that the resulting method also has a positive effect on bloat control. Finally, the effectiveness of the method relative to existing bagging approaches such as random forests is explored and encouraging performance is demonstrated on a range of benchmark problems.

# What About Interpolation? A Radial Basis Function Approach to Classifier Prediction Modeling in XCSF

Anthony Stein, University of Augsburg, Simon Menssen, University of Augsburg, Jörg Hähner, University of Augsburg

Learning Classifier Systems (LCS) have been strongly investigated in the context of regression tasks and great successes have been achieved by applying the function approximating Extended Classifier System (XCSF) endowed with sophisticated prediction models. In this paper, a novel approach to model a classifier's payoff prediction is proposed. Radial Basis Function (RBF) interpolation is utilized as a new means to capture the underlying function surface complexity. We pose the hypothesis that by the use of a more flexible RBF-based classifier prediction, that alleviates the a priori bias injected via choosing the degree of a polynomial approximation, the classifiers can evolve toward a higher generality by maintaining at least a competitive level of performance compared to the current and probably mostly used state of the art approach - polynomial approximation in combination with the Recursive Least Squares (RLS) technique for incremental coefficient optimization. The presented experimental results underpin our assumptions by revealing that the RBF-based classifier prediction outperforms the *n*-th order polynomial approximation on several test functions of varying complexity. Additionally, results of experiments with various degrees of noise will be reported to touch upon the proposed approach's applicability in real world situations.

# Attribute Tracking: Strategies Towards Improved Detection and Characterization of Complex Associations

Ryan Urbanowicz, University of Pennsylvania, Christopher Lo, University of Pennsylvania, John Holmes, University of Pennsylvania, Jason H. Moore, University of Pennsylvania

The detection, modeling and characterization of complex patterns of association in bioinformatics has focused on feature interactions and, more recently, instancesubgroup specific associations (e.g. genetic heterogeneity). Previously, attribute tracking was proposed as an instance-linked memory approach, leveraging the incremental learning of learning classifier systems (LCSs) to track which features were most useful in making class predictions within individual instances. These 'attribute tracking' signatures could later be used to characterize patterns of association in the data. While effective, true underlying patterns remain difficult to characterize in noisy problems, and the original approach places equal weight on tracked feature scores obtained early as well as late in learning. In this work we investigate alternative strategies for attribute tracking scoring, including the adoption of a time recency weighting scheme taken from reinforcement learning, to gain insight into how to optimize this approach to improve modeling performance and downstream pattern interpretability. We observe mixed results over a variety of performance metrics that point to promising future directions for building effective building blocks and improving model interpretability.

Session: EML2

Tuesday, July 17, 14:00-15:40, Training Room 2 (2F)

# ES Is More Than Just a Traditional Finite-Difference Approximator

Joel Lehman, *Uber Al Labs*, Jay Chen, *Uber Al Labs*, Jeff Clune, *Uber Al Labs*, Kenneth O. Stanley, *Uber Al Labs* 

An evolution strategy (ES) variant based on a simplification of a natural evolution strategy recently attracted attention because it performs surprisingly well in challenging deep reinforcement learning domains. It searches for neural network parameters by generating perturbations to the current set of parameters, checking their performance, and moving in the aggregate direction of higher reward. Because it resembles a traditional finite-difference approximation of the reward gradient, it can naturally be confused with one. However, this ES optimizes for a different gradient than just reward: It optimizes for the average reward of the entire population, thereby seeking parameters that are robust to perturbation. This difference can channel ES into distinct areas of the search space relative to gradient descent, and also consequently to networks with distinct properties. This unique robustness-seeking property, and its consequences for optimization, are demonstrated in several domains. They include humanoid locomotion, where networks from policy gradient-based reinforcement learning are significantly less robust to parameter perturbation than ES-based policies solving the same task. While the implications of such robustness and robustnessseeking remain open to further study, this work's main contribution is to highlight such differences and their potential importance.

# Autostacker: A Compositional Evolutionary Learning System

Boyuan Chen, *Columbia University*, Harvey Wu, *Columbia University*, Warren Mo, *University of Chicago*, Ishanu Chat-topadhyay, *University of Chicago*, Hod Lipson, *Columbia University* 

In this work, an automatic machine learning (AutoML) modeling architecture called Autostacker is introduced. Autostacker combines an innovative hierarchical stacking architecture and an evolutionary algorithm (EA) to perform efficient parameter search without the need for prior do-

main knowledge about the data or feature preprocessing. Using EA, Autostacker quickly evolves candidate pipelines with high predictive accuracy. These pipelines can be used in their given form, or serve as a starting point for further augmentation and refinement by human experts. Autostacker finds innovative machine learning model combinations and structures, rather than selecting a single model and optimizing its hyperparameters. When its performance on fifteen datasets is compared with that of other AutoML systems, Autostacker produces superior or competitive results in terms of both test accuracy and time cost.

# Evolutionary Feature Subspaces Generation for Ensemble Classification

Boyu Zhang, Swinburne University of Technology, A. K. Qin, Swinburne University of Technology, Timos Sellis, Swinburne University of Technology

Ensemble learning is a powerful machine learning paradigm which leverages a collection of diverse base learners to achieve better prediction performance than that could be achieved by any individual base learner. This work proposes an evolutionary feature subspaces generation based ensemble learning framework, which formulates the tasks of searching for the most suitable feature subspace for each base learner into a multi-task optimization problem and solve it via an evolutionary multi-task optimizer. Multiple such problems which correspond to different base learners are solved simultaneously via an evolutionary multi-task feature selection algorithm such that solving one problem may help solve some other problems via implicit knowledge transfer. The quality of thus generated feature subspaces is supposed to outperform those obtained by individually seeking the optimal feature subspace for each base learner. We implement the proposed framework by using SVM, KNN, and decision tree as the base learners, proposing a multi-task binary particle swarm optimization algorithm for evolutionary multi-task feature selection, and utilizing the major voting scheme to combine the outputs of the base learners. Experiments on several UCI datasets demonstrate the effectiveness of the proposed method.

# Cooperative Multi-Objective Evolutionary Support Vector Machines for Multiclass Problems

Alejandro Rosales-Pérez, *Tecnologico de Monterrey*, Andres Eduardo Gutierrez-Rodríguez, *Tecnologico de Monterrey*, Salvador García, *University of Granada*, Hugo Terashima-Marín, *Tecnologico de Monterrey*, Carlos A. Coello Coello, *CINVESTAV-IPN*, Francisco Herrera, *University of Granada* 

In recent years, evolutionary algorithms have been found to be effective and efficient techniques to train support vector machines (SVMs) for binary classification problems while multiclass problems have been neglected. This paper proposes CMOE-SVM: Cooperative Multi-Objective Evolutionary SVMs for multiclass problems. CMOE-SVM enables SVMs to handle multiclass problems via coevolutionary optimization, by breaking down the original M-class problem into M simpler ones, which are optimized simultaneously in a cooperative manner. Furthermore, CMOE-SVM can explicitly maximize the margin and reduce the training error (the two components of the SVM optimization), by means of multi-objective optimization. Through a comprehensive experimental evaluation using a suite of benchmark datasets, we validate the performance of CMOE-SVM. The experimental results, supported by statistical tests, give evidence of the effectiveness of the proposed approach for solving multiclass classification problems.

Session: EML3

Tuesday, July 17, 16:00-17:40, Training Room 2 (2F)

# Divide and Conquer: Neuroevolution for Multiclass Classification

Tyler McDonnell, SparkCognition, Inc., Sari Andoni, SparkCognition, Inc., Elmira Bonab, SparkCognition, Inc., Sheila Cheng, SparkCognition, Inc., Jun-Hwan Choi, SparkCognition, Inc., Jimmie Goode, SparkCognition, Inc., Keith Moore, SparkCognition, Inc., Gavin Sellers, SparkCognition, Inc., Jacob Schrum, SparkCognition, Inc.

Neuroevolution is a powerful and general technique for evolving the structure and weights of artificial neural networks. Though neuroevolutionary approaches such as NeuroEvolution of Augmenting Topologies (NEAT) have been successfully applied to various problems including classification, regression, and reinforcement learning problems, little work has explored application of these techniques to larger-scale multiclass classification problems. In this paper, NEAT is evaluated in several multiclass classification problems, and then extended via two ensemble approaches: One-vs-All and One-vs-One. These approaches decompose multiclass classification problems into a set of binary classification problems, in which each binary problem is solved by an instance of NEAT. These ensemble models exhibit reduced variance and increasingly superior accuracy as the number of classes increases. Additionally, higher accuracy is achieved early in training, even when artificially constrained for the sake of fair comparison with standard NEAT. However, because the approach can be trivially distributed, it can be applied quickly at large scale to solve real problems. In fact, these approaches are incorporated into Darwin, an enterprise automatic machine learning solution that also incorporates various other algorithmic enhancements to NEAT. The resulting complete system has proven robust to a wide variety of client datasets.

# A Genetic Algorithm for Finding an Optimal Curing Strategy for Epidemic Spreading in Weighted Networks

Clara Pizzuti, Institute for High Performance Computing and Networking - ICAR National Research Council of Italy - CNR, Annalisa Socievole, Institute for High Performance and Networking - ICAR National Research Council of Italy - CNR

Contact networks have been recognized to have a central role in the dynamic behavior of spreading processes. The availability of cost-optimal curing strategies, able to control the epidemic propagation, are of primary importance for the design of efficient treatments reducing the number of infected individuals and the extinction time of the infection. In this paper, we investigate the use of Genetic Algorithms for solving the problem of finding an optimal curing strategy in a network where a virus spreads following the Susceptible-Infected-Susceptible (SIS) epidemic model. Exploiting the N-Intertwined Mean-Field Approximation (NIMFA) of the SIS spreading process, we propose a constrained genetic algorithm which determines specific curing rates to each node composing the network, in order to minimize the total curing cost, while suppressing the epidemic. Experiments on both synthetic and real-world networks show that the approach finds solutions whose curing cost is lower than that obtained by a classical baseline method.

# Towards an Adaptive Encoding for Evolutionary Data Clustering

Cameron Shand, University of Manchester, Richard Allmendinger, University of Manchester, Julia Handl, University of Manchester, John Keane, University of Manchester

A key consideration in developing optimization approaches for data clustering is the choice of a suitable encoding. Existing encodings for data clustering strike different tradeoffs between model and search complexity, limiting the applicability to data sets with particular properties or to clustering problems of moderate size. Recent research has shown how the introduction of an additional hyperparameter can serve to directly govern the granularity of the encoding in the multi-objective clustering algorithm MOCK. Here, we conduct a first investigation into adapting this important hyperparameter during run-time. In particular, we consider a number of different trigger mechanisms to control the timing of changes to this hyperparameter and strategies to rapidly explore the newly "opened" search space resulting from this change. Experimental results illustrate distinct performance differences between the approaches tested, which can be explained in light of the relative importance of initialization, crossover and mutation in the MOCK algorithm. The most successful of our strategies can meet the clustering performance achieved for an optimal (a priori) setting of the hyperparameter, at a 40%

reduction of the computational expense.

# Theoretical Adaptation of Multiple Rule-Generation in XCS

Masaya Nakata, Yokohama National University, Will Neil Browne, Victoria University of Wellington, Tomoki Hamagami, Yokohama National University

Most versions of the XCS Classifier System have been designed to evolve only two rules for each rule discovery invocation, which restricts the search capacity. A difficulty behind generating multiple rules each time is the increase in the probability of deleting immature rules, which conflicts with the requirement that parent rules be sufficiently updated so that fitness represents worth. Thus the aim of this paper is to argue how XCS determines when rules can be deleted safely. The objectives are to certainly identify inaccurate rules and then to maximize how many rules XCS can generate. The novel method introduced enables adaptation of rule-generation that maximizes the number of generated rules, under the assumption that the reliably inaccurate rules can be replaced with new rules. Experiments show our modification strongly improves the XCS performance on large scale problems, since it can take advantage of multi-point search more efficiently. For example, on the 135-bit multiplexer problem, XCS with our modification requires 1.57 million less training inputs compared with the standard XCS while utilizing the same number of final rules.

Session: EML4

Wednesday, July 18, 10:40-12:20, Training Room 2 (2F)

# **Neuroevolution of Hierarchical Reservoir Computers**

Matthew Dale, University of York

Reservoir Computers such as Echo State Networks (ESN) represent an alternative recurrent neural network model that provides fast training and state-of-the-art performances for supervised learning problems. Classic ESNs suffer from two limitations; hyperparameter selection and learning of multiple temporal and spatial scales. То learn multiple scales, hierarchies are proposed, and to overcome manual tuning, optimisation is used. However, the autonomous design of hierarchies and optimisation of multi-reservoir systems has not yet been demonstrated. In this work, an evolvable architecture is proposed called Reservoir-of-Reservoirs (RoR) where subnetworks of neurons (ESNs) are interconnected to form the reservoir. The design of each sub-network, hyperparameters, global connectivity and its hierarchical structure are evolved using a genetic algorithm (GA) called the Microbial GA. To evaluate the RoR and microbial GA, single

networks and other hierarchical ESNs are evolved. The results show the microbial GA can dramatically increase the performance of single networks compared to other optimisation techniques. The evolutionary process also leads to competitive results with RoRs and other hierarchical ESNs, despite having fewer connections than a single network. In the final section, it is revealed that the RoR architecture may learn generalised features other architectures cannot, offering improvements in network generalisation to other tasks.

# Combating catastrophic forgetting with developmental compression.

Shawn L. Beaulieu, University of Vermont, Sam Kriegman, University of Vermont, Josh C. Bongard, University of Vermont

Generally intelligent agents exhibit successful behavior across problems in several settings. Endemic in approaches to realize such intelligence in machines is catastrophic forgetting: sequential learning corrupts knowledge obtained earlier in the sequence, or tasks antagonistically compete for system resources. Methods for obviating catastrophic forgetting have sought to identify and preserve features of the system necessary to solve one problem when learning to solve another, or to enforce modularity such that minimally overlapping sub-functions contain task specific knowledge. While successful, both approaches scale poorly because they require larger architectures as the number of training instances grows, causing different parts of the system to specialize for separate subsets of data. Here we present a method for addressing catastrophic forgetting called developmental compression. It exploits the mild impacts of developmental mutations to lessen adverse changes to previously-evolved capabilities and 'compresses' specialized neural networks into a generalized one. In the absence of domain knowledge, developmental compression produces systems that avoid overt specialization, alleviating the need to engineer a bespoke system for every task permutation and suggesting better scalability than existing approaches. We validate this method on a robot control problem and hope to extend this approach to other machine learning domains in the future.

# NEAT for Large-Scale Reinforcement Learning through Evolutionary Feature Learning and Policy Gradient Search

Yiming Peng, Victoria University of Wellington, Gang Chen, Victoria University of Wellington, Harman Singh, Victoria University of Wellington, Mengjie Zhang, Victoria University of Wellington

NeuroEvolution of Augmenting Topology (NEAT) is one of the most successful algorithms for solving traditional reinforcement learning (RL) tasks such as pole-balancing. However the algorithm faces serious challenges while tackling problems with large state spaces, particularly the Atari game playing tasks. This is due to the major flaw that NEAT aims at evolving a single neural network (NN) that must be able to simultaneously extract high-level state features and select action outputs. However such complicated NNs cannot be easily evolved directly through NEAT. To address this issue, we propose a new reinforcement learning scheme based on NEAT with two key technical advancements: (1) a new three-stage learning scheme is introduced to clearly separate feature learning and policy learning to allow effective knowledge sharing and learning across multiple agents; (2) various policy gradient search algorithms can be seamlessly integrated with NEAT for training policy networks with deep structures to achieve effective and sample efficient RL. Experiments on several Atari games confirm that our new learning scheme can be more effective and has higher sample efficiency than NEAT and three state-of-the-art algorithms from the most recent RL literature.

Session: EML5 Wednesday, July 18, 15:30-17:10, Training Room 2 (2F)

# Optimizing Floating Centroids Method Neural Network Classifier Using Dynamic Multilayer Particle Swarm Optimization

Changwei Cai, University of Jinan, Shuangrong Liu, University of Jinan, Lin Wang, University of Jinan, Bo Yang, University of Jinan, Zhenxiang Chen, University of Jinan, Jin Zhou, University of Jinan

The floating centroids method (FCM) effectively enhances the performance of neural network classifiers. However, the problem of optimizing the neural network continues to restrict the further improvement of FCM. Traditional particle swarm optimization algorithm (PSO) sometimes converges to a local optimal solution in multimodal landscape, particularly for optimizing neural networks. Therefore, the dynamic multilayer PSO (DMLPSO) is proposed to optimize the neural network for improving the performance of FCM. DMLPSO adopts the basic concepts of multi-layer PSO to introduce a dynamic reorganizing strategy, which achieves that valuable information dynamically interacts among different subswarms. This strategy increases population diversity to promote the performance of DMLPSO when optimizing multimodal functions. Experimental results indicate that the proposed DMLPSO enables FCM to obtain improved solutions in many data sets.

# Evolutionary Architecture Search for Deep Multitask Networks

Jason Zhi Liang, Sentient Technologies Inc., Elliot Meyerson, Sentient Technologies Inc., Risto Miikkulainen, Sentient Technologies Inc.

Multitask learning, i.e. learning several tasks at once with the same neural network, can improve performance in each of the tasks. Designing deep neural network architectures for multitask learning is a challenge: There are many ways to tie the tasks together, and the design choices matter. The size and complexity of this problem exceeds human design ability, making it a compelling domain for evolutionary optimization. Using the existing state of the art soft ordering architecture as the starting point, methods for evolving the modules of this architecture and for evolving the overall topology or routing between modules are evaluated in this paper. A synergetic approach of evolving custom routings with evolved, shared modules for each task is found to be very powerful, significantly improving the state of the art in the Omniglot multitask, multialphabet character recognition domain. This result demonstrates how evolution can be instrumental in advancing deep neural network and complex system design in general.

#### Memetic Evolution of Deep Neural Networks

# Pablo Ribalta Lorenzo, *Future Processing*, Jakub Nalepa, *Silesian University of Technology*

Deep neural networks (DNNs) have proven to be effective at solving challenging problems, but their success relies on finding a good architecture to fit the task. Designing a DNN requires expert knowledge and a lot of trial and error, especially as the difficulty of the problem grows. This paper proposes a fully automatic method with the goal of optimizing DNN topologies through memetic evolution. By recasting the mutation step as a series of progressively refined educated local-search moves, this method achieves results comparable to best human designs. Our extensive experimental study showed that the proposed memetic algorithm supports building a real-world solution for segmenting medical images, it exhibits very promising results over a challenging CIFAR-10 benchmark, and works very fast. Given the ever growing availability of data, our memetic algorithm is a very promising avenue for hands-free DNN architecture design to tackle emerging classification tasks.

Session: EML6 Thursday, July 19, 09:00-10:40, Training Room 2 (2F)

# Efficient Sample Reuse in Policy Search by Multiple Importance Sampling

Eiji Uchibe, Advanced Telecommunications Research Institute International Policy search such as reinforcement learning and evolutionary computation is a framework for finding an optimal policy of control problems, but it usually requires a huge number of samples. Importance sampling is a common tool to use samples drawn from a proposal distribution different from the targeted one, and it is widely used by the policy search methods to update the policy from a set of datasets that are collected by previous sampling distributions. However, the proposal distribution is created by a mixture of previous distributions with fixed mixing weights in most of previous studies, and it is often numerically unstable. To overcome this problem, we propose the method of adaptive multiple importance sampling that optimizes the mixing coefficients to minimize the variance of the importance sampling estimator while utilizing as many samples as possible. We apply the proposed method to the five policy search methods such as PGPE, PoWER, CMA-ES, REPS, and NES, and their algorithms are evaluated by some benchmark control tasks. Experimental results show that all the five methods improve sample efficiency. In addition, we show that optimizing the mixing weights achieves stable learning.

#### **Evolutionary Expectation Maximization**

# Enrico Guiraud, University of Oldenburg, Jakob Drefs, University of Oldenburg, Jörg Lücke, University of Oldenburg

We establish a link between evolutionary algorithms (EAs) and learning of probabilistic generative models with binary hidden variables. Learning is formulated as approximate maximum likelihood optimization using variational expectation maximization. When choosing truncated posteriors as variational distributions, the variational parameters take the form of sets of latent states. By (A) identifying these sets with populations of genomes, and by (B) defining the fitness of individuals as the joint probability of the chosen generative model, the sets of latent states can be optimized using EAs. We obtain scalable learning algorithms that effectively improve the tractable free energy objective of truncated posteriors. While this novel approach is applicable to any model with binary latents and tractable joint probability, as a proof of concept, we here apply it to the optimization of parameters of noisy-OR Bayes Nets (modeling binary data) and Binary Sparse Coding (modelling continuous data). We find that the data likelihood is efficiently improved by employing genetic algorithms with point mutations and single-point cross-over as EAs. In general we believe that, with the novel link established here, standard as well as recent results in evolutionary optimization can be leveraged to address the difficult problem of parameter optimization in generative models.

# Online Meta-Learning by Parallel Algorithm Competition

Stefan Elfwing, ATR, Eiji Uchibe, ATR, Kenji Doya, OIST

The efficiency of reinforcement learning algorithms depends critically on a few meta-parameters that modulate the learning updates and the trade-off between exploration and exploitation. The adaptation of the meta-parameters is an open question, which arguably has become a more important issue recently with the success of deep reinforcement learning. The long learning times in domains such as Atari 2600 video games makes it not feasible to perform comprehensive searches of appropriate metaparameter values. In this study, we propose the Online Meta-learning by Parallel Algorithm Competition (OMPAC) method, which is a novel Lamarckian evolutionary approach to online meta-parameter adaptation. The population consists of several instances of a reinforcement learning algorithm which are run in parallel with small differences in initial meta-parameter values. After a fixed number of learning episodes, the instances are selected based on their performance on the task at hand, i.e., the fitness. Before continuing the learning, Gaussian noise is added to the meta-parameters with a predefined probability. We validate the OMPAC method by improving the state-of-the-

art results in stochastic SZ-Tetris and in 10x10 Tetris by 31% and 84%, respectively, and by improving the learning speed and performance for deep Sarsa( $\lambda$ ) agents in the Atari 2600 domain.

# Ensembles of Evolved Nested Dichotomies for Classification

Marcel Wever, Paderborn University, Felix Mohr, Paderborn University, Eyke Hüllermeier, Paderborn University

In multinomial classification, reduction techniques are commonly used to decompose the original learning problem into several simpler problems. For example, by recursively bisecting the original set of classes, so-called nested dichotomies define a set of binary classification problems that are organized in the structure of a binary tree. In contrast to the existing one-shot heuristics for constructing nested dichotomies and motivated by recent work on algorithm configuration, we propose a genetic algorithm for optimizing the structure of such dichotomies. A key component of this approach is the proposed genetic representation that facilitates the application of standard genetic operators, while still supporting the exchange of partial solutions under recombination. We evaluate the approach in an extensive experimental study, showing that it yields classifiers with superb generalization performance.

Session: EML7 Thursday, July 19, 09:00-10:40, Conference Room B (3F)

Automatically Evolving Difficult Benchmark Feature Selection Datasets with Genetic Programming Andrew Lensen, Victoria University of Wellington, Bing Xue, Victoria University of Wellington, Mengjie Zhang, Victoria University of Wellington

There has been a wealth of feature selection algorithms proposed in recent years, each of which claims superior performance in turn. A wide range of datasets have been used to compare these algorithms, each with different characteristics and quantities of redundant and noisy features. Hence, it is very difficult to comprehensively and fairly compare these feature selection methods in order to find which are most robust and effective. In this work, we examine using Genetic Programming to automatically synthesise redundant features for augmenting existing datasets in order to more scientifically test feature selection performance. We develop a method for producing complex multi-variate redundancies, and present a novel and intuitive approach to ensuring a range of redundancy relationships are automatically created. The application of these augmented datasets to well-established feature selection algorithms shows a number of interesting and useful results and suggests promising directions for future research in this area.

# CovSel: A New Approach for Ensemble Selection Applied to Symbolic Regression Problems

Dominik Sobania, University of Mainz, Franz Rothlauf, University of Mainz

Ensemble methods combine the predictions of a set of models to reach a better prediction quality compared to a single model's prediction. The ensemble process consists of three steps: 1) the generation phase where the models are created, 2) the selection phase where a set of possible ensembles is composed and one is selected by a selection method, 3) the fusion phase where the individual models' predictions of the selected ensemble are combined to an ensemble's estimate. This paper proposes CovSel, a selection approach for regression problems that ranks ensembles based on the coverage of adequately estimated training points and selects the ensemble with the highest coverage to be used in the fusion phase. An ensemble covers a training point if at least one of its models produces an adequate prediction for this training point. The more training points are covered this way, the higher is the ensemble's coverage. The selection of the "right" ensemble has a large impact on the final prediction. Results for two symbolic regression problems show that Cov-Sel improves the predictions for various state-of-the-art fusion methods for ensembles composed of independently evolved GP models and also beats approaches based on single GP models.

#### Limited Evaluation Cooperative Co-evolutionary Differential Evolution for Large-scale Neuroevolution

Anil Yaman, Technical University of Eindhoven, Decebal Constantin Mocanu, Technical University of Eindhoven, Giovanni Iacca, University of Trento, George Fletcher, Technical University of Eindhoven, Mykola Pechenizkiy, Technical University of Eindhoven

Many real-world control and classification tasks involve a large number of features. When artificial neural networks (ANNs) are used for modeling these tasks, the network architectures tend to be large. Neuroevolution is an effective approach for optimizing ANNs; however, there are two bottlenecks that make their application challenging in case of high-dimensional networks using direct encoding. First, classic evolutionary algorithms tend not to scale well for searching large parameter spaces; second, the network evaluation over a large number of training instances is in general time-consuming. In this work, we propose an approach called the Limited Evaluation Cooperative Coevolutionary Differential Evolution algorithm (LECCDE) to optimize high-dimensional ANNs. The proposed method aims to optimize the pre-synaptic weights of each postsynaptic neuron in different subpopulations using a Cooperative Co-evolutionary Differential Evolution algorithm, and employs a limited evaluation scheme where fitness evaluation is performed on a relatively small number of training instances based on fitness inheritance. We test LECCDE on three datasets with various sizes, and our results show that cooperative co-evolution significantly improves the test error comparing to standard Differential Evolution, while the limited evaluation scheme facilitates a significant reduction in computing time.

# EMO — Evolutionary Multiobjective Optimization

Session: EMO1 Tuesday, July 17, 10:40-12:20, Conference Room D (3F)

# ming for the Bi-Objective Travelling Thief Problem

Junhua Wu, *The University of Adelaide*, Sergey Polyakovskiy, *Deakin University*, Markus Wagner, *The University of Adelaide*, Frank Neumann, *The University of Adelaide* 

Evolutionary Computation plus Dynamic Program-

This research proposes a novel indicator-based hybrid

evolutionary approach that combines approximate and exact algorithms. We apply it to a new bi-criteria formulation of the travelling thief problem, which is known to the Evolutionary Computation community as a benchmark multi-component optimisation problem that interconnects two classical NP-hard problems: the travelling salesman problem and the 0-1 knapsack problem. Our approach employs the exact dynamic programming algorithm for the underlying Packing-While-Travelling problem as a subroutine within a bi-objective evolutionary algorithm. This design takes advantage of the data extracted from Pareto fronts generated by the dynamic program to achieve better solutions. Furthermore, we develop a number of novel indicators and selection mechanisms to strengthen synergy of the two algorithmic components of our approach. The results of computational experiments show that the approach is capable to outperform the state-of-the-art results for the single-objective case of the problem.

# An Improved Version of a Reference-Based Multi-Objective Evolutionary Algorithm based on IGD+

# Edgar Manoatl Lopez, *CINVESTAV-IPN*, Carlos A. Coello Coello, *CINVESTAV-IPN*

In recent years, the design of new selection mechanisms has become a popular trend in the development of Multi-Objective Evolutionary Algorithms (MOEAs). This trend has been motivated by the aim of maintaining a good balance between convergence and diversity of the solutions. Reference-based selection is, with no doubt, one of the most promising schemes in this area. However, reference-based MOEAs are known to have difficulties for solving multi-objective problems with complicated Pareto fronts, mainly because they rely on the consistency between the Pareto front shape and the distribution of the reference weight vectors. In this paper, we propose a reference-based MOEA, which uses the Inverted Generational Distance plus (IGD<sup>+</sup>) indicator. The proposed approach adopts a novel method for approximating the reference set, based on an hypercube-based method. Our results indicate that our proposed approach is able to obtain solutions of a similar quality to those obtained by RVEA, MOEA/DD, NSGA-III and MOMBI-II in several test problems traditionally adopted in the specialized literature, and is able to outperform them in problems with complicated Pareto fronts.

# Parallel Pareto Local Search Revisited - First experimental results on Bi-objective UBQP

Jialong Shi, Xi'an Jiaotong University, Qingfu Zhang, City University of Hong Kong, Bilel Derbel, Univ. Lille, Arnaud Liefooghe, Univ. Lille, Jianyong Sun, Xi'an Jiaotong University

Pareto Local Search (PLS) is a simple, yet effective optimization approach dedicated to multi-objective combinatorial optimization. It can however suffer from a high computational cost, especially when the size of the Pareto optimal set is relatively large. Recently, incorporating decomposition in PLS had revealed a high potential, not only in providing high-quality approximation sets, but also in speeding-up the search process. Using the bi-objective Unconstrained Binary Quadratic Programming (bUBQP) problem as an illustrative benchmark, we demonstrate some shortcomings in the resulting decomposition-guided Parallel Pareto Local Search (PPLS), and we propose to revisit the PPLS design accordingly. For instances with a priori unknown Pareto front shape, we show that a simple pre-processing technique to estimate the scale of the Pareto front can help PPLS to better balance the workload. Furthermore, we propose a simple technique to deal with the critically-important scalability issue raised by PPLS when deployed over a large number of computing nodes. Our investigations show that the revisited version of PPLS provides a consistent performance, suggesting that decomposition-guided PPLS can be further generalized in order to improve both parallel efficiency and approximation quality.

# Two Enhancements for Improving the Convergence Speed of a Robust Multi-Objective Coevolutionary Algorithm

Alexandru-Ciprian Zavoianu, Department of Knowledge-Based Mathematical Systems, Susanne Saminger-Platz, Department of Knowledge-Based Mathematical Systems, Edwin Lughofer, Department of Knowledge-Based Mathematical Systems, Wolfgang Amrhein, Institute for Electrical Drives and Power Electronics

We describe two enhancements that significantly improve the rapid convergence behavior of DECMO2 - a previously proposed robust coevolutionary algorithm that integrates three different multi-objective space exploration paradigms: differential evolution, two-tier Pareto-based selection for survival and decomposition-based evolutionary guidance. The first enhancement is a refined active search adaptation mechanism that relies on run-time subpopulation performance indicators to estimate the convergence stage and dynamically adjust and steer certain parts of the coevolutionary process in order to improve its overall efficiency. The second enhancement consists in a directional intensification operator that is applied in the early part of the run during the decomposition-based search phases. This operator creates new random local linear individuals based on the recent historically successful solution candidates of a given directional decomposition vector. As the two efficiency-related enhancements are complementary, our results show that the resulting coevolutionary algorithm is a highly competitive improvement of the baseline strategy when considering a comprehensive test set aggregated from 25 (standard) benchmark

multi-objective optimization problems.

#### Session: EMO2

Tuesday, July 17, 14:00-15:40, Conference Room D (3F)

# mQAPViz: A divide-and-conquer multi-objective optimization algorithm to compute large data visualizations

Claudio Sanhueza, *The University of Newcastle*, Francia Jiménez, *The University of Newcastle*, Regina Berretta, *The University of Newcastle*, Pablo Moscato, *The University of Newcastle* 

Algorithms for data visualizations are essential tools for transforming data into useful narratives. Unfortunately, very few visualization algorithms can handle the large datasets of many real-world scenarios. In this study, we address the visualization of these datasets as a Multi-Objective Optimization Problem. We propose mQAPViz, a divide-and-conquer multi-objective optimization algorithm to compute large-scale data visualizations. Our method employs the Multi-Objective Quadratic Assignment Problem (mQAP) as the mathematical foundation to solve the visualization task at hand. The algorithm applies advanced sampling techniques originating from the field of machine learning and efficient data structures to scale to millions of data objects. The algorithm allocates objects onto a 2D grid layout. Experimental results on real-world and large datasets demonstrate that mQAPViz is a competitive alternative to existing techniques.

# Surrogate-assisted Evolutionary Biobjective Optimization for Objectives with Non-uniform Latencies

Tinkle Chugh, University of Exeter, UK, Richard Allmendinger, University of Manchester, Vesa Ojalehto, University of Jyväskylä, Kaisa Miettinen, University of Jyväskylä

We consider multiobjective optimization problems where objective functions have different (or heterogeneous) evaluation times or latencies. This is of great relevance for (computationally) expensive multiobjective optimization as there is no reason to assume that all objective functions should take an equal amount of time to be evaluated (particularly when objectives are evaluated separately). To cope with such problems, we propose a variation of the Kriging-assisted reference vector guided evolutionary algorithm (K-RVEA) called heterogeneous K-RVEA (short HK-RVEA). This algorithm is a merger of two main concepts designed to account for different latencies: A singleobjective evolutionary algorithm for selecting training data to train surrogates and K-RVEA's approach for updating the surrogates. HK-RVEA is validated on a set of biobjective benchmark problems varying in terms of latencies and correlations between the objectives. The results are also compared to those obtained by previously proposed strategies for such problems, which were embedded in a non-surrogate-assisted evolutionary algorithm. Our experimental study shows that, under certain conditions, such as short latencies between the two objectives, HK-RVEA can outperform the existing strategies as well as an optimizer operating in an environment without latencies.

#### A set-oriented MOEA/D

Bilel Derbel, Univ. Lille, Arnaud Liefooghe, Univ. Lille, Qingfu Zhang, City University of Hong Kong, Sébastien Verel, Université du Littoral Côte d'Opale, Hernán Aguirre, Shinshu University, Kiyoshi Tanaka, Shinshu University

The working principle of the well-established multiobjective MOEA/D algorithm relies on the iterative and cooperative improvement of a number of single-objective subproblems obtained by decomposition. Besides the definition of sub-problems, selection and replacement are, like in any evolutionary algorithm, the two core elements in MOEAD. We argue that these two steps are however loosely coupled with the population maintained by MOEA/D. There-by, we propose to re-design the working principles of MOEA/D by adopting a set-oriented perspective where a many-to-one mapping between subproblems and solutions is considered. Selection is then performed by defining a neighborhood relation among solutions in the population set depending to the corresponding subproblem mapping. Replacement is performed following an elitist mechanism allowing the population to have a variable, but bounded, size during the evolutionary search process. By conducting a comprehensive empirical analysis on a range of combinatorial multi- and many- rMNKlandscapes, we show that the proposed approach leads to significant improvements especially when dealing with an increasing number of objectives, which indicates that a set-oriented design can constitute a sound alternative for strengthening the practice of evolutionary multi- and manyobjective optimization based on decomposition.

# A Taxonomy of Methods for Visualizing Pareto Front Approximations

Bogdan Filipic, Jozef Stefan Institute, Tea Tusar, Jozef Stefan Institute

In multiobjective optimization, many techniques are used to visualize the results, ranging from traditional generalpurpose data visualization techniques to approaches tailored to the specificities of multiobjective optimization. The number of specialized approaches rapidly grows in the recent years. To assist both the users and developers in this field, we propose a taxonomy of methods for visualizing Pareto front approximations. It builds on the nature of the visualized data and the properties of visualization methods rather than on the employed visual representations. It covers the methods for visualizing individual approximation sets resulting from a single algorithm run as well as multiple approximation sets produced in repeated runs. The proposed taxonomy categories are characterized and illustrated with selected examples of visualization methods. We expect that proposed taxonomy will be insightful to the multiobjective optimization community, make the communication among the participants easier and help focus further development of visualization methods.

Session: EMO3

Tuesday, July 17, 16:00-17:40, Conference Room D (3F)

#### Dual-Grid Model of MOEA/D for Evolutionary Constrained Multiobjective Optimization

Hisao Ishibuchi, Southern University of Science and Technology, Takafumi Fukase, Osaka Prefecture University, Naoki Masuyama, Osaka Prefecture University, Yusuke Nojima, Osaka Prefecture University

A promising idea for evolutionary constrained optimization is to efficiently utilize not only feasible solutions (feasible individuals) but also infeasible ones. In this paper, we propose a simple implementation of this idea in MOEA/D. In the proposed method, MOEA/D has two grids of weight vectors. One is used for maintaining the main population as in the standard MOEA/D. In the main population, feasible solutions always have higher fitness than infeasible ones. Among infeasible solutions, solutions with smaller constraint violations have higher fitness. The other grid is for maintaining a secondary population where nondominated solutions with respect to scalarizing function values and constraint violations are stored. More specifically, a single non-dominated solution with respect to the scalarizing function and the total constraint violation is stored for each weight vector. A new solution is generated from a pair of neighboring solutions in the two grids. That is, there exist three possible combinations of two parents: both from the main population, both from the secondary population, and each from each population. The proposed MOEA/D variant is compared with the standard MOEA/D and other evolutionary algorithms for constrained multiobjective optimization through computational experiments.

# Directed Mating in Decomposition-based MOEA for Constrained Many-objective Optimization

Minami Miyakawa, Hosei University, Hiroyuki Sato, The University of Electro-Communications, Yuji Sato, Hosei University

This work proposes a decomposition-based algorithm, CMOEA/D-DMA, for constrained many-objective optimization. For constrained multi-objective optimization, the TNSDM algorithm using the directed mating selecting infeasible solutions having better objective values than feasible ones as parents was proposed and verified its effectiveness on several test problems. However, since TNSDM uses the non-dominated sorting, its search performance deteriorates when the number of objectives is increased. For many-objective optimization, the decomposing objective space is a promising approach, and MOEA/D is known as its representative algorithm. However, since the conventional MOEA/D maintains only one solution for each weight vector, feasible solutions are preferred rather than infeasible ones. Infeasible solutions are just discarded even if they have better objective values than maintained feasible solutions and can provide clues for the search. For solving constrained many-objective optimization problems, in this work, we propose CMOEA/D-DMA combining MOEA/D with the Directed Mating and Archives of infeasible solutions. The directed mating in CMOEA/D-DMA selects useful infeasible solutions having better scalarizing function values than feasible ones as parents and maintains them in archives. The experimental results using continuous mCDTLZ and discrete knapsack problems with many-objectives show that the proposed CMOEA/D-DMA achieves higher search performance than the conventional TNSDM, MOEA/D, and NSGA-III.

#### MOEA/D with Uniformly Randomly Adaptive Weights

Lucas Rodolfo Celestino Farias, Universidade Federal de Pernambuco, Pedro Henrique Magalhães Braga, Universidade Federal de Pernambuco, Hansenclever França Bassani, Universidade Federal de Pernambuco, Aluizio Fausto Ribeiro Araújo, Universidade Federal de Pernambuco

When working with decomposition-based algorithms, an appropriate set of weights might improve quality of the final solution. A set of uniformly distributed weights usually leads to well-distributed solutions on a Pareto front. However, there are two main difficulties with this approach. Firstly, it may fail depending on the problem geometry. Secondly, the population size becomes not flexible as the number of objectives increases. In this paper, we propose the MOEA/D with Uniformly Randomly Adaptive Weights (MOEA/D-URAW) which uses the Uniformly Randomly method as an approach to subproblems generation, allowing a flexible population size even when working with many objective problems. During the evolutionary process, MOEA/D-URAW adds and removes subproblems as a function of the sparsity level of the population. Moreover, instead of requiring assumptions about the Pareto front shape, our method adapts its weights to the shape of the problem during the evolutionary process. Experimental results using WFG41-48 problem classes, with different Pareto front shapes, shows that the present method presents better or equal results in 77.5% of the problems evaluated from 2 to 6 objectives when compared with

state-of-the-art methods in the literature.

# Component-level study of a decomposition-based multi-objective optimizer on a limited evaluation budget

Oliver P. H. Jones, *The University of Sheffield*, Jeremy E. Oakley, *The University of Sheffield*, Robin C. Purshouse, *The University of Sheffield* 

Decomposition-based algorithms have emerged as one of the most popular classes of solvers for multi-objective optimization. Despite their popularity, a lack of guidance exists for how to configure such algorithms for real-world problems, based on the features or contexts of those problems. One context that is important for many real-world problems is that function evaluations are expensive, and so algorithms need to be able to provide adequate convergence on a limited budget (e.g. 500 evaluations). This study contributes to emerging guidance on algorithm configuration by investigating how the convergence of the popular decomposition-based optimizer MOEA/D, over a limited budget, is affected by choice of component-level configuration. Two main aspects are considered: (1) impact of sharing information; (2) impact of normalisation scheme. The empirical test framework includes detailed trajectory analysis, as well as more conventional performance indicator analysis, to help identify and explain the behaviour of the optimizer. Use of neighbours in generating new solutions is found to be highly disruptive for searching on a small budget, leading to better convergence in some areas but far worse convergence in others. The findings also emphasise the challenge and importance of using an appropriate normalisation scheme.

Session: EMO4 Wednesday, July 18, 10:40-12:20, Conference Room D (3F)

# Improving the Performance of MO-RV-GOMEA on Problems with Many Objectives using Tchebycheff Scalarizations

Ngoc Hoang Luong, *Centrum Wiskunde & Informatica* (*CWI*), Tanja Alderliesten, *Academic Medical Center*, Peter A.N. Bosman, *Centrum Wiskunde & Informatica (CWI*)

The Multi-Objective Real-Valued Gene-pool Optimal Mixing Evolutionary Algorithm (MO-RV-GOMEA) has been shown to exhibit excellent performance in solving various bi-objective benchmark and real-world problems. We assess the competence of MO-RV-GOMEA in tackling manyobjective problems, which are normally defined as problems with at least four conflicting objectives. Most Pareto dominance-based Multi-Objective Evolutionary Algorithms (MOEAs) typically diminish in performance if the number

of objectives is more than three because selection pressure toward the Pareto-optimal front is lost. This is potentially less of an issue for MO-RV-GOMEA because its variation operator creates each offspring solution by iteratively altering a currently existing solution in a few decision variables each time, and changes are only accepted if they result in a Pareto improvement. For most MOEAs, integrating scalarization methods is potentially beneficial in the many-objective context. Here, we investigate the possibility of improving the performance of MO-RV-GOMEA by further guiding improvement checks during solution variation in MO-RV-GOMEA with carefully constructed Tchebycheff scalarizations. Results obtained from experiments performed on a selection of well-known problems from the DTLZ and WFG test suites show that MO-RV-GOMEA is by design already well-suited for many-objective problems. Moreover, by enhancing it with Tchebycheff scalarizations, it outperforms MOEA/D-2TCHMFI, a state-of-theart decomposition-based MOEA.

# Collaborative Multi-Objective Optimization for Distributed Design of Complex Products

Joao Antonio Fialho Vilas Boas Duro, *The University of Sheffield*, Yiming Yan, *The University of Sheffield*, Robin C. Purshouse, *The University of Sheffield*, Peter J. Fleming, *The University of Sheffield* 

Multidisciplinary design optimization problems with competing objectives that involve several interacting components can be called complex systems. Nowadays, it is common to partition the optimization problem of a complex system into smaller subsystems, each with a subproblem, in part because it is too difficult to deal with the problem all-at-once. Such an approach is suitable for large organisations where each subsystem can have its own (specialised) design team. However, this requires a design process that facilitates collaboration, and decision making, in an environment where teams may exchange limited information about their own designs, and also where the design teams work at different rates, have different time schedules, and are normally not co-located. A multi-objective optimization methodology to address these features is described. Subsystems exchange information about their own optimal solutions on a peer-to-peer basis, and the methodology enables convergence to a set of optimal solutions that satisfy the overall system. This is demonstrated on an example problem where the methodology is shown to perform as well as the ideal, but unrealistic, approach that treats the optimization problem all-at-once.

# Generalized Offline Orthant Search: One Code for Many Problems in Multiobjective Optimization

Maxim Buzdalov, ITMO University

We introduce generalized offline orthant search, an algorithmic framework that can be used to solve many problems coming from evolutionary multiobjective optimization using a common well-optimized algorithmic core and relatively cheap reduction procedures. The complexity of the core procedure is  $O(n \cdot (\log n)^{k-1})$  for *n* points of dimension *k*, and it has a good performance in practice. We show that the presented approach can perform various flavors of non-dominated sorting, dominance counting, evaluate the  $\varepsilon$ -indicator and perform initial fitness assignment for IBEA. It is either competitive with the state-of-the-art algorithms or completely outperforms them for higher problem sizes. We hope that this approach will simplify future development of efficient algorithms for evolutionary multiobjective optimization.

# Transfer Strategies from Single- to Multi-objective Grouping Mechanisms

Frederick Sander, Otto-von-Guericke University Magdeburg, Heiner Zille, Otto-von-Guericke University Magdeburg, Sanaz Mostaghim, Otto-von-Guericke University Magdeburg

In large-scale optimisation, most algorithms require a separation of the variables into multiple smaller groups and aim to optimise these variable groups independently. In single-objective optimisation, a variety of methods aim to identify best variable groups, most recently the Differential Grouping 2. However, it is not trivial to apply these methods to multiple objectives, as the variable interactions might differ between objective functions. In this work, we introduce four different transfer strategies that allow to use any single-objective grouping mechanisms directly on multi-objective problems. We apply these strategies to a popular single-objective grouping method (Differential Grouping 2) and compare the performance of the obtained groups inside three recent large-scale multi-objective algorithms (MOEA/DVA, LMEA, WOF). The results show that the performance of the original MOEA/DVA and LMEA can in some cases be improved by our proposed grouping variants or even random groups. At the same time the computational budget is dramatically reduced. In the WOF algorithm, a significant improvement in performance compared to random groups or the standard version of the algorithm can on average not be observed.

Session: EMO5 Wednesday, July 18, 10:40-12:20, Conference Room 2 (3F)

#### A Differential Prediction Model for Evolutionary Dynamic Multiobjective Optimization

Leilei Cao, *Tongji University*, Lihong Xu, *Tongji University*, Erik D. Goodman, *Michigan State University*, Shuwei Zhu, *Tongji University*, Hui Li, *Xi'an Jiaotong University*  This paper introduces a differential prediction model to predict the varying Pareto-Optimal Solutions (POS) when solving dynamic multiobjective optimization problems (DMOPs). In dynamic multiobjective optimization problems, several competing objective functions and/or constraints change over time. As a consequence, the Pareto-Optimal Solutions and/or Pareto-Optimal Front may vary over time. When detecting the environmental change, the differential prediction model is used to forecast the shift vector in the decision space of the centroid in the population through the centroid's historical locations in three previous environments. This differential prediction model is incorporated into a multiobjective evolutionary algorithm based on decomposition to solve DMOPs. After detecting the environmental change, half of individuals in the population are forecasted their new positions in the decision space by using the differential prediction model and the others' positions are retained. The proposed model is tested on a number of typical benchmark problems with several dynamic characteristics. Experimental results show that the proposed model is competitively in comparisons with the other state-of-the-art models or approaches that were proposed for solving DMOPs.

# Multiobjective Sparse Unmixing Approach with Noise Removal

Xiangming Jiang, The Key Laboratory of Intelligent Perception and Image Understanding of Ministry of Education, Xidian University, Maoguo Gong, The Key Laboratory of Intelligent Perception and Image Understanding of Ministry of Education, Xidian University, Tao Zhan, The Key Laboratory of Intelligent Perception and Image Understanding of Ministry of Education, Xidian University, Zedong Tang, The Key Laboratory of Intelligent Perception and Image Understanding of Ministry of Education, Xidian University

In sparse hyperspectral unmixing, regularization methods inevitably suffer from the "decision ahead of solution" issue concerning the regularization parameter, which is not conducive to practical applications. To settle this issue, a two-phase multiobjective sparse unmixing (Tp-MoSU) approach has been proposed recently. However, Tp-MoSU has limited performance on high noise data and uses little spatial-contextual information in estimating abundances. To address the first problem, a tri-objective optimization model is established for each of the two phases to model mixed additive noise automatically. To address the second problem, a dual spatial exploiting objective is specially designed in the second phase to exploit similarity among adjacent pixels, which can improve the guality of estimated abundances. In addition, the memetic based evolutionary algorithms are elaborately modified for each of the two phases for better convergence. The experimental results on several representative data sets demonstrate that the proposed method performs better than Tp-MoSU in both

of the two phases and completely better than some advanced regularization algorithms in abundance estimation under mixed additive noise.

# Less Detectable Environmental Changes in Dynamic Multiobjective Optimisation

Shouyong Jiang, Newcastle University, Marcus Kaiser, Newcastle University, Jinglei Guo, Central China Normal University, Shengxiang Yang, De Montfort University, Natalio Krasnogor, Newcastle University

Multiobjective optimisation in dynamic environments is challenging due to the presence of dynamics in the problems in question. Whilst much progress has been made in benchmarks and algorithm design for dynamic multiobjective optimisation, there is a lack of work on the detectability of environmental changes and how this affects the performance of evolutionary algorithms. This is not intentionally left blank but due to the unavailability of suitable test cases to study. To bridge the gap, this work presents several scenarios where environmental changes are less likely to be detected. Our experimental studies suggest that the less detectable environments pose a big challenge to evolutionary algorithms.

# A Steady-State NSGA-II based Multi-objective Multicast Routing Algorithm for Optical Networks

#### Ying Xu, Hunan University, Yan Zhou, Hunan University

Multicast routing for wavelength division multiplexing optical network is a challenging problem in optical networks. The Multicast Routing and Wavelength Assignment (MRWA) problem has been proved to be a NP complete problem. In this paper, the MRWA problem in WDM has been modeled as a Multi-Objective Multicast Routing and Wavelength Assignment (MOMRWA) optimization problem with three optimization objectives, including minimizing the resource cost, minimizing the end-to-end delay and minimizing the used channels. Some Quality of Service metrics have also been considered in MOMRWA. To tackle the MOMRWA problem, a multi-objective genetic algorithm, namely MRWA SSNSGA-II, has been proposed, which is based on the Steady-State Non-Dominated Sorting Genetic Algorithm II combined with the Efficient Non-Domination Level Update(ENLU) strategy. The purpose of the ENLU strategy is to reduce the computing time of maintaining the Non-Domination Level structure. In order to avoid the loop generated by the gene recombination, a light tree recovery mechanism based on the Minimum Path Cost Heuristic has been proposed. We evaluate our proposed MRWA\_SSNSGA-II on a large number of test instances with different sizes. Experimental results demonstrate that MRWA SSNSGA-II outperformed some recent GA based multi-objective optimization algorithms for MOMRWA problem in terms of the solution quality.

Session: EMO6 Wednesday, July 18, 15:30-17:10, Conference Room D (3F)

# Preference-based 3-Dimensional En-route Airspace Sectorization

Cheryl Sze Yin Wong, Nanyang Technological University, Suresh Sundaram, Nanyang Technological University

The problem of 3-Dimensional en-route airspace sectorization has been modelled as a multi-objective optimization by taking into account of conflicting air traffic controller workloads. In practice, air traffic controllers impose limits on these objectives, which may not be captured completely in Pareto front obtained using the multiobjective model. Hence, in this paper, we propose a preference-based multi-objective optimization model for 3dimensional en-route sectorization. Through the use of reference point(s), the proposed model is able to find multiple solutions that satisfy the air traffic controller preference(s) faster. Population-based NSGA-II has been used to solve the preference-based 3-dimensional en-route sectorization problem. The performance of preference based sectorization is evaluated using actual flight data from the Singapore regional airspace. The results are compared with conventional multi-objective optimization model which integrates the preference as a constraint. Results indicate that the preference-based model generally performs better than the constraint-based model. Further, multiple parallel runs of preference-based optimization could provide a greater variety of choices in airspace sectorization for the air traffic controllers.

# Interactive Multiobjective Optimisation: Preference Changes And Algorithm Responsiveness

Kendall Peter Taylor, *RMIT University*, Xiaodong Li, *RMIT University* 

For optimisation problems with multiple objectives and large search spaces, it may not be feasible to find all optimal solutions. Even if possible, a decision maker (DM) is only interested in a small number of these solutions. Incorporating a DM's solution preferences into the process reduces the problem's search space by focusing only on regions of interest. Allowing a DM to interact and alter their preferences during a single optimisation run facilitates learning and mistake correction, and improves the search for desired solutions. In this paper, we apply an interactive framework to four leading multi-objective evolutionary algorithms (MOEAs), which use reference points to model preferences. Furthermore, we propose a new performance metric for algorithm responsiveness to preference changes, and evaluate these algorithms using this metric. Interactive algorithms must respond to changes in DM preferences and we show how our new metric is able

to differentiate between the four algorithms when run on the ZDT suite of test problems. Finally, we identify characteristics of these methods that determine their level of response to change.

# Local Search Effects in Bi-Objective Orienteering

Jakob Bossek, University of Münster, Christian Grimme, University of Münster, Stephan Meisel, University of Münster, Günter Rudolph, TU Dortmund University, Heike Trautmann, University of Münster

We analyze the effects of including local search techniques into a multi-objective evolutionary algorithm for solving a bi-objective orienteering problem with a single vehicle while the two conflicting objectives are minimization of travel time and maximization of the number of visited customer locations. Experiments are based on a large set of specifically designed problem instances with different characteristics and it is shown that local search techniques focusing on one of the objectives only, improve the performance of the evolutionary algorithm in terms of both objectives. The analysis also shows that local search techniques are capable of sending locally optimal solutions to foremost fronts of the multi-objective optimization process, and that these solutions then become the leading factors of the evolutionary process.

Session: EMO7: Best Papers Thursday, July 19, 09:00-10:40, Terrsa Hall (1F)

#### **Data-Driven Analysis of Pareto Set Topology**

Naoki Hamada, Fujitsu Laboratories Ltd., Keisuke Goto, Fujitsu Laboratories Ltd.

When and why can evolutionary multi-objective optimization (EMO) algorithms cover the entire Pareto set? That is a major concern for EMO researchers and practitioners. A recent theoretical study revealed that (roughly speaking) if the Pareto set forms a topological simplex (a curved line, a curved triangle, a curved tetrahedron, etc.), then decomposition-based EMO algorithms can cover the entire Pareto set. Usually, we cannot know the true Pareto set and have to estimate its topology by using the population of EMO algorithms during or after the runtime. This paper presents a data-driven approach to analyze the topology of the Pareto set. We give a theory of how to recognize the topology of the Pareto set from data and implement an algorithm to judge whether the true Pareto set may form a topological simplex or not. Numerical experiments show that the proposed method correctly recognizes the topology of high-dimensional Pareto sets within reasonable population size.

Multi-Objective Evolutionary Hyper-heuristic based on

#### **Multiple Indicator-based Density Estimators**

Jesús Guillermo Falcón-Cardona, CINVESTAV-IPN, Carlos A. Coello Coello, CINVESTAV-IPN

In recent years, Indicator-based Multi-Objective Evolutionary Algorithms (IB-MOEAs) have become a relatively popular alternative for solving multi-objective optimization problems. IB-MOEAs are normally based on the use of a single performance indicator. However, the effect of the combination of multiple performance indicators for selecting solutions is a topic that has rarely been explored. In this paper, we propose a hyper-heuristic which combines the strengths and compensates for the weaknesses of four density estimators based on R2, IGD<sup>+</sup>,  $\epsilon^+$  and  $\Delta_p$ . The selection of the indicator to be used at a particular moment during the search is done using online learning and a Markov chain. Additionally, we propose a novel framework that aims to reduce the computational cost involved in the calculation of the indicator contributions. Our experimental results indicate that our proposed approach can outperform state-of-the-art MOEAs based on decomposition (MOEA/D) reference points (NSGA-III) and the R2 indicator (R2-EMOA) for problems with both few and many objectives.

# A new R2 indicator for better hypervolume approximation

Ke Shang, Southern University of Science and Technology, Hisao Ishibuchi, Southern University of Science and Technology, Min-Ling Zhang, Southeast University, Yiping Liu, Osaka Prefecture University

In this paper, a new R2 indicator is proposed for better hypervolume approximation. First the fact that the original R2 indicator is not a good approximation for the hypervolume is illustrated by examples. Then the new R2 indicator is derived based on the Divergence theorem and Riemann sum approximation. The difference between the original R2 and the new R2 is only the added exponential in the new R2 where the exponential is the same as the dimensionality of the objective space (i.e., the number of objectives). The new R2, the original R2 and some other R2 variants are compared through comprehensive numerical studies on different solution sets under different scenarios. The results show the superiority of the proposed new R2 indicator over other R2 variants for the hypervolume approximation, where the new R2 indicator achieves the best linear relation with the true hypervolume.

# Efficient Search Techniques Using Adaptive Discretization of Design Variables on Real-Coded Evolutionary Computations

Toshiki Kondo, *Tokyo University of Science*, Tomoaki Tatsukawa, *Tokyo University of Science* 

In this paper, we evaluate the effects of adaptive discretiza-

tion of design variables in real-coded evolutionary computations (RCECs). While the appropriate granularity of design variables can improve convergence in RCECs, it is difficult to decide the appropriate one in advance in most of the practical optimization problems. Besides, when the granularity is too coarse, the diversity may be lost. To address these difficulties, we propose two adaptive discretization techniques that discretize each design variable using granularity determined according to the indicator of solutions distribution state in design-variable space. In this study, standard deviation(SD) or estimated probability density function(ePDF) is used as an indicator for determining granularities of design variables. We use NSGA-II as an RCEC and thirteen benchmark problems including engineering problems. The generational distance (GD) and inverted generational distance (IGD) metrics are used for investigating the performance of convergence and diversity, respectively. To make sure the statistical difference of GD/IGD trends, the Wilcoxon rank-sum test is applied in each problem. The results of experiments show that both of the proposed methods can automatically improve convergence in many problems. In addition, it is confirmed that the diversity is also maintained.

# ENUM — Evolutionary Numerical Optimization

Session: ENUM1

Tuesday, July 17, 10:40-12:20, Training Room 1 (2F)

#### Drift Theory in Continuous Search Spaces: Expected Hitting Time of the (1+1)-ES with 1/5 Success Rule

Youhei Akimoto, University of Tsukuba, Anne Auger, Inria and Ecole Polytechnique, Tobias Glasmachers, Ruhr-University Bochum

This paper explores the use of the standard approach for proving runtime bounds in discrete domains-often referred to as drift analysis-in the context of optimization on a continuous domain. Using this framework we analyze the (1+1) Evolution Strategy with one-fifth success rule on the sphere function. To deal with potential functions that are not lower-bounded, we formulate novel drift theorems. We then use the theorems to prove bounds on the expected hitting time to reach a certain target fitness in finite dimension d. The bounds are akin to linear convergence. We then study the dependency of the different terms on d proving a convergence rate dependency of  $\Theta(1/d)$ . Our results constitute the first non-asymptotic analysis for the algorithm considered as well as the first explicit application of drift analysis to a randomized search heuristic with continuous domain.

# Real-Valued Evolutionary Multi-Modal Optimization driven by Hill-Valley Clustering

Stef C. Maree, Academic Medical Center, Tanja Alderliesten, Academic Medical Center, Dirk Thierens, Utrecht University, Peter A.N. Bosman, Centrum Wiskunde & Informatica (CWI)

Model-based evolutionary algorithms (EAs) adapt an underlying search model to features of the problem at hand, such as the linkage between problem variables. The performance of EAs often deteriorates as multiple modes in the fitness landscape are modelled with a unimodal search model. The number of modes is however often unknown a priori, especially in a black-box setting, which complicates adaptation of the search model. In this work, we focus on models that can adapt to the multi-modality of the fitness landscape. Specifically, we introduce Hill-Valley Clustering, a remarkably simple approach to adaptively cluster the search space in niches, such that a single mode resides in each niche. In each of the located niches, a core search algorithm is initialized to optimize that niche. Combined with an EA and a restart scheme, the resulting Hill-Valley EA (HillVallEA) is compared to current state-of-the-art niching methods on a standard benchmark suite for multi-modal optimization. Numerical results in terms of the detected number of global optima show that, in spite of its simplicity, HillVallEA is competitive within the limited budget of the benchmark suite, and shows superior performance in the long run.

# Adaptive Threshold Parameter Estimation with Recursive Differential Grouping for Problem Decomposition

Yuan Sun, The University of Melbourne, Mohammad Nabi Omidvar, The University of Birmingham, Michael Kirley, The University of Melbourne, Xiaodong Li, RMIT University

Problem decomposition plays an essential role in the success of cooperative co-evolution (CC), when used for solving large-scale optimization problems. The recently proposed recursive differential grouping (RDG) method has been shown to be very efficient, especially in terms of time complexity. However, it requires an appropriate parameter setting to estimate a threshold value in order to determine if two subsets of decision variables interact or not. Furthermore, using one global threshold value may be insufficient to identify variable interactions in compo-

nents with different contribution to the fitness value. Inspired by the different grouping 2 (DG2) method, in this paper, we adaptively estimates a threshold value based on computational round-off errors for RDG. We derive an upper bound of the round-off errors, which is shown to be sufficient when identifying variable interactions across a wide range of large-scale benchmark problems. Comprehensive numerical experimental results showed that the proposed RDG2 method achieved higher decomposition accuracy than RDG and DG2. When embedded into a CC framework, it achieved statistically equal or significantly better solution quality than RDG and DG2, when used to solve the benchmark problems.

Session: ENUM2

Tuesday, July 17, 16:00-17:40, Training Room 1 (2F)

# Learning-Based Topology Variation in Evolutionary Level Set Topology Optimization

Mariusz Bujny, Technical University of Munich, Nikola Aulig, Honda Research Institute Europe GmbH, Markus Olhofer, Honda Research Institute Europe GmbH, Fabian Duddeck, Technical University of Munich

The main goal in structural Topology Optimization is to find an optimal distribution of material within a defined design domain, under specified boundary conditions. This task is frequently solved with gradient-based methods, but for some problems, e.g. in the domain of crash Topology Optimization, analytical sensitivity information is not available. The recent Evolutionary Level Set Method (EA-LSM) uses Evolutionary Strategies and a representation based on geometric Level Set Functions to solve such problems. However, computational costs associated with Evolutionary Algorithms are relatively high and grow significantly with rising dimensionality of the optimization problem. In this paper, we propose an improved version of EA-LSM, exploiting an adaptive representation, where the number of structural components increases during the optimization. We employ a learning-based approach, where a pretrained neural network model predicts favorable topological changes, based on the structural state of the design. The proposed algorithm converges quickly at the beginning, determining good designs in low-dimensional search spaces, and the representation is gradually extended by increasing structural complexity. The approach is evaluated on a standard minimum compliance design problem and its superiority with respect to a random adaptive method is demonstrated.

#### A Global Information Based Adaptive Threshold for Grouping Large Scale Global Optimization Problems

An Chen, Xi'an Jiaotong University, Yipeng Zhang, Xi'an Jiaotong University, Yang Yang, Xi'an Jiaotong University

Shenzhen Research School, Zhigang Ren, Xi'an Jiaotong University, Yongsheng Liang, Xi'an Jiaotong University, Bei Pang, Xi'an Jiaotong University

By taking the idea of divide-and-conquer, cooperative coevolution (CC) provides a powerful architecture for large scale global optimization (LSGO) problems, but its efficiency highly relies on the decomposition strategy. It has been shown that differential grouping (DG) performs well on decomposing LSGO problems by effectively detecting the interaction among decision variables. However, its decomposition accuracy highly depends on the threshold. To improve the decomposition accuracy of DG, a global information based adaptive threshold setting algorithm (GIAT) is proposed in this paper. On the one hand, by reducing the sensitivities of the indicator in DG to the roundoff error and the magnitude of contribution weight of subcomponent, we proposed a new indicator for two variables which is much more sensitive to their interaction. On the other hand, instead of setting the threshold only based on one pair of variables, the threshold is generated from the interaction information for all pair of variables. By conducting the experiments on two sets of LSGO benchmark functions, the correctness and robustness of this new indicator and GIAT were verified.

# Analysis of Evolution Strategies with the Optimal Weighted Recombination

# Chun-kit Au, *Toronto, Ontario*, Ho-fung Leung, *The Chinese* University of Hong Kong

This paper studies the performance for evolution strategies with the optimal weighed recombination on spherical problems in finite dimensions. We first discuss the different forms of functions that are used to derive the optimal recombination weights and step size, and then derive an inequality that establishes the relationship between these functions. We prove that using the expectation of random variables to derive the optimal recombination weights and step size can be disappointing in terms of the expected performance of evolution strategies. We show that using the realizations of random variables is a better choice. We generalize the results to any convex functions and establish an inequality for the normalized quality gain. We prove that the normalized quality gain of the evolution strategies have a better and robust performance when they use the optimal recombination weights and the optimal step size that are derived from the realizations of random variables rather than using the expectations of random variables.

Session: ENUM3 Wednesday, July 18, 10:40-12:20, Training Room 1 (2F)

Expanding variational autoencoders for learning and

# exploiting latent representations in search distributions

Unai Garciarena, University of the Basque Country, Roberto Santana, University of the Basque Country, Alexander Mendiburu, University of the Basque Country

In the past, evolutionary algorithms (EAs) that use probabilistic modeling of the best solutions incorporated latent or hidden variables to the models as a more accurate way to represent the search distributions. Recently, a number of neural-network models that compute approximations of posterior (latent variable) distributions have been introduced. In this paper, we investigate the use of the variational autoencoder (VAE), a class of neural-network based generative model, for modeling and sampling search distributions as part of an estimation of distribution algorithm. We show that VAE can capture dependencies between decision variables and objectives. This feature is proven to improve the sampling capacity of model based EAs. Furthermore, we extend the original VAE model by adding a new, fitness-approximating network component. We show that it is possible to adapt the architecture of these models and we present evidence of how to extend VAEs to better fulfill the requirements of probabilistic modeling in EAs. While our results are not yet competitive with state of the art probabilistic-based optimizers, they represent a promising direction for the application of generative models within EDAs.

#### Analysis of Information Geometric Optimization with Isotropic Gaussian Distribution Under Finite Samples

Kento Uchida, Yokohama National University, Youhei Akimoto, University of Tsukuba, Shinichi Shirakawa, Yokohama National University

In this article, we theoretically investigate the convergence properties of the information geometric optimization (IGO) algorithm given the family of isotropic Gaussian distributions on the sphere function. Differently from previous studies, where the exact natural gradient is taken, i.e., the infinite samples are assumed, we consider the case that the natural gradient is estimated from finite samples. We derive the rates of the expected decrease of the squared distance to the optimum and the variance parameter as functions of the learning rates, dimension, and sample size. From the rates of decrease deduces that the rates of decreases of the squared distance to the optimum and the variance parameter must agree for geometric convergence of the algorithm. In other words, the ratio between the squared distance to the optimum and the variance must be stable, which is observed empirically but is not derived in the previous theoretical studies. We further derive the condition on the learning rates that the rates of decreases agree and derive the stable value of the ratio. We confirm in simulation that the derived rates of decreases and the stable value of the ratio well approximate the behavior of the IGO algorithm.

### A Novel Similarity-based Mutant Vector Generation Strategy for Differential Evolution

Eduardo Segredo, Edinburgh Napier University, Eduardo Lalla-Ruiz, University of Hamburg, Emma Hart, Edinburgh Napier University

The mutant vector generation strategy is an essential component of Differential Evolution (DE), introduced to promote diversity, resulting in exploration of novel areas of the search space. However, it is also responsible for promoting intensification, to improve those solutions located in promising regions. In this paper we introduce a novel similarity-based mutant vector generation strategy for DE, with the goal of inducing a suitable balance between exploration and exploitation, adapting its behaviour depending on the current state of the search. In order to achieve this balance, the strategy considers similarities among individuals in terms of their Euclidean distance in the decision space. A variant of DE incorporating the novel mutant vector generation strategy is compared to well-known explorative and exploitative self-adaptive DE variants. An experimental evaluation performed on a well-known suite of large-scale continuous problems shows that the new DE algorithm that makes use of the similarity-based approach provides better performance in comparison to the explorative and exploitative DE variants for a wide range of the problems tested, demonstrating the ability of the new component to properly balance exploration and exploitation.

# Inheritance-Based Diversity Measures for Explicit Convergence Control in Evolutionary Algorithms

Thomas Gabor, *LMU Munich*, Lenz Belzner, *LMU Munich*, Claudia Linnhoff-Popien, *LMU Munich* 

Diversity is an important factor in evolutionary algorithms to prevent premature convergence towards a single local optimum. In order to maintain diversity throughout the process of evolution, various means exist in literature. We analyze approaches to diversity that (a) have an explicit and quantifiable influence on fitness at the individual level and (b) require no (or very little) additional domain knowledge such as domain-specific distance functions. We also introduce the concept of genealogical diversity in a broader study. We show that employing these approaches can help evolutionary algorithms for global optimization in many cases.

Session: ENUM4: Best Papers Thursday, July 19, 09:00-10:40, Conference Room Medium (2F)

An Empirical Comparison of Metamodeling Strategies

# in Noisy Environments

Sunith Bandaru, University of Skövde, Amos H.C. Ng, University of Skövde

Metamodeling plays an important role in simulation-based optimization by providing computationally inexpensive approximations for the objective and constraint functions. Additionally, metamodeling can also serve to filter noise, which is inherent in many simulation problems causing optimization algorithms to be mislead. In this paper, we conduct a thorough statistical comparison of four popular metamodeling methods with respect to their approximation accuracy at various levels of noise. We use six scalable benchmark problems from the optimization literature as our test suite. The problems have been chosen to represent different types of fitness landscapes, namely, bowlshaped, valley-shaped, steep ridges and multi-modal, all of which can significantly influence the impact of noise. Each metamodeling technique is used in combination with four different noise handling techniques that are commonly employed by practitioners in the field of simulation-based optimization. The goal is to identify the metamodeling strategy, i.e. a combination of metamodeling and noise handling, that performs significantly better than others on the fitness landscapes under consideration. We also demonstrate how these results carry over to a simulationbased optimization problem concerning a scalable discrete event model of a simple but realistic production line.

# PSA-CMA-ES: CMA-ES with Population Size Adaptation

Kouhei Nishida, Shinshu University, Youhei Akimoto, University of Tsukuba

The population size, i.e., the number of candidate solutions generated at each iteration, is the most critical strategy parameter in the covariance matrix adaptation evolution strategy, CMA-ES, which is one of the state-of-the-art search algorithms for black-box continuous optimization.

The population size is required to be larger than its default value when the objective function is well-structured multimodal and/or noisy, while we want to keep it as small as possible for optimization speed. However, the strategy parameter tuning based on trial and error is, in general, prohibitively expensive in black-box optimization scenario. This paper proposes a novel strategy to adapt the population size for CMA-ES. The population size is adapted based on the estimated accuracy of the update of the normal distribution parameters. The CMA-ES with the proposed population size adaptation mechanism, PSA-CMA-ES, is tested both on noiseless and noisy benchmark functions, and compared with existing strategies. The results revealed that the PSA-CMA-ES works well on wellstructured multimodal and/or noisy functions, but causes inefficient increase of the population size on unimodal functions. Furthermore, it is shown that the PSA-CMA-ES can tackle noise and multimodality at the same time.

# Performance Improvements for Evolutionary Strategybased One-Class Constraint Synthesis

Tomasz P. Pawlak, Institute of Computing Science

Mathematical Programming (MP) models are common in optimization of systems. Designing those models, however, is challenging for human experts facing deficiencies in domain knowledge, rigorous technical requirements for the model (e.g., linearity) or lack of experience. Evolutionary Strategy-based One-Class Constraint Synthesis (ES-OCCS) is a recently proposed method for computer-aided modeling, aimed at reduction of the burden on the expert by acquiring the MP constraints from historical data and letting the expert to freely modify them, supplement with an objective function and optimize using an off-the-shelf solver. In this study, we extend ESOCCS with five improvements aimed at increasing its performance in typical problems. Three of them turn out beneficial in a rigorous experimental evaluation and one prevents ESOCCS from producing degenerate models.

# GA — Genetic Algorithms

Session: GA1 Tuesday, July 17, 10:40-12:20, Conference Room B (3F)

# Shaper-GA: Automatic Shape Generation for Modular House Design

Ana Maria Carvalho de Almeida, *ISCTE-IUL*, Bruno Taborda, *ISCTE-IUL*, Filipe Santos, *ISCTE-IUL*, Krystian Kwiecinski,

Warsaw University of Technology, Sara Eloy, ISCTE-IUL

This work presents a Genetic Algorithm (GA) approach to produce automatic designs for modular houses: Shaper-GA. A set of architectural design rules defining a language of design is incorporated into the GA fitness function. When possible genetic drift or local convergence might be occurring, the method starts an adaptive mutation rate to overcome fitness stagnation. The GA tool efficiently produces several layout solutions obeying the design rules and further placement constraints. Such a tool can be integrated into an appropriate user interface allowing future house owners to customize their own house or construction companies to answer client's' requirements while complying with a language of design.

# Analysis of the Use of Genetic Algorithms for Indoor Localisation via Cloud Point Matching

Miguel d'Arcangues Boland, University of York, Leandro Soares Indrusiak, University of York

A system's ability to precisely locate itself in a known physical environment is key to its capacity to interact with the environment in an intricate manner. The indoor localisation problem has been approached in a variety of ways, ranging from the identification of pre-defined features or topologies to the more general cloud-point matching. Cloud point matching can be achieved using a variety of algorithms, each with benefits and capabilities. Recent improvements have focused on the application of genetic algorithms to solve the initial 'global' search for a solution, before refining this solution to a precise position through a non-genetic algorithm. This project aims to demonstrate the inefficacy of genetic algorithms applied to the global search problem for the problem of indoor localisation; this is thought to be caused by the solution space's low dimensionality, solution landscape topology and the inefficacy of crossover operators in the problem. Based on our assumptions of map topologies, we conclude that significant redundancies can be found in some purely genetic heuristics and suggest further development of landscape analysis to allow the use of algorithms appropriate to the problem's complexity.

# Towards a Theory-Guided Benchmarking Suite for Discrete Black-Box Optimization: Profiling $(1+\lambda)$ EA Variants on OneMax and LeadingOnes

Carola Doerr, *CNRS and Sorbonne University*, Furong Ye, *Leiden University*, Sander van Rijn, *Leiden University*, Hao Wang, *Leiden University*, Thomas Bäck, *Leiden University* 

Theoretical and empirical research on evolutionary computation methods complement each other by providing two fundamentally different approaches towards a better understanding of black-box optimization heuristics. In discrete optimization, both streams developed rather independently of each other, but we observe today an increasing interest in reconciling these two sub-branches. In continuous optimization, the COCO (COmparing Continuous Optimisers) benchmarking suite has established itself as an important platform that theoreticians and practitioners use to exchange research ideas and questions. No widely accepted equivalent exists in the research domain of discrete black-box optimization. Marking an important step towards filling this gap, we adjust the COCO software to pseudo-Boolean optimization problems, and obtain from this a benchmarking environment that allows a fine-grained empirical analysis of discrete black-box heuristics. In this documentation we demonstrate how this test bed can be used to profile the performance of evolutionary algorithms. More concretely, we study the optimization behavior of several  $(1 + \lambda)$  EA variants on the two benchmark problems OneMax and LeadingOnes. This comparison motivates a refined analysis for the optimization time of the  $(1 + \lambda)$  EA on LeadingOnes.

Session: GA2 Tuesday, July 17, 16:00-17:40, Conference Room B (3F)

# Grammatical Evolution Algorithm for Evolution of Swarm Behaviors

Aadesh Neupane, Brigham Young University, Michael A. Goodrich, Brigham Young University, Eric G. Mercer, Brigham Young University

Animals such as bees, ants, birds, fish, and others are able to perform complex coordinated tasks like foraging, nest-selection, flocking and escaping predators efficiently without centralized control or coordination. Conventionally, mimicking these behaviors with robots requires researchers to study actual behaviors, derive mathematical models, and implement these models as algorithms. We propose a distributed algorithm, Grammatical Evolution algorithm for Evolution of Swarm bEhaviors (GEESE), which uses genetic methods to generate collective behaviors for robot swarms. GEESE uses grammatical evolution to evolve a primitive set of human-provided rules into productive individual behaviors. The GEESE algorithm is evaluated in two different ways. First, GEESE is compared to state-of-the-art genetic algorithms on the canonical Santa Fe Trail problem. Results show that GEESE outperforms the state-of-the-art by (a) providing better solution guality given sufficient population size while (b) utilizing fewer evolutionary steps. Second, GEESE outperforms both a hand-coded and a Grammatical Evolutiongenerated solution on a collective swarm foraging task.

#### Learning an Evolvable Genotype-Phenotype Mapping

Matthew Andres Moreno, *Michigan State University*, Banzhaf Wolfgang, *Michigan State University*, Charles Ofria, *Michigan State University* 

We present AutoMap, a pair of methods for automatic generation of evolvable genotype-phenotype mappings. Both use an artificial neural network autoencoder trained on phenotypes harvested from fitness peaks as the basis for a genotype-phenotype mapping. In the first, the decoder segment of a bottlenecked autoencoder serves as the genotype-phenotype mapping. In the second, a denoising autoencoder serves as the genotype-phenotype mapping. Automatic generation of evolvable genotypephenotype mappings are demonstrated on the n-legged table problem, a toy problem that defines a simple rugged fitness landscape, and the Scrabble string problem, a more complicated problem that serves as a rough model for linear genetic programming. For both problems, the automatically generated genotype-phenotype mappings are found to enhance evolvability.

# Serendipitous Scaffolding to improve a Genetic Algorithm's Speed and Quality

Heather J. Goldsby, *Michigan State University*, Rebecca L. Young, *University of Texas at Austin*, Jory Schossau, *Michigan State University*, Hans A. Hofmann, *University of Texas at Austin*, Arend Hintze, *Michigan State University* 

A central challenge to evolutionary computation is enabling techniques to evolve increasingly complex target end products. Frequently, direct approaches that reward only the target end product itself are not successful because the path between the starting conditions and the target end product traverses through a complex fitness landscape, where the directly accessible intermediary states may be require deleterious or even simply neutral mutations. As such, a host of techniques have sprung up to support evolutionary computation techniques taking these paths. One technique is scaffolding where intermediary targets are used to provide a path from the starting state to the end state. While scaffolding can be successful within well-understood domains it also poses the challenge of identifying useful intermediaries. Within this paper we first identify some shortcomings of scaffolding approaches - namely, that poorly selected intermediaries may in fact hurt the evolutionary computation's chance of producing the desired target end product. We then describe a light-weight approach to selecting intermediate scaffolding states that improve the efficacy of the evolutionary computation.

Session: GA3

Wednesday, July 18, 10:40-12:20, Conference Room B (3F)

#### Discrepancy-Based Evolutionary Diversity Optimization

Aneta Neumann, *The University of Adelaide*, Wanru Gao, *The University of Adelaide*, Carola Doerr, *CNRS and Sorbonne Universite*, Frank Neumann, *The University of Adelaide*, Markus Wagner, *The University of Adelaide* 

Diversity plays a crucial role in evolutionary computation. While diversity has been mainly used to prevent the population of an evolutionary algorithm from premature convergence, the use of evolutionary algorithms to obtain a

diverse set of solutions has gained increasing attention in recent years. Diversity optimization in terms of features on the underlying problem allows to obtain a better understanding of possible solutions to the problem at hand and can be used for algorithm selection when dealing with combinatorial optimization problems such as the Traveling Salesperson Problem. We consider discrepancy-based diversity optimization approaches for evolving diverse sets of images as well as instances of the Traveling Salesperson problem where a local search is not able to find near optimal solutions. Our experimental investigations comparing three diversity optimization approaches show that a discrepancy-based diversity optimization approach using a tie-breaking rule based on weighted differences to surrounding feature points provides the best results in terms of the star discrepancy measure.

# Simple On-the-Fly Parameter Selection Mechanisms for Two Classical Discrete Black-Box Optimization Benchmark Problems

# Carola Doerr, Sorbonne University, CNRS, Markus Wagner, The University of Adelaide

Despite significant empirical and theoretically supported evidence that non-static parameter choices can be strongly beneficial in evolutionary computation, the question \*how\* to best adjust parameter values plays only a marginal role in contemporary research on discrete blackbox optimization. This has led to the unsatisfactory situation in which feedback-free parameter selection rules such as the cooling schedule of Simulated Annealing are predominant in state-of-the-art heuristics, while, at the same time, we understand very well that such time-dependent selection rules can not perform as well as adjustment rules that \*do\* take into account the evolution of the optimization process. A number of adaptive and self-adaptive parameter control strategies have been proposed in the literature, but did not (yet) make their way to a broader public. A key obstacle seems to lie in their rather complex update rules. The purpose of our work is to demonstrate that high-performing online parameter selection rules do not have to be very complicated. More precisely, we experiment with a multiplicative, comparison-based update rule to adjust the mutation rate of a (1+1) Evolutionary Algorithm. We show that this simple self-adjusting rule outperforms the best static unary unbiased black-box algorithm on LeadingOnes, achieving an almost optimal speedup of about 18%.

# On the Runtime Dynamics of the Compact Genetic Algorithm on Jump Functions

Václav Hasenöhrl, *University of Minnesota Duluth*, Andrew M. Sutton, *University of Minnesota Duluth* 

Jump functions were originally introduced as benchmarks on which recombinant evolutionary algorithms can provably outperform those that use mutation alone. To optimize a jump function, an algorithm must be able to execute an initial hill-climbing phase, after which a point across a large gap must be generated. Standard GAs mix mutation and crossover to achieve both behaviors. It seems likely that other techniques, such as estimation of distribution algorithms (EDAs) may exhibit such behavior, but an analysis is so far missing. We analyze an EDA called the compact Genetic Algorithm (cGA) on jump functions with gap k. We prove that the cGA initially exhibits a strong positive drift resulting in good hillclimbing behavior. Interpreting diversity as the variance of the underlying probabilistic model, we show the existence of a critical point beyond which progress slows and diversity vanishes. If k is not too large, the cGA generates with high probability an optimal solution in polynomial time before losing diversity. For  $k = \Omega(\log n)$ , this yields a superpolynomial speedup over mutation-only approaches. We show a small modification that creates  $\lambda > 2$  offspring boosts the critical threshold and allows the cGA to solve functions with a larger gap within the same number of fitness evaluations.

# Investigation of the Exponential Population Scheme for Genetic Algorithms

Yuen-Jen Lin, National Taiwan University, Tian-Li Yu, National Taiwan University

Early development of GAs requires many parameters to be tuned. The tuning process increases the difficulty for inexperienced practitioners. Modern GAs have most of these parameters pre-determined, and therefore recent research concerning parameterless schemes has focused on population size. The techniques developed in this paper are mainly based on Harik and Lobo's work and the exponential population scheme (EPS), which double the population until the solution is satisfactory. In this paper, we modify EPS based on theoretical analyses. Specifically, we propose a new termination criterion and an optimized population multiplier. The experiment results show that our scheme reduces 33.4%, 19.1% and 29.6% number of function evaluations (NFE) on hBOA (the parameterless hBOA), LT-GOMEA and DSMGA-II respectively when compared to Harik-Lobo scheme, and reduces 28.5%, 4.7% and 11.0% NFE on hBOA, LT-GOMEA and DSMGA-Il respectively when compared to EPS. In addition, compared to EPS, our scheme empirically reduces the number of failures when using LT-GOMEA to solve the folded trap and MAX-SAT problems.

Session: GA4: Best Papers Wednesday, July 18, 15:30-17:10, Terrsa Hall (1F)

Fast Algorithm for Fair Comparison of Genetic Algorithms

Chia-Sheng Chen, National Taiwan University, Hung-Wei Hsu, National Taiwan University, Tian-Li Yu, National Taiwan University

Since numerous genetic algorithms (GAs) are developed every year, GA researchers need a fast algorithm to fairly compare their performances. In this paper, we formalized the performance metric and listed three algorithms to find the right population size for performance comparing in terms of the Number of Fitness Evaluations (NFE). Instead of finding the population  $n_{mNFE}$  producing minimum NFE (mNFE), we took the methodology of finding  $n^*$  which would converge to an arbitrary notion of success with a desired probability  $p^*$  . Among all three algorithms, the first, the most commonly used bisection method, was proved to be biased and without generality. The second is an unbiased modification of the first with trade-off of more function evaluations. The third, called Greedy Approach Regarding Locality (GARL), is our recommendation, empirically outperforming the second one by an exponential factor. We also analyzed the time complexity of the second and third algorithms, providing the upper bound for an average case. This work could be viewed as a general efficiency-comparing framework to almost all GAs except for parameterless schemes.

# Runtime Analysis of Probabilistic Crowding and Restricted Tournament Selection for Bimodal Optimisation

Edgar Covantes Osuna, *The University of Sheffield*, Dirk Sudholt, *The University of Sheffield* 

Many real optimisation problems lead to multimodal domains and so require the identification of multiple optima. Niching methods have been developed to maintain the population diversity, to investigate many peaks in parallel and to reduce the effect of genetic drift. Using rigorous runtime analysis, we analyse for the first time two well known niching methods: probabilistic crowding and restricted tournament selection (RTS). We incorporate both methods into a (mu+1)EA on the bimodal function TwoMax where the goal is to find two optima at opposite ends of the search space. In probabilistic crowding, the offspring compete with their parents and the survivor is chosen proportionally to its fitness. On TwoMax probabilistic crowding fails to find any reasonable solution quality even in exponential time. In RTS the offspring compete against the closest individual amongst w (window size) individuals. We prove that RTS fails if w is too small, leading to exponential times with high probability. However, if w is chosen large enough, it finds both optima for TwoMax in time O(mu n log n) with high probability. Our theoretical results are accompanied by experimental studies that match the theoretical results and also shed light on parameters not covered by the theoretical results.

# Tunneling Between Plateaus: Improving on a State-ofthe-Art MAXSAT Solver using Partition Crossover

Wenxiang Chen, Colorado State University, Darrell D. Whitley, Colorado State University, Francisco Chicano, University of Málaga, Renato Tinós, University of Saõ Paulo

There are two important challenges for local search algorithms when applied to Maximal Satisfiability (MAXSAT). 1) Local search spends a great deal of time blindly exploring plateaus in the search space and 2) local search is less effective on application instances. We propose a genetic recombination operator to address both of these issues. On problems with well defined local optima, partition crossover is able to "tunnel" between local optima to discover new local optima in O(n) time. The PXSAT algorithm combines partition crossover and local search to produce a new way to escape plateaus. Partition crossover locally decomposes the evaluation function for a given instance into independent components, and is guaranteed to find the best solution among an exponential number of candidate solutions in O(n) time. Empirical results on an extensive set of application instances show that the proposed framework substantially improves two of best local search solvers, AdaptG2WSAT and Sparrow, on many application instances. PXSAT combined with AdaptG2WSAT is also able to outperform CCLS, winner of several recent MAXSAT competitions.

#### Learning Bayesian Network Structures with GOMEA

Kalia Orphanou, *Centrum Wiskunde & Informatica (CWI)*, Dirk Thierens, *Utrecht University*, Peter A.N. Bosman, *Centrum Wiskunde & Informatica (CWI)* 

Bayesian networks (BNs) are probabilistic graphical models which are widely used for knowledge representation and decision making tasks, especially in the presence of uncertainty. Finding or learning the structure of BNs from data is an NP-hard problem. Evolutionary algorithms (EAs) have been extensively used to automate the learning process. In this paper, we consider the use of the Gene-Pool Optimal Mixing Evolutionary Algorithm (GOMEA). GOMEA is a relatively new type of EA that belongs to the class of model-based EAs. The model used in GOMEA is aimed at modeling the dependency structure between problem variables, so as to improve the efficiency and effectiveness of variation. This paper shows that the excellent performance of GOMEA transfers from well-known academic benchmark problems to the specific case of learning BNs from data due to its model-building capacities and the potential to compute partial evaluations when learning BNs. On commonly-used datasets of varying size, we find that GOMEA outperforms standard algorithms such as Order-based search (OBS), as well as other EAs, such as Genetic Algorithms (GAs) and Estimation of Distribution algorithms (EDAs), even when efficient local search techniques are added.

# GECH — General Evolutionary-, Computation and Hybrids

Session: GECH1 Tuesday, July 17, 10:40-12:20, Training Room 2 (2F)

# Adaptive Asynchrony in Semi-Asynchronous Evolutionary Algorithm Based on Performance Prediction Using Search History

#### Tomohiro Harada, Ritsumeikan University

This paper proposes an adaptation technique in an asynchronous evolutionary algorithm (EA) and verifies its effectiveness on multi-objective optimization problems. A parallel EA, which executes EA on a parallel computational environment, can be classified into two approaches, a synchronous EA and an asynchronous EA. A synchronous approach generates new population after all solutions are evaluated, while an asynchronous approach continuously generates a new solution immediately after one solution evaluation completes. Beside this, a semi-asynchronous EA was proposed that can vary the number of waited solution evaluations before generating new solutions, which parameter is called asynchrony. This paper explores a technique to adjust the asynchrony during the optimization process. For this purpose, the proposed method predicts the search performance of EA with different asynchronies from the simulation using search history, and chooses the best asynchrony depending on the predicted performance. To verify the effectiveness of the proposed method, this paper compares these approaches on multi-objective optimization problems. The experimental result reveals that the performance of the proposed method is equal to or better than that of the semi-asynchronous approach with appropriate asynchrony not depending on the variance of the evaluation time of solutions.

# Termination Detection Strategies in Evolutionary Algorithms: A Survey

Yanfeng Liu, East China Normal University, Aimin Zhou, East China Normal University, Hu Zhang, Beijing Electromechanical Engineering Institute

This paper provides an overview of developments on ter-

mination conditions in evolutionary algorithms (EAs). It seeks to give a representative picture of the termination conditions in EAs over the past decades, segment the contributions of termination conditions into progress indicators and termination criteria. With respect to progress indicators, we consider a variety of indicators, in particular in convergence indicators and diversity indicators. With respect to termination criteria, this paper reviews recent research on threshold strategy, statistical inference, i.e., Kalman filters, as well as Fuzzy methods, and other methods. Key developments on termination conditions over decades include: (i) methods of judging the algorithm's search behavior based on statistics, and (ii) methods of detecting the termination based on different distance formulations.

# Memetic Algorithms Beat Evolutionary Algorithms on the Class of Hurdle Problems

# Phan Trung Hai Nguyen, University of Birmingham, Dirk Sudholt, University of Sheffield

Memetic algorithms (MAs) are popular hybrid search heuristics that integrate local search into the search process of an evolutionary algorithm in order to combine the advantages of rapid exploitation and global optimisation. However, these algorithms are not well understood and the field is lacking a solid theoretical foundation that explains when and why MAs are effective. We provide a rigorous runtime analysis of a simple memetic algorithm, the (1+1) MA, on the Hurdle problem class, a landscape class of tuneable difficulty that shows a "big valley structure", a characteristic feature of many hard problems from combinatorial optimisation. The only parameter of this class is the hurdle width w, which describes the %Hamming distance between local optima and the length of fitness valleys that have to be overcome. We show that the (1+1) EA requires  $\Theta(n^w)$  expected function evaluations to find the optimum, whereas the (1+1) MA with best-improvement and first-improvement local search can find the optimum in  $\Theta(n^2 + n^3/w^2)$  and  $\Theta(n^3/w^2)$  function evaluations, respectively. Surprisingly, while increasing the hurdle width makes the problem harder for evolutionary algorithms, the problem becomes easier for MAs. We discuss how these findings can explain and illustrate the success of MAs for problems with big valley structures.

Session: GECH2 Tuesday, July 17, 14:00-15:40, Training Room 3 (2F)

#### Neural Estimation of Interaction Outcomes

Paweł Liskowski, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems, Bartosz Wieloch, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems, Krzysztof Krawiec, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems

We propose Neural Estimation of Interaction Outcomes (NEIO), a method that reduces the number of required interactions between candidate solutions and tests in testbased problems. Given the outcomes of a random sample of all solution-test interactions, NEIO uses a neural network to predict the outcomes of remaining interactions and so estimate the fitness of programs. We apply NEIO to genetic programming (GP) problems, i.e. test-based problems in which candidate solutions are programs, while tests are examples of the desired input-output program behavior. In an empirical comparison to several reference methods on categorical GP benchmarks, NEIO attains the highest rank on the success rate of synthesizing correct programs.

# Talakat: Bullet Hell Generation through Constrained Map-Elites

Ahmed Khalifa, New York University, Scott Lee, New York University, Andy Nealen, New York University, Julian Togelius, New York University

We describe a search-based approach to generating new levels for bullet hell games, which are action games characterized by and requiring avoidance of a very large amount of projectiles. Levels are represented using a domain-specific description language, and search in the space defined by this language is performed by a novel variant of the Map-Elites algorithm which incorporates a feasible-infeasible approach to constraint satisfaction. Simulation-based evaluation is used to gauge the fitness of levels, using an agent based on best-first search. The performance of the agent can be tuned according to the two dimensions of strategy and dexterity, making it possible to search for level configurations that require a specific combination of both. As far as we know, this paper describes the first generator for this game genre, and includes several algorithmic innovations.

# Expected Improvement of Constraint Violation for Expensive Constrained Optimization

Ruwang Jiao, China University of Geosciences, Sanyou Zeng, China University of Geosciences, Changhe Li, China University of Geosciences, Yuhong Jiang, China University of Geosciences, Junchen Wang, China University of Geosciences

For computationally expensive constrained optimization problems, one crucial issue is that the existing expected improvement (EI) criteria are no longer applicable when a feasible point is not initially provided. To address this challenge, this paper uses the expected improvement of constraint violation to reach feasible region. A new constrained expected improvement criterion is proposed to select sample solutions for the update of Gaussian process (GP) surrogate models. The validity of the proposed constrained expected improvement criterion is proved theoretically. It is also verified by experimental studies and results show that it performs better than or competitive to compared criteria.

# Cooperative Co-evolution with Online Optimizer Selection for Large-Scale Optimization

Yuan Sun, The University of Melbourne, Michael Kirley, The University of Melbourne, Xiaodong Li, RMIT University

Cooperative co-evolution (CC) is an effective framework that can be used to solve large-scale optimization problems. It typically divides a problem into components and uses one optimizer to solve the components in a roundrobin fashion. However the relative contribution of each component to the overall fitness value may vary. Furthermore, using one optimizer may not be sufficient when solving a wide range of components with different characteristics. In this paper, we propose a novel CC framework which can select an appropriate optimizer to solve a component based on its contribution to the fitness improvement. In each evolutionary cycle, the candidate optimizer and component that make the greatest contribution to the fitness improvement are selected for evolving. We evaluated the efficacy of the proposed CC with Optimizer Selection (CCOS) algorithm using large-scale benchmark problems. The numerical experiments showed that CCOS outperformed the CC model without optimizer selection ability. When compared against several other state-of-the-art algorithms, CCOS generated competitive solution quality.

Session: GECH3 Tuesday, July 17, 16:00-17:40, Conference Room A (3F)

# Quasi-Bistability of Walk-Based Landscape Measures in Stochastic Fitness Landscapes

Bernhard Werth, Heuristic and Evolutionary Algorithms Laboratory, University of Applied Sciences Upper Austria, Erik Pitzer, Heuristic and Evolutionary Algorithms Laboratory, University of Applied Sciences Upper Austria, Gerald Ostermayer, Research Group Networks and Mobility, University of Applied Sciences Upper Austria, Michael Affenzeller, Heuristic and Evolutionary Algorithms Laboratory, University of Applied Sciences Upper Austria

Exploratory landscape analysis is a useful method for algorithm selection, parametrization and creating an understanding of how a heuristic optimization algorithm performs on a problem and why. A prominent family of fitness landscape analysis measures are based on random walks through the search space. However, most of these features were only introduced on deterministic fitness functions and it is unclear, under which conditions walk-based landscape features are applicable to noisy optimization problems. In this paper, we empirically analyze the effects of noise in the fitness function on these measures and identify two dominant regimes, where either the underlying problem or the noise are described. Additionally, we observe how step sizes and walk lengths of random walks influence this behavior.

# Sequential Sampling for Noisy Optimisation with CMA-ES

Matthew Groves, University of Warwick, Juergen Branke, University of Warwick

This paper proposes a novel sequential sampling scheme to allocate samples to individuals in order to maximally inform the selection step in Covariance Matrix Adaptation Evolution Strategies (CMA-ES) for noisy function optimisation. More specifically, we adopt the well-known Knowledge Gradient (KG) method to minimise the Kullback-Leibler divergence (relative entropy) between the distribution used for generating the next offspring population based on the  $\mu$  selected individuals, and the distribution based on the true  $\mu$  best individuals that would have been chosen in the absence of noise. Empirical tests demonstrate the benefit of integrating sequential sampling into CMA-ES, and that the proposed KG technique specifically adapted to the needs of CMA-ES indeed outperforms a more straightforward application of KG.

# Changing or Keeping Solutions in Dynamic Optimization Problems with Switching Costs

Danial Yazdani, *LJMU*, Juergen Branke, *Warwick Business School*, Mohammad Nabi Omidvar, *CERCIA*, Trung Thanh Nguyen, *LJMU*, Xin Yao, *CERCIA* 

Dynamic optimization problems (DOPs) are problems that change over time. However, most investigations in this domain are focused on tracking moving optima (TMO) without considering the cost of switching from one solution to another when the environment changes. Robust optimization over time (ROOT) tries to address this shortcoming by finding solutions which remain acceptable for several environments. However, ROOT methods change solutions only when they become unacceptable. Indeed, TMO and ROOT are two extreme cases in the sense that in the former, the switching cost is considered zero and in the latter, it is considered very large. In this paper, we propose a new semi ROOT algorithm based on a new approach to switching cost. This algorithm changes solutions when: 1) the current solution is not acceptable and 2) the current solution is still acceptable but algorithm has found a better solution and switching is preferable despite the cost. The main objective of the proposed algorithm is to maximize the performance based on the fitness of solutions and their

switching cost. The experiments are done on modified moving peaks benchmark (mMPB) and the performance of the proposed algorithm alongside state-of-the-art ROOT and TMO methods is investigated.

Session: DETA2+THEORY3+GECH4: Best Papers Wednesday, July 18, 15:30-17:10, Conference Room Medium (2F)

#### Working Principles of Binary Differential Evolution

Weijie Zheng, Department of Computer Science and Technology, Tsinghua University, Guangwen Yang, Department of Computer Science and Technology, Tsinghua University, Benjamin Doerr, Ecole Polytechnique

We conduct a first fundamental analysis of the working principles of binary differential evolution (BDE), an optimization heuristic for binary decision variables that was derived by Gong and Tuson (2007) from the very successful classic differential evolution (DE) for continuous optimization. We show that unlike most other optimization paradigms, it is stable in the sense that neutral bit values are sampled with probability close to 1/2. This is generally a desirable property, however, it makes it harder to find the optima for decision variables with small influence on the objective function. This can result in an optimization time exponential in the dimension when optimizing simple symmetric functions like OneMax. On the positive side, BDE quickly detects and optimizes the most important decision variables. For example, dominant bits converge to the optimal value in time logarithmic in the population size. This leads to a very good performance in the situation where the decision variables have a differently strong influence on the result, in particular, when the target is not to find the optimal solution, but only a good one. Overall, our results indicate that BDE is an interesting optimization paradigm having characteristics significantly different from the classic evolutionary algorithms or EDAs.

# On the Runtime Analysis of Selection Hyper-Heuristics with Adaptive Learning Periods

Benjamin Doerr, *Ecole Polytechnique*, Andrei Lissovoi, *University of Sheffield*, Pietro S. Oliveto, *University of Sheffield*, John Alasdair Warwicker, *University of Sheffield* 

Selection hyper-heuristics are randomised optimisation techniques that select from a set of low-level heuristics which one should be applied in the next step of the optimisation process. Recently it has been proven that a Random Gradient hyper-heuristic optimises the LeadingOnes benchmark function in the best runtime achievable with any combination of its low-level heuristics, up to lower order terms. To achieve this runtime, the learning period  $\tau$ , used to evaluate the performance of the currently chosen heuristic, should be set appropriately, i.e., superlinear in the problem size but not excessively larger. In this paper we automate the hyper-heuristic further by allowing it to self-adjust the learning period  $\tau$  during the run. To achieve this we equip the algorithm with a simple self-adjusting mechanism, called 1-o(1) rule, inspired by the 1/5 rule traditionally used in continuous optimisation. We rigorously prove that the resulting hyper-heuristic solves LeadingOnes in optimal runtime by automatically adapting  $\tau$  and achieving a 1-o(1) ratio of the desired behaviour. Complementary experiments for realistic problem sizes show the value of  $\tau$  adapting as desired and that the hyper-heuristic with adaptive learning period outperforms the hyper-heuristic with fixed learning periods.

# **GP** — Genetic Programming

Session: GP1 Tuesday, July 17, 14:00-15:40, AV Study Room (2F)

# An Analysis of the Bias of Variation Operators of Estimation of Distribution Programming

Dirk Schweim, Johannes Gutenberg University Mainz, Franz Rothlauf, Johannes Gutenberg University Mainz

Estimation of distribution programming (EDP) replaces standard GP variation operators with sampling from a learned probability model. To ensure a minimum amount of variation in a population, EDP adds random noise to the probabilities of random variables. This paper studies the bias of EDP's variation operator by performing random walks. The results indicate that the complexity of the EDP model is high since the model is overfitting the parent solutions when no additional noise is being used. Adding only a low amount of noise leads to a strong bias towards small trees. The bias gets stronger with an increased amount of noise. Our findings do not support the hypothesis that sampling drift is the reason for the loss of diversity. Furthermore, we suggest using property vectors to study the bias of variation operators. Property vectors can represent the distribution of a population's relevant property, such as tree depth or tree size. The Bhattacharyya coefficient of two property vectors is a measure of the similarity of the two distributions of population properties. The results for EDP and standard GP illustrate that search bias can be assessed by representing distributions using property vectors and measuring their similarity using the Bhattacharyya coefficient.

# Towards Effective Semantic Operators for Program Synthesis in Genetic Programming

Stefan Forstenlechner, University College Dublin, David Fagan, University College Dublin, Miguel Nicolau, University College Dublin, Michael O'Neill, University College Dublin

The use of semantic information in genetic programming operators has shown major improvements in recent years, especially in the regression and boolean domain. As semantic information is domain specific, using it in other areas poses certain problems. Semantic operators require being adapted for the problem domain they are applied to. An attempt to create a semantic crossover for program synthesis has been made with rather limited success, but the results have provided insights about using semantics in program synthesis. Based on this initial attempt, this paper presents an improved version of semantic operators for program synthesis, which contains a small but significant change to the overall functionality, as well as a novel measure for the comparison of the semantics of subtrees. The results show that the improved semantic crossover is superior to the previous semantic operator in the program synthesis domain.

# Schema-based Diversification in Genetic Programming

Bogdan Burlacu, University of Applied Sciences Upper Austria, Michael Affenzeller, University of Applied Sciences Upper Austria

Population diversity is a key aspect of genetic programming (GP) and a major factor in algorithm performance. We propose a new schema-based approach for observing and steering the loss of diversity in GP populations. Schemas are generated from genealogical information and matched against the population using tree pattern matching. A mutation strategy based on schema frequencies is then applied on the population with the aim of improving the algorithm's exploratory behaviour. Our schema generation procedure exploits typical GP inheritance patterns and uses crossover root parents as basic structural templates, in which subtrees at cutpoint locations are replaced with wildcard nodes. We adopt a well known schema definition from the literature, namely Poli's hyperschema, and calculate schema frequencies using a query matching algorithm. We additionally employ a semantic similarity measure to maintain phenotypic diversity between individuals matching the same schema. We implement our diversification strategy as an extension to the offspring selection genetic algorithm and test it using different wildcard symbols and mutation rate update rules on a number of symbolic regression benchmark problems. The new algorithm called OSGP-S delivers improved results with minimal additional effort. A detailed discussion of our findings will be provided in the full paper.

# **Evolving Event-driven Programs with SignalGP**

Alexander Lalejini, *Michigan State University*, Charles Ofria, *Michigan State University* 

We present SignalGP, a new genetic programming (GP) technique designed to incorporate the event-driven programming paradigm into computational evolution's toolbox. Event-driven programming is a software design philosophy that simplifies the development of reactive programs by automatically triggering program modules (event-handlers) in response to external events, such as signals from the environment or messages from other programs. SignalGP incorporates these concepts by extending existing tag-based referencing techniques into an event-driven context. Both events and functions are labeled with evolvable tags; when an event occurs, the function with the closest matching tag is triggered. In this work, we apply SignalGP in the context of linear GP. We demonstrate the value of the event-driven paradigm using two distinct test problems (an environment coordination problem and a distributed leader election problem) by comparing SignalGP to variants that are otherwise identical, but must actively use sensors to process events or messages. In each of these problems, rapid interaction with the environment or other agents is critical for maximizing fitness. We also discuss ways in which SignalGP can be generalized beyond our linear GP implementation.

Session: GP2 Tuesday, July 17, 16:00-17:40, AV Study Room (2F)

# Adaptive Charting Genetic Programming for Dynamic Flexible Job Shop Scheduling

Su Nguyen, La Trobe University, Mengjie Zhang, Victoria University of Wellington, Kay Chen Tan, City University of Hong Kong, Damminda Alahakoon, La Trobe University

Genetic programming has been considered as a powerful approach to automated design of production scheduling heuristics in recent years. Flexible and variable representations allow genetic programming to discover very competitive scheduling heuristics to cope with a wide range of dynamic production environments. However, evolving sophisticated heuristics to handle multiple scheduling decisions can greatly increase the search space and poses a great challenge for genetic programming. To tackle this challenge, a new genetic programming algorithm is proposed to incrementally construct the map of explored areas in the search space and adaptively guide the search towards potential heuristics. In the proposed algorithm, growing neural gas and principal component analysis are applied to efficiently generate and update the map of explored areas based on the phenotypic characteristics of evolved heuristics. Based on the obtained map, a surrogate assisted model will help genetic programming determine which heuristics to be explored in the next generation. When applied to evolve scheduling heuristics for dynamic flexible job shop scheduling problems, the proposed algorithm shows superior performance as compared to the standard genetic programming algorithm. The analyses also show that the proposed algorithm can balance its exploration and exploitation better than the existing surrogate-assisted algorithm.

# Genetic Programming Approach to Learning Multipass Heuristics for Resource Constrained Job Scheduling

Su Nguyen, *La Trobe University*, Dhananjay Thiruvady, *Monash University*, Andreas T. Ernst, *Monash University*, Damminda Alahakoon, *La Trobe University* 

This study considers a resource constrained job scheduling problem arising in the mining supply chain. Jobs need to be scheduled on different machines satisfying a due time. If delayed, the jobs incur a penalty which is measured as a weighted tardiness. Furthermore, the jobs use up some proportion of an available resource and hence there are limits on multiple jobs executing at the same time. Due to complex constraints and a large number of decision variables, the existing solution methods, based on meta-heuristics and mathematical programming, are very time-consuming and mainly suitable for small-scale problem instances. We investigate a genetic programming approach to automatically designing reusable scheduling heuristics for this problem. A new representation and evaluation mechanisms are developed to provide the evolved heuristics with the abilities to effectively construct and refine schedules. The experiments show that the proposed approach is more efficient than other genetic programming algorithms previously developed for evolving scheduling heuristics. In addition, we find that the obtained heuristics can be effectively reused to solve unseen and large-scale instances and often find higher quality solutions compared to algorithms already known in the literature in significantly reduced time-frames.

### Neuro-Guided Genetic Programming: Prioritizing Evolutionary Search with Neural Networks

Paweł Liskowski, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems, Iwo Błądek, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems, Krzysztof Krawiec, Poznan University of Technology/Laboratory of Intelligent Decision Support Systems When search operators in genetic programming (GP) insert new instructions into programs, they usually draw them uniformly from the available instruction set. Prefering some instructions to others would require additional domain knowledge, which is typically unavailable. However, it has been recently demonstrated that the likelihoods of instructions' occurrence in a program can be reasonably well estimated from its input-output behavior using a neural network. We exploit this idea to bias the choice of instructions used by search operators in GP. Given a large sample of programs and their input-output behaviors, a neural network is trained to predict the presence of individual instructions. When applied to a new program synthesis task, the network is first queried on the set of examples that define the task, and the obtained probabilities determine the frequencies of using instructions in initialization and mutation operators. This priming leads to significant improvements of the odds of successful synthesis on a range of benchmarks.

# Measuring Evolvability and Accessibility using the Hyperlink-Induced Topic Search Algorithm

Kyle Nickerson, *Memorial University*, Yuanzhu Chen, *Memorial University*, Feng Wang, *Wuhan University*, Ting Hu, *Memorial University* 

The redundant mapping from genotype to phenotype is common in evolutionary algorithms, where multiple genotypes can map to the same phenotype. Such a redundancy has been suggested to make an evolutionary system robust as well as evolvable. However, the impact of the redundant genotype-to-phenotype mapping and its resulted robustness and evolvability have not been well characterized quantitatively. In this article, we used a Boolean linear genetic programming system to construct a weighted and directed phenotype network, where vertices are phenotypes and a weighted link represents the number of possible point mutations that can transition genotypes from one phenotype to another. The direction of the links ensures moving from less fit phenotypes to fitter or equally fit ones. We used two fitness functions to investigate how it influences the network structure. Then we employed the Hyperlink-Induced Topic Search (HITS) algorithm to quantitatively characterize the evolvability and accessibility of phenotypes in the network. We found more robust phenotypes are both more evolvable and accessible. Our results help elucidate the effects of redundant mapping in evolution and the relationship of robustness, evolvability, and accessibility in evolutionary systems.

Session: GP3: Best Papers Wednesday, July 18, 10:40-12:20, Conference Room Medium (2F)

## Program Synthesis using Uniform Mutation by Addition and Deletion

Thomas Helmuth, *Hamilton College*, Nicholas Freitag McPhee, *University of Minnesota, Morris*, Lee Spector, *Hampshire College* 

Most genetic programming systems use mutation and crossover operators to create child programs from selected parent programs. Typically, the mutation operator will replace a randomly chosen subprogram in the parent with a new, randomly generated subprogram. In systems with linear genomes, a uniform mutation operator can be used that has some probability of replacing any particular gene with a new, randomly chosen gene. In this paper, we present a new uniform mutation operator called Uniform Mutation by Addition and Deletion (UMAD), which first adds genes with some probability before or after every existing gene, and then deletes random genes from the resulting genome. In UMAD it is not necessary that the new genes replace old genes, as the additions and deletions can occur in different locations. We find that UMAD, with relatively high rates of addition and deletion, results in significant increases in problem-solving performance on a range of program synthesis benchmark problems. In our experiments, we compare this method to a variety of alternatives, showing that it equals or outperforms all of them. We explore this new mutation operator and other well-performing high-rate mutation schemes to determine what traits are crucial to improved performance.

# Solving the Exponential Growth of Symbolic Regression Trees in Geometric Semantic Genetic Programming

Joao Francisco Barreto da Silva Martins, Universidade Federal de Minas Gerais, Luiz Otavio Vilas Boas Oliveira, Universidade Federal de Minas Gerais, Luis Fernando Miranda, Universidade Federal de Minas Gerais, Felipe Casadei, Universidade Federal de Minas Gerais, Gisele Lobo Pappa, Universidade Federal de Minas Gerais

Advances in Geometric Semantic Genetic Programming

(GSGP) have shown that this variant of Genetic Programming (GP) reaches better results than its predecessor for supervised machine learning problems, particularly in the task of symbolic regression. However, by construction, the geometric semantic crossover operator generates individuals that grow exponentially with the number of generations, resulting in solutions with limited use. This paper presents a new method for individual simplification named GSGP with Reduced trees (GSGP-Red). GSGP-Red works by expanding the functions generated by the geometric semantic operators. The resulting expanded function is guaranteed to be a linear combination that, in a second step, has its repeated structures and respective coefficients aggregated. Experiments in 12 real-world datasets show that it is not only possible to create smaller and completely equivalent individuals in competitive computational time, but also to reduce the number of nodes composing them by 58 orders of magnitude, on average.

#### Where are we now? A large benchmark study of recent symbolic regression methods

Patryk Orzechowski, *University of Pennsylvania*, William La Cava, *University of Pennsylvania*, Jason H. Moore, *University of Pennsylvania* 

In this paper we provide a broad benchmarking of recent genetic programming approaches to symbolic regression in the context of state of the art machine learning approaches. We use a set of nearly 100 regression benchmark problems culled from open source repositories across the web. We conduct a rigorous benchmarking of four recent symbolic regression approaches as well as nine machine learning approaches from scikit-learn. The results suggest that symbolic regression performs strongly compared to state-of-the-art gradient boosting algorithms, although in terms of running times is among the slowest of the available methodologies. We discuss the results in detail and point to future research directions that would allow symbolic regression to gain wider adoption in the machine learning community.

# HOP — Hot Off the Press

Session: HOP1 Wednesday, July 18, 10:40-12:20, Conference Room C (3F)

#### Better Runtime Guarantees Via Stochastic Domination (Hot-off-the-Press Track at GECCO 2018)

Benjamin Doerr, Ecole Polytechnique

Apart from few exceptions, the mathematical runtime analysis of evolutionary algorithms is mostly concerned with expected runtimes. In this work, we argue that stochastic domination is a notion that should be used more frequently in this area. Stochastic domination allows to formulate much more informative performance guarantees than the expectation alone, it allows to decouple the algorithm analysis into the true algorithmic part of detecting a domination
statement and probability theoretic part of deriving the desired probabilistic guarantees from this statement, and it allows simpler and more natural proofs. As particular results, we prove a fitness level theorem which shows that the runtime is dominated by a sum of independent geometric random variables, we prove tail bounds for several classic problems, and we give a short and natural proof for Witt's result that the runtime of any  $(\mu, p)$  mutationbased algorithm on any function with unique optimum is subdominated by the runtime of a variant of the (1+1) EA on the OneMax function. This abstract for the Hot-off-the-Press track of GECCO 2018 summarizes work that has appeared in Benjamin Doerr. Better runtime guarantees via stochastic domination. In Evolutionary Computation in Combinatorial Optimization (EvoCOP 2018), pages 1-17. Springer, 2018.

#### Towards Automation & Augmentation of the Design of Schedulers for Cellular Communications Networks

Michael Fenton, *Corvil Ltd*, David Fagan, *University College Dublin* 

Evolutionary Computation is used to automatically evolve small cell schedulers on a realistic simulation of a 4G-LTE heterogeneous cellular network. Evolved schedulers are then further augmented by human design to improve robustness. Extensive analysis of evolved solutions and their performance across a wide range of metrics reveals evolution has uncovered a new human-competitive scheduling technique which generalises well across cells of varying sizes. Furthermore, evolved methods are shown to conform to accepted scheduling frameworks without the evolutionary process being explicitly told the form of the desired solution. Evolved solutions are shown to outperform a human-engineered state-of-the-art benchmark by up to 50%. Finally, the approach is shown to be flexible in that tailored algorithms can be evolved for specific scenarios and corner cases, allowing network operators to create unique algorithms for different deployments, and to postpone the need for costly hardware upgrades. This work appears in full in Fenton et al., "Towards Automation & Augmentation of the Design of Schedulers for Cellular Communications Networks", Evolutionary Computation, 2018. DOI 10.1162/evco\_a\_00221.

### Summary of Evolutionary Computation for Wind Farm Layout Optimization

Dennis Wilson, *IRIT*, Silvio Rodrigues, *Delft University of Technology*, Carlos Segura, *Center for Research in Mathematics*, Ilya Loshchilov, *University of Freiburg*, Frank Hutter, *University of Freiburg*, Guillermo López Buenfil, *Center for Research in Mathematics*, Ahmed Kheiri, *Lancaster University*, Ed Keedwell, *University of Exeter*, Mario Ocampo Pineda, *Center for Research in Mathematics*, Ender Ozcan, *University of Nottingham*, Sergio Ivvan Valdez Peña, *Cen-*

ter for Research in Mathematics, Brian Goldman, Michigan State University, Salvador Botello Rionda, Center for Research in Mathematics, Arturo Hernández Aguirre, Center for Research in Mathematics, Kalyan Veeramachaneni, MIT, Sylvain Cussat-Blanc, IRIT

This paper presents the results of the second edition of the Wind Farm Layout Optimization Competition, which was held at the 22nd Genetic and Evolutionary Computation COnference (GECCO) in 2015. During this competition, competitors were tasked with optimizing the layouts of five generated wind farms based on a simplified cost of energy evaluation function of the wind farm layouts. Online and offline APIs were implemented in C++, Java, Matlab and Python for this competition to offer a common framework for the competitors. The top four approaches out of eight participating teams are presented in this paper and their results are compared. All of the competitors' algorithms use evolutionary computation.

### Parameter-less (Meta)heuristics for Vehicle Routing Problems

### Jakub Nalepa, *Silesian University of Technology*, Miroslaw Blocho, *Silesian University of Technology*

Solving rich vehicle routing problems (VRPs) is a vital research topic due to their wide applicability. Although there exist various (meta)heuristics to tackle VRPs, most of them require a practitioner to tune their parameters before the execution. It is challenging in practice, since different algorithm variants often perform well for different scenarios. In this work, we present our adaptive heuristics for this task, in which we benefit from the adaptation schemes executed before the optimization. Extensive experiments backed up with statistical tests revealed that our heuristics is automatically adapted to effectively solve a given transportation problem, and retrieve routing schedules of the state-of-the-art quality.

Session: HOP2 Wednesday, July 18, 15:30-17:10, Conference Room C (3F)

#### Approximating Complex Arithmetic Circuits with Formal Error Guarantees: 32-bit Multipliers Accomplished

Milan Češka, Brno University of Technology, Jiří Matyáš, Brno University of Technology, Vojtech Mrazek, Brno University of Technology, Lukas Sekanina, Brno University of Technology, Zdenek Vasicek, Brno University of Technology, Tomas Vojnar, Brno University of Technology

We present a novel method allowing one to approximate complex arithmetic circuits with formal guarantees on the approximation error. The method integrates in a unique way formal techniques for approximate equivalence checking into a search-based circuit optimisation algorithm. The key idea of our approach is to employ a novel search strategy that drives the search towards promptly verifiable approximate circuits. The method was implemented within the ABC tool and extensively evaluated on functional approximation of multipliers (with up to 32-bit operands) and adders (with up to 128-bit operands). Within a few hours, we constructed a high-quality Pareto set of 32-bit multipliers providing trade-offs between the circuit error and size. This is for the first time when such complex approximate circuits with formal error guarantees have been derived, which demonstrates an outstanding performance and scalability of our approach compared with existing methods that have either been applied to the approximation of multipliers limited to 8-bit operands or statistical testing has been used only. Our approach thus significantly improves capabilities of the existing methods and paves a way towards an automated design process of provably-correct circuit approximations.

### Evolutionary Computation: An Investigation of Parameter Space

Moshe Sipper, University of Pennsylvania, Weixuan Fu, University of Pennsylvania, Karuna Ahuja, University of Pennsylvania, Jason H. Moore, University of Pennsylvania

Through an extensive series of experiments over multiple evolutionary algorithm implementations and 25 problems we showed that parameter space tends to be rife with viable parameters, somewhat in contrast with common lore.

#### Energy-consumption prediction of Genetic Programming Algorithms using a Fuzzy Rule-Based System

Franciso Chavez de la O, *Universidad de Extremadura*, Francisco Fernandez de Vega, *Universidad de Extremadura*, Josefa Diaz-Alvarez, *Universidad de Extremadura*, Juan A. Garcia, *Universidad de Extremadura*, Francisco J. Rodriguez, *Universidad de Extremadura*, Pedro A. Castillo, *Universidad de Granada* 

Energy awareness has gained momentum over the last decade in the software industry, as well as in environmentally concious society. Thus, algorithm designers and programmers are paying increasing attention this issue, particularly when handheld devices are considered, given their battery-consuming characteristics. When we focus on Evolutionary Algorithms, few works have attempted to study the relationship between the main features of the algorithm, the problem to be solved and the underlying hardware where it runs. This work presents a preliminary analysis and modeling of energy consumption of EAs. We try to predict it by means of a fuzzy rule-based system, so that different devices are considered as well as a number of problems and Genetic Programming parameters. Experimental results performed show that the proposed model can predict energy consumption with very low error values.

## Deep Statistical Comparison of Meta-heuristic Stochastic Optimization Algorithms

Tome Eftimov, *Jožef Stefan Institute*, Peter Korošec, *Jožef Stefan Institute*, Barbara Koroušić Seljak, *Jožef Stefan Institute* 

In this paper a recently proposed approach for making a statistical comparison of meta-heuristic stochastic optimization algorithms is presented. The main contribution of this approach is that the ranking scheme is based on the whole distribution, instead of using only one statistic to describe the distribution, such as average or median. Experimental results showed that our approach gives more robust results compared to state-of-the-art approaches in case when the results are affected by outliers or by statistical insignificant differences that could exist between data values.

Session: HOP3 Thursday, July 19, 09:00-10:40, Conference Room C (3F)

### On Botnet Detection with Genetic Programming under Streaming Data, Label Budgets and Class Imbalance

Sara Khanchi, *Dalhousie University*, Ali Vahdat, *Huawei Technologies, Noah's Ark Lab.*, Malcolm Heywood, *Dalhousie University*, Nur Zincir-Heywood, *Dalhousie University* 

Botnets represent a widely deployed framework for remotely infecting and controlling hundreds of networked computing devices for malicious ends. Traditionally, detection of Botnets from network data using machine learning approaches is framed as an offline, supervised learning activity. However, in practice both normal behaviours and Botnet behaviours represent non-stationary processes in which there are continuous developments to both as new services/applications and malicious behaviours appear. This work formulates the task of Botnet detection as a streaming data task in which finite label budgets, class imbalance and incremental/online learning predominate. We demonstrate that effective Botnet detection is possible for label budgets as low as 0.5% when an active learning approach is adopted for genetic programming (GP) streaming data analysis. The full article appears as S. Khanchi et al., (2018) "On Botnet Detection with Genetic Programming under Streaming Data, Label Budgets and Class Imbalance" in Swarm and Evolutionary Computation, 39:139-140. https://doi.org/10.1016/j. swevo.2017.09.008

### A multidimensional genetic programming approach for identifying epsistatic gene interactions

William La Cava, University of Pennsylvania, Sara Silva, University of Lisbon, Kourosh Danai, University of Massachusetts Amherst, Leonardo Vanneschi, Universidade Nova de Lisboa, Jason H. Moore, University of Pennsylvania, Lee Spector, Hampshire College, University of Massachusetts Amherst

We propose a novel methodology for binary and multiclass classification that uses genetic programming to construct features for a nearest centroid classifier. The method, coined M4GP, improves upon earlier approaches in this vein (M2GP and M3GP) by simplifying the program encoding, using advanced selection methods, and archiving solutions during the run. In our recent paper, we test this stategy against traditional GP formulations of the classification problem, showing that this framework outperforms boolean and floating point encodings. In comparison to several machine learning techniques, M4GP achieves the best overall ranking on benchmark problems. We then compare our algorithm against state-ofthe-art machine learning approaches to the task of disease classification using simulated genetics datasets with up to 5000 features. The results suggest that our proposed approach performs on par with the best results in literature with less computation time, while producing simpler models.

#### Standard Steady State Genetic Algorithms Can Hillclimb Faster than Evolutionary Algorithms using Standard Bit Mutation

### Dogan Corus, *The University of Sheffield*, Pietro S. Oliveto, *The University of Sheffield*

Genetic Algorithms (GAs) evolve a population of candidate solutions obtained by the recombination of individuals of the current generation. Despite their popularity, providing natural examples where standard GAs provably outperform more traditional mutation-based heuristics has turned out to be a challenging task. We rigorously prove that a standard steady state ( $\mu$ +1) GA outperforms any evolutionary algorithm that relies only on Standard Bit Mutation (SBM) as variation operator, for hillclimbing the classical OneMax benchmark function. In particular, we show that the GA is 25% faster by providing an upper bound of (3/4)en In n on its expected runtime versus the en In n required by any algorithm using only SBM. To achieve the result, we devise a mathematical framework which extends the classical artificial fitness levels method by coupling each level with a Markov chain. This Markov chain allows to bound the improvement probabilities of the current population based on its diversity. We show how larger populations sustain diversity for a longer time, giving crossover more chances of finding improvements. Since diversity is created via mutation, higher rates than the standard 1/n lead to better runtime bounds. This paper summarises the

work in [Corus, Oliveto - IEEE TEVC 2017].

### Constraint Handling Guided by Landscape Analysis in Combinatorial and Continuous Search Spaces

Katherine Malan, University of South Africa, Irene Moser, Swinburne University of Technology

We present a novel method allowing one to approximate complex arithmetic circuits with formal guarantees on the approximation error. The method integrates in a unique way formal techniques for approximate equivalence checking into a search-based circuit optimisation algorithm. The key idea of our approach is to employ a novel search strategy that drives the search towards promptly verifiable approximate circuits. The method was implemented within the ABC tool and extensively evaluated on functional approximation of multipliers (with up to 32-bit operands) and adders (with up to 128-bit operands). Within a few hours, we constructed a high-quality Pareto set of 32-bit multipliers providing trade-offs between the circuit error and size. This is for the first time when such complex approximate circuits with formal error guarantees have been derived, which demonstrates an outstanding performance and scalability of our approach compared with existing methods that have either been applied to the approximation of multipliers limited to 8-bit operands or statistical testing has been used only. Our approach thus significantly improves capabilities of the existing methods and paves a way towards an automated design process of provably-correct circuit approximations.

Session: HOP4 Thursday, July 19, 09:00-10:40, Conference Room D (3F)

### ED-LS - A Heuristic Local Search for the Firefighter Problem

#### Krzysztof Michalak, Wroclaw University of Economics

This abstract summarizes the results reported in the paper "ED-LS - A heuristic local search for the multiobjective Firefighter Problem". In this paper a new method of performing the local search for the multiobjective Firefighter Problem (FFP) is proposed. The proposed method reduces the size of the neighbourhood in which the local search looks for improved solutions by using heuristics to decide which solutions in the neighbourhood should be visited. In the paper the proposed local search method is used for improving solutions produced by two commonly used evolutionary algorithms: the MOEA/D and the NSGA-II. In the experiments the proposed method outperformed both the evolutionary algorithms without any local search as well as the algorithms combined with the local search visiting all solutions in the neighbourhood. Comparison to the local search selecting the same number of solutions as the ED-LS, but at random shows that the proposed heuristics are indeed selecting good solutions to visit. Presented research can be extended in further studies. One possibility is to study in-depth how to balance computational resources between the evolutionary and local search algorithms. Second possibility is to employ more advanced models instead of the heuristics used in the paper.

#### Detection of Minimum Biomarker Features via Bi-level Optimization Framework by Nested Hybrid Differential Evolution

Kai-Cheng Hsu, Department of Neurology, National Taiwan University Hospital, Feng-Sheng Wang, Department of Chemical Engineering, National Chung Cheng University

Support vector machine (SVM) using full features is a common approach for classifying diseases in healthcare systems. However, little literature reported to use it towards determining minimum features of biomarkers. This study introduced a bilevel mixed-integer optimization framework to detect minimum biomarker features for SVM. We proposed the two-population nested hybrid differential evolution (NHDE) to solve the problem. In case studies, two dominant biomarkers were found. The two-population NHDE algorithm was more efficient to achieve minimum biomarkers compared with one-population NHDE and traditional genetic algorithm.

#### Employing Multi-Objective Search to Enhance Reactive Test Generation and Prioritization for Testing Industrial Cyber-Physical Systems

Aitor Arrieta, Mondragon Univeristy, Shuai Wang, Testify, Urtzi Markiegi, Mondragon Univeristy, Goiuria Sagardui, Mondragon Univeristy, Leire Etxeberria, Mondragon Univeristy

Cyber-Physical Systems (CPSs) integrate digital cyber computations with physical processes. Testing these systems in a time consuming task. Furthermore, the input space for test cases is huge, and several issues need to be considered when generating them. In [2] we tackle the test case generation and prioritization problem for CPSs. The approach is empirically evaluated with four different case studies from different domains and complexities. Five pareto-based algorithms were evaluated and overall, the NSGA-II algorithm outperformed the remaining algorithms. The NSGA-II algorithm improved RS by 43.8% on average for each objective and 49.25% for the Hypervolume quality indicator.

### **RWA** — Real World Applications

#### Session: RWA1

Tuesday, July 17, 10:40-12:20, Training Room 3 (2F)

#### A Genetic Programming based Iterated Local Search for Software Project Scheduling

## Nasser R. Sabar, La Trobe University, Ayad Turky, RMIT University, Andy Song, RMIT University

Project Scheduling Problem (PSP) plays a crucial role in large-scale software development, directly affecting the productivity of the team and on-time delivery of software projects. PSP concerns with the decision of who does what and when during the software project lifetime. PSP is a combinatorial optimisation problem and inherently NPhard, indicating that approximation algorithms are highly advisable for real-world instances which are often large in size. In this work, we propose an iterated local search (ILS) algorithm for PSP. ILS is a simple, yet effective for combinatorial optimisation problems. However, its performance highly depends on its perturbation operator which is to guide the search to new starting points. Hereby, we propose a Genetic Programming (GP) approach to evolve perturbation operators based on a range of low-level operators and rules. The evolution process will go along with the iterated search process and supply better operators continuously. The GP based ILS algorithm is tested using a set of well known PSP benchmark instances and compared with state-of-the-art algorithms. The experimental results demonstrated the effectiveness of GP generated perturbation operators as they can outperform existing leading methods.

### Multi-Objective Journey Planning Under Uncertainty: A Genetic Approach

Mohammad Haqqani, *RMIT University*, Xiaodong Li, *RMIT University*, Xinghuo Yu, *RMIT University* 

Multi-modal journey planning, which allows multiple modes of transport to be used within a single trip, is becoming increasingly popular, due to a strong practical interest and an increasing availability of data. In real life situations, transport networks often involve uncertainty, and yet, most approaches assume a deterministic environment, making plans more prone to failures such as major delays in the arrival or waiting for a long time at stations. In this paper, we tackle the multi-objective stochastic journey planning problem in multi-modal transportation networks. The problem is modeled as a Markov decision process with two objective functions: expected arrival time and journey convenience. We develop a GA-based MDP solver as a baseline search method for producing optimal policies for traveling from a given origin to a given destination. Our empirical evaluation uses Melbourne transportation network using probabilistic density functions for estimated departure/arrival time of the trips. Numerical results suggest that the proposed method is effective for practical purposes and provide strong evidence in favor of switching from deterministic to non-deterministic planning.

### Evolving Boolean Functions for Fast and Efficient Randomness Testing

Vojtech Mrazek, Brno University of Technology, Marek Sýs, Masaryk University Brno, Zdenek Vasicek, Brno University of Technology, Lukas Sekanina, Brno University of Technology, Vashek Matyas, Masaryk University Brno

The security of cryptographic algorithms (such as block ciphers and hash functions) is often evaluated in terms of their output randomness. This paper presents a novel method for the statistical randomness testing of cryptographic primitives, which is based on the evolutionary construction of the so-called randomness distinguisher. Each distinguisher is represented as a Boolean polynomial in the Algebraic Normal Form. The previous approach, in which the distinguishers were developed in two phases by means of the brute-force method, is replaced with a more scalable evolutionary algorithm (EA). On seven complex datasets, this EA provided distinguishers of the same quality as the previous approach, but the execution time was in practice reduced 40 times. This approach allowed us to perform a more efficient search in the space of Boolean distinguishers and to obtain more complex high-quality distinguishers than the previous approach.

#### Estimating Cement Compressive Strength from Microstructural Images using GEP with Probabilistic Polarized Similarity Weight Tournament Selection

Liangliang Zhang, University of Jinan, Xinya Yue, University of Jinan, Lin Wang, University of Jinan, Bo Yang, University of Jinan

The safety of building facilities is directly affected by the physical properties of cement, among which cement compressive strength plays the most important role in evaluating them. Therefore, the investigation of cement compressive strength is helpful in improving the cement properties. Traditionally, chemical composition, curing condition, and water-cement ratio are used to estimate the strength of cement paste. However, this approach is limited by the extreme complexity of physical changes and chemical reactions during cement hydration. Considering the cement microstructure contains information related to strength microscopically, microtomography, which can image three-dimensional microstructure, provides scientists with another way to study cement compressive strength nondestructively. This study estimates cement compressive strength using microstructure features extracted from microtomography images and gene expression programming. A probabilistic polarized similarity weight tournament selection operator is also proposed to balance the exploration and exploitation. Experimental results corroborate that the obtained relationship possesses higher estimation accuracy, good interpretability and the evolutionary capability performs well.

Session: RWA2: Best Papers Tuesday, July 17, 14:00-15:40, Conference Room Medium (2F)

## Genetic Programming for Tuberculosis Screening from Raw X-ray Images

Armand Rashad Burks, *Michigan State University*, William Fitzgerald Punch, *Michigan State University* 

Genetic programming has been successfully applied to several real-world problem domains. One such application area is image classification, wherein genetic programming has been used for a variety of problems such as breast cancer detection, face detection, and pedestrian detection, to name a few. We present the use of genetic programming for detecting active tuberculosis in raw X-ray images. Our results demonstrate that genetic programming evolves classifiers that achieve promising accuracy results compared to that of traditional image classification techniques. Our classifiers do not require pre-processing, segmentation, or feature extraction beforehand. Furthermore, our evolved classifiers process a raw X-ray image and return a classification orders of magnitude faster than the reported times for traditional techniques.

### Benchmarking Evolutionary Computation Approaches to Insider Threat Detection

Duc C. Le, *Dalhousie University*, Sara Khanchi, *Dalhousie University*, Nur Zincir-Heywood, *Dalhousie University*, Malcolm Heywood, *Dalhousie University* 

Insider threat detection represents a challenging problem to companies and organizations where malicious actions are performed by authorized users. This is a highly skewed data problem, where the huge class imbalance makes the adaptation of learning algorithms to the real world context very difficult. In this work, applications of genetic programming (GP) and stream active learning are evaluated for insider threat detection. Linear GP with lexicase/multi-objective selection is employed to address the problem under a stationary data assumption. Moreover, streaming GP is employed to address the problem under a non-stationary data assumption. Experiments conducted on a publicly available corporate data set show the capability of the approaches in dealing with extreme class imbalance, stream learning and adaptation to the real world context.

#### A Detailed Comparison of Meta-Heuristic Methods for Optimising Wave Energy Converter Positions

Mehdi Neshat, Optimization and Logistics Group, School of Computer Science, The University of Adelaide, Bradley Alexander, Optimization and Logistics Group, School of Computer Science, The University of Adelaide, Markus Wagner, Optimization and Logistics Group, School of Computer Science, The University of Adelaide, Yuanzhong Xia, Optimization and Logistics Group, School of Computer Science, The University of Adelaide

In order to address environmental concerns and meet growing energy demand the development of green energy technology has expanded tremendously. One of the most promising types of renewable energy is ocean wave energy. While there has been strong research in the development of this technology to date there remain a number of technical hurdles to overcome. This research explores a type of wave energy converter (WEC) called a buoy. This work models a power station as an array of fully submerged three-tether buoys. The target problem of this work is to place buoys in a size-constrained environment to maximise power output. This article improves prior work by using a more detailed model and exploring the search space using a wide variety of search heuristics. We show that a hybrid method of stochastic local search combined with Nelder-Mead Simplex direct search performs better than previous search techniques.

Session: RWA3

Tuesday, July 17, 16:00-17:40, Training Room 3 (2F)

#### Informed Mutation Operator using Machine Learning for Optimization in Epidemics Prevention

#### Krzysztof Michalak, Wroclaw University of Economics

This paper concerns using evolutionary algorithms for optimization in epidemics prevention. Spreading of the epidemic is simulated on a graph and the goal of optimization is to determine which vertices in the graph to vaccinate in order to minimize the number of vertices affected by the epidemic. Decisions whether to vaccinate a vertex or not are represented using a binary genotype. In this paper an informed mutation operator is introduced. The presented operator uses machine learning approach for determining which positions in the genotype to flip. The learning model used in the paper is a neural network trained using graphbased features of the vertices (such as a vertex degree) and the information how often on average a given vertex is infected. Once trained, the learning model helps determine which positions in the current solution to mutate. Results presented in the paper suggest that the proposed informed operator improves the ability of the evolutionary algorithm to produce good solutions to the tackled problem. Interestingly, a very good generalization was achieved. The model built using problem instances with 1000 vertices in the graph improved solutions for problem instances with up to 20000 vertices.

# Symbolic Regression and Feature Construction with GP-GOMEA applied to Radiotherapy Dose Reconstruction of Childhood Cancer Survivors

Marco Virgolin, Centrum Wiskunde & Informatica, Tanja Alderliesten, Academic Medical Center, Arjan Bel, Academic Medical Center, Cees Witteveen, Delft University of Technology, Peter A.N. Bosman, Centrum Wiskunde & Informatica (CWI)

The recently introduced Gene-pool Optimal Mixing Evolutionary Algorithm for Genetic Programming (GP-GOMEA) has been shown to find much smaller solutions of equally high quality compared to other state-of-the-art GP approaches. This is an interesting aspect as small solutions better enable human interpretation. In this paper, an adaptation of GP-GOMEA to tackle real-world symbolic regression is proposed, in order to find small yet accurate mathematical expressions, and with an application to a problem of clinical interest. For radiotherapy dose reconstruction, a model is sought that captures anatomical patient similarity. This problem is particularly interesting because while features are patient-specific, the variable to regress is a distance, and is defined over patient pairs. We show that on benchmark problems as well as on the application, GP-GOMEA outperforms variants of standard GP. To find even more accurate models, we further consider an evolutionary meta learning approach, where GP-GOMEA is used to construct small, yet effective features for a different machine learning algorithm. Experimental results show how this approach significantly improves the performance of linear regression, support vector machines, and random forest, while providing meaningful and interpretable features.

#### Better and Faster Catheter Position Optimization in HDR Brachytherapy for Prostate Cancer using Multi-Objective Real-Valued GOMEA

Marjolein C. van der Meer, Academic Medical Center, Bradley R. Pieters, Academic Medical Center, Yury Niatsetski, Elekta, Tanja Alderliesten, Academic Medical Center, Arjan Bel, Academic Medical Center, Peter A.N. Bosman, Centrum Wiskunde & Informatica The recently-introduced Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) family has been shown to be capable of excellent performance on academic benchmark problems, outperforming other state-of-the-art EAs, especially when efficient partial evaluations are possible. This holds true also for the latest extension, the Multi-Objective Real-Valued GOMEA (MO-RV-GOMEA). In this paper, we apply MO-RV-GOMEA to the real-world multi-objective optimization problem of catheter placement in High-Dose-Rate (HDR) brachytherapy for prostate cancer, a problem that is non-trivial to solve and has high real-world importance and relevance. Due to the underlying geometric structure of the real-valued variables, partial evaluations can be performed, allowing MO-RV-GOMEA to exploit this structure. The performance of MO-RV-GOMEA is tested on three real-world patient cases and compared to a recent state-of-the-art mixed-integer EA that is aimed at a restricted version of the problem. We find that with MO-RV-GOMEA better solutions can be found much faster, making our proposed approach much more realistic to be used in clinical practice, and enabling new insights into both catheter placement for prostate brachytherapy and on objectives used for automated treatment planning. First results indicate that richer problem models are needed to better match real-world clinical preferences.

#### Large-Scale Parallelization of Partial Evaluations in Evolutionary Algorithms for Real-World Problems

Anton Bouter, Centrum Wiskunde & Informatica, Tanja Alderliesten, Academic Medical Center, Arjan Bel, Academic Medical Center, Cees Witteveen, Delft University of Technology, Peter A.N. Bosman, Centrum Wiskunde & Informatica

The importance and potential of Gray-Box Optimization (GBO) with evolutionary algorithms is becoming increasingly clear lately, both for benchmark and real-world problems. We consider the GBO setting where partial evaluations are possible, meaning that sub-functions of the evaluation function are known and can be exploited to improve optimization efficiency. In this paper, we show that the efficiency of GBO can be greatly improved through largescale parallelism, exploiting the fact that each evaluation function requires the calculation of a number of independent sub-functions. This is especially interesting for realworld problems where often the majority of the computational effort is spent on the evaluation function. Moreover, we show how the best parallelization technique largely depends on factors including the number of sub-functions and their required computation time, revealing that for different parts of the optimization the best parallelization technique should be selected based on these factors. As an illustration, we show how large-scale parallelization can be applied to optimization of high-dose-rate brachytherapy treatment plans for prostate cancer. We find that use of a modern Graphics Processing Unit (GPU) was the most efficient parallelization technique in all realistic scenarios, leading to substantial speed-ups up to a factor of 73.

Session: RWA4 Wednesday, July 18, 10:40-12:20, Training Room 3 (2F)

#### Rate-Setter : Roadmap for Faster, Safer, and Better Platform Train Interface Design and Operation using Evolutionary Optimization

David Fletcher, The University of Sheffield, Rob Harrison, The University of Sheffield, Twin Karmakharm, The University of Sheffield, Paul Richmond, The University of Sheffield, Samadhi Nallaperuma, The University of Sheffield There is a challenge ahead in the rail industry to accommodate increased demand. Time spent at the platform train interface (PTI) as passengers board and alight, rather than on the move, represents a limitation on system capacity. To overcome this, we propose Rate-Setter: an evolutionary optimizer for the first time that provides more effective PTI design choices based on passenger flow time and safety. An agent based passenger simulation model validated with CCTV footage is employed for fitness evaluation. The initial results provide guidelines not only for future PTI designs but also for retro-fit designs to existing infrastructure such as diminishing returns of PTI features for the considered scenarios. Furthermore, it is observed that the proposed optimal PTI designs could significantly reduce the flow time for the case examined. Results show that retro-fit designs could reduce the flow time in the range of 10%-35%.

#### Comparison of Parallel Surrogate-Assisted Optimization Approaches

Frederik Rehbach, *TH Köln*, Martin Zaefferer, *TH Köln*, Jörg Stork, *TH Köln*, Thomas Bartz-Beielstein, *TH Köln* 

The availability of several CPU cores on current computers enables parallelization and increases the computational power significantly. Optimization algorithms have to be adapted to exploit these highly parallelized systems and evaluate multiple candidate solutions in each iteration. This issue is especially challenging for expensive optimization problems, where surrogate models are employed to reduce the load of objective function evaluations. This paper compares different approaches for surrogate model-based optimization in parallel environments. Additionally, an easy to use method, which was developed for an industrial project, is proposed. All described algorithms are tested with a variety of standard benchmark functions. Furthermore, they are applied to a real-world engineering problem, the electrostatic precipitator problem. Expensive computational fluid dynamics simulations are required to estimate the performance of the precipitator. The task is to optimize a gas-distribution system so that a desired velocity distribution is achieved for the gas flow throughout the precipitator. The vast amount of possible configurations leads to a complex discrete valued optimization problem. The experiments indicate that a hybrid approach works best, which proposes candidate solutions based on different surrogate model-based infill criteria and evolutionary operators.

### Surrogate assisted optimization of particle reinforced metal matrix composites

Lorenzo Gentile, *TH Köln - University of Applied Sciences*, Martin Zaefferer, *TH Köln - University of Applied Sciences*, Dario Giugliano, *University of Strathclyde*, Haofeng Chen, *University of Strathclyde*, Thomas Bartz-Beielstein, *TH Köln - University of Applied Sciences* 

Surrogate Model Based Optimization (SMBO) is an established technique for handling computationally expensive optimization problems. One important application is the optimization of Particle Reinforced Metal Matrix Composites (PRMMCs), multi-phase materials are gaining attention for the capability to be optimized targeting the request for more performing structures. Their performance is strongly affected by the microscale. Current manufacturing techniques have limited control over the distribution of reinforcing particles, and are subject to considerable uncertainty. Moreover, the simulation and optimization of PRMMCs requires significant computational effort. We propose an approach that tackles the problem of optimizing the characteristics of PRMMCs subject to uniaxial load, by improving the particles' spatial distribution. The optimization problem is split into a bilevel problem: The upperlevel optimization aims to find the particle distribution parameters which maximize the PRMMC limit load. Due to potentially infeasible distributions, the lower-level problem attempts to create a particle placement that reflects the specifications of an upper-level candidate solution. We employed an SMBO approach that combines Kriging, Sequential Parameter Optimization, and a Genetic Algorithm. Experimental results indicate that our approach can find promising solutions within few evaluations, handles uncertainty, and allows insight into the most important effects on the limit load.

#### A Rolling Window with Genetic Algorithm Approach to Sorting Aircraft for Automated Taxi Routing

Alexander Edward Ian Brownlee, University of Stirling, John R. Woodward, Queen Mary University of London, Michal Weiszer, Queen Mary University of London, Jun Chen, Queen Mary University of London

With increasing demand for air travel and overloaded airport facilities, inefficient airport taxiing operations are a significant contributor to unnecessary fuel burn and a substantial source of pollution. Although taxiing is only a small part of a flight, aircraft engines are not optimised for taxiing speed and so contribute disproportionately to the overall fuel burn. Delays in taxiing also waste scarce airport resources and frustrate passengers. Consequently, reducing the time spent taxiing is an important investment. An exact algorithm for finding shortest paths based on A\* allocates routes to aircraft that maintains aircraft at a safe distance apart, has been shown to yield efficient taxi routes. However, this approach depends on the order in which aircraft are chosen for allocating routes. Finding the right order in which to allocate routes to the aircraft is a combinatorial optimization problem in itself. We apply a rolling window approach incorporating a genetic algorithm for permutations to this problem, for real-world scenarios at three busy airports. This is compared to an exhaustive approach over small rolling windows, and the conventional first-come-first-served ordering. We show that the GA is able to reduce overall taxi time with respect to the other approaches.

#### Session: RWA5

Wednesday, July 18, 15:30-17:10, Training Room 3 (2F)

#### Investigation of the Latent Space of Stock Market Patterns with Genetic Programming

Sungjoo Ha, Seoul National University, Sangyeop Lee, Seoul National University, Byung-Ro Moon, Seoul National University

We suggest a use of genetic programming for transformation from a vector space to an understandable graph representation, which is part of a project to inspect the latent space in matrix factorization. Given a relation matrix, we can apply standard techniques such as non-negative matrix factorization to extract low dimensional latent space in vector representation. While the vector representation of the latent space is useful, it is not intuitive and hard to interpret. The transformation with the help of genetic programming allows us to better understand the underlying latent structure. Applying the method in the context of a stock market, we show that it is possible to recover the tree representation of technical patterns from a relation matrix. Leveraging the properties of the vector representations, we are able to find patterns that correspond to cluster centers of technical patterns. We further investigate the geometry of the latent space.

# Optimizing Residential Energy Resources with an Improved Multi-Objective Genetic Algorithm based on Greedy Mutations

Ivo Gonçalves, INESC Coimbra, DEEC, University of Coimbra, Álvaro Gomes, INESC Coimbra, DEEC, University of Coimbra, Carlos Henggeler Antunes, INESC Coimbra, DEEC, University of Coimbra

Energy management is increasingly becoming an important issue in face of the penetration of renewable generation and the evolution to smart grids. Home energy management systems are aimed to make the integrated optimization of residential energy resources, taking into account energy prices and end-user's requirements. This paper addresses a residential scenario where energy resources are automatically managed to reduce the overall energy cost while considering a set of user-defined comfort preferences. These energy resources include the grid, shiftable appliances, thermostatic loads, static batteries, electric vehicles, and local energy production. The comfort specifications consist of the time slots where the shiftable appliances are preferred to operate and the temperature ranges desired for the thermostatically controlled loads. The conflicting objectives are addressed by a multiobjective genetic algorithm that aims to minimize the overall energy cost and the user's dissatisfaction. This paper proposes a set of novel operators that result in statistically significant improvements in terms of hypervolume values when compared to a recently proposed genetic algorithm customized to address this same scenario. These novel operators include a different population initialization, a greedy mutation, and two geometric crossovers. The effect of the proposed operators on the resulting allocation of energy resources is analyzed.

#### Value-Based Manufacturing Optimisation in Serverless Clouds for Industry 4.0

Piotr Dziurzanski, University of York, Jerry Swan, University of York, Leandro Soares Indrusiak, University of York

There is increasing impetus towards 'Industry 4.0', a recently proposed roadmap for process automation across a broad spectrum of manufacturing industries. The proposed approach uses Evolutionary Computation to optimise real-world metrics. Features of the proposed approach are that it is generic (i.e. applicable across multiple problem domains) and decentralised, i.e. hosted remotely from the physical system upon which it operates. In particular, by virtue of being serverless, the project goal is that computation can be performed 'just in time' in a scalable fashion. We describe a case study for value-based optimisation, applicable to a wide range of manufacturing processes. In particular, value is expressed in terms of Overall Equipment Effectiveness (OEE), grounded in monetary units. We propose a novel online stopping condition that takes into account the predicted utility of further computational effort. We apply this method to scheduling problems in the (max,+) algebra, and compare against a baseline stopping criterion with no prediction mechanism. Near optimal profit is obtained by the proposed approach, across multiple problem instances.

#### Impacts of Constraints and Constraint Handling Strategies for Multi-Objective Mechanical Design Problems

Cyril Picard, École Polytechnique Fédérale de Lausanne, Jürg Schiffmann, École Polytechnique Fédérale de Lausanne

Multi-objective optimization tools are becoming increasingly popular in mechanical engineering and allow decision-makers to better understand the inevitable tradeoffs. Mechanical design problems can however combine properties that make the use of optimization more complex: (i) expensive cost functions; (ii) discrete or step-like behavior of the cost functions; and (iii) non-linear constraints. The latter in particular has a great impact on the convergence and the diversity of the obtained Pareto set and front. In this paper, we present five bi-objective mechanical design optimization problems with various levels of constraint complexity. They are used to rigorously benchmark two common constraint handling strategies (constrained-dominance and penalty function). The results suggest that both strategies have similar performance, and that as constraints become more intricate, convergence to the best-known Pareto front is not guaranteed. Indeed, analyzing the evolution of the hypervolume along generations reveals that the optimizer can get trapped in local optima. A detailed analysis of the obtained Pareto fronts for the proposed problems allows us to qualify the effects of the different constraints.

Session: RWA6 Thursday, July 19, 09:00-10:40, Training Room 3 (2F)

#### Genetic Algorithm to Study Practical Quantum Adversaries

Walter O. Krawec, University of Connecticut, Sam A. Markelon, University of Connecticut

In this paper we show how genetic algorithms can be effectively applied to study the security of arbitrary quantum key distribution (QKD) protocols when faced with adversaries limited to current-day technology. We compare two approaches, both of which take into account practical limitations on the quantum power of an adversary (which can be specified by the user). Our system can be used to determine upper-bounds on noise tolerances of novel QKD protocols in this scenario, thus making it a useful tool for researchers. We compare our algorithm's results with current known numerical results, and also evaluate it on newer, more complex, protocols where no results are currently known.

#### A GA based Network Optimization Tool for Passive In-Building Distributed Antenna Systems

Siddhartha Shakya, *EBTIC, Khalifa University*, Kin Poon, *EBTIC, Khalifa University*, Anis Ouali, *EBTIC, Khalifa University* 

With an explosive increase in data traffic over recent years, it has become increasingly difficult to rely on outdoor base stations to support the traffic generated indoors mainly due to the penetration issue of wireless signals. Mobile operators have investigated different options to provide adequate capacity and good in-building coverage such as by deploying femtocells, Wi-Fi off-load or in-building distributed antenna systems (IB-DAS). A passive IB-DAS extends indoor coverage by connecting antennas to a base station through coaxial cables and passive components. This paper focuses on automated design of IB-DAS based on the real world requirements of a telecom service provider. A Genetic Algorithm (GA) is derived for this purpose, giving consideration to different factors, such as minimizing cabling and passive splitter costs, reducing power spillage and power deviation between the required and supplied power for antennas. The solution representation of the problem and the customized genetic operators to assist the evolution are described. The experimental results showing the effectiveness of the GA model on a number of different scenarios are also presented. The built model is incorporated into a software tool, which is being trialled by our industrial partner, delivering encouraging results, saving cost and design time.

#### Estimation of the Heterogeneous Strategies from Action Log

### Keiichi Namikoshi, Chiba University, Sachiyo Arai, Chiba University

Agent-based crowd simulation is a widely used technique for designing and evaluating human-in-the-loop situations such as evacuation plans and building design. Valid evaluation requires a correct model of an individual agent's action rule, which causes human behavior in a crowd. However, in general, designing a specific action rule of each agent depends strongly on a trial-and-error approach because a real crowd shows diverse behavior. To avoid trialand-error approaches, we specifically examine an automated method to estimate an agent's strategy to select a goal state from trajectories extracted from human's action log. The previous method assumes a homogeneous strategy, meaning that all agents have a common strategy, but to reproduce the diversity of a real crowd it is more natural to assume a heterogeneous strategy: not all agents have the same strategy. Our proposed method of estimating individual and different strategies of agents can estimate a heterogeneous strategy that incorporates readability by evolutionary computation, even for trajectories that are the result not only of homogeneous strategies but also of heterogeneous strategies. The experiment results demonstrate the validity of our method. Additionally, some cases exhibiting multiple strategies will be extracted for a single trajectory. They show applicability to actual action log data.

### Functional Generative Design: An Evolutionary Approach to 3D-Printing

Cem C. Tutum, *The University of Texas at Austin*, Supawit Chockchowwat, *The University of Texas at Austin*, Etienne Vouga, *The University of Texas at Austin*, Risto Miikkulainen, *The University of Texas at Austin* 

Producing a working, reliable mechanical spring using a consumer-grade extrusion-based 3D printer is not a trivial problem. The usual helical design is not printable, and the number of design parameters that must be explored to invent an effective alternative geometry is prohibitive for both human designers and optimization algorithms. Successful designs must take the nuances of fabrication into account: first, the amount of required support structure should be minimized, since this structures must be removed after printing at the risk of breaking delicate parts. Second, conversion of the digital model into printing instructions, and printer resolution limits, both introduce additional noise, which creates unpredictable gaps within the printed layers that alter the elastic behavior and fatigueresistance of the spring. This paper proposes a methodology for designing functional 3D-printed springs, using a car-launcher mechanism as proof of concept. A genetic algorithm, integrated within a surrogate-based framework, explores a low-dimensional representation of the space of spring designs, as learned by a variational autoencoder. Designs were 3D-printed and evaluated to update the surrogate model. This procedure generates interesting, successful, and reliable spring geometries robust to the noise inherent in the 3D printing process.

#### Session: RWA7

Thursday, July 19, 09:00-10:40, AV Study Room (2F)

#### Multi-Objective Aerodynamic Design with User Preference using Truncated Expected Hypervolume Improvement

Pramudita Satria Palar, *Tohoku University*, Kaifeng Yang, *Leiden University*, Koji Shimoyama, *Tohoku University*, Michael Emmerich, *Leiden University*, Thomas Bäck, *Leiden University* 

Multi-objective optimization in aerodynamic design plays an important role in capturing the trade-off and useful knowledge that would be useful for real-world design processes. In the preliminary design phase, aerodynamic designers usually have an interest in focusing the optimization process in a certain direction of interest. To this end, we propose the use of user preference multi-objective Bayesian global optimization (MOBGO) for aerodynamic design using truncated expected hypervolume improvement (TEHVI). Taking into account the apriori knowledge of objective functions. TEHVI acts as an infill criterion to search for the optimal solutions based on the Kriging models in MOBGO. In TEHVI-MOBGO, the first step is to obtain a coarse approximation of the Pareto front in order to capture the general trend and trade off using standard EHVI; following this step, TEHVI is then applied to focus the search on a defined region of interest. We demonstrate the capabilities and usefulness of TEHVI method on the design optimization of an inviscid transonic wing and a viscous transonic airfoil in order to minimize the drag coefficient and absolute value of pitching moment, which leads to a reduced fuel burn and easier control characteristic.

#### Evolving the Autosteering of a Car Featuring a Realistically Simulated Steering Response

Vsevolod Nikulin, *Doshisha University*, Albert Podusenko, *Doshisha University*, Ivan Tanev, *Doshisha University*, Katsunori Shimohara, *Doshisha University* 

We consider the area of intelligent road vehicles, especially, the topic of automated vehicles. Focusing on the importance of the automated steering, we address the challenge of automated keeping of a car in the middle of the driving lane. Our objective is to investigate the feasibility of employing genetic programming to evolve the automated steering of a car. The latter is implemented in the Open Source Racing Car Simulator (TORCS) with a realistically modeled steering featuring both a delay of response and a rate limit. We propose two approaches aiming at improving the efficiency of evolution via GP. In the first approach, we implement an incremental evolution of the steering function by commencing the evolution with an ideal car and gradually increasing the degree of its realism (i.e., the amount of steering delay) in due course of evolution. The second approach is based on incorporating expert knowledge about the (expected) structure of the steering function according to the servo control model of steering. The experimental results verify that the proposed approaches yield an improved efficiency of evolution in that the obtained solutions are a better quality, could be obtained faster and more consistent than those of the canonical GP.

Orthogonalization of Linear Representations for Efficient Evolutionary Design Optimization Andreas Richter, *Bielefeld University*, Stefan Dresselhaus, *Bielefeld University*, Stefan Menzel, *Honda Research Institute Europe GmbH*, Mario Botsch, *Bielefeld University* 

Real-world evolutionary design optimizations of complex shapes can efficiently be solved using linear deformation representations, but the optimization performance crucially depends on the initial deformation setup. For instance, when modeling the deformation by radial basis functions (RBF) the convergence speed depends on the condition number of the involved kernel matrix, which previous work therefore tried to optimize through careful placement of RBF kernels. We show that such representation-specific techniques are inherently limited and propose a generic, representation-agnostic optimization based on orthogonalization of the deformation matrix. This straightforward black-box optimization projects any given linear deformation setup to optimal condition number without changing its design space, which, as we show through extensive numerical experiments, can boost the convergence speed of evolutionary optimizations by up to an order of magnitude.

# Predicting Friction System Performance with Symbolic Regression and Genetic Programming with Factor Variables

Gabriel Kronberger, University of Applied Sciences Upper Austria, Michael Kommenda, University of Applied Sciences Upper Austria, Andreas Promberger, Miba Frictec, Falk Nickel, Miba Frictec

Friction systems are mechanical systems wherein friction is used for force transmission (e.g. mechanical braking systems or automatic gearboxes). For finding optimal and safe design parameters, engineers have to predict friction system performance. This is especially difficult in realworlds applications, because it is affected by many parameters. We have used symbolic regression and genetic programming for finding accurate and trustworthy prediction models for this task. However, it is not straight-forward how nominal variables can be included. In particular, a onehot-encoding is unsatisfactory because genetic programming tends to remove such indicator variables. We have therefore used so-called factor variables for representing nominal variables in symbolic regression models. Our results show that GP is able to produce symbolic regression models for predicting friction performance with predictive accuracy that is comparable to artificial neural networks. The symbolic regression models with factor variables are less complex than models using a one-hot encoding.

### SBSE — Search-Based Software Engineering

Session: SBSE1 Wednesday, July 18, 10:40-12:20, Conference Room A (3F)

#### Dependent Input Sampling Strategies: Using Metaheuristics for Generating Parameterised Random Sampling Regimes

Komsan Srivisut, University of York, John Andrew Clark, University of Sheffield, Richard Freeman Paige, University of York

Understanding extreme execution times is of great importance in gaining assurance in real-time embedded systems. The standard benchmark for dynamic testinguniform randomised testing-is inadequate for reaching extreme execution times in these systems. Metaheuristics have been shown to be an effective means of directly searching for inputs with such behaviours but the increasing complexity of modern systems is now posing challenges to the effectiveness of this approach. The research reported in this paper investigates the use of metaheuristic search to discover biased random sampling regimes. Rather than search for test inputs, we search for distributions of test inputs that are then sampled. The search proceeds to discover and exploit relationships between test input variables, leading to sampling regimes where the distribution of a sampled parameter depends on the values of previously sampled input parameters. Our results show that test vectors indirectly generated from our dependent approach produce significantly more extreme (longer) execution times than those generated by direct metaheuristic searches.

#### Test suite minimization for mutation testing of WS-BPEL compositions

Francisco Palomo-Lozano, *Universidad de Cádiz*, Inmaculada Medina-Bulo, *Universidad de Cádiz*, Antonia Estero-Botaro, *Universidad de Cádiz*, Manuel Núñez, *Universidad Complutense de Madrid* 

This paper presents an exact search-based technique to minimize test suites while maintaining their mutation coverage. The minimization of test suites is a hard problem whose solution is important both to reduce the cost of mutation testing and to precisely assess the quality of existing test suites. This problem can be addressed with Search-Based Software Engineering (SBSE) techniques, including metaheuristics and exact techniques. We have applied Integer Linear Programming (ILP) as an exact technique to reduce the effort of testing with very promising results. Our technique can be adapted to different formalisms but this paper focuses on testing WS-BPEL compositions, as it poses several interesting problems. Despite the fact that web service compositions are relatively small, as they just orchestrate web services, their execution can be very expensive because the deployment and execution of web services, and the underlying infrastructure, are not trivial. Therefore, although test suites for the compositions themselves are also usually small, it is fundamental to reduce, as much as possible and without losing coverage, their size.

### Multi-Objective Black-Box Test Case Selection for Cost-Effectively Testing Simulation Models

Aitor Arrieta, Mondragon University, Shuai Wang, Simula Research Laboratory, Ainhoa Arruabarrena, Mondragon University, Urtzi Markiegi, Mondragon University, Goiuria Sagardui, Mondragon University, Leire Etxeberria, Mondragon University

In many domains, engineers build simulation models (e.g., Simulink) before developing code to simulate the behavior of complex systems (e.g., Cyber-Physical Systems). Those models are commonly heavy to simulate which makes it difficult to execute the entire test suite. Furthermore, it is often difficult to measure white-box coverage of test cases when employing such models. In addition, the historical data related to failures might not be available. This paper proposes a cost-effective approach for test case selection that relies on black-box data related to inputs and outputs of the system. The approach defines in total five effectiveness measures and one cost measure followed by deriving in total 15 objective combinations and integrating them within Non-Dominated Sorting Genetic Algorithm-II (NSGA-II). We empirically evaluated our approach with all these 15 combinations using four case studies by employing mutation testing to assess the fault revealing capability. The results demonstrated that our approach managed to improve Random Search by 26% on average in terms of the Hypervolume quality indicator.

Session: SBSE2 Wednesday, July 18, 15:30-17:10, Conference Room A (3F)

### A Novel Fitness Function for Automated Program Repair Based on Source Code Checkpoints

Eduardo Faria de Souza, *Universidade Federal de Goiás*, Celso Gonçalves Camilo-Junior, *Universidade Federal de Goiás*, Claire Le Goues, *Carnegie Mellon University* 

Software maintenance, especially bug fixing, is one of the most expensive problems in software practice. Bugs have global impact in terms of cost and time, and they also reflect negatively on a company's brand. GenProg is a method for Automated Program Repair based on an evolutionary approach. It aims to generate bug repairs without human intervention or a need for special instrumentation or source code annotations. Its canonical fitness function evaluates each variant as the weighted sum of the test cases that a modified program passes. However, it evaluates distinct individuals with the same fitness score (plateaus). We propose a fitness function that minimizes these plateaus using dynamic analysis to increase the granularity of the fitness information that can be gleaned from test case execution, increasing the diversity of the population, the number of repairs found (expressiveness), and the efficiency of the search. We evaluate the proposed fitness functions on two standard benchmarks for Automated Program Repair: IntroClass and Many-Bugs. We find that our proposed fitness function minimizes plateaus, increases expressiveness, and the efficiency of the search.

#### On the Effects of Seeding Strategies: A Case for Search-based Multi-Objective Service Composition

Tao Chen, Department of Computing and Technology, Nottingham Trent University, UK, Miqing Li, CERCIA, School of Computer Science, University of Birmingham, UK, Xin Yao, Department of Computer Science and Engineering, Southern University of Science and Technology, Shenzhen, China

Service composition aims to search a composition plan of candidate services that produces the optimal results with respect to multiple and possibly conflicting Qualityof-Service (QoS) attributes, e.g., latency, throughput and cost. This leads to a multi-objective optimization problem for which evolutionary algorithm is a promising solution. In this paper, we investigate different ways of injecting knowledge about the problem into the Multi-Objective Evolutionary Algorithm (MOEA) by seeding. Specifically, we propose four alternative seeding strategies to strengthen the quality of the initial population for the MOEA to start working with. By using the real-world WS-DREAM dataset, we conduced experimental evaluations based on 9 different workflows of service composition problems and several metrics. The results confirm the effectiveness and efficiency of those seeding strategies. We also observed that, unlike the discoveries for other problem domains, the implication of the number of seeds on the service composition problems is minimal, for which we investigated and discussed the possible reasons.

#### Towards the Automated Recovery of Complex Temporal API-Usage Patterns

Mohamed Aymen Saied, *Concordia University*, Houari Sahraoui, *DIRO, Université de Montréal*, Edouard Batot, *DIRO, Université de Montréal*, Michalis Famelis, *DIRO, Université de Montréal*, Pierre-Olivier Talbot, *DIRO, Université de Montréal* 

Despite the many advantages, the use of external libraries through their APIs remains difficult because of the usage patterns and constraints that are hidden or not properly documented. Existing work provides different techniques to recover API usage patterns from client programs in order to help developers understand and use those libraries. However, most of these techniques produce basic patterns that generally do not involve temporal properties. In this paper, we discuss the problem of temporal usage patterns recovery and propose a genetic-programming algorithm to solve it. Our evaluation on different APIs shows that the proposed algorithm allows to derive non-trivial temporal usage patterns that are useful and generalizable to new API clients.

### Theory — Theory

Session: THEORY1 Tuesday, July 17, 10:40-12:20, Conference Room A (3F)

### The linear hidden subset problem for the (1+1) EA with scheduled and adaptive mutation rates

Hafsteinn Einarsson, *ETH Zurich*, Marcelo Matheus Gauy, *ETH Zurich*, Johannes Lengler, *ETH Zurich*, Florian Meier, *ETH Zurich*, Asier Mujika, *ETH Zurich*, Angelika Steger, *ETH Zurich*, Felix Weissenberger, *ETH Zurich* 

We study unbiased (1 + 1) evolutionary algorithms on linear functions with an unknown number n of bits with nonzero weight. Static algorithms achieve an optimal runtime of  $O(n(logn)^{(2+\epsilon)})$ , however, it remained unclear whether more dynamic parameter policies could yield better runtime guarantees. We consider two setups: one where the mutation rate follows a fixed schedule, and one where it may be adapted depending on the history of the run. For the first setup, we give a schedule that achieves a runtime of  $(1 \pm o(1))\beta n \ln n$ , where  $\beta \approx 3.552$ , which is an asymptotic improvement over the runtime of the static setup. Moreover, we show that no schedule admits a better runtime guarantee and that the optimal schedule is essentially unique. For the second setup, we show that the runtime can be further improved to  $(1 \pm o(1))$ en log n, which matches the performance of algorithms that know n in advance. Finally, we study the related model of initial segment uncertainty with static position-dependent mutation rates, and derive asymptotically optimal lower bounds. This answers a question by Doerr, Doerr, and Kötzing.

#### **Runtime Analysis for Self-adaptive Mutation Rates**

Benjamin Doerr, Ecole Polytechnique, Carsten Witt, Technical University of Denmark, Jing Yang, Ecole Polytechnique

We consider the so-called self-adaptive  $(1, \lambda)$  EA where the current mutation rate is encoded in the individual in addition to the current search point and also subjected to mutation. A rigorous runtime analysis on the OneMax benchmark function reveals that a simple local mutation scheme for the rate leads to an expected optimization time (number of fitness evaluations) of  $O(n\lambda/\log \lambda + n\log n)$ . This time is asymptotically smaller than the optimization time of the classic  $(1, \lambda)$  EA and  $(1+\lambda)$  EA for all static mutation rates and best possible among all  $\lambda$ -parallel mutation-based unbiased black-box algorithms. Our result shows that selfadaptation in evolutionary computation can find optimal parameter settings on the fly. At the same time, it proves that a relatively complicated self-adjusting scheme for the mutation rate proposed by Doerr et al. (GECCO 2017) can be replaced by our simple endogenous scheme. Moreover, the paper contributes new tools for the analysis of the two dimensional drift processes arising in self-adaptive EAs, including bounds on occupation probabilities in processes with non-constant drift.

#### A Tight Runtime Analysis for the $(\mu + \lambda)$ EA

Denis Antipov, *ITMO University*, Benjamin Doerr, *Ecole Polytechnique*, Jiefeng Fang, *Ecole Polytechnique*, Tangi Hetet, *Ecole Polytechnique* 

Despite significant progress in the theory of evolutionary algorithms, the theoretical understanding of true population-based evolutionary algorithms remains challenging and only few rigorous results exist. Already for the most basic problem, the determination of the asymptotic runtime of the ( $\mu + \lambda$ ) evolutionary algorithm on the simple OneMax benchmark function, only the special cases  $\mu = 1$  and  $\lambda = 1$  have been solved. In this work, we analyze this long-standing problem and show the asymptotically tight result that the runtime T, the number of iterations until the optimum is found, satisfies

$$E[T] = \Theta\left(\frac{n\log n}{\lambda} + \frac{n}{\lambda/\mu} + \frac{n\log^+\log^+\lambda/\mu}{\log^+\lambda/\mu}\right)$$

where  $\log^+ x := \max\{1, \log x\}$  for all x > 0.

Session: THEORY2 Tuesday, July 17, 14:00-15:40, Conference Room A (3F)

### Significance-based Estimation-of-Distribution Algorithms

Benjamin Doerr, École Polytechnique, Martin S. Krejca, Hasso Plattner Institute

Estimation-of-distribution algorithms (EDAs) are randomized search heuristics that maintain a stochastic model of the solution space. This model is updated from iteration to iteration based on the quality of the solutions sampled according to the model. As previous works show, this short-term perspective can lead to erratic updates of the model, in particular, to bit-frequencies approaching a random boundary value. This can lead to significant performance losses. In order to overcome this problem, we propose a new EDA that takes into account a longer history of samples and updates its model only with respect to information which it classifies as statistically significant. We prove that this significance-based compact genetic algorithm (sig-cGA) optimizes the common benchmark functions OneMax and LeadingOnes both in  $O(n \log n)$  time, a result shown for no other EDA or evolutionary algorithm so far. For the recently proposed scGA - an EDA that tries to prevent erratic model updates by imposing a bias to the uniformly distributed model - we prove that it optimizes OneMax only in a time exponential in the hypothetical population size  $1/\rho$ .

## Crossover Can Simulate Bounded Tree Search on a Fixed-Parameter Tractable Optimization Problem

#### Andrew M. Sutton, University of Minnesota Duluth

We investigate the effect of crossover in the context of parameterized complexity on a well-known fixed-parameter tractable combinatorial optimization problem known as the closest string problem. We prove that a multi-start ( $\mu$ +1) GA solves arbitrary length-n instances of closest string in  $2^{O(d^2+d\log k)} \cdot \operatorname{poly}(n)$  steps in expectation. Here, k is the number of strings in the input set, and d is the value of the optimal solution. This confirms that the multi-start ( $\mu$ +1) GA runs in randomized fixed-parameter tractable (FPT) time with respect to the above parameterization. On the other hand, if the crossover operation is disabled, we show there exist instances that require  $n^{\Omega(\log(d+k))}$  steps in expectation. The lower bound asserts that crossover is a necessary component in the FPT running time.

### Medium Step Sizes are Harmful for the Compact Genetic Algorithm

Johannes Lengler, ETH Zürich, Dirk Sudholt, The University of Sheffield, Carsten Witt, Technical University Of Denmark

We study the intricate dynamics of the Compact Genetic Algorithm (cGA) on OneMax, and how performance depends on the step size 1/K that determines how quickly decisions about promising bit values are fixed in the probabilistic model. It is known that cGA and UMDA, a re-

lated algorithm, run in expected time  $O(n \log n)$  when the step size is just small enough  $(K = \Theta(\sqrt{n}\log n))$  to avoid wrong decisions being fixed. UMDA also shows the same performance in a very different regime (equivalent to  $K = \Theta(\log n)$  in the cGA) with much larger steps sizes, but for very different reasons: many wrong decisions are fixed initially, but then reverted efficiently. We show that step sizes in between these two optimal regimes are harmful as they yield larger runtimes: we prove a lower bound of  $\Omega(K^{1/3}n + n \log n)$  for the cGA on One-Max for  $K = O(\sqrt{n}/\log^2 n)$ . For  $K = \Omega(\log^3 n)$  the runtime increases with growing K before dropping again to  $O(K\sqrt{n} + n\log n)$  for  $K = \Omega(\sqrt{n}\log n)$ . This suggests that the expected runtime for cGA is a bimodal function in K with two very different optimal regions and worse performance in between.

Session: DETA2+THEORY3+GECH4: Best Papers Wednesday, July 18, 15:30-17:10, Conference Room Medium (2F)

### Domino Convergence: Why One Should Hill-Climb on Linear Functions

#### Carsten Witt, Technical University Of Denmark

In the theory community of evolutionary computation, linear pseudo-boolean functions are often regarded as easy problems since all of them can be optimized in expected time  $\Theta(n \log n)$  by simple unbiased hill-climbers. However, results from genetic algorithms and estimation-ofdistribution algorithms indicate that these algorithms treat different linear functions differently. More precisely, an effect called "domino convergence" is described in the literature, which means that bits of large weight in the linear function are optimized earlier than bits of low weight. Hence, different linear functions may lead to rather different expected optimization times. The present paper conducts a study of domino convergence. By rigorous runtime analyses, it is shown that domino convergence is mostly a consequence of the crossover underlying genetic algorithms and EDAs. Here a performance gap of order  $\Omega(n/\log n)$  between different linear functions is proved. In simple mutation-only EAs the effect of domino convergence is much less pronounced, with the typical performance gap being logarithmic in the population size. The effect disappears when population size 1 is used and the algorithm is reduced to hillclimbing. Different selection mechanisms, including cut and tournament selection are investigated and their impact on domino convergence is analyzed.

Session: THEORY4 Thursday, July 19, 09:00-10:40, Conference Room A (3F)

### Analysis of Noisy Evolutionary Optimization When Sampling Fails

Chao Qian, University of Science and Technology of China, Chao Bian, University of Science and Technology of China, Yang Yu, Nanjing University, Ke Tang, Southern University of Science and Technology, Xin Yao, Southern University of Science and Technology

In noisy evolutionary optimization, sampling is a common strategy to deal with noise, which evaluates the fitness of a solution multiple times (called sample size) independently and then uses the average to approximate the true fitness. Previous studies mainly focused on the empirical design of efficient sampling strategies, and the few theoretical analyses mainly proved the effectiveness of sampling with a fixed sample size in some situations. There are many fundamental theoretical issues to be addressed. In this paper, we first investigate the effect of sample size. By analyzing the (1+1)-EA on noisy LeadingOnes, we show that as the sample size increases, the running time can reduce from exponential to polynomial, but then return to exponential. This discloses that a proper sample size is crucial in practice. Then, we investigate what other strategies can work when sampling with any fixed sample size fails. By two illustrative examples, we prove that using parent populations can be better, and if using parent populations is also ineffective, adaptive sampling (i.e., sampling with an adaptive sample size) can work.

## A New Analysis Method for Evolutionary Optimization of Dynamic and Noisy Objective Functions

Raphaël Dang-Nhu, École Polytechnique, Thibault Dardinier, École Polytechnique, Benjamin Doerr, Ecole Polytechnique, Gautier Izacard, École Polytechnique, Dorian Nogneng, École Polytechnique

Evolutionary algorithms, being problem-independent and randomized heuristics, are generally believed to be robust to dynamic changes and noisy access to the problem instance. We propose a new method to obtain rigorous runtime analysis results for such settings. In contrast to many previous works, our new approach mostly relies on general parameters of the dynamics or the noise models, such as the expected change of the dynamic optimum or the probability to have a dynamic change in one iteration. Consequently, we obtain bounds which are valid for large varieties of such models. Despite this generality, for almost all particular models regarded in the past our bounds are stronger than those given in previous works.

On the Robustness of Evolutionary Algorithms to

### Noise: Refined Results and an Example Where Noise Helps

Dirk Sudholt, University of Sheffield

We present refined results for the expected optimisation time of the (1+1)EA and the  $(1+\lambda)EA$  on LeadingOnes in the prior noise model, where in each fitness evaluation the search point is altered before evaluation with probability p. Previous work showed that the (1+1)EA runs in polynomial time if  $p = O((\log n)/n^2)$  and needs superpolynomial time if  $p = \Omega((\log n)/n)$ , leaving a huge gap for which no results were known. We close this gap by showing that the expected optimisation time is  $\Theta(n^2) \cdot \exp(\Theta(pn^2))$ , allowing for the first time to locate the threshold between polynomial and superpolynomial expected times at p = $\Theta((\log n)/n^2)$ . Hence the (1+1)EA on LeadingOnes is much more sensitive to noise than previously thought. We also show that offspring populations of size  $\lambda \geq 3.42 \log n$ can effectively deal with much higher noise than known before. Finally, we present an example of a rugged landscape where prior noise can help to escape from local optima by blurring the landscape and allowing a hill climber to see the underlying gradient.

## Runtime Analysis of Randomized Search Heuristics for the Dynamic Weighted Vertex Cover Problem

Feng Shi, Central South University, Frank Neumann, The University of Adelaide, Jianxin Wang, Central South University

Randomized search heuristics such as evolutionary algorithms are frequently applied to dynamic combinatorial optimization problems. Within this paper, we present a dynamic model of the classic Weighted Vertex Cover problem and analyze the performances of the two wellstudied algorithms Randomized Local Search and (1+1) EA adapted to it, to contribute to the theoretical understanding of evolutionary computing for problems with dynamic changes. In our investigations, we use an edgebased representation based on the dual formulation of the problem and study the expected runtimes that the two algorithms require to maintain a 2-approximate solution when the given weighted graph is modified by an edge-editing or weight-editing operation. Considering the weights on the vertices may be exponentially large with respect to the size of the graph, the step size adaption strategy is incorporated. Our results show that both algorithms can recompute 2-approximate solutions for the studied dynamic changes efficiently.

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.
- 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 Tuedsday, July 17, 18:00-20:00 in Terrsa 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.

# **Author Index**

Abdel-Hakim, Alaa, 46 Acosta León, Andrés Felipe, 100 Adam, Marc T.P., 100 Affenzeller, Michael, 41, 45, 48, 57, 75, 79, 86, 96, 114, 138, 140 Agapitos, Alexandros, 99 Agarwal, Manoj, 99 Aguirre, Hernán, 75, 96, 97, 123 Ahiod, Belaïd, 86, 114 Ahmad, Hammad, 49 Ahmeti, Arben, 70, 110 Ahn, Chang Wook, 94, 97 Ahuja, Karuna, 87, 144 Akimoto, Youhei, 37, 40, 42, 46, 49, 67, 71, 82, 90, 97, 129, 131, 132 Akira, Oyama, 96 Akman, Ozgur E., 47, 98 Al-Hammadi, Yousof, 93 Alaguna Córdoba, Camilo Alejandro, 47 Alahakoon, Damminda, 79, 140, 141 Alba, Enrique, 100 Albantakis, Larissa, 85, 107 Alderliesten, Tanja, 71, 79, 80, 82, 125, 129, 148, 149 Alexander, Bradley, 76, 148 Alhammadi, Yousof, 100 Ali, Bassel, 95 Ali, Shaukat, 36 Allmendinger, Richard, 75, 77, 117, 123 Alves Ribeiro, Victor Henrique, 49, 93 Alyahya, Khulood, 47, 98 Amos, Martyn, 48 Amrhein, Wolfgang, 71, 122 Andoni, Sari, 77, 117 Andraud, Martin, 43 Andre, Robin, 74, 111 Andreae, Peter, 85, 103 Antipov, Denis, 49, 73, 156 Araújo, Aluizio Fausto Ribeiro, 78, 124 Arai, Sachiyo, 91, 152

Aranha, Claus, 93 Araujo, Matheus de Freitas, 70, 110 Arrieta, Aitor, 84, 91, 146, 154 Arruabarrena, Ainhoa, 84, 154 Ascheid, Gerd, 43 Asteroth, Alexander, 66, 77, 105 Au, Chun-kit, 78, 130 Auger, Anne, 40, 71, 129 Aulig, Nikola, 78, 130 Awasthi, Abhishek, 45 Avres. Phil. 81, 106 Bäck, Thomas, 37, 42, 44, 72, 74, 91, 97, 98, 102, 133, 152 Bakurov, Illya, 99 Balcar, Štěpán, 98 Bandaru, Sunith, 67, 90, 132 Barbe, Sophie, 86, 114 Barlow, Michael, 85, 107 Bartashevich, Palina, 99 Bartoli, Alberto, 48, 99 Bartz-Beielstein, Thomas, 84, 149, 150 Bassani, Hansenclever França, 78, 124 Batot, Edouard, 88, 155 Beaulieu, Shawn L., 81, 118 Beham, Andreas, 41, 45, 86, 114 Bel, Arjan, 79, 80, 148, 149 Belzner, Lenz, 82, 131 Benecki, Pawel, 99 Bentley, Peter, 95 Bergmann, Sören, 96 Berlanga, Antonio, 40 Berretta, Regina, 75, 96, 123 Bian, Chao, 92, 157 Biswas, Subir, 48, 98 Błądek, Iwo, 79, 141 Blank, Julian, 96 Blelly, Aurore, 40 Blocho, Miroslaw, 83, 143 Bochenina, Klavdiya O., 98

Boland, Miguel d'Arcangues, 72, 133 Bonab, Elmira, 77, 117 Bongard, Josh C., 70, 81, 94, 104, 118 Bosman, Anna Sergeevna, 43 Bosman, Peter A.N., 36, 67, 71, 79, 80, 82, 87, 125, 129, 136, 148, 149 Bossek, Jakob, 43, 45, 86, 128 Botello Rionda, Salvador, 83, 143 Botsch, Mario, 91, 153 Botterweck, Goetz, 100 Bouter, Anton, 80, 149 Braga, Pedro Henrique Magalhães, 78, 124 Branke, Juergen, 37, 79, 138 Braun, Eric, 43 Braune, Roland, 57 Bredeche, Nicolas, 38, 43 Brest, Janez, 42 Brizuela, Carlos, 74, 111 Brockhoff, Dimo, 37, 40 Browne, Will Neil, 46, 77, 118 Brownlee, Alexander Edward Ian, 84, 95, 97, 150 Bryans, Jeremy, 49 Buckley, Jim, 100 Bucur, Doina, 41 Bujny, Mariusz, 78, 130 Bulanova, Nina, 100 Burks, Armand Rashad, 68, 76, 147 Burlacu, Bogdan, 75, 140 Butcher, Stephyn G. W., 48, 74, 93, 102 Buzdalov, Maxim, 49, 82, 97, 100, 125 Buzdalova, Arina, 49 Cagnoni, Stefano, 38 Cai, Changwei, 86, 119 Cairns, David, 86, 114 Calvo, Borja, 100 Camilo-Junior, Celso Gonçalves, 88, 154 Cantatore, Eugenio, 43 Cao, Leilei, 82, 96, 126 Casadei, Felipe, 68, 83, 142 Castelli, Mauro, 95 Castillo, Pedro A., 87, 144 Ceberio, Josu, 95, 100 Češka, Milan, 87, 143 Champagne, Samuel, 45 Chang, Yu-Cheng, 94 Chattopadhyay, Ishanu, 74, 116 Chavez de la O, Franciso, 87, 144 Chelly Dagdia, Zaineb, 94

Chen, An, 48, 78, 97, 130

Chen, Boyuan, 74, 116

Chen, Chen, 98 Chen, Chia-Sheng, 87, 135 Chen, Gang, 81, 95, 118 Chen, Guanrong Ron, 47 Chen, Hao, 96 Chen, Haofeng, 84, 150 Chen, Huanhuan, 96 Chen, Jay. 66, 74, 77, 105, 116 Chen, Jun, 84, 150 Chen, Tao, 88, 155 Chen, Wei-Neng, 95 Chen, Wenxiang, 67, 87, 136 Chen, Xin, 100 Chen, Xingguo, 93 Chen, Yi, 98 Chen, Yuanzhu, 79, 141 Chen, Zhenxiang, 86, 119 Cheney, Nick, 70, 104 Cheng, Sheila, 77, 117 Cheriet, Abdelhakim, 96 Chicano, Francisco, 66, 67, 81, 87, 100, 113, 136 Chiong, Raymond, 100 Chiu, Pei-Ling, 50 Cho, Hwi-Yeon, 50 Cho, Sung-Bae, 46 Chockchowwat, Supawit, 91, 152 Choi, Jun-Hwan, 77, 117 Choi, Tae Jong, 97 Christie, Lee Ashley, 97 Chugh, Tinkle, 75, 123 Chung, I-Fang, 94 Chung, Yu-Hsiang, 98 Cintrano, Christian, 100 Clark, Anthony J., 43, 94 Clark, John Andrew, 84, 154 Claudio Arroyo, Jose Elias, 70, 110 Cleahorn, Christopher Wesley, 37 Clune, Jeff, 41, 66, 74, 77, 105, 116 Coello Coello, Carlos A., 37, 49, 67, 71, 74, 90, 96, 116, 122, 128 Collins, Jack, 70, 104 Coninx, Alexandre, 94 Contreras Paredes, Sergio Felipe, 100 Cortés Guerrero, Camilo Andrés, 100 Corucci, Francesco, 70, 104 Corus, Dogan, 90, 145 Covantes Osuna, Edgar, 67, 87, 135 Cudova, Marta, 46 Cully, Antoine, 85, 108 Cussat-Blanc, Sylvain, 70, 83, 109, 143

Díaz, Antonio Francisco, 40 Da, Bingshui, 97 Dai, Zhengjia, 100 Dale, Matthew, 81, 118 Damas, Miguel, 40, 98 Danai, Kourosh, 90, 145 Dang-Nhu, Raphaël, 92, 157 Dardinier, Thibault, 92, 157 Dasgupta, Dipankar, 45 de Almeida, Ana Maria Carvalho, 72, 132 De Jong, Kenneth, 37, 94 De Lorenzo, Andrea, 99 De Mesentier Silva, Fernando, 70, 108 De Palma, Paul, 51 De Roosa, Jaro, 43 de Vladar, Harold P., 41 Deb, Kalyanmoy, 96 Dehsarvi, Amir, 99 Delgado, Myriam, 86, 114 Delgado-Pérez, Pedro, 100 Demiris, Yiannis, 85, 108 Deng, Changshou, 93 Derbel, Bilel, 71, 75, 96, 97, 122, 123 Desell, Travis, 85, 96, 103 Di Caro, Gianni A., 74, 102 Diao, Yiya, 96 Dias, Douglas Mota, 40 Diaz, Antonio, 98 Diaz-Alvarez, Josefa, 87, 144 Dick, Grant, 67, 71, 115 Dobashi, Koji, 46 Doerr, Benjamin, 36, 68, 73, 76, 84, 85, 92, 139, 142, 156, 157 Doerr, Carola, 37, 44, 72, 83, 133, 134 Dohan, David, 51 Doherty, Kevin, 47, 98 Dolson, Emily L., 41, 94 Doncieux, Stephane, 38, 41, 94 Dou, Liang, 98 Dou, Lihua, 98 Doya, Kenji, 41, 89, 120 Drefs, Jakob, 89, 120 Dresselhaus, Stefan, 91, 153 du Plessis, Mathys Cornelius, 81, 106 Du, Wei, 47 Duddeck, Fabian, 78, 130 Duepmeier, Clemens, 43 Dulin, Maxwell, 51 Duro, Joao Antonio Fialho Vilas Boas, 82, 125 Dziurzanski, Piotr, 87, 151

Ebert, Samuel, 48 Eftimov, Tome, 47, 87, 144 Einarsson, Hafsteinn, 73, 155 Eklund, Peter, 94 El Jamiy, Fatima, 85, 103 El Krari, Mehdi, 86, 114 El Yafrani, Mohamed, 86, 114 Eledlebi, Khouloud, 100 Elfwing, Stefan, 89, 120 Eliiyi, Ugur, 95 Eloy, Sara, 72, 132 ElSaid, AbdElRahman, 85, 103 Emmerich, Michael, 91, 96, 152 Engelbrecht, Andries, 37, 43, 44, 47 Englert, Paul, 93 Ernst, Andreas T., 79, 81, 113, 141 Escobar, Juan José, 40 Espina, Kennedy, 99 Estero-Botaro, Antonia, 84, 154 Estuar, Ma. Regina Justina, 99 Etxeberria, Leire, 84, 91, 146, 154 Fachada, Nuno, 93 Fagan, David, 75, 83, 140, 143 Falcón-Cardona, Jesús Guillermo, 49, 67, 90, 128 Falco, Ivanoe De, 48 Famelis, Michalis, 88, 155 Fan, Qingna, 48 Fan, Tuan-Fang, 98 Fan, Zongwen, 100 Fang, Jiefeng, 73, 156 Farhana, Effat, 48 Farias, Lucas Rodolfo Celestino, 78, 124 Fehst, Valerie Aenne Nicola, 93 Feldkamp, Niclas, 96 Felipe-Gomes, Matheus, 40 Feng, Fan, 93 Feng, Liang, 97 Fenton, Michael, 83, 143 Fernández Romero, Miguel Ángel, 70, 110 Fernandes, Carlos M., 93 Fernandez de Vega, Francisco, 87, 144 Fernando, Chrisantha, 41, 94 Fiebig, Karl-Heinz, 93 Fieldsend, Jonathan E., 44, 47, 98 Filipic, Bogdan, 37, 40, 75, 123 Fischer, Dominik, 85, 107 Fister, Iztok, 42 Fister, Iztok Jr., 42 Fleming, Peter J., 82, 125 Fletcher, David, 84, 149

Fletcher, George, 89, 121 Fletcher, Sam, 46 Fonlupt, Cyril, 99 Forstenlechner, Stefan, 75, 140 Friederichs, Petra, 51 Friedrich, Tobias, 74, 77, 111-113 Fu, Weixuan, 87, 144 Fujii, Akihiro, 46 Fujimoto, Kousuke, 50 Fujiwara, Masaki, 51 Fujiyoshi, Natsuki, 46 Fukase, Takafumi, 78, 124 Fukuda, Osamu, 42 Fukui, Ken-ichi, 95 Fukumoto, Hiroaki, 97 Fukumoto, Makoto, 94 Fukuyama, Yoshikazu, 100 Funkner, Anastasia A., 98 Furuta, Kazuo, 98 Gómez Perdomo, Jonatan, 47 Gabor, Thomas, 82, 131 Gaier, Adam, 66, 77, 105 Gambardella, Luca Maria, 74, 102 Gao, Wanru, 74, 83, 111, 134 Gao, Weifeng, 97 García Valdez, José-Mario, 40, 43 García, Salvador, 74, 116 García-Valdez, Mario, 97 Garcia, Juan A., 87, 144 Garciarena, Unai, 67, 71, 82, 115, 131 Gausmann, Adam, 45 Gauy, Marcelo Matheus, 73, 155 Gedeon, Tom, 94 Geles, Wade, 70, 104 Gentile, Lorenzo, 84, 150 Georgiev, Milen, 46, 47 Ghassemi Toosi, Farshad, 100 Gillespie, Lauren E., 89, 109 Giugliano, Dario, 84, 150 Giusti, Alessandro, 74, 102 Glasmachers, Tobias, 71, 129 Glette, Kyrre, 70, 104 Goldberg, David E., 34, 36 Goldman, Brian, 83, 143 Goldsby, Heather J., 78, 134 Gomes, Álvaro, 88, 151 Gomez Perdomo, Jonatan, 48 Gonçalves, Ivo, 88, 95, 151 Gong, Maoguo, 48, 82, 126 Gong, Yue-Jiao, 93, 100

González de Prado Salas, Pablo, 94 González, Jesús, 40, 98 Goode, Jimmie, 77, 117 Goodman, Erik D., 58, 82, 100, 126 Goodrich, Michael A., 78, 133 Goto, Keisuke, 67, 90, 128 Gravina, Daniele, 70, 104 Grimme, Christian, 86, 128 Groves, Matthew, 79, 138 Gu, Yongfeng, 48 Guerrero, José Luis, 40 Guiraud, Enrico, 89, 120 Guo, Jinglei, 82, 127 Gupta, Abhishek, 42 Gupta, Shikha, 99 Gutierrez-Rodríguez, Andres Eduardo, 74, 116 Guzzi, Jerome, 74, 102 Ha, David, 36 Ha, Sungjoo, 87, 150 Haberman, Brian, 93 Hagenmeyer, Veit, 43 Hähner, Jörg, 46, 67, 71, 115 Hallawa, Ahmed, 43 Hamada, Naoki, 67, 90, 128 Hamagami, Tomoki, 77, 118 Hamann, Heiko, 81, 106 Hameed, Ibrahim Abdul, 45 Han, Xing-Chi, 93 Hanada, Yoshiko, 50 Handa, Hisashi, 51 Handl, Julia, 77, 117 Hansen, Nikolaus, 36, 37 Hao, Lina, 98 Hao, Rong, 98 Haqqani, Mohammad, 72, 146 Harada, Tomohiro, 50, 72, 98, 136 Harris, Sean, 45 Harrison, Rob, 84, 149 Hart, Emma, 44, 66, 77, 82, 105, 131 Hasegawa, Ryoichi, 51 Hasenöhrl, Václav, 83, 134 Hashimoto, Ryuichi, 49 Hatanaka, Toshiharu, 50 Hauder, Viktoria, 45 He, Yaodong, 97 He, Yunan, 42 Heber, Steffen, 48 Hedar, Abdel-Rahman, 46 Hein, Daniel, 44 Heinrich, Mary Katherine, 81, 106

Helbig, Marde, 41, 43 Helmuth, Thomas, 49, 68, 83, 142 Hemberg, Erik, 45, 99 Henggeler Antunes, Carlos, 88, 151 Hercher, Christian, 74, 111 Herman, Joshua, 45 Hernández Aguirre, Arturo, 83, 143 Herrera, Francisco, 74, 116 Hetet, Tangi, 73, 156 Heywood, Malcolm, 38, 45, 68, 76, 90, 144, 147 Higgins, James, 85, 103 Hintze, Arend, 78, 134 Hiroyasu, Tomoyuki, 46 Hiwa, Satoru, 46 Hock, Patrick, 42 Hofmann, Hans A., 78, 134 Hofstadler, Daniel Nicolas, 81, 106 Holmes, John, 71, 115 Howard, Gerard, 70, 104 Hsu, Ching-Chi, 99 Hsu, Hung-Wei, 87, 135 Hsu, Kai-Cheng, 91, 146 Hsu, Sung-Ming, 99 Hu, Chenxu, 49 Hu, Ting, 79, 141 Hu, Xiao-Min, 95 Hu, Zhongyi, 100 Huang, Xiuzhen, 51 Huang, Zhixing, 99 Hüllermeier, Eyke, 89, 120 Husain, Zainab, 93 Hussein, Ravan, 96 Hutter, Frank, 83, 143 lacca, Giovanni, 41, 89, 121 lacob, Andrei, 97 Ibrahim, Abdel-Monem, 46 Iglesias, Andres, 42 Indrusiak, Leandro Soares, 72, 133 Isakovic, Abdel F., 93, 100 Ishibuchi, Hisao, 49, 67, 78, 90, 124, 128 Izacard, Gautier, 92, 157 Izumiya, Kousuke, 96

Jagusch, Jan-Benedikt, 95 Jain, Pallavi, 100 Jakob, Wilfried, 43 Jan, Zohaib Muhammad, 46 Jansen, Bart, 50 Jaros, Jiri, 46 Jia, Xiangyang, 48 Jiang, He, 100 Jiang, Shouyong, 82, 127 Jiang, Tianyi, 45 Jiang, Xiangming, 48, 82, 126 Jiang, Yuhong, 75, 97, 137 Jiao, Li, 100 Jiao, Ruwang, 75, 97, 137 Jiménez, Francia, 75, 96, 123 Jin, Yaochu, 85, 103 Jing, Ning, 96 Jones, Oliver P. H., 78, 125 Jørgensen, Jonas, 81, 106 Juang, Chia-Feng, 94 Juarez, Julio, 74, 111 Junior, Jair Pereira, 93 Kadish, David, 95 Kaidan, Misaki, 50, 98 Kaiser, Marcus, 82, 127 Kalintha, Wasin, 95 Kalyuzhnaya, Anna V., 98 Kammerer, Lukas, 96 Kanesh, Lawqueen, 100 Kanno, Taro, 98 Kanoh, Hitoshi, 93 Kappes, Martin, 45 Karakatič, Sašo, 95 Karder, Johannes, 41 Karimpanal George, Thommen, 50 Karmakharm, Twin, 84, 149 Kasmarik, Kathryn, 85, 107 Kawasaki, Hiroshi, 94 Kawulok, Michal, 50, 99 Kava, Onur, 95 Kazuya, Seo, 57 Ke, Hao-Wen, 93 Keane, John, 77, 117 Keedwell, Ed, 83, 143 Kemmotsu, Hiromasa, 96 Kenny, Angus, 81, 113 Kent, Alexander, 45 Kerschke, Pascal, 45 Khalifa, Ahmed, 75, 137 Khalloof, Hatem, 43 Khanchi, Sara, 68, 76, 90, 144, 147 Kheiri, Ahmed, 83, 143 Kim, Hye-Jin, 50 Kim, Man-Je, 94 Kim, Yong-Hyuk, 50 Kirley, Michael, 72, 75, 129, 138 Kisliakovskii, Ilia O., 98

Kizilay, Damla, 95 Ko, Seong Young, 93 Kobayashi, Akira, 46 Kohira, Takehisa, 57, 96 Komarnicki, Marcin Michal, 98 Kommenda, Michael, 91, 153 Kondo, Toshiki, 90, 128 Korošec, Peter, 47, 87, 144 Koroušić Seljak, Barbara, 87, 144 Kostrzewa, Daniel, 99 Kotenko, Igor, 45 Kötzing, Timo, 77, 113 Kovacs, Tim, 42, 46 Kovalchuk, Sergey V., 98 Kowatari, Naoya, 57 Kozłowski, Norbert, 46 Kramer, Oliver, 74, 102 Krantz, Jacob, 51 Krasnogor, Natalio, 82, 127 Krauss, Oliver, 48 Krawec, Walter O., 91, 151 Krawiec, Krzysztof, 38, 75, 79, 137, 141 Krejca, Martin S., 76, 156 Kriegman, Sam, 70, 81, 94, 104, 118 Kronberger, Gabriel, 91, 153 Kulkarni, Divya D., 85, 107 Kulkarni, Sandeep, 48, 98 Kumar, Naveen, 99 Kundu, Sonia, 99 Kwiecinski, Krystian, 72, 132 López Buenfil, Guillermo, 83, 143 López-Ibáñez, Manuel, 38, 77, 112 López-López, Victor R., 48 La Cava, William, 68, 83, 90, 96, 142, 145 La, Huu Chuong, 93 Lakshika, Erandi, 85, 107 Lalejini, Alexander, 75, 140 Lalla-Ruiz, Eduardo, 82, 131 Lantz, Frank, 70, 108 Laredo, Juan L.J., 93 Laskowski, Eryk, 48 Lässig, Jörg, 45 Le Goues, Claire, 88, 154 Le, Duc C., 68, 76, 147 Le, Quoc, 51 Lee, Chian-Her, 99 Lee, Hyeon-Chang, 50 Lee, Junghwan, 50 Lee, Kai-Hui, 50 Lee, Sangyeop, 87, 150

Lee, Scott, 75, 137 Legrand, Pierrick, 48 Lehman, Joel, 41, 66, 74, 77, 105, 116 Lehre, Per Kristian, 36 Lengler, Johannes, 73, 76, 155, 156 Lensen, Andrew, 89, 121 Leprêtre, Florian, 99 Leu, Jeng-Shiou, 95 Leung, Ho-fung, 78, 130 Li, Changhe, 75, 96, 97, 137 Li, Genahui, 97 Li, Hui, 82, 126 Li, Jingjing, 99 Li, Jun, 96 Li. Ke. 37 Li, Longmei, 96 Li, Min, 95 Li, Minghan, 48 Li, Miging, 88, 155 Li, Xiaochen, 100 Li, Xiaodong, 72, 75, 81, 86, 113, 127, 129, 138, 146 Li, Xun, 70, 108 Liang, Jason Zhi, 86, 119 Liang, Yongsheng, 48, 78, 97, 130 Liapis, Antonios, 70, 104 Liau, Churn-Jung, 98 Liefooghe, Arnaud, 71, 75, 77, 96, 97, 112, 122, 123 Lin, Ying, 93, 100 Lin, Yuen-Jen, 83, 135 Linnhoff-Popien, Claudia, 82, 131 Lipson, Hod, 74, 116 Liskowski, Paweł, 75, 79, 137, 141 Lissovoi, Andrei, 85, 139 Liu, Jialin, 66, 85, 109 Liu, Jianlei, 43 Liu, Shuangrong, 86, 119 Liu, Siming, 45 Liu, Wei-Li, 93, 99 Liu, Wenyu, 93 Liu, Yanfeng, 72, 136 Liu, Yiping, 67, 90, 128 Liu, Yunan, 98 Llera, José R., 100 Llovd, Huw, 48 Lo, Christopher, 71, 115 Loshchilov, Ilya, 83, 143 Lou, Yang, 47, 97 Louis, Sushil J., 45 Lozano, Jose Antonio, 95, 100

Lu, Chengyu, 93 Lucas, Simon M., 66, 85, 109 Lücke, Jörg, 89, 120 Lüders, Ricardo, 86, 114 Luga, Hervé, 70, 109 Lughofer, Edwin, 71, 122 Luo, Yu, 95 Luo, Zhipeng, 99 Luong, Ngoc Hoang, 82, 125 Lutz, Bernhard, 100 Ma, Hui, 95 Madathil, Javakrishnan, 100 Maire, Frederic, 70, 104 Makanju, Tokunbo, 45 Malan, Katherine, 44, 90, 145 Manoatl Lopez, Edgar, 71, 122 Marca, Yuri, 97 Marcelli, Andrea, 41 Maree, Stef C., 71, 129 Marion, Virginie, 99 Markelon, Sam A., 91, 151 Markiegi, Urtzi, 84, 91, 146, 154 Martí, Luis, 38, 40 Martin, Charles Patrick, 70, 104 Martins, Joao Francisco Barreto da Silva, 47, 68, 83, 142 Martins, Marcella Scoczynski Ribeiro, 86, 114 Masataka, Koishi, 57 Masuyama, Naoki, 49, 78, 124 Matei, Oliviu, 77, 112 Mathew, Jimson, 96 Matsumoto, Kazuma, 46 Matváš, Jiří, 87, 143 Matyas, Vashek, 72, 147 Mayer, Ben E., 93 Mazyad, Ahmad, 99 McDonnell, Tyler, 77, 117 McKay, Robert, 94 McKinley, Philip K., 43 McPhee, Nicholas Freitag, 37, 49, 68, 83, 142 Medina-Bulo, Inmaculada, 45, 84, 100, 154 Medvet, Eric, 48, 99 Mei, Yi, 95 Meier, Almuth, 74, 102 Meier, Florian, 73, 155 Meisel, Stephan, 86, 128 Mendiburu, Alexander, 67, 71, 82, 95, 115, 131 Menssen, Simon, 67, 71, 115 Menzel, Stefan, 91, 153 Mercer, Eric G., 78, 133

Merelo, JJ, 38, 40, 43, 93, 97 Metsker, Oleg G., 98 Meyerson, Elliot, 86, 119 Michalak, Eric, 45 Michalak, Krzysztof, 79, 91, 145, 148 Miettinen, Kaisa, 75, 123 Miikkulainen, Risto, 36, 47, 70, 86, 91, 108, 119, 152 Miller, Julian F., 70, 109 Miranda, Luis Fernando, 47, 68, 83, 142 Mironovich, Vladimir, 49 Mishra, Rahul Shivnarayan, 43 Miura, Katsunori, 99 Miyagi, Atsuhiro, 42 Miyakawa, Minami, 50, 52, 78, 124 Miyashita, Tomoyuki, 40, 42 Mo, Warren, 74, 116 Mocanu, Decebal Constantin, 89, 121 Mohammed, Hadi, 45 Mohr, Felix, 89, 120 Molina, José Manuel, 40 Monzón, Hugo, 96 Moon, Byung-Ro, 87, 95, 150 Moore, Jared M., 43, 94 Moore, Jason H., 51, 68, 71, 83, 87, 90, 96, 115, 142, 144, 145 Moore, Keith, 77, 117 Mora Gutiérrez, Roman Anselmo, 70, 110 Moreira, Orlando, 74, 111 Moreno, Matthew Andres, 78, 133 Moreno, Salvador, 98 Moriyama, Koichi, 95 Morning, Robert, 45 Morosan, Mihail, 97 Moscato, Pablo, 75, 96, 123 Moser, Irene, 90, 145 Mössenböck, Hanspeter, 48 Mostaghim, Sanaz, 52, 82, 85, 99, 107, 126 Mostert, Werner, 44 Mouret, Jean-Baptiste, 38, 66, 77, 81, 105, 106 Mrazek, Vojtech, 72, 87, 100, 143, 147 Mueller-Bady, Robin, 45 Mujika, Asier, 73, 155 Munetomo, Masaharu, 51, 96, 99 Musliu, Nysret, 70, 110 Núñez, Manuel, 84, 154 Nader-Palacio, David, 48 Nagai, Hidetoshi, 50 Nair, Shivashankar B., 43, 85, 107

Nakata, Masaya, 77, 118

Nakayama, Koichi, 42 Nalepa, Jakub, 50, 83, 86, 119, 143 Nallaperuma, Samadhi, 84, 149 Nam, Yong-Wook, 50 Namikoshi, Keiichi, 91, 152 Nealen, Andy, 70, 75, 108, 137 Neshat, Mehdi, 76, 148 Neumann, Aneta, 37, 83, 134 Neumann, Dirk, 100 Neumann, Frank, 37, 71, 74, 83, 92, 111, 121, 134, 158 Neupane, Aadesh, 78, 133 Ng, Amos H.C., 67, 90, 132 Ng, Bryan, 98 Ng, Sin Chun, 49 Nghiem, Tri-Duc, 93 Nguyen, Bach Hoai, 85, 103 Nguyen, Duc Manh, 40, 97 Nguyen, Phan Trung Hai, 72, 137 Nguyen, Su, 79, 140, 141 Nguyen, Trung Thanh, 79, 138 Ni, Xizi, 49 Niatsetski, Yury, 79, 148 Nickel, Falk, 91, 153 Nickerson, Kyle, 79, 141 Nicolau, Miguel, 45, 75, 99, 140 Nikitin, Nikolai O., 98 Nikulin, Vsevolod, 91, 153 Nishida, Kouhei, 40, 67, 90, 132 Nissen, Volker, 96 Nitschke, Geoff, 94 Nogneng, Dorian, 92, 157 Nojima, Yusuke, 49, 78, 124 Nomura, Kota, 94 Nugent, Ronan, 58 Numao, Masayuki, 89, 95, 109 Nygaard, Tønnes F., 70, 104 O'Neill, Michael, 75, 140 O'Reilly, Una-May, 36, 45, 99 Oakley, Jeremy E., 78, 125 Ocampo Pineda, Mario, 83, 143 Ochoa, Gabriela, 36, 52, 66, 81, 86, 113, 114 Ofria, Charles, 41, 51, 75, 78, 94, 133, 140 Ohashi, Kyotaro, 46 Ohmura, Ren, 42 Ohnishi, Kei, 50 Ohta, Yoshihiro, 99 Ohtsuka, Hiro, 50 Ojalehto, Vesa, 75, 123 Okabe, Daisuke, 89, 109

Okabe, Tatsuya, 32 Okumura, Hiroshi, 42 Olejnik, Richard, 48 Olhofer, Markus, 78, 97, 130 Oliveira, Luiz Otavio Vilas Boas, 47, 68, 83, 142 Oliveto, Pietro S., 36, 85, 90, 139, 145 Omidvar, Mohammad Nabi, 72, 79, 129, 138 Ono, Keiko, 50 Ono, Satoshi, 94 Orlov, Michael, 48 Orphanou, Kalia, 67, 87, 136 Ortega, Julio, 40, 98 Orzechowski, Patryk, 51, 68, 83, 142 Oshima, Chika, 42 Osindero, Simon, 41, 94 Ostermayer, Gerald, 79, 138 Otani, Noriko, 89, 109 Ouali, Anis, 91, 152 Owen, Caitlin A., 67, 71, 115 Oyama, Akira, 57, 97 Ozcan, Ender, 83, 143 Ozkok, Dogus, 95 Öztop, Hande, 70, 95, 110 Paechter, Ben, 66, 77, 105 Paige, Richard Freeman, 84, 154 Palar, Pramudita Satria, 91, 152 Palomo-Lozano, Francisco, 45, 84, 154 Pan, Quan-Ke, 70, 95, 110 Pang, Bei, 48, 78, 97, 130 Pang, Lee Ping, 49 Pantridge, Edward R., 43, 49 Papavasileiou, Evgenia, 50 Pappa, Gisele Lobo, 47, 68, 83, 142 Paguete, Luís, 77, 112 Parque, Victor, 40, 42 Pätzel, David, 46 Paul, Dipanivoti, 96 Pawełczyk, Krzysztof, 50 Pawlak, Tomasz P., 66, 81, 90, 113, 132 Peake, Joshua, 48 Pechenizkiy, Mykola, 89, 121 Peng, Hu, 93, 98 Peng, Yiming, 81, 118 Pereira, Cristiane Salgado, 40 Perino, Lorenzo, 46 Pertierra, Marcos A., 99 Pescador-Rojas, Miriam, 96 Picard, Cyril, 87, 151 Pieters, Bradley R., 79, 148 Pilát, Martin, 98

Pintea, Camelia, 77, 112 Pitzer, Erik, 79, 138 Pizzuti, Clara, 77, 117 Podgorelec, Vili, 95 Podusenko, Albert, 91, 153 Poli, Riccardo, 97 Polyakovskiy, Sergey, 71, 121 Pomares, Hector, 98 Ponsich, Antonin, 70, 110 Pontes, Anselmo, 51 Poon. Kin. 91, 152 Pop, Petrica Claudiu, 77, 112 Pope, Aaron Scott, 45 Popp, Merten, 74, 111 Powell, Courtney Ricardo, 99 Powers, Joshua P., 94 Prado Sánchez, Daniel, 99 Pritzel, Alexander, 41, 94 Promberger, Andreas, 91, 153 Przewozniczek, Michal Witold, 98 Punch, William Fitzgerald, 68, 76, 147 Purshouse, Robin C., 78, 82, 125 Qian, Chao, 92, 157 Qin, A. K., 74, 116 Qin, Zhenyue, 94 Qiu, Xin, 47 Qu, Rong, 52 Quinzan, Francesco, 77, 112, 113 Raggl, Sebastian, 45 Rawlings, Chris, 45 Reedy, Cara L., 49 Rehbach, Frederik, 84, 149 Reinbolt, Hannah, 45 Ren, Zhigang, 48, 78, 97, 130 Ren, Zhilei, 48, 100 Reynoso Meza, Gilberto, 49, 93 Ribalta Lorenzo, Pablo, 86, 119 Richmond, Paul, 84, 149 Richter, Andreas, 91, 153 Richter, Samuel N., 44 Rincón García, Eric Alfredo, 70, 110 Risi, Sebastian, 36, 66, 81, 85, 94, 106, 109 Rodríguez-Cárdenas, Daniel, 48 Rodrigues, Silvio, 83, 143 Rodriguez, Francisco J., 87, 144 Rodriguez-Vazquez, Katya, 51 Rogers, Ian, 99 Roohitavaf, Mohammad, 48, 98 Rosa, Agostinho C., 93

Rosales, John Clifford, 99 Rosales-Pérez, Alejandro, 74, 116 Rothlauf, Franz, 36, 75, 89, 121, 139 Roy, Proteek Chandan, 96 Rudolph, Günter, 86, 128 Runkle, Erik S., 100 Runkler, Thomas A., 44 Rusu, Andrei, 41, 94 Ruta, Dymitr, 93, 100 Sánchez, Ana B., 100 Sýs, Marek, 72, 147 Sabar, Nasser R., 72, 146 Saenko, Igor, 45 Saffre, Fabrice, 93, 100 Sagardui, Goiuria, 84, 91, 146, 154 Saha, Sriparna, 96 Sahraoui, Houari, 88, 155 Saied, Mohamed Aymen, 88, 155 Saito, Shota, 49 Sakamoto, Naoki, 46 Samarasinghe, Dilini, 85, 107 Saminger-Platz, Susanne, 71, 122 Samuelsen, Eivind, 70, 104 Sanchez-Pi, Nayat, 40 Sander, Frederick, 82, 126 Sanhueza, Claudio, 75, 96, 123 Santana, Roberto, 67, 71, 82, 96, 115, 131 Santos, Filipe, 72, 132 Sato, Hiroyuki, 42, 46, 50, 78, 93, 99, 124 Sato, Mayuko, 100 Sato, Mikiko, 50 Sato, Yuji, 50, 78, 124 Saurabh, Saket, 100 Sawada, Ikushi, 42 Scafuri, Umberto, 48 Scaini, Giovanni, 48 Schaul, Tom, 41, 94 Schiex, Thomas, 86, 114 Schiffmann, Jürg, 87, 151 Schlag, Sebastian, 74, 111 Schlueter, Martin, 99 Schmickl, Thomas, 81, 106 Schmitt, Sebastian, 97 Schoenauer, Marc, 38 Schoonover, Kevin, 45 Schossau, Jory, 78, 134 Schrum, Jacob, 66, 70, 77, 85, 89, 108, 109, 117 Schulte, Julian, 96 Schulz, Christian, 74, 111 Schweim, Dirk, 75, 139

Scirea, Marco, 94 Scott, Eric O., 94 Segredo, Eduardo, 82, 131 Segura, Carlos, 83, 143 Segura, Sergio, 100 Seidu, Razak, 45 Sekanina, Lukas, 72, 87, 143, 147 Sellers, Gavin, 77, 117 Sellis, Timos, 74, 116 Semwal, Tushar, 43, 85, 107 Seo, Suin, 46 Sepulveda, Francisco, 97 Sewisy, Adel, 46 Shabash, Boris, 46 Shahoud, Shadi, 43 Shaikh, Siraj Ahmed, 49 Shakya, Siddhartha, 91, 152 Shand, Cameron, 77, 117 Shang, Ke, 49, 67, 90, 128 Sheppard, John, 48, 74, 93, 102 Shi, Feng, 92, 158 Shi, Jialong, 71, 122 Shi, Jiao, 48 Shigenobu, Takuto, 94 Shima, Ryusei, 42 Shimada, Koki, 95 Shimohara, Katsunori, 46, 47, 91, 153 Shimoyama, Koji, 91, 152 Shir, Ofer M., 36, 37, 44 Shirakawa, Shinichi, 49, 82, 131 Silva, Sara, 90, 145 Simmer, Clemens, 51 Simon, Glen A., 43 Simoncini, David, 86, 114 Singh, Harman, 81, 118 Sipper, Moshe, 51, 87, 144 Skonieczny, Lukasz, 99 Skowyra, Richard W., 45 Smith, Adam M., 66, 85, 109 Smith, Stephen L., 38, 99 So, David, 51 Soares Indrusiak, Leandro, 87, 151 Sobania, Dominik, 89, 121 Socievole, Annalisa, 77, 117 Song, Andy, 72, 146 Souza, Eduardo Faria de, 88, 154 Spector, Lee, 37, 43, 49, 68, 83, 90, 142, 145 Sprechmann, Pablo, 41, 94 Squillero, Giovanni, 37, 41 Srivastava, Ranjan, 99 Srivisut, Komsan, 84, 154

Sroka, Daniel, 66, 81, 113 Stankevich, Andrew, 49 Stanley, Kenneth O., 41, 66, 74, 77, 105, 116 Steger, Angelika, 73, 155 Stein, Anthony, 67, 71, 115 Steyven, Andreas Siegfried Wilhelm, 66, 77, 105 Stolfi, Daniel H., 100 Stork, Jörg, 84, 149 Strasser, Shane, 74, 102 Stützle, Thomas, 38 Su, Kuan-Wu, 95 Sudholt, Dirk, 67, 72, 76, 87, 92, 135, 137, 156, 158 Sugihara, Taro, 42 Sun, Chaoli, 85, 103 Sun, Jianyong, 71, 96, 122 Sun, Yuan, 72, 75, 129, 138 Sundaram, Suresh, 86, 127 Sutton, Andrew M., 76, 77, 83, 113, 134, 156 Swan, Jerry, 87, 151 Sygnowski, Jakub, 41, 94 Taborda, Bruno, 72, 132 Tagawa, Kiyoharu, 97 Takadama, Keiki, 42, 46, 93 Takagi, Hideyuki, 93 Takano, Ryo, 46, 93 Talamini, Jacopo, 48 Talbot, Pierre-Olivier, 88, 155 Talukder, AKM Khaled Ahsan, 96 Tan, Kay Chen, 79, 140 Tan, Li-Tao, 95 Tan, Ying, 85, 93, 103 Tanaka, Kiyoshi, 75, 96, 97, 123 Tanaka, Mariko, 50 Tanev, Ivan, 46, 47, 91, 153 Tang, Ke, 92, 157 Tang, Yang, 47 Tang, Zedong, 48, 82, 126 Tarantino, Ernesto, 48 Tasgetiren, M. Fatih, 70, 95, 110 Tatsukawa, Tomoaki, 90, 96, 128 Tatsumi, Takato, 42, 46 Tauritz, Daniel R., 36, 44, 45 Tavares, Ricardo Goncalves, 70, 110 Taylor, Kendall Peter, 86, 127 Teplyashin, Denis, 41, 94 Terashima-Marín, Hugo, 74, 116 Teytaud, Fabien, 99 Thawonmas, Ruck, 50, 98 Thierens, Dirk, 36, 67, 71, 87, 129, 136

Thiruvady, Dhananjay, 79, 141 Thomson, Sarah Louise, 86, 114 Tinós, Renato, 66, 67, 81, 87, 113, 136 Togelius, Julian, 36, 70, 75, 94, 108, 137 Tomlinson, Andrew, 49 Tonda, Alberto, 37, 41 Tong, Le, 47 Torresen, Jim, 70, 104 Trautmann, Heike, 45, 86, 128 Treeby, Bradley E., 46 Trujillo, Leonardo, 48 Tudruj, Marek, 48 Turky, Ayad, 72, 146 Türsel Eliiyi, Deniz, 70, 110 Tusar, Tea, 37, 40, 75, 123 Tutum, Cem C., 91, 152 Tweraser, Isabel, 89, 109 Uchibe, Eiji, 89, 119, 120 Uchida, Kento, 82, 131 Udluft, Steffen, 44 Ueda, Suguru, 42 Ullrich, Markus, 45 Umenai, Yuta, 93 Unold, Olgierd, 46 Urbanowicz, Ryan, 36, 71, 115 Ushinohama, Takuya, 94 Uwano, Fumito, 46, 93 Uyheng, Joshua, 99 Vaganov, Danila A., 98 Vahdat, Ali, 90, 144 Valdez Peña, Sergio Ivvan, 83, 143 van der Blom, Koen, 74, 102 van der Meer, Marjolein C., 79, 148 van Leeuwen, Matthijs, 97 van Rijn, Sander, 72, 97, 133 VanDam, Mark, 51 Vanneschi, Leonardo, 90, 99, 145 Vargas, Danilo, 36 Vasconcellos Vargas, Danilo, 37 Vasicek, Zdenek, 72, 87, 100, 143, 147 Vassiliades, Vassilis, 81, 106 Veenstra, Frank, 81, 106 Veeramachaneni, Kalyan, 83, 143 Veerapen, Nadarajen, 36, 86, 95, 114 Vellasco, Marley Rebuzzi, 40 Venema, Victor, 51 Verel, Sébastien, 75, 77, 86, 96, 97, 99, 112, 114, 123 Verhelst, Marian, 43

Verma, Brijesh, 46 Viana, Francisco Henrique F., 40 Virgolin, Marco, 79, 148 Vodopija, Aljosa, 40 Vojnar, Tomas, 87, 143 Volz, Vanessa, 66, 85, 109 Vouga, Etienne, 91, 152 Vyatkin, Valeriy, 49 Wagner, Markus, 71, 76, 77, 83, 86, 112, 114, 121, 134, 148 Wagner, Neal, 45 Wagner, Stefan, 41, 45, 86, 114 Wahby, Mostafa, 81, 106 Waku, Tsuyoshi, 46 Wan, Jianvi, 98 Wan, Kanzhen, 49 Wang, Chen, 95 Wang, Feng, 79, 141 Wang, Feng-Sheng, 91, 146 Wang, Han, 100 Wang, Hao, 72, 98, 133 Wang, Hui, 93, 96, 98 Wang, Jane, 41, 94 Wang, Jianxin, 92, 158 Wang, Junchen, 75, 96, 137 Wang, Lin, 72, 86, 119, 147 Wang, Mingwen, 98 Wang, Rui, 41 Wang, Shuai, 84, 91, 146, 154 Wang, Wenjun, 93, 98 Warwicker, John Alasdair, 85, 139 Wasala, Asanka, 100 Watanabe, Tetsuroh, 98 Wei, Jingxuan, 48 Weise, Thomas, 45 Weissenberger, Felix, 73, 155 Weiszer, Michal, 84, 150 Werth, Bernhard, 41, 79, 138 Wever, Marcel, 89, 120 Whigham, Peter A., 67, 71, 115 White, David R., 47 Whitley, Darrell D., 37, 66, 67, 81, 87, 113, 136 Wieloch, Bartosz, 75, 137 Wiese, Kay, 46 Wild, Brandon, 85, 103 Wilson, Dennis, 70, 83, 109, 143 Wineberg, Mark, 36 Witkowski, Olaf, 94 Witt, Carsten, 38, 68, 73, 76, 85, 156, 157 Witteveen, Cees, 79, 80, 148, 149

Wolfgang, Banzhaf, 78, 133 Wong, Cheryl Sze Yin, 86, 127 Woodford, Grant Warren, 81, 106 Woodward, John R., 36, 84, 95, 97, 150 Wu, Harvey, 74, 116 Wu, Jikai, 93 Wu, Jing, 96 Wu, Junhua, 71, 121 Wu, Zhijian, 93 Wu, Zhou, 97, 99 Wu, Zihui, 100 Wu, Zijun, 45 Xia, Yuanzhong, 76, 148 Xiao, Heng, 50 Xin, Bin, 98 Xiong, Tao, 50 Xu, Lihong, 82, 96, 100, 126 Xu, Xiong, 100 Xu, Ying, 82, 127 Xuan, Jifeng, 48 Xue, Bing, 38, 85, 89, 103, 121 Yakupov, Ilya, 97 Yamagishi, Yuki, 50 Yamaguchi, Nobuhiko, 42 Yamaguchi, Takahiro, 97 Yamamoto, Hajime, 42 Yaman, Anil, 89, 121 Yamazaki, Naoko, 33 Yan, Yiming, 82, 125 Yang, Bo, 72, 86, 119, 147 Yang, Guangwen, 68, 85, 139 Yang, Jing, 73, 156 Yang, Kaifeng, 91, 152 Yang, Shengxiang, 82, 127 Yang, Yang, 48, 78, 130 Yannakakis, Georgios N., 36, 70, 104 Yano, Kazuo, 32 Yao, Chengchao, 45 Yao, Xin, 79, 88, 92, 138, 155, 157 Yazdani, Danial, 79, 138 Ye, Furong, 72, 133 Yiapanis, Paraskevas, 48 Yoshikawa, Tomohiro, 50 Young, Rebecca L., 78, 134 Yska, Daniel, 95 Yu, Dong-Pil, 50

Yu, Jun, 93 Yu, Min-Chieh, 95 Yu, Tian-Li, 83, 87, 135 Yu, Xinghuo, 72, 146 Yu, Yang, 92, 157 Yue, Xinya, 72, 147 Yuen, Shiu Yin, 47, 97 Yun, Hansang, 95 Zaefferer, Martin, 84, 149, 150 Zahadat, Payam, 81, 106 Zaman, Asaduz, 93 Zamuda, Ales, 45 Zapotecas, Saúl, 97 Zarges, Christine, 45 Zavoianu, Alexandru-Ciprian, 71, 122 Zeng, Sanyou, 75, 96, 97, 137 Zeng, Zhi-Wei, 95 Zerenner, Tanja, 51 Zhan, Tao, 48, 82, 126 Zhang, Boyu, 74, 116 Zhang, Caili, 42 Zhang, Guixu, 98 Zhang, Hu, 72, 96, 136 Zhang, Jia, 98 Zhang, Jinyuan, 98 Zhang, Jun, 93, 95, 100 Zhang, Liangliang, 72, 147 Zhang, Mengjie, 38, 79, 81, 89, 95, 118, 121, 140 Zhang, Min-Ling, 67, 90, 128 Zhang, Qingfu, 37, 71, 75, 96, 97, 122, 123 Zhang, Yipeng, 78, 130 Zheng, Weijie, 68, 85, 139 Zhong, Jinghui, 93, 97, 99 Zhou, Aimin, 72, 98, 136 Zhou, Jin, 86, 119 Zhou, Lei, 97 Zhou, Xinyu, 93, 98 Zhou, Yan, 82, 127 Zhu, Ling, 48, 98 Zhu, Shuwei, 82, 96, 126 Zhu, Zexuan, 97 Zhu, Ziming, 100 Zhuang, Chukun, 49 Zille, Heiner, 82, 126 Zincir-Heywood, Nur, 45, 68, 76, 90, 144, 147 Zipkin, Joseph R., 45