Genetic and Evolutionary Computation Conference 2016

Conference Program

Denver, CO, USA
July 20-24, 2016

Association for Computing Machinery
Advancing Computing as a Science & Profession

sigevo

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Welcome

On behalf of the Organizing Committee, I would like to welcome you to The Genetic and Evolutionary Computation Conference (GECCO) 2016 in Denver, Colorado, USA, July 20-24. GECCO is sponsored by the Association for Computing Machinery (ACM) Special Interest Group on Genetic and Evolutionary Computation (SIGEVO). It is the top quality conference in the area of evolutionary computation ensuring excellent quality by a selective reviewing process. Decisions on the acceptance of papers are made by expert track chairs handling the different areas of evolutionary computation. This ensures a high quality reviewing process making sure that only the best work in the different areas of evolutionary computation gets accepted and presented at this leading conference.

This year 381 papers were submitted to 15 different tracks, and 1740 reviews assigned. Approximately 36% of papers have been accepted as full papers, with a further 32% accepted for poster presentation.

Highlights of the conference include invited keynote presentations by Bernard Chazelle (Princeton) and Holger H. Hoos (University of British Columbia), and a plenary lecture in memory of John Holland by Stephanie Forrest (University of New Mexico).

Attending GECCO gives an unparalleled opportunity to catch up with the leading experts in the field, establish new collaborations, and also enjoy your pick from 17 free workshops and 32 free tutorials. Furthermore, 5 competitions are being run and the annual Humies event sponsored by John Koza presents the latest human competitive results in the field.

I would like to thank all authors for submitting their excellent work to GECCO 2016 and all people who contributed to the organization of the conference. In particular, I am very much in debt to the organization committee, track chairs, and reviewers for their tremendous work. I would also like to mention and thank Cara Candler and Roxane Rose from Executive Events for handling registrations and logistics, and Franz Rothlauf and Marc Schoenauer for their excellent support and advice on running GECCO 2016.

I am grateful to our industry sponsors Sentient and WorldQuant as well as ACM SIGEVO for their contribution and support.

I wish you an excellent conference with a lot of new insights, collaborations, and ideas for future research.

Frank Neumann
GECCO 2016 General Chair
The University of Adelaide, Australia

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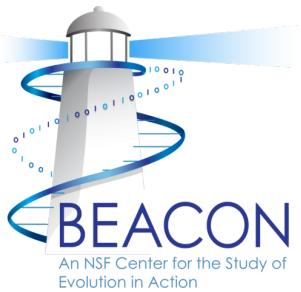

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Moraglio, Alberto, *University of Exeter*
Moritz, Ruby, *Otto-von-Guericke-Universität Magdeburg*
Mostaghim, Sanaz, *University of Magdeburg*
Mouret, Jean-Baptiste, *INRIA Nancy*
Muelas, Santiago, *Lurtis Rules*
Munetomo, Masaharu, *Hokkaido University*
Musliu, Nysret, *Vienna University of Technology*
Nakib, Amir, *Laboratoire LISSI*
Nallaperuma, Samadhi, *University of Adelaide*
Naujoks, Boris, *Cologne University of Applied Sciences*
Nealen, Andy, *New York University*
Nebro, Antonio, *University of Málaga*
Neruda, Roman, *Institute of Computer Science, Academy of Sciences of the Czech Republic*
Neumann, Frank, *University of Adelaide*
Nguyen Xuan, Hoai, *Hanoi University*
Nicolau, Miguel, *University College Dublin*
Nievola, Julio Cesar, *PUCPR Pontifícia Universidade Católica do Paraná*
Nijssen, Siegried, *Universiteit Leiden*
Nitschke, Geoff, *University of Cape Town*
Nojima, Yusuke, *Osaka Prefecture University*
Ó Cinnéide, Mel, *National University of Ireland, Dublin*
O'Neill, Michael, *University College Dublin*
O'Reilly, Una-May, *Massachusetts Institute of Technology*
Ochoa, Gabriela, *University of Stirling*

Ofria, Charles, *Michigan State University*
Olhofer, Markus, *Honda Research Institute Europe*
Oliveira, Pedro, *University of Porto*
Oliveto, Pietro S., *University of Sheffield*
Oliwa, Tomasz, *University of Georgia*
Ono, Isao, *Tokyo Institute of Technology*
Orsenigo, Carlotta, *Politecnico di Milano*
Ortega, Julio, *University of Granada*
Otero, Fernando, *University of Kent*
Ouni, Ali, *Osaka University*
Paechter, Ben, *Edinburgh Napier University*
Pagnozzi, Federico, *Université Libre de Bruxelles*
Paixão, Tiago, *IST Austria*
Palafox, Leon, *University of Arizona*
Pang, Wei, *University of Aberdeen*
Paquete, Luis, *University of Coimbra*
Parque, Victor, *Toyota Technological Institute*
Parsopoulos, Konstantinos, *University of Ioannina*
Pedemonte, Martín, *Universidad de la República*
Pereira, Francisco Baptista, *Instituto Superior de Engenharia de Coimbra*
Perez, Diego, *University of Essex*
Perez Caceres, Leslie, *Université Libre de Bruxelles*
Phelps, Steve, *University of Essex*
Philippides, Andrew, *University of Sussex*
Pilát, Martin, *Charles University in Prague*
Pillay, Nelishia, *University of KwaZulu-Natal*
Pizzuti, Clara, *ICAR-CNR*
Platos, Jan, *Technical University of Ostrava*
Polani, Daniel, *University of Hertfordshire*
Poles, Silvia, *EnginSoft*
Pop, Petrica, *North University of Baia Mare, Romania*
Porumbel, Daniel, *Conservatoire National des Arts et Métiers*
Potter, Walter, *University of Georgia*
Poulding, Simon, *Blekinge Institute of Technology*
Powers, Simon, *Edinburgh Napier University*
Pošík, Petr, *Czech Technical University in Prague*
Prandtstetter, Matthias, *Austrian Institute of Technology GmbH*
Prestwich, Steve, *University College Cork*
Preuss, Mike, *Technische Universität Dortmund*
Jayadeva, *Indian Institute of Technology, Delhi*
Prugel-Bennett, Adam, *University of Southampton*
Puente, Cesar, *Universidad Autónoma de San Luis Potosi*
Punch, William F., *Michigan State University*
Purshouse, Robin, *University of Sheffield*
Qi, Jianlong, *Ancestry.com*
Qian, Chao, *Nanjing University*
Qin, A. K., *Royal Melbourne Institute of Technology*
Rahat, Alma, *University of Exeter*
Raidl, Günther R., *Vienna University of Technology*
Rasheed, Khaled, *University of Georgia*
Ray, Tom, *University of Oklahoma*
Ray, Tapabrata, *University of New South Wales*
Raymer, Michael, *Wright State University*
Read, Mark, *University of Sydney*
Rhyd, Lewis, *Cardiff University*
Richter, Hendrik, *Leipzig University of Applied Sciences*
Rieffel, John, *Union College*
Riff, Maria Cristina, *Universidad Técnica Federico Santa María*
Risi, Sebastian, *IT University of Copenhagen*
Robert, Wille, *University of Bremen*
Robilliard, Denis, *LISIC/ULCO/Univeristé Lille*
Rockett, Peter, *University of Sheffield*
Rodriguez-Tello, Eduardo, *CINVESTAV,Tamaulipas*
Rohlfshagen, Philipp, *Schneider-Electric*
Rojas, José Miguel, *University of Sheffield*
Roli, Andrea, *Università di Bologna*
Rombo, Simona E., *University of Palermo*
Romero, Carlos, *Technical University of Madrid*
Roper, Marc, *University of Strathclyde*
Ross, Brian J., *Brock University*
Rothlauf, Franz, *University of Mainz*
Rowe, Jonathan, *University of Birmingham*
Rudolph, Guenter, *Technische Universität Dortmund*
Ruhe, Guenther, *University of Calgary*
Ruiz, Ruben, *Polytechnic University of Valencia*
Runkler, Thomas, *Siemens AG*
Ryan, Conor, *University of Limerick*
Saborido, Ruben, *Ecole Polytechnique de Montréal*
Sahraoui, Houari, *Université de Montréal*
Salem, Ziad, *Graz University*
Salto, Carolina, *Universidad Nacional de La Pampa*
Samothrakis, Spyridon, *University of Essex*
Sanchez, Luciano, *Universidad de Oviedo*
Santana, Roberto, *University of the Basque Country*
Santibáñez Koref, Iván, *Technical University of Berlin*
Sarro, Federica, *University College London*
Sato, Hiroyuki, *The University of Electro-Communications*
Sato, Yuji, *Hosei University*
Saubion, Fredéric, *University of Angers*
Sawada, Hideyuki, *Kagawa University*
Schillaci, Massimiliano, *STMicroelectronics*
Schmitt, Manuel, *University of Erlangen-Nuremberg*
Schrum, Jacob, *Southwestern University*
Schuetze, Oliver, *CINVESTAV-IPN*
Scully, Peter, *Aberystwyth University*
Sebag, Michele, *Université Paris-Sud*
Segovia-Dominguez, Ignacio, *CIMAT*
Segredo, Eduardo, *Universidad de La Laguna*
Segura, Carlos, *CIMAT*
Sekanina, Lukas, *Brno University of Technology*
Seppi, Kevin, *Brigham Young University*
Sevaux, Marc, *Université de Bretagne-Sud*
Shaheen, Fatima, *Loughborough University*
Shaker, Noor, *IT University of Copenhagen*
Shengxiang, Yang, *De Montfort Unviersity*
Shukla, Pradyumn Kumar, *Karlsruher Institut für Technologie*
Siarry, Patrick, *University of Paris-Est Créteil*
Silva, Arlindo, *Polytechnic Institute of Castelo Branco*
Silva, Fernando, *Universidade de Lisboa*

Sim, Kevin, *Edinburgh Napier University*
Simões, Anabela, *Coimbra Polytechnic*
Sipper, Moshe, *Ben-Gurion University*
Skurikhin, Alexei N., *Los Alamos National Laboratory*
Smith, Alice, *Auburn University*
Smith, Jim, *University of the West of England*
Solnon, Christine, *INSA de Lyon Institut National des Sciences Appliquées de Lyon*
Solteiro Pires, Eduardo J., *Universidade de Trás-os-Montes e Alto Douro*
Soltoggio, Andrea, *Loughborough University*
Song, Andy, *Royal Melbourne Institute of Technology*
Sosa Hernandez, Victor Adrian, *CINVESTAV-IPN*
Soule, Terence, *University of Idaho*
Spector, Lee, *Hampshire College*
Squillero, Giovanni, *Politecnico di Torino*
Stanley, Kenneth O., *University of Central Florida*
Stich, Sebastian, *Université Catholique de Louvain*
Stolfi, Daniel H., *University of Málaga*
Stonedahl, Forrest, *Northwestern University*
Stork, Jörg, *Cologne University of Applied Sciences*
Straccia, Umberto, *ISTI-CNR*
Stützle, Thomas, *Université Libre de Bruxelles*
Sudholt, Dirk, *University of Sheffield*
Suganthan, Ponnuthurai, *Nanyang Technological University*
Sun, Chaoli, *Taiyuan University of Science and Technology*
Sutton, Andrew M., *Hasso-Plattner-Institut*
Suzuki, Reiji, *Nagoya University*
Takadama, Keiki, *University of Electro-Communications*
Takahashi, Ricardo, *Universidade Federal de Minas Gerais*
Talbi, El-Ghazali, *INRIA Lille*
Tan, Ying, *Peking University*
Tanabe, Ryoji, *University of Tokyo*
Tanev, Ivan, *Doshisha University*
Tarantino, Ernesto, *ICAR-CNR*
Tauritz, Daniel R., *Missouri University of Science and Technology*
Tavares, Jorge, *Microsoft*
Tavares, Roberto, *Universidade Federal de São Carlos*
Taylor, Tim, *University of London International Academy*
Teich, Jürgen, *University of Erlangen-Nuremberg*
Terashima Marín, Hugo, *Tecnológico de Monterrey*
Tettamanzi, Andrea G. B., *Université de Nice Sophia Antipolis*
Teuscher, Christof, *Portland State University*
Textor, Johannes, *University of Utrecht*
Thawonmas, Ruck, *Ritsumeikan University*
Thiele, Lothar, *ETH Zürich*
Thierens, Dirk, *Utrecht University*
Thompson, Tommy, *University of Derby*
Timmis, Jonathan, *University of York*
Ting, Chuan-Kang, *National Chung Cheng University*
Tino, Peter, *University of Birmingham*
Tinos, Renato, *University of São Paulo*
Tiwari, Santosh, *General Motors Company*
Tiwari, Ashutosh, *Cranfield University*
Togelius, Julian, *IT University of Copenhagen*
Tonda, Alberto, *Institut National de la Recherche Agronomique*
Torkar, Richard, *Blekinge Institute of Technology*
Toutouh, Jamal, *University of Málaga*
Trautmann, Heike, *University of Münster*
Trefzer, Martin, *University of York*
Trianni, Vito, *ISTC-CNR*
Trojanowski, Krzysztof, *Institute of Computer Science, Polish Academy of Sciences*
Trujillo, Leonardo, *Instituto Tecnológico de Tijuana*
Tsoukias, Alexis, *Université Paris Dauphine*
Tušar, Tea, *Jožef Stefan Institute*
Tutum, Cem C., *University of Texas at Austin*
Twycross, Jamie, *University of Nottingham*
U, Man Chon, *Las Vegas Sands Corporate*
Urbano, Paulo, *University of Lisbon*
Urbanowicz, Ryan, *Dartmouth College*
Urquhart, Neil, *Edinburgh Napier University*
Vanneschi, Leonardo, *Universidade Nova de Lisboa*
Vašíček, Zdeněk, *Brno University of Technology*
Vatolkin, Igor, *Technische Universität Dortmund*
Veerapen, Nadarajen, *University of Stirling*
Velasco, Nubia, *Universidad de los Andes*
Ventura, Sebastian, *Universidad de Cordoba*
Verel, Sebastien, *Université du Littoral Côte d'Opale*
Vergilio, Silvia, *Federal University of Paraná*
Viana, Ana, *Polytechnic of Porto*
Vidnerova, Petra, *Institute of Computer Science, Academy of Sciences of the Czech Republic*
Villagra, Andrea, *Universidad Nacional de la Patagonia Austral*
Volz, Vanessa, *Technische Universität Dortmund*
Von Zuben, Fernando J., *University of Campinas*
Vrahatis, Michael N., *University of Patras*
Wagner, Tobias, *Technische Universität Dortmund*
Walker, David, *University of Exeter*
Wanka, Rolf, *University of Erlangen-Nuremberg*
Wanner, Elizabeth, *Federal Center of Technologic Education - Minas Gerais*
Webb, Andrew, *University of Manchester*
Wessing, Simon, *Technische Universität Dortmund*
Whigham, Peter Alexander, *Univ. of Otago*
White, David, *University of Glasgow*
Wilkerson, Josh, *NAVAIR*
Wilson, Garnett, *Afinin Labs Inc.*
Wimmer, Manuel, *Vienna University of Technology*
Wineberg, Mark, *University of Guelph*
Winkler, Stephan, *University of Applied Sciences Upper Austria*
Witt, Carsten, *Technical University of Denmark*
Wong, M. L. Dennis, *Swinburne University of Technology*
Woodward, John R., *University of Stirling*
Wrobel, Borys, *Adam Mickiewicz University*
Wu, Annie S., *University of Central Florida*
Xhafa, Fatos, *Birkbeck, University of London*
Xie, Huayang, *Oracle New Zealand*

Xue, Bing, *Victoria University of Wellington*
Yamada, Takeshi, *NTT Communication Science Labs.*
Yannakakis, Georgios N., *University of Malta*
Yeh, Wei-Chang, *National Tsing Hua University*
Yen, Gary G., *Oklahoma State University*
Yliniemi, Logan, *University of Nevada, Reno*
Yoo, Shin, *Korea Advanced Institute of Science and Technology*
Yu, Yang, *Nanjing University*
Yu, Tina, *Memorial University of Newfoundland*
Zafra, Amelia, *University of Córdoba*
Zahadat, Payam, *University of Graz*
Zaharie, Daniela, *West University of Timisoara*
Zambetta, Fabio, *Royal Melbourne Institute of Technology*
Zapotecas Martínez, Saúl, *CINVESTAV-IPN*
Zarges, Christine, *University of Birmingham*
Zell, Andreas, *University of Tübingen*
Zexuan, Zhu, *Shenzhen University*
Zhang, Yuanyuan, *University College London*
Zhang, Mengjie, *Victoria University of Wellington*
Zhong, Yanfei, *Wuhan University*
Zhou, Aimin, *East China Normal University*

Schedule and Floor Plans

Schedule at a Glance

Wednesday, July 20	Thursday, July 21	Friday, July 22	Saturday, July 23	Sunday, July 24
Tutorials and Workshops 08:30-10:20	Tutorials and Workshops 08:30-10:20	Opening 08:50-09:00		
		Keynote Bernard Chazelle 09:00-10:10	Keynote Holger Hoos 09:00-10:10	Paper Sessions 09:00-10:40
Coffee Break	Coffee Break	Coffee Break	Coffee Break	
Tutorials and Workshops 10:40-12:30	Tutorials and Workshops 10:40-12:30	Paper Sessions 10:40-12:20	Paper Sessions 10:40-12:20	Coffee Break
				Plenary Stephanie Forrest 11:10-11:55
Lunch on Your Own	Lunch on Your Own	Lunch on Your Own	Lunch on Your Own	SIGEVO meeting/awards 11:55-13:30
Tutorials and Workshops 14:00-15:50	Tutorials and Workshops 14:00-15:50	Paper Sessions 14:00-15:40	Paper Sessions 14:00-15:40	
Coffee Break	Coffee Break	Coffee Break	Coffee Break	
Tutorials and Workshops 16:10-18:00	Tutorials and Workshops 16:10-18:00	Paper Sessions 16:10-17:50	Paper Sessions 16:10-17:50	
Evolution in Action! 19:00-21:00		LBA and Poster Session 18:15-20:00	Conference Reception 18:30-21:00	

registration desk hours: Wednesday and Thursday, 8:00-16:00
Friday and Saturday, 8:00-16:30
Sunday, 8:00-11:00

coffee breaks: Atrium

keynotes, posters and competitions, and SIGEVO meeting: Grand Mesa Ballroom DEF

conference reception: Atrium

Workshop and Tutorial Sessions, Wednesday, July 20

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
Chasm Creek A	**EC: A Unified Approach** De Jong	**Genetic Programming** O'Reilly	**Evolutionary Multiobjective Optimization** Brockoff, Wagner	**Visualization in Multiobjective Optimization** Tušar, Filipič
Chasm Creek B	**Hyper-Heuristics** Tauritz, Woodward	**Model-based EAs** Thierens, Bosman	**Theory for Non-Theoreticians** Doerr, Doerr	**Model-based EAs** p. 30
Wind River A	**Measuring and Promoting Diversity in EAs** p. 28	**Industrial Applications o Metaheuristics (IAM)** p. 29	**EC in Practice** p. 49	
Wind River B	**Simulation Optimization** Branke	**Expressive Genetic Programming** Spector, McPhee	**Semantic GP** Moraglio, Krawiec	**Theory of Swarm Intelligence** Sudholt
Wind Star A	**EC and Games** Togelius	**Medical Applications of EC** Smith	**Cloudy Distributed EC** Merelo	**EC and Cryptology** Picek
Wind Star B	**BBOB - Bi-Objective Blackbox Optimization Benchmarking** p. 28			
Mesa Verde A		**Introducing Rule-based Machine Learning** Urbanowicz	**Evolutionary Rule-based Machine Learning** p. 30	
Mesa Verde B	**Medical Applications of Genetic and Evolutionary Computation (MedGEC)** p. 28	**Genetic Improvement (GI 2016)** p. 30		
Mesa Verde C				

Tutorials Workshops

Workshop and Tutorial Sessions, Thursday, July 21

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
Chasm Creek A	**Complex Networks** Tomassini	**Representations for EAs** Rothlauf	**Introductory Statistics for EC** Wineberg	**Autmated (Offline) Configuration of Algorithms** Stützle, López-Ibáñez
Chasm Creek B	**Runtime Analysis of Population-based EAs** Lehre, Oliveto	**Introduction to Randomized Continuous Optimization** Akimoto, Auger, Hansen	**Evolving Neural Networks** Miikkulainen	**Blind No More** Whitley
Wind River A	**Evolutionary Computation Software Systems (EvoSoft)** p. 31	**Student Workshop** p. 32		
Wind River B	**Constraint Handling Techniques** Coello Coello	**Generative and Developmental Systems** Stanley	**CMA-ES and Advanced Adaptation Mechanisms** Akimoto, Auger, Hansen	**Solving Complex Problems with Coevolutionary Algorithms** Krawiec, Heywood
Wind Star A	**Intelligent Systems for Smart Cities** Alba	**EC for Feature Selection and Feature Construction** Zhang, Xue	**Biased Random-Key GAs** Resende, Ribeiro	**HOP1** p. 52
Wind Star B	**Workshop on Evolutionary Computation for the Automated Design of Algorithms (ECADA)** p. 32		**Evolution in Cognition** p. 33	
Mesa Verde A	**Visualisation Methods in Genetic and Evolutionary Computation (VizGEC)** p. 32		**Surrogate-Assisted Evolutionary Optimisation (SAEOpt)** p. 34	
Mesa Verde B	**GEC in Defense, Security, and Risk Management (SecDef)** p. 31	**Algorithms and Data Structures for EC** p. 32	**Women@GECCO** p. 33	**Work/Life Balance**
Mesa Verde C			**EC in Computational Structural Biology** p. 34	

Tutorials Workshops HOP session

Parallel Sessions, Friday, July 22 through Sunday, July 24

	Friday July 22 10:40-12:20	Friday July 22 14:00-15:40	Friday July 22 16:10-17:50	Saturday July 23 10:40-12:20	Saturday July 23 14:00-15:40	Saturday July 23 16:10-17:50	Sunday July 24 09:00-10:40
Chasm Creek A	CO+THEORY +ACO-SI ☆ p. 53	EMO ☆ p. 55	GP ☆ p. 57	ECOM ☆ p. 59	RWA ☆ p. 61	GA+CS ☆ p. 63	EML ☆ p. 65
Chasm Creek B	DETA+PES +SBS-SS ☆ p. 53	AIS-BIO1 +CO1 p. 55	EML1 p. 57	PES1 p. 60	GA2 p. 62	ACO-SI2 p. 63	ECOM4 p. 65
Wind River A	CS1 p. 53	CS2 p. 55	SBS-SS1 p. 58	RWA4+IGEC1 p. 60	ECOM2 p. 61	ECOM3 +RWA5 p. 64	RWA6 p. 66
Wind River B	EMO1 p. 54	THEORY1 p. 56	EMO2 p. 57	CO2 p. 59	ACO-SI1 p. 61	EML2 p. 64	
Wind Star A	ECOM1 p. 54	GA1 p. 56	THEORY2 p. 58	HOP2 p. 60	HOP3 p. 62	HOP4 p. 64	
Wind Star B		Humies p. 46		Competitions p. 47			
Mesa Verde B	RWA1 p. 54	RWA2 p. 56	RWA3 p. 58	GP1 p. 59	GP2 p. 62	DETA1 p. 63	CS3+IGEC2 p. 65

☆ *Sessions with best paper nominees*

Track List and Abbreviations

ACO-SI: Ant Colony Optimization and Swarm Intelligence

AIS-BIO: Artificial Immune Systems and Biological and Medical Applications

CO: Continuous Optimization (formerly ESEP)

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

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

GA: Genetic Algorithms

GP: Genetic Programming

HOP: Hot Off the Press

IGEC: Integrative Genetic and Evolutionary Computation

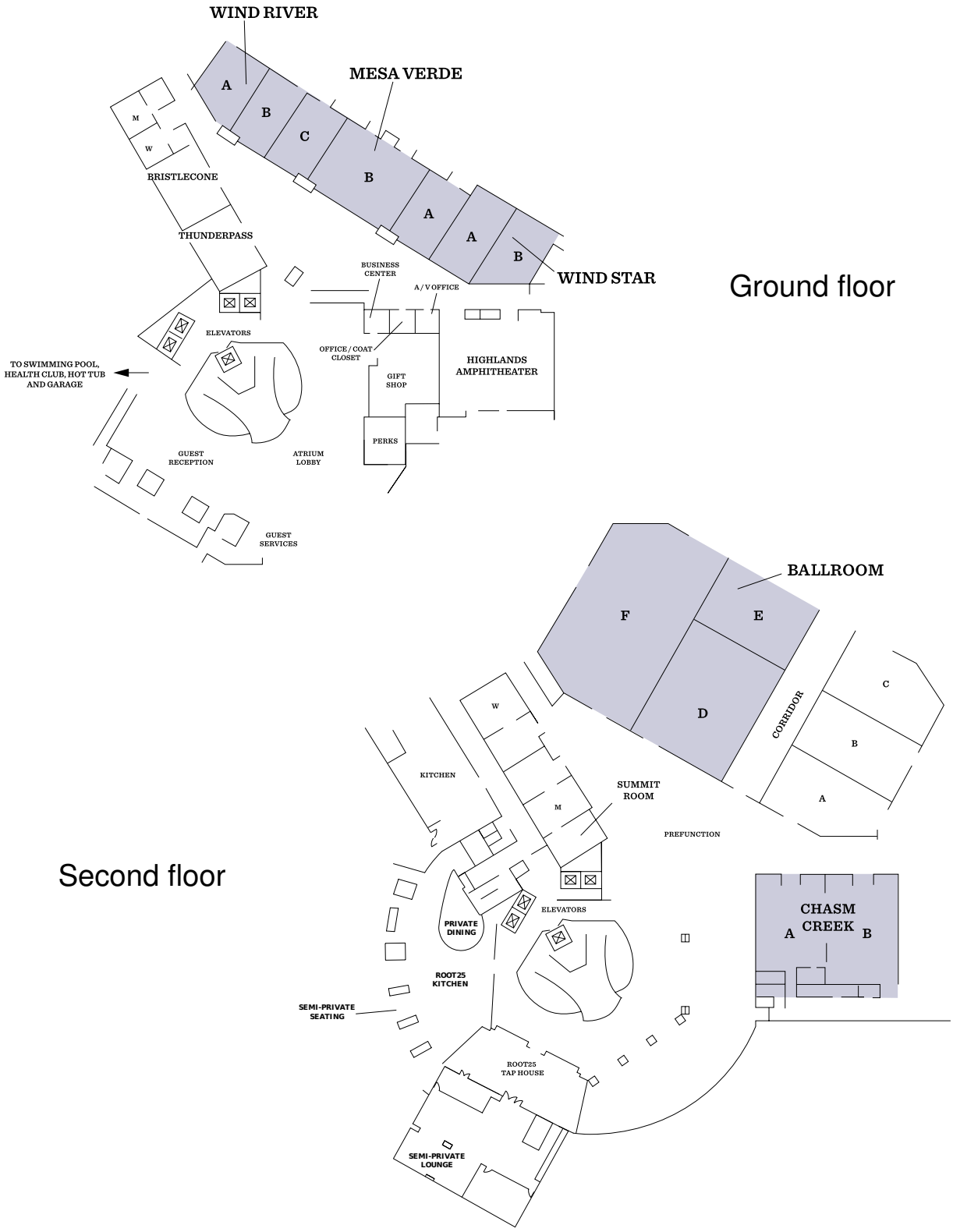
PES: Parallel Evolutionary Systems

RWA: Real World Applications

SBS-SS: Search Based Software Engineering and Self-* Search

THEORY: Theory

Floor Plans


WIND RIVER
MESA VERDE
A
B
C
B
A
A
B
M
W
BRISTLECONE
THUNDERPASS
BUSINESS CENTER
A/V OFFICE
WIND STAR
Ground floor
ELEVATORS
OFFICE / COAT CLOSET
HIGHLANDS AMPHITHEATER
TO SWIMMING POOL, HEALTH CLUB, HOT TUB AND GARAGE
GIFT SHOP
PERKS
GUEST RECEPTION
ATRIUM LOBBY
GUEST SERVICES
BALLROOM
F
E
D
C
B
A
CORRIDOR
W
KITCHEN
M
SUMMIT ROOM
PREFUNCTION
Second floor
ELEVATORS
PRIVATE DINING
CHASM CREEK
A
B
ROOT25 KITCHEN
SEMI-PRIVATE SEATING
ROOT25 TAP HOUSE
SEMI-PRIVATE LOUNGE

Evolution in Action!

Evolution in Action!

An interactive workshop introducing computational thinking to kids 10-14

evolutioninaction.mit.edu

The Evolution in Action! exercises teach the fundamentals of computational thinking by having the kids or act out algorithms in the classroom. This workshop encourages kids to think logically and computationally, teaching how to problem-solve without using a computer!

The Evolution in Action! workshop offers kids a fun way to explore concepts related to computational thinking by participating in open-ended, group exercises that integrate concepts from game theory and evolution. Evolution in Action! exercises administer simple but profound ways for kids to think about the procedural aspects of processes and systems they see in the world. We believe there's a lot of computation going on in the world and our goal is to develop with each child an implicit awareness of this in subtle, kid-friendly ways.

Children must be registered for this workshop to attend.
Email us at *evoinact@mit.edu* to register.
Registration deadline for Evolution in Action! is July 10.

All children must be accompanied by a registered adult.

Session 1: Wednesday, July 20, 19:00–21:00; Wind River A
Session 2: Saturday, July 23, 13:00–15:00; Wind Star B

Activities led by:

Una-May O'Reilly (MIT),

Erik Hemberg (MIT),

Nicole Hoffman (MIT)

Tutorials

Intoductory Tutorials

Evolutionary Computation: A Unified Approach — Wednesday, July 20, 08:30-10:20, Chasm Creek A
Kenneth A. De Jong, *George Mason University*

Hyper-Heuristics — Wednesday, July 20, 08:30-10:20, Chasm Creek B
Daniel R. Tauritz, *Missouri University of Science and Technology*
John R. Woodward, *University of Stirling*

Genetic Programming — Wednesday, July 20, 10:40-12:30, Chasm Creek A
Una-May O'Reilly, *Massachusetts Institute of Technology*

Introducing Rule-Based Machine Learning: Capturing Complexity — Wednesday, July 20, 10:40-12:30, Mesa Verde A
Ryan Urbanowicz, *University of Pennsylvania*

Model-Based Evolutionary Algorithms — Wednesday, July 20, 10:40-12:30, Chasm Creek B
Dirk Thierens, *Utrecht University*
Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*

Evolutionary Multiobjective Optimization — Wednesday, July 20, 14:00-15:50, Chasm Creek A
Dimo Brockoff, *INRIA Lille*
Tobias Wagner, *TU Dortmund*

Theory for Non-Theoreticians — Wednesday, July 20, 14:00-15:50, Chasm Creek B
Benjamin Doerr, *Ecole Polytechnique*
Carola Doerr, *CNRS and Université Pierre et Marie Curie*

Introduction to Complex Networks — Thursday, July 21, 08:30-10:20, Chasm Creek A
Marco Tomassini, *University of Lausanne*

Runtime Analysis of Population-based Evolutionary Algorithms — Thursday, July 21, 08:30-10:20, Chasm Creek B
Per Kristian Lehre, *University of Nottingham*
Pietro S. Oliveto, *University of Sheffield*

Introduction to Randomized Continuous Optimization — Thursday, July 21, 10:40-12:30, Chasm Creek B
Youhei Akimoto, *Shinshu University*
Anne Auger, *INRIA*
Nikolaus Hansen, *INRIA*

Representations for Evolutionary Algorithms — Thursday, July 21, 10:40-12:30, Chasm Creek A
Franz Rothlauf, *Universität Mainz*

Evolving Neural Networks — Thursday, July 21, 14:00-15:50, Chasm Creek B
Risto Miikkulainen, *The University of Texas, Austin*

Introductory Statistics for EC — Thursday, July 21, 14:00-15:50, Chasm Creek A
Mark Wineberg, *University of Guelph*

Advanced Tutorials

Simulation Optimisation — Wednesday, July 20, 08:30-10:20, Wind River B
Juergen Branke, *University of Warwick*

Expressive Genetic Programming: Concepts and Applications — Wednesday, July 20, 10:40-12:30, Wind River B
Lee Spector, *Hampshire College*
Nicholas Freitag McPhee, *University of Minnesota, Morris*

Semantic Genetic Programming — Wednesday, July 20, 14:00-15:50
Alberto Moraglio, *University of Exeter* — Wind River B
Krzysztof Krawiec, *Poznan University of Technology*

Theory of Swarm Intelligence — Wednesday, July 20, 16:10-18:00
Dirk Sudholt, *University of Sheffield* — Wind River B

Visualization in Multiobjective Optimization — Wednesday, July 20, 16:10-18:00
Tea Tušar, *INRIA Lille* — Chasm Creek A
Bogdan Filipič, *Jozef Stefan Institute*

Constraint-Handling Techniques used with Evolutionary Algorithms — Thursday, July 21, 08:30-10:20
Carlos Artemio Coello Coello, *CINVESTAV-IPN* — Wind River B

Generative and Developmental Systems — Thursday, July 21, 10:40-12:30
Kenneth O. Stanley, *University of Central Florida* — Wind River B

Biased Random-Key Genetic Algorithms — Thursday, July 21, 14:00-15:50
Mauricio G. C. Resende, *Amazon.com, Inc.* — Wind Star A
Celso C. Ribeiro, *U. Federal Fluminense*

CMA-ES and Advanced Adaptation Mechanisms — Thursday, July 21, 14:00-15:50
Youhei Akimoto, *Shinshu University* — Wind River B
Anne Auger, *INRIA*
Nikolaus Hansen, *INRIA*

Blind No More: Deterministic Partition Crossover and Deterministic Improving Moves — Thursday, July 21, 16:10-18:00
Darrell Whitley, *Colorado State University* — Chasm Creek B

Solving Complex Problems with Coevolutionary Algorithms — Thursday, July 21, 16:10-18:00
Krzysztof Krawiec, *Poznan University of Technology* — Wind River B
Malcolm Heywood, *Dalhousie University*

Specialized Tutorials

Evolutionary Computation and Games — Wednesday, July 20, 08:30-10:20
Julian Togelius, *New York University* — Wind Star A

Medical Applications of Evolutionary Computation — Wednesday, July 20, 10:40-12:30
Stephen L. Smith, *University of York* — Wind Star A

Cloudy Distributed Evolutionary Algorithms — Wednesday, July 20, 14:00-15:50
Juan J. Merelo, *University of Granada/CITIC* — Wind Star A

Evolutionary Computation and Cryptology — Wednesday, July 20, 16:10-18:00
Stjepan Picek, *KU Leuven & iMinds* — Wind Star A

Intelligent Systems for Smart Cities — Thursday, July 21, 08:30-10:20
Enrique Alba, *Universidad de Málaga* — Wind Star A

Evolutionary Computation for Feature Selection and Feature Construction — Thursday, July 21, 10:40-12:30
Mengjie Zhang, *Victoria University of Wellington* — Wind Star A
Bing Xue, *Victoria University of Wellington*

Automatic (Offline) Configuration of Algorithms
Thomas Stützle, *IRIDIA, Université libre de Bruxelles*
Manuel López-Ibáñez, *University of Manchester*

Thursday, July 21, 16:10-18:00
Chasm Creek A

Workshops and
Late Breaking Abstracts

Measuring and Promoting Diversity in Evolutionary Algorithms

Organizers: Giovanni Squillero, *Politecnico di Torino*
Alberto Tonda, *INRA, Université Paris-Saclay*

Time and Location: Wednesday, July 20, 08:30-10:20, Wind River A

Promoting Diversity in Evolutionary Algorithms
Giovanni Squillero, Alberto Tonda

Maintaining Diversity in The Bounded Pareto-Set: A Case of Opposition Based Solution Generation Scheme
AKM Khaled Ahsan Talukder, Kalyanmoy Deb, Shahryar Rahnamayan

Population Diversity as a Selection Factor: Improving Fitness by Increasing Diversity
James Byron, Wayne Iba

Harnessing Phenotypic Diversity towards Multiple Independent Objectives
Davy Smith, Laurissa Tokarchuk, Geraint Wiggins

On Synergies between Diversity and Task Decomposition in Constructing Complex Systems with GP
Jessica P. C. Bonson, Stephen Kelly, Andrew R. McIntyre, Malcolm I. Heywood

A Modified Grid Diversity Operator for Discrete Optimization and its Application to Wind Farm Layout Optimization Problems
Ahmed Salah, Emma Hart

Effects of Lexicase and Tournament Selection on Diversity Recovery and Maintenance
Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector

Medical Applications of Genetic and Evolutionary Computation

Organizers: Stephen L. Smith, *University of York*
Stefano Cagnoni, *Università degli Studi di Parma*
Robert M. Patton, *Oak Ridge National Laboratory, USA*

Time and Location: Wednesday, July 20, 08:30-10:20, Mesa Verde B

A Multi-Objective Approach to Predicting Motor and Cognitive Deficit in Parkinson's Disease Patients
Marta Vallejo, Jeremy Cosgrove, Jane E. Alty, Stuart Jamieson, Stephen L. Smith, David W. Corne, Michael A. Lones

Exploring the Application of Hybrid Evolutionary Computation Techniques to Physical Activity Recognition
Alejandro Baldominos, Carmen del Barrio, Yago Saez

An Optimized Feed-forward Artificial Neural Network Topology to Support Radiologists in Breast Lesions Classification
Vitoantonio Bevilacqua, Antonio Brunetti, Maurizio Triggiani, Domenico Magaletti, Michele Telegrafo, Marco Moschetta

Predicting Glycemia in Diabetic Patients By Evolutionary Computation and Continuous Glucose Monitoring
J. Manuel Colmenar, Stephan M. Winkler, Gabriel Kronberger, Esther Maqueda, Marta Botella, J. Ignacio Hidalgo

BBOB - Bi-Objective Blackbox Optimization Benchmarking

Organizers: Anne Auger, *INRIA Saclay-Île-de-France*
Dimo Brockhoff, *INRIA Lille*
Nikolaus Hansen, *INRIA Saclay-Île-de-France*
Tea Tušar, *INRIA Lille*
Dejan Tušar, *INRIA Lille*
Tobias Wagner, *TU Dortmund*

Time and Location: Wednesday, July 20, 08:30-15:50, Wind Star B

Performance of the DEMO Algorithm on the Bi-objective BBOB Test Suite
Tea Tušar, Bogdan Filipic

Anytime Bi-Objective Optimization with a Hybrid Multi-Objective CMA-ES (HMO-CMA-ES)
Ilya Loshchilov, Tobias Glasmachers

Hypervolume-Based DIRECT for Multi-Objective Optimisation
Cheryl Sze Yin Wong, Abdullah Al-Dujaili, Suresh Sundaram

A MATLAB Toolbox for Surrogate-Assisted Multi-Objective Optimization: A Preliminary Study
Abdullah Al-Dujaili, Suresh Sundaram

Unbounded Population MO-CMA-ES for the Bi-Objective BBOB Test Suite
Oswin Krause, Tobias Glasmachers, Nikolaus Hansen, Christian Igel

Evaluating the Population Size Adaptation Mechanism for CMA-ES on the BBOB Noiseless Testbed
Kouhei Nishida, Youhei Akimoto

Industrial Applications of Metaheuristics (IAM)

Organizers: Silvino Fernandez Alzueta, *ArcelorMittal*
Thomas Stützle, Université Libre de Bruxelles
Pablo Valledor Pellicer, *ArcelorMittal*

Time and Location: Wednesday, July 20, 10:40-12:30, Wind River A

Optimising a Waste Heat Recovery System using Multi-Objective Evolutionary Algorithm
Maizura Mokhtar, Ian Hunt, Stephen Burns, Dave Ross

Multi-Line Batch Scheduling by Similarity
Ignacio Arnaldo, Erik Hemberg, Una-May O'Reilly

Granular-Based Dimension Reduction for Solar Radiation Prediction Using Adaptive Memory Programming
Abdel-Rahman Hedar, Alaa E. Abdel-Hakim, Majid Almaraashi

Criticality of Response Time in the usage of Metaheuristics in Industry
Silvino Fernandez Alzueta, Pablo Valledor, Diego Diaz, Eneko Malatsetxebarria, Miguel Iglesias

Genetic Improvement GI 2016

Organizers: Justyna Petke, *University College London*
Westley Weimer, *University of Virginia*
David R. White, *University College London*

Time and Location: Wednesday, July 20, 10:40-18:00, Mesa Verde B

Evolutionary Optimization of Compiler Flag Selection by Learning and Exploiting Flags Interactions
Unai Garciarena, Roberto Santana

Genetic Programming: From Design to Improved Implementation
Víctor R. López-López, Leonardo Trujillo, Pierrick Legrand, Gustavo Olague

Automatic Improvement of Apache Spark Queries using Semantics-preserving Program Reduction
Zoltan A. Kocsis, John H. Drake, Douglas Carson, Jerry Swan

Benchmarking Genetically Improved BarraCUDA on Epigenetic Methylation NGS datasets and nVidia GPUs
William B. Langdon, Albert Vilella, Brian Yee Hong Lam, Justyna Petke, Mark Harman

Speeding up the Proof Strategy in Formal Software Verification
Markus Wagner

GP vs GI: If You Can't Beat Them, Join Them
John R. Woodward, Colin G. Johnson, Alexander E. I. Brownlee

Optimising Energy Consumption Heuristically on Android Mobile Phones
Mahmoud A. Bokhari, Markus Wagner

Genetic Improvement for Code Obfuscation
Justyna Petke

Evals is Not Enough: Why We Should Report Wall-clock Time
John R. Woodward, Alexander E. I. Brownlee, Colin G. Johnson

Guiding Unconstrained Genetic Improvement
David R. White

Evolutionary Rule-Based Machine Learning

Organizers: Karthik Kuber, *Microsoft*
Masaya Nakata, *The University of Electro-Communications*
Kamran Shafi, *University of New South Wales*

Time and Location: Wednesday, July 20, 14:00-18:00, Mesa Verde A

Hands-on Workshop on Learning Classifier Systems
Ryan J. Urbanowicz, Will N. Browne, Karthik Kuber

Code Fragments: Past and Future use in Transfer Learning
Will N. Browne

Pareto Inspired Multi-objective Rule Fitness for Adaptive Rule-based Machine Learning
Ryan J. Urbanowicz, Randal S. Olson, Jason H. Moore

Model Based Evolutionary Algorithms

Organizers: Peter A. N. Bosman, *Centrum Wiskunde & Informatica (CWI)*
John McCall, *Robert Gordon University*

Time and Location: Wednesday, July 20, 16:10-18:00, Chasm Creek B

The Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA): what and why?
Dirk Thierens

The Long (and Fun) Road that Led to DSMGA-II
Tian-Li Yu

When the gray box was opened, model-based evolutionary algorithms were already there
Roberto Santana

Adding value to optimisation by interrogating fitness models
Alexander Brownlee

BODI: Black-box Optimization by Deterministic Identification
Manuel Valenzuela-Rendón

SecDef – Workshop on Genetic and Evolutionary Computation in Defense, Security, and Risk Management

Organizers: Gunes Kayacik, *Qualcomm Research*
Frank Moore, *University of Alaska Anchorage*

Time and Location: Thursday, July 21, 08:30-10:20, Mesa Verde B

Initiating a Moving Target Network Defense with a Real-time Neuro-evolutionary Detector
Robert J. Smith, Ayse Nur Zincir-Heywood, Malcolm I. Heywood, John T. Jacobs

Automatic Course of Action Generation using Soft Data for Maritime Domain Awareness
Alex Plachkov, Rami Abielmona, Moufid Harb, Rafael Falcon, Diana Inkpen, Voicu Groza, Emil Petriu

Dynamics of Adversarial Co-evolution in Tax Non-Compliance Detection
Jacob Rosen, Erik Hemberg, Una-May O'Reilly

Multi-UAV Path Planning with Parallel Genetic Algorithms on CUDA Architecture
Ugur Cekmez, Mustafa Ozsiginan, Ozgur Koray Sahingoz

An Incremental Ensemble Evolved by using Genetic Programming to Efficiently Detect Drifts in Cyber Security Datasets
Gianluigi Folino, Francesco Sergio Pisani, Pietro Sabatino

Evolutionary Computation Software Systems (EvoSoft)

Organizers: Stefan Wagner, *University of Applied Sciences Upper Austria*
Michael Affenzeller, *University of Applied Sciences Upper Austria*

Time and Location: Thursday, July 21, 08:30-10:20, Wind River A

elephant56: Design and Implementation of a Parallel Genetic Algorithms Framework on Hadoop MapReduce
Pasquale Salza, Filomena Ferrucci, Federica Sarro

NodIO: A Framework and Architecture for Pool-based Evolutionary Computation
Juan J. Merelo, Pedro A. Castillo, Pablo García-Sánchez, Paloma de las Cuevas, Mario García Valdez

Optimization Knowledge Center
Andreas Beham, Stefan Wagner, Michael Affenzeller

6th Workshop on Evolutionary Computation for the Automated Design of Algorithms (ECADA)

Organizers: Manuel López-Ibáñez, *University of Manchester*
Daniel R. Tauritz, *Missouri University of Science and Technology*
John R. Woodward, *University of Stirling*

Time and Location: Thursday, July 21, 08:30-12:30, Wind Star B

Exploration of Metaheuristics through Automatic Algorithm Configuration Techniques and Algorithmic Frameworks
Alberto Franzin, Thomas Stützle

Why Asynchronous Parallel Evolution is the Future of Hyper-heuristics: A CDCL SAT Solver Case Study
Alex R. Bertels, Daniel R. Tauritz

Evolution Evolves with Autoconstruction
Lee Spector, Nicholas Freitag McPhee, Thomas Helmuth, Maggie M. Casale, Julian Oks

Connecting Automatic Parameter Tuning, Genetic Programming as a Hyper-heuristic, and Genetic Improvement Programming
John R. Woodward, Colin G. Johnson, Alexander E. I. Brownlee

Visualisation Methods in Genetic and Evolutionary Computation (VizGEC 2016)

Organizers: David Walker, *University of Exeter* Jonathan Fieldsend, *University of Exeter* Richard Everson, *University of Exeter*

Time and Location: Thursday, July 21, 08:30-12:30, Mesa Verde A

Algorithms and Data Structures for Evolutionary Computation

Organizer: Maxim Buzdalov, *ITMO University*

Time and Location: Thursday, July 21, 10:40-12:30, Mesa Verde B

Best Order Sort: A New Algorithm to Non-dominated Sorting for Evolutionary Multi-objective Optimization
Proteek Chandan Roy, Md. Monirul Islam, Kalyanmoy Deb

Efficient Removal of Points with Smallest Crowding Distance in Two-dimensional Incremental Non-dominated Sorting
Niyaz Nigmatullin, Maxim Buzdalov, Andrey Stankevich

Student Workshop

Organizers: Vanessa Volz, *TU Dortmund University*
Samadhi Nallaperuma, *University of Sheffield*
Boris Naujoks, *TH Köln*

Time and Location: Thursday, July 21, 10:40-18:00, Wind River A

Integrating Local Search within neat-GP
Perla Juárez-Smith, Leonardo Trujillo

Simulated Annealing as a Pre-Processing Step for Force-Directed Graph Drawing
Farshad Ghassemi Toosi, Nikola S. Nikolov, Malachy Eaton

FdDCA: A Novel Fuzzy Deterministic Dendritic Cell Algorithm
Nura Mukhtar, George M. Coghill, Wei Pang

A Two Stages Invasive Weed Optimization via a New Clustering Strategy
Shanshan Huang, Zhigang Ren, Muju Wang, Chenlin Sun

Parallel SMS-EMOA for Many-Objective Optimization Problems
Raquel Hernández Gómez, Carlos A. Coello Coello

Evolution of Layer Based Neural Networks: Preliminary Report
Edward R. Pantridge, Lee Spector

Random Tree Generator for an FPGA-based Genetic Programming System
Carlos A. Goribar Jiménez, Yazmín Maldonado, Leonardo Trujillo

Small-Moves Based Mutation For Pick-Up And Delivery Problem
Viacheslav Shalamov, Andrey Filchenkov, Daniil Chivilikhin

Variable Selection for Multivariate Calibration in Chemometrics: A Real-World Application with Building Blocks Disruption Problem
Lauro C. M. de Paula, Anderson S. Soares, Telma Woerle de Lima, Arlindo R. G. Filho, Clarimar J. Coelho

Adding Program Length Bias to the Lexicase and Tournament Selection Algorithms
Eva Moscovici

Bee-Inspired Landmark Recognition in Robotic Navigation
Kodi C. A. Cumbo, Samantha Heck, Ian Tanimoto, Travis DeVault, Robert B. Heckendorn, Terence Soule

Women@GECCO

Organizers: Carola Doerr, *Université Pierre et Marie Curie, CNRS*
Julia Handl, *University of Manchester*
Emma Hart, *Edinburgh Napier University*
Gabriela Ochoa, *University of Stirling*
Amarda Shehu, *George Mason University*
Tea Tušar, *INRIA Lille*
Anya E. Vostinar, *Michigan State University*
Christine Zarges, *University of Birmingham*
Nur Zincir-Heywood, *Dalhousie University*

Time and Location: Thursday, July 21, 14:00-15:50, Mesa Verde B

Evolution in Cognition

Organizers: Stephane Doncieux, *UPMC Univ Paris 06, CNRS, ISIR*
Joshua E. Auerbach, *Ecole Polytéchnique Fédérale de Lausanne*
Richard J. Duro, *Universidade da Coruna*
Harold P. de Vladar, *Parmenides Foundation*

Time and Location: Thursday, July 21, 14:00-18:00, Wind Star B

The Evolution of Artificial Neurogenesis
Dennis Wilson, Sylvain Cussat-Blanc, Hervé Luga

An Attractor Network-Based Model with Darwinian Dynamics
Harold P. de Vladar, Anna Fedor, András Szilágyi, István Zachar, Eörs Szathmáry

Darwinian Dynamics of Embodied Chaotic Exploration
Yoonsik Shim, Joshua E. Auerbach, Phil Husbands

Considering Memory Networks in the LTM Structure of the Multilevel Darwinist Brain
Richard J. Duro, José Antonio Becerra, Juan Monroy, Pilar Caamano

Gaining Insight into Quality Diversity
Joshua E. Auerbach, Giovanni Iacca, Dario Floreano

Neuroevolutionary Motivational Engine for Autonomous Robots
Rodrigo Salgado, Abraham Prieto, Francisco Bellas, Luis Calvo-Varela, Richard J. Duro

Evolutionary Computation in Computational Structural Biology

Organizers: José Santos, *University of A Coruña*
Julia Handl, *University of Manchester*
Amarda Shehu, *George Mason University*

Time and Location: Thursday, July 21, 14:00-18:00, Mesa Verde C

Using Crowding-Distance in a Multiobjective Genetic Algorithm for Protein Structure Prediction
Gregorio Kappaun Rocha, Fabio Lima Custodio, Helio J. C. Barbosa, Laurent Emmanuel Dardenne

Path-based Guidance of an Evolutionary Algorithm in Mapping a Fitness Landscape and its Connectivity
Emmanuel Sapin, Kenneth A. De Jong, Amarda Shehu

An Ecologically-inspired Parallel Approach Applied to the Protein Structure Reconstruction from Contact Maps
César M. V. Benítez, Rafael Stubs Parpinelli, Heitor Silvério Lopes

Protein Folding Modeling with Neural Cellular Automata Using Rosetta
Daniel Varela, José Santos

Surrogate-Assisted Evolutionary Optimisation (SAEOpt)

Organizers: Alma Rahat, *University of Exeter*
Richard Everson, *University of Exeter*
Jonathan Fieldsend, *University of Exeter*
Yaochu Jin, *University of Surrey*
Handing Wang, *University of Surrey*

Time and Location: Thursday, July 21, 14:00-18:00, Mesa Verde A

Data Driven Evolutionary Optimization of Complex Systems: Big Data Versus Small Data
Yaochu Jin

The Use of Surrogates in Genetic Programming.
Jürgen Branke

Mining Markov Network Surrogates for Value-Added Optimisation
Alexander E. I. Brownlee

Uncertainty in Surrogate Models
Handing Wang

Fitness Estimation Strategy Assisted Competitive Swarm Optimizer for High Dimensional Expensive Problems
Chaoli Sun, Yaochu Jin, Jinliang Ding, Jianchao Zeng

Adaptation of Surrogate Tasks for Bipedal Walk Optimization
Patrick MacAlpine, Elad Liebman, Peter Stone

Evolution in Action!

Organizers: Una-May O'Reilly, *MIT*
Erik Hemberg, *MIT*
Nicole Hoffman, *MIT*

Time and Location: Wednesday, July 20, 19:00-21:00, Wind River A (Session 1)
Saturday, July 23, 13:00-15:00, Wind Star B (Session 2)

Late Breaking Abstracts

Organizer: Francisco Chicano, *University of Málaga*

Time and Location: Friday, July 22, 18:15-18:45, Chasm Creek A (Introduction)
Friday, July 22, 18:45-20:00, Grand Mesa Ballroom DEF (Posters)

BeamGA Median: A Hybrid Heuristic Search Framework
Ghada Badr, Manar Hosny, Nuha Bintayyash, Eman Albilali, Souad Larabi Marie-Sainte

A Multimodal Adaptive Genetic Clustering Algorithm
Sawsan Al-Malak, Manar Hosny

Comparison between Golden Ball Meta-heuristic, Evolutionary Simulated Annealing and Tabu Search for the Traveling Salesman Problem
Eneko Osaba, Roberto Carballedo, Pedro Lopez-Garcia, Fernando Diaz

Keynotes

GECCO Keynote

The Challenges of Natural Algorithms

Friday, July 22, 9:00-10:10
Grand Mesa Ballroom DEF

Bernard Chazelle, *Princeton University*

This talk will sketch an algorithmic approach to the dynamics of living systems. Our working models consist of entropy-producing dissipative dynamic networks driven by a supply of free energy. They can be found in opinion dynamics, synchronization systems, and in many evolutionary contexts. The main challenge posed by these "natural algorithms" is the dearth of analytical tools currently at our disposal. The focus of our work has been on building a new theory of endogenously-driven dynamic networks rich enough to allow for the renormalization of large-scale systems. The main novelty of our approach to dynamical systems is to make algorithms the centerpiece of the analysis.

Biosketch: Bernard Chazelle is Eugene Higgins Professor of Computer Science at Princeton University, where he has been on the faculty since 1986. His current research focuses on the "algorithmic nature" of living systems. A professor at the Collège de France in Paris in recent years as well as a member of the Institute for Advanced Study in Princeton, he received his Ph.D in computer science from Yale University in 1980. The author of the book, "The Discrepancy Method," he is a fellow of the American Academy of Arts and Sciences, the European Academy of Sciences, and the recipients of three Best-Paper awards from SIAM.

GECCO Keynote

Taming the Complexity Monster or: How I learned to Stop Worrying and Love Hard Problems

Saturday, July 23, 9:00-10:10
Grand Mesa Ballroom DEF

Holger Hoos, *University of British Columbia*

We live in interesting times - as individuals, as members of various communities and organisations, and as inhabitants of planet Earth, we face many challenges, ranging from climate change to resource limitations, from market risks and uncertainties to complex diseases. To some extent, these challenges arise from the complexity of the systems we are dealing with and of the problems that arise from understanding, modelling and controlling these systems. As computing scientists and IT professionals, we have much to contribute: solving complex problems by means of computer systems, software and algorithms is an important part of what our field is about.

In this talk, I will focus on one particular type of complexity that has been of central interest to the evolutionary computation community, to artificial intelligence and far beyond, namely computational complexity, and in particular, NP-hardness. I will investigate the question to which extent NP-hard problems are as formidable as is often thought, and present an overview of several directions of research that aim to characterise and improve the behaviour of cutting-edge algorithms for solving NP hard problems in a pragmatic, yet principled way. For prominent problems ranging from propositional satisfiability (SAT) to TSP and from AI planning to mixed integer programming (MIP), I will demonstrate how automated analysis and design techniques can be used to model and enhance the performance characteristics of cutting-edge solvers, sharing some surprising insights along the way.

Biosketch: Holger H. Hoos is a Professor of Computer Science and a Faculty Associate at the Peter Wall Institute for Advanced Studies at the University of British Columbia (Canada). His main research interests span empirical algorithmics, artificial intelligence, bioinformatics and computer music. He is known for his work on the automated design of high-performance algorithms and on stochastic local search methods. Holger is a co-author of the book "Stochastic Local Search: Foundations and Applications", and his research has been published in numerous book chapters, journals, and at major conferences in artificial intelligence, operations research, molecular biology and computer music. Holger was elected a Fellow of the Association for the Advancement of Artificial Intelligence (AAAI) in 2015 and won two prestigious IJCAI/JAIR best paper prizes in 2009 and 2010. He is a past president of the Canadian Artificial Intelligence Association / Association pour l'intelligence artificielle au Canada (CAIAC) and Associate Editor of the Journal of Artificial Intelligence Research (JAIR). Recently, his group has helped UBC to produce better exam timetables,

Actenum Inc. to increase production efficiency in the oil and gas industry, and IBM to improve their CPLEX optimisation software, which is used by 50% of the world's largest companies and thousands of universities.

SIGEVO Plenary Lecture

SIGEVO Plenary Lecture in Memory of John Holland: The Biology of Software

Sunday, July 24, 11:10-11:55
Grand Mesa Ballroom DEF

Stephanie Forrest, *The University of New Mexico*

Biological design principles can potentially change the way we study, engineer, maintain, and develop large dynamic software systems. For example, computer programmers like to think of software as the product of intelligent design, carefully crafted to meet well-specified goals. In reality, large software systems evolve inadvertently through the actions of many individual programmers, often leading to unanticipated consequences. Because software is subject to constraints similar to those faced by evolving biological systems, we have much to gain by viewing software through the lens of biology. The talk will highlight how abstractions of biological processes can lead to new computational algorithms and engineering principles using examples from my own research. Specifically, it will show how the biological concepts of Darwinian evolution and immunology can be applied to problems such as repairing software bugs and cybersecurity.
The lecture is dedicated to John H. Holland, whose lifelong study of the mechanisms that produce adaptive behavior in complex systems left an intellectual legacy that will guide research in intelligent and complex systems for many years to come.

Biosketch: Stephanie Forrest is the Regents Distinguished Professor of Computer Science at the University of New Mexico in Albuquerque. She is renowned for her work in adaptive systems, including genetic algorithms, computational immunology, biological modeling, automated software repair, and computer security. Her research accomplishments include developing the first practical anomaly intrusion-detection system; designing automated responses to cyber attacks; writing an early influential paper proposing automatic diversity and introducing instruction-set randomization as a particular implementation; developing noncryptographic privacy-enhancing data representations; agent-based modeling of large-scale computational networks; and recently, work on automated repair of security vulnerabilities. She has conducted many computational modeling projects in biology, where her specialties are immunology and evolutionary diseases, such as influenza and cancer.

A University of Michigan alum and doctoral student of John Holland, Prof. Forrest was awarded the NSF Presidential Young Investigator Award in 1991, the IFIP TC2 Manfred Paul Award for Excellence in Software in 2009, and the ACM - AAAI Allen Newell Award in in 2011. She is an I.E.E.E. Fellow. She has contributed exemplary leadership to the Evolutionary Computation community, SIGEVO and GECCO. She served as ICGA Chair in 1993, was elected a Senior Fellow of the International Society for Genetic and Evolutionary Computation in 2003, shared the ACM SIGEVO GECCO Impact Award in 2009 (for a paper published in 1999), shared the gold award in the 2009 HUMIES competition and the bronze award in 2012 and served on the editorial board of Evolutionary Computation. An outstanding ambassador for evolutionary computation, she has won highly regarded paper awards at the International Conference on Software Engineering (2009 and 2012), held an appointment as Senior Science Advisor for Communication and Information Policy at the U.S. Dept. of State (2013-2014), co-chaired the Science Board of the Santa Fe Institute (2010-2013), was a member of the DARPA Information Science and Technology (ISAT) advisory group (2001-2004) and held a Jefferson Science Fellowship of the USA National Academies of Science and Engineering (2013-2014).

Best Paper Nominations

Best Paper Nominations

Ant Colony Optimization and Swarm Intelligence (ACO-SI)

Update Strength in EDAs and ACO: How to Avoid Genetic Drift
Dirk Sudholt, Carsten Witt
Friday, July 22, 10:40-11:05, Chasm Creek A

Continuous Optimization (CO)

Analysis of Linear Convergence of a (1 + 1)-ES with Augmented Lagrangian Constraint Handling
Asma Atamna, Anne Auger, Nikolaus Hansen
Friday, July 22, 11:05-11:30, Chasm Creek A

Complex Systems (CS)

Identifying Core Functional Networks and Functional Modules within Artificial Neural Networks via Subsets Regression
Roby Velez, Jeff Clune
Saturday, July 23, 17:00-17:25, Chasm Creek A

Quantifying Deception: A Case Study in the Evolution of Antimicrobial Resistance
Margaret J. Eppstein, C. Brandon Ogbunugafor
Saturday, July 23, 17:25-17:50, Chasm Creek A

Digital Entertainment Technologies and Arts (DETA)

Demonstrating the Feasibility of Automatic Game Balancing
Vanessa Volz, Günter Rudolph, Boris Naujoks
Friday, July 22, 10:40-11:05, Chasm Creek B

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

Extension of the CMSA Algorithm: An LP-based Way for Reducing Sub-instances
Christian Blum, Jordi Pereira
Saturday, July 23, 10:40-11:05, Chasm Creek A

Multi-objective Neutral Neighbors? What could be the definition(s)?
Marie-Eléonore Marmion, Hernan E. Aguirre, Clarisse Dhaenens, Laetitia Jourdan, Kiyoshi Tanaka
Saturday, July 23, 11:05-11:30, Chasm Creek A

On the Impact of the Renting Rate for the Unconstrained Nonlinear Knapsack Problem
Junhua Wu, Sergey Polyakovskiy, Frank Neumann
Saturday, July 23, 11:30-11:55, Chasm Creek A

Evolutionary Machine Learning (EML)

Evolving Probabilistically Significant Epistatic Classification Rules for Heterogeneous Big Datasets
John P. Hanley, Margaret J. Eppstein, Jeffrey S. Buzas, Donna M. Rizzo
Sunday, July 24, 09:50-10:15, Chasm Creek A

Simple Evolutionary Optimization Can Rival Stochastic Gradient Descent in Neural Networks
Gregory Morse, Kenneth O. Stanley
Sunday, July 24, 09:00-09:25, Chasm Creek A

Evaluation of a Tree-based Pipeline Optimization Tool for Automating Data Science
Randal S. Olson, Nathan Bartley, Ryan J. Urbanowicz, Jason H. Moore
Sunday, July 24, 09:25-09:50, Chasm Creek A

Evolutionary Multiobjective Optimization (EMO)

A Generative Kriging Surrogate Model for Constrained and Unconstrained Multi-objective Optimization
Rayan Hussein, Kalyanmoy Deb
Friday, July 22, 14:50-15:15, Chasm Creek A

Active Learning in Multi-objective Evolutionary Algorithms for Sustainable Building Design
Siamak Safarzadegan Gilan, Naman Goyal, Bistra Dilkina
Friday, July 22, 14:00-14:25, Chasm Creek A

A Multi-Objective Evolutionary Algorithm based on Parallel Coordinates
Raquel Hernández Gómez, Carlos A. Coello Coello, Enrique Alba Torres
Friday, July 22, 14:25-14:50, Chasm Creek A

Genetic Algorithms (GA)

Breaking the Billion-Variable Barrier in Real-World Optimization Using a Customized Evolutionary Algorithm
Kalyanmoy Deb, Christie Myburgh
Saturday, July 23, 16:10-16:35, Chasm Creek A

Expanding from Discrete Cartesian to Permutation Gene-pool Optimal Mixing Evolutionary Algorithms
Peter A.N. Bosman, Ngoc Hoang Luong, Dirk Thierens
Saturday, July 23, 16:35-17:00, Chasm Creek A

Genetic Programming (GP)

Quantitative Analysis of Evolvability using Vertex Centralities in Phenotype Network
Ting Hu, Wolfgang Banzhaf
Friday, July 22, 16:10-16:35, Chasm Creek A

A Dispersion Operator for Geometric Semantic Genetic Programming
Luiz Otavio V. B. Oliveira, Fernando E. B. Otero, Gisele L. Pappa
Friday, July 22, 16:35-17:00, Chasm Creek A

The Impact of Hyperselection on Lexicase Selection
Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector
Friday, July 22, 17:00-17:25, Chasm Creek A

Parallel Evolutionary Systems (PES)

Evaluation-Time Bias in Quasi-Generational and Steady-State Asynchronous Evolutionary Algorithms
Eric O. Scott, Kenneth A. De Jong
Friday, July 22, 11:05-11:30, Chasm Creek B

Real World Applications (RWA)

A Real World Multi-UAV Evolutionary Planner for Minimum Time Target Detection
Sara Perez-Carabaza, Eva Besada-Portas, Jose A. Lopez-Orozco, Jesus M. de la Cruz
Saturday, July 23, 14:00-14:25, Chasm Creek A

Tackling the IFP Problem with the Preference-Based Genetic Algorithm
Sune S. Nielsen, Christof Ferreira Torres, Grégoire Danoy, Pascal Bouvry
Saturday, July 23, 14:25-14:50, Chasm Creek A

Finding Reliable Solutions in Bilevel Optimization Problems Under Uncertainties
Zhichao Lu, Kalyanmoy Deb, Ankur Sinha
Saturday, July 23, 15:15-15:40, Chasm Creek A

Planning Inspection Paths through Evolutionary Multi-objective Optimization
Kai Olav Ellefsen, Herman A. Lepikson, Jan C. Albiez
Saturday, July 23, 14:50-15:15, Chasm Creek A

Search Based Software Engineering and Self-* Search (SBS-SS)

Learning Overtime Dynamics Through Multiobjective Optimization
Marcio de O. Barros, Luiz Antonio O. de Araujo Jr
Friday, July 22, 11:30-11:55, Chasm Creek B

Theory (THEORY)

The (1+1) Elitist Black-Box Complexity of LeadingOnes
Carola Doerr, Johannes Lengler
Friday, July 22, 11:30-11:55, Chasm Creek A

Humies, Competitions, and Evolutionary Computation in Practice

Human Competitive Results: 13th Annual Humies Awards

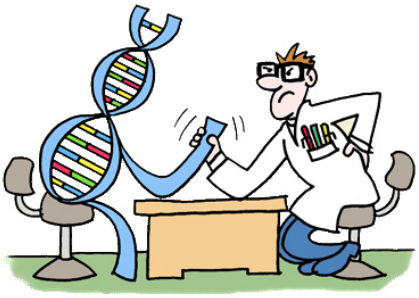
Presentations: Friday, July 22, 14:00-15:50
Wind Star B

Announcement of Awards: Sunday, July 24, 11:55-13:10
Grand Mesa Ballroom DEF

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

Prizes: prizes totalling $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.

This prize competition is based on *published* results. The publication may be a paper at the GECCO conference (i.e., regular paper, poster paper, or any other full-length paper), a paper published anywhere in the open literature (e.g., another conference, journal, technical report, thesis, book chapter, book), or a paper in final form that has been unconditionally accepted by a publication and is "in press" (that is, the entry must be identical to something that will be published imminently without any further changes). The publication may *not* be an intermediate or draft version that is still subject to change or revision by the authors or editors. The publication must meet the usual standards of a scientific publication in that it must clearly describe a problem, the methods used to address the problem, the results obtained, and sufficient information about how the work was done in order to enable the work described to be independently replicated.

Cash prizes of $5,000 (gold), $3,000 (silver), and bronze (either one prize of $2,000 or two prizes of $1,000) will be awarded for the best entries that satisfy the criteria for human-competitiveness. The awards will be divided equally among co-authors unless the authors specify a different division at the time of submission. Prizes are paid by check in U.S. dollars after the GECCO conference. The judges may, based on submissions, rearrange the prize amounts and prize categories within the total amount available for prizes.

Black Box Optimization Competition

Organizers: Ilya Loshchilov, Tobias Glasmachers

Time and Location: Saturday, July 23, 10:40-12:30, Wind Star B

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 the optimizer and participant is the dimension of the problem, bounds on all variables, and a budget of black box queries.
The competition is also the first web/online optimization competition in evolutionary computation domain, it allows to collect and disseminate the results in an automatic way. The competition aims at attacking a growing impact of over-fitting of optimization algorithms to a narrow set of existing benchmark problems.
This year the competition will be extended to the area of multi-objective optimization, which is a vibrant field of research at GECCO. Even more than in single-objective optimization, a platform offering a rigorous and independent assessment of algorithm performance is missing to date, and BBComp aims to fill this gap.
The competition was run twice last year (at CEC and GECCO) with good success, attracting 25 and 28 participants, respectively. With the addition of multi-objective optimization we hope to attract even more participants.

Combinatorial Black Box Optimization Competition

Organizers: Alex Bertels, Brian Goldman, Jerry Swan, Daniel R. Tauritz

Time and Location: Saturday, July 23, 10:40-12:30, Wind Star B

This competition is designed to provide the GECCO community with detailed performance comparisons of a wide variety of meta-heuristics and hyper-heuristics on combinatorial problems, where the real-world problems which induce combinatorial problems have been categorized into those with no training time (good fit for parameter-less algorithms), those with short training time (good fit for typical evolutionary algorithms), and those with long training time (good fit for hyper-heuristics). Training and testing time is measured in terms of number of fitness evaluations, although wall time will be used to time-out algorithms taking infeasibly long to complete. Competitors choose which category or categories they want to submit to. While trained differently, all three categories will be compared employing instances drawn from the same test set. This can create a Pareto set of winners, maximizing solution quality while minimizing training time, with at most three nondominated points. The competition problems will be randomly generated by a meta-class based on Mk-Landscapes which can represent all NK-Landscapes, Ising Spin Glasses, MAX-kSAT, Concatenated Traps, etc. (this is a generalization of the NK-Landscapes meta-class employed in the GECCO 2015 CBBOC). A light-weight API will be made available in several popular programming languages several months in advance of the submission deadline to allow competitors a standardized way to test their submissions. Competitors will be encouraged, though not required, to allow the source code of their competing algorithms to be made available on the competition website.

Niching Methods for Multimodal Optimization

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

Time and Location: Saturday, July 23, 10:40-12:30, Wind Star B

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. Researchers are welcome to evaluate their niching algorithms using this benchmark suite, and report the results by submitting a paper to the main tracks of GECCO 2016 (i.e., submitting via the online submission system of GECCO 2016). The description of the benchmark suite, evaluation procedures, and established baselines can be found in the following technical report:
X. Li, A. Engelbrecht, and M.G. Epitropakis, "Benchmark Functions for CEC'2013 Special Session and Competition on Niching Methods for Multimodal Function Optimization", Technical Report, Evolutionary Computation and Machine Learning Group, RMIT University, Australia, 2013.

The test suite for the competition and the performance measures are implemented in Matlab, Java, Python and C++, and will be available for download from the competition website (URL will be provided later). Notice that, apart from the benchmark function suite, the competition facilitates the evaluation and comparison of different niching algorithms. The procedures developed takes into consideration two main objectives: 1) the test suite should be simple to use; and 2) the test suite can be used to facilitate fair comparisons of different niching algorithms. The procedure should be easy to follow since user interaction with unnecessary details will be kept at minimal. This will allow interested researchers to focus their effort primarily on the development of state-of-the-art niching algorithms. A framework with such facilities has already proved to be valuable to the research community and has led to major developments of the field, e.g., the Black-Box Optimization Benchmark (BBOB) competition organized at GECCO each year.

Virtual Creatures

Organizers: Joel Lehman, Nicholas Cheney

Time and Location: Saturday, July 23, 10:40-12:30, Wind Star B

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 will be judged by technical achievement, aesthetic appeal, innovation, and perceptual animacy (perceived aliveness).

Windfarm Layout Optimization Competition

Organizers: Dennis Wilson, Ilya Loshchilov, Kalyan Veeramachaneni

Time and Location: Saturday, July 23, 10:40-12:30, Wind Star B

Wind farm design has long been an application domain for evolutionary learning and optimization due to the complexity of the design space, and the discontinuities in the search space caused by the wake effects that make it hard to optimize analytically. Now, with a need to increase the renewable energy portfolio, existing wind farm layout approaches are being tested under a variety of scenarios.Newer models to evaluate layouts and newer constraints emerge, demanding more sophistication from the algorithms.

Evolutionary Computation in Practice

Organizers: Thomas Bartz-Beielstein, *Cologne University of Applied Sciences*
Jörn Mehnen, *Cranfield University*

In the Evolutionary Computation in Practice (ECiP) track, well-known speakers with outstanding reputation in academia and industry present background and insider information on how to establish reliable cooperation with industrial partners. They actually run companies or are involved in cooperations between academia and industry. If you attend, you will learn multiple ways to extend EC practice beyond the approaches found in textbooks. Experts in real-world optimization with decades of experience share their approaches to creating successful projects for real-world clients. Some of what they do is based on sound project management principles, and some is specific to our type of optimization projects. In this session 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

Wednesday, July 20, 14:00-15:50
Wind River A

Challenges of deploying evolutionary computation in steel industry
Bogdan Filipic

Evolutionary Multi-Objective Optimization in Real-World Applications
Carlos A. Coello Coello

EC in industry: the quest for the Holy Grail - from Brain Computer Interfaces to automated testing with TESTAR
Anna Esparcia Alcazar

Heuristic Optimization in Production and Logistics
Michael Affenzeller

Session 2

Wednesday, July 20, 16:10-18:00
Wind River A

Divis - Intelligent Industry Solutions
Thomas Bäck

EAs for aeronautical optimization - some results and challenges
Felipe Campelo

How to Introduce Academic-developed EC Technology to Industry
Erik Goodman

Panel Discussion
Anna Esparcia Alcazar, Thomas Bäck, Thomas Bartz-Beielstein, Felipe Campelo, Silvino Fernández, Bogdan Filipic, Erik Goodman, Thomas Stützle

A panel of experts with decades of real-world application experience will be answering questions posed by attendees of the sessions. We expect interesting discussions related - but not only restricted - to the following topics: 1) Industrial problems that lie on the cutting edge of EA development. This session gives you the opportunity to get free consulting from the experts. 2) Getting a job with training in evolutionary computation can be much easier if you know the things to do and the things not to do in your last year or two of study. You will hear from a panel of experts who have trained students and who have hired students to carry out real-world optimization. Highly recommended if you will be looking for a job in the next few years - or if you are thinking of changing jobs.

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 a few minutes early to check on room and equipment set-up. Let the conference organizers at the registration desk know if problems arise or adjustments are needed.
- Please follow the scheduled order of talks, as well as presentation times.
- In the unlikely event that a speaker is absent, we ask you to announce a short 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 presenting accepted full papers during the technical sessions are allocated 25 minutes for each presentation; 20 minutes for set up and presentation and 5 minutes for questions.
- Moderate questions.
- 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 votes at the end of the session. After the session, please bring the ballots to the registration desk.

If a session is without a chair, we ask the last scheduled speaker to perform those duties.

Instructions for Paper Presenters

Projectors and screens will be available for all presentations and larger rooms will have microphones. Presenters are requested to bring their own laptops.

- Please adhere to the scheduled slot of your presentation.
- Please quickly check that the computer you are using for the presentation works with the video projector before the beginning of your session.
- Speakers presenting accepted full papers during the technical sessions are allocated 25 minutes for each presentation, 20 minutes for set-up and presentation and 5 minutes for questions.

Instructions for Poster Presenters

- The poster session will be held on Friday, July 22, 18:30-20:00, Grand Mesa Ballroom DEF.
- Poster set-up is 30 minutes prior to the start of the session.
- Poster boards and thumbtacks or tape will be available.
- Posters should be no more than 90cm (36”) wide and 120cm (48”) high.

Papers and Posters

HOP1

Thursday, July 21, 16:10-17:50, Wind Star A
Chair: Benjamin Doerr (Ecole Polytechnique)

Best Papers: CO+THEORY+ACO-SI

(Best Paper nominees are marked with a star)

Friday, July 22, 10:40-11:55, Chasm Creek A
Chair: Tobias Friedrich (Hasso Plattner Institute)

Update Strength in EDAs and ACO: How to Avoid Genetic Drift ☆
Dirk Sudholt, Carsten Witt 10:40-11:05

Analysis of Linear Convergence of a (1 + 1)-ES with Augmented Lagrangian Constraint Handling ☆
Asma Atamna, Anne Auger, Nikolaus Hansen 11:05-11:30

The (1+1) Elitist Black-Box Complexity of LeadingOnes ☆
Carola Doerr, Johannes Lengler 11:30-11:55

Best Papers: DETA+PES+SBS-SS

(Best Paper nominees are marked with a star)

Friday, July 22, 10:40-12:20, Chasm Creek B
Chair: Juan Julián Merelo Guervós (U. Granada)

Demonstrating the Feasibility of Automatic Game Balancing ☆
Vanessa Volz, Günter Rudolph, Boris Naujoks 10:40-11:05

Evaluation-Time Bias in Quasi-Generational and Steady-State Asynchronous Evolutionary Algorithms ☆
Eric O. Scott, Kenneth A. De Jong 11:05-11:30

Learning Overtime Dynamics Through Multiobjective Optimization ☆
Marcio de O. Barros, Luiz Antonio O. de Araujo Jr 11:30-11:55

Search-Based Cost-Effective Test Case Selection within a Time Budget: An Empirical Study
Dipesh Pradhan, Shuai Wang, Shaukat Ali, Tao Yue 11:55-12:20

CS1

Friday, July 22, 10:40-12:20, Wind River A
Chair: Sebastian Risi (IT University of Copenhagen)

Does Aligning Phenotypic and Genotypic Modularity Improve the Evolution of Neural Networks?
Joost Huizinga, Jean-Baptiste Mouret, Jeff Clune 10:40-11:05

Neuromodulation Improves the Evolution of Forward Models
Mohammad Sadegh Norouzzadeh, Jeff Clune 11:05-11:30

EvoRBC: Evolutionary Repertoire-based Control for Robots with Arbitrary Locomotion Complexity
Miguel Duarte, Jorge Gomes, Sancho Moura Oliveira, Anders Lyhne Christensen 11:30-11:55

Evolving Neural Turing Machines for Reward-based Learning
Rasmus Boll Greve, Emil Juul Jacobsen, Sebastian Risi 11:55-12:20

ECOM1

Friday, July 22, 10:40-12:20, Wind Star A
Chair: Thomas Stützle (Université Libre de Bruxelles)

Efficient Hill Climber for Constrained Pseudo-Boolean Optimization Problems
Francisco Chicano, Darrell Whitley, Renato Tinós 10:40-11:05

Feature Selection in Evolving Job Shop Dispatching Rules with Genetic Programming
Yi Mei, Mengjie Zhang, Su Nyugen 11:05-11:30

Fast Heuristics for the Multiple Traveling Thieves Problem
Shelvin Chand, Markus Wagner 11:30-11:55

Multi-hard Problems in Uncertain Environment
Michal Roman Przybylek, Adam Wierzbicki, Zbigniew Michalewicz 11:55-12:20

EMO1

Friday, July 22, 10:40-12:20, Wind River B
Chair: Pascal Kerschke (University of Münster)

Runtime Analysis of Evolutionary Diversity Maximization for OneMinMax
Benjamin Doerr, Wanru Gao, Frank Neumann 10:40-11:05

A Toolkit for Generating Scalable Stochastic Multiobjective Test Problems
Shaul Salomon, Robin Charles Purshouse, Ioannis Giaghiozis, Peter John Fleming 11:05-11:30

Tuning of Multiple Parameter Sets in Evolutionary Algorithms
Martin Andersson, Sunith Bandaru, Amos H.C. Ng 11:30-11:55

A Correlation Analysis of Set Quality Indicator Values in Multiobjective Optimization
Arnaud Liefooghe, Bilel Derbel 11:55-12:20

RWA1

Friday, July 22, 10:40-12:20, Mesa Verde B
Chair: Enrique Alba (University of Málaga)

A Genetic Algorithm for Rule-based Chart Pattern Search in Stock Market Prices
Myoung Hoon Ha, Sangyeop Lee, Byung-Ro Moon 10:40-11:05

Evolutionary Learning of Scheduling Heuristics for Heterogeneous Wireless Communications Networks
David Lynch, Michael Fenton, Stepan Kucera, Holger Claussen, Michael O'Neill 11:05-11:30

Benchmarks for the Coal Processing and Blending Problem
Sven Schellenberg, Xiaodong Li, Zbigniew Michalewicz 11:30-11:55

Fine Tuning of Traffic in our Cities with Smart Panels: The Quito City Case Study
Daniel H. Stolfi, Rolando Armas, Enrique Alba Torres, Hernan E. Aguirre, Kiyoshi Tanaka 11:55-12:20

AIS-BIO1+CO1

Friday, July 22, 14:00-15:15, Chasm Creek B
Chair: Emma Hart (Napier University)

Population Size Adaptation for the CMA-ES Based on the Estimation Accuracy of the Natural Gradient
Kouhei Nishida, Youhei Akimoto 14:00-14:25

Permuted Orthogonal Block-Diagonal Transformation Matrices for Large Scale Optimization Benchmarking
Ouassim Ait ElHara, Anne Auger, Nikolaus Hansen 14:25-14:50

A Novel EA-based Memetic Approach for Efficiently Mapping Complex Fitness Landscapes
Emmanuel Sapin, Kenneth A. De Jong, Amarda Shehu 14:50-15:15

Best Paper: EMO

(Best Paper nominees are marked with a star)

Friday, July 22, 14:00-15:40, Chasm Creek A
Chair: Heike Trautmann (University of Münster)

Active Learning in Multi-objective Evolutionary Algorithms for Sustainable Building Design ☆
Siamak Safarzadegan Gilan, Naman Goyal, Bistra Dilkina 14:00-14:25

A Multi-Objective Evolutionary Algorithm based on Parallel Coordinates ☆
Raquel Hernández Gómez, Carlos A. Coello Coello, Enrique Alba Torres 14:25-14:50

A Generative Kriging Surrogate Model for Constrained and Unconstrained Multi-objective Optimization ☆
Rayan Hussein, Kalyanmoy Deb 14:50-15:15

Bio-inspired Multi-objective Optimization Design of a Highly Efficient Squirrel Cage Induction Motor
Sergio F. Contreras, Camilo A. Cortés, María A. Guzmán 15:15-15:40

CS2

Friday, July 22, 14:00-15:40, Wind River A
Chair: Jean-Baptiste Mouret (ISIR/UPMC)

How do Different Encodings Influence the Performance of the MAP-Elites Algorithm?
Danesh Tarapore, Jeff Clune, Antoine Cully, Jean-Baptiste Mouret 14:00-14:25

Evolvability Search: Directly Selecting for Evolvability in order to Study and Produce It
Henok Mengistu, Joel Lehman, Jeff Clune 14:25-14:50

Convolution by Evolution: Differentiable Pattern Producing Networks
Chrisantha Fernando, Dylan Banarse, Malcolm Reynolds, Frederic Besse, David Pfau, Max Jaderberg, Marc Lanctot, Daan Wierstra 14:50-15:15

Accelerating the Evolution of Cognitive Behaviors Through Human-Computer Collaboration
Mathias Löwe, Sebastian Risi 15:15-15:40

GA1

Friday, July 22, 14:00-15:40, Wind Star A
Chair: Jonathan Edward Fieldsend (University of Exeter)

Exploiting Diverse Distance Metrics for Surrogate-Based Optimisation of Ordering Problems
Jim Smith, Christopher Stone, Martin Serpell 14:00-14:25

Estimating the Advantage of Age-Layering in Evolutionary Algorithms
Hormoz Shahrzad, Babak Hodjat, Risto Miikkulainen 14:25-14:50

Surprise Search: Beyond Objectives and Novelty
Daniele Gravina, Antonios Liapis, Georgios Yannakakis 14:50-15:15

Hidden Genes Genetic Algorithms for Systems Architecture Optimization
Ossama Abdelkhalik, Shadi Darani 15:15-15:40

RWA2

Friday, July 22, 14:00-15:40, Mesa Verde B
Chair: Enrique Alba (University of Málaga)

Fast and Effective Optimisation of Arrays of Submerged Wave Energy Converters
Junhua Wu, Slava Shekh, Nataliia Y. Sergiienko, Benjamin S. Cazzolato, Boyin Ding, Frank Neumann, Markus Wagner 14:00-14:25

Evolutionary Feature Subset Selection with Compression-based Entropy Estimation
Pavel Krömer, Jan Platoš 14:25-14:50

Finding Interactions or Relationships between Customer Orders for Building Better Batches by Means of an Estimation of Distribution Algorithm-based Approach for the Online Order Batching Problem
Ricardo Pérez-Rodríguez, Arturo Hernández-Aguirre 14:50-15:15

Planning Habitat Restoration with Genetic Algorithms
Jana Brotankova, Tommaso Urli, Philip Kilby 15:15-15:40

THEORY1

Friday, July 22, 14:00-15:40, Wind River B
Chair: Dirk Sudholt (University of Sheffield)

The Right Mutation Strength for Multi-Valued Decision Variables
Benjamin Doerr, Carola Doerr, Timo Kötzing 14:00-14:25

When Non-Elitism Outperforms Elitism for Crossing Fitness Valleys
Pietro S. Oliveto, Tiago Paixão, Jorge Pérez Heredia, Dirk Sudholt, Barbora Trubenová 14:25-14:50

Optimal Mutation Rates for the (1+λ) EA on OneMax
Christian Gießen, Carsten Witt 14:50-15:15

Noisy Optimization: Fast Convergence Rates with Comparison-Based Algorithms
Marie-Liesse Cauwet, Olivier Teytaud 15:15-15:40

Best Paper: GP

(Best Paper nominees are marked with a star)

Friday, July 22, 16:10-17:50, Chasm Creek A
Chair: Krzysztof Krawiec (Poznan University of Technology)

Quantitative Analysis of Evolvability using Vertex Centralities in Phenotype Network ☆
Ting Hu, Wolfgang Banzhaf 16:10-16:35

A Dispersion Operator for Geometric Semantic Genetic Programming ☆
Luiz Otavio V. B. Oliveira, Fernando E. B. Otero, Gisele L. Pappa 16:35-17:00

The Impact of Hyperselection on Lexicase Selection ☆
Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector 17:00-17:25

Non-negative Matrix Factorization for Unsupervised Derivation of Search Objectives in Genetic Programming
Paweł Liskowski, Krzysztof Krawiec 17:25-17:50

EML1

Friday, July 22, 16:10-17:50, Chasm Creek B
Chair: Fernando Otero (University of Kent)

A Wavelet-based Encoding for Neuroevolution
Sjoerd van Steenkiste, Jan Koutník, Kurt Driessens, Jürgen Schmidhuber 16:10-16:35

Evolving Deep LSTM-based Memory Networks using an Information Maximization Objective
Aditya Rawal, Risto Miikkulainen 16:35-17:00

Fast Bi-Objective Feature Selection Using Entropy Measures and Bayesian Inference
Yi Mei, Bing Xue, Mengjie Zhang 17:00-17:25

Improving the Canny Edge Detector Using Automatic Programming: Improving Non-Max Suppression
Lars Vidar Magnusson, Roland Olsson 17:25-17:50

EMO2

Friday, July 22, 16:10-17:50, Wind River B
Chair: Heike Trautmann (University of Münster)

Karush-Kuhn-Tucker Proximity Measure for Multi-Objective Optimization Based on Numerical Gradients
Mohamed Abouhawwash, Kalyanmoy Deb 16:10-16:35

A Faster Algorithm for the Binary Epsilon Indicator Based on Orthant Minimum Search
Andrey Vasin, Maxim Buzdalov 16:35-17:00

A novel Multi-objective Optimization-based Image Registration Method
Meifeng Shi, Zhongshi He, Ziyu Chen, Hang Zhang 17:00-17:25

Experiments on Greedy and Local Search Heuristics for d–dimensional Hypervolume Subset Selection
Matthieu Basseur, Bilel Derbel, Adrien Goëffon, Arnaud Liefooghe 17:25-17:50

RWA3

Friday, July 22, 16:10-17:50, Mesa Verde B
Chair: Boris Naujoks (Cologne University of Applied Sciences)

Evolutionary Design of Fast High-quality Hash Functions for Network Applications
David Grochol, Lukas Sekanina 16:10-16:35

Multiobjective Neuroevolutionary Control for a Fuel Cell Turbine Hybrid Energy System
Mitchell Colby, Logan Yliniemi, Paolo Pezzini, David Tucker, Kenneth Bryden , Kagan Tumer 16:35-17:00

Neuroevolution of a Hybrid Power Plant Simulator
Shauharda Khadka, Kagan Tumer, Mitchell Colby, David Tucker, Paolo Pezzini, Kenneth Bryden 17:00-17:25

Grammatical Evolution Enhancing Simulated Annealing for the Load Balancing Problem in Cloud Computing
Nasser R. Sabar, Andy Song 17:25-17:50

SBS-SS1

Friday, July 22, 16:10-17:50, Wind River A
Chair: Gabriela Ochoa (University of Stirling)

Grammatical Evolution for the Multi-Objective Integration and Test Order Problem
Thainá Mariani, Giovani Guizzo, Silvia R. Vergilio, Aurora T. R. Pozo 16:10-16:35

A Search-based Training Algorithm for Cost-aware Defect Prediction
Annibale Panichella, Carol V. Alexandru, Sebastiano Panichella, Alberto Bacchelli, Harald C. Gall 16:35-17:00

A Combined Generative and Selective Hyper-heuristic for the Vehicle Routing Problem
Kevin Sim, Emma Hart 17:00-17:25

Test Case Prioritization of Configurable Cyber-Physical Systems with Weight-Based Search Algorithms
Aitor Arrieta, Shuai Wang, Goiuria Sagardui, Leire Etxeberria 17:25-17:50

THEORY2

Friday, July 22, 16:10-17:50, Wind Star A
Chair: Timo Kötzing (Hasso Plattner Institute)

The Impact of Migration Topology on the Runtime of Island Models in Dynamic Optimization
Andrei Lissovoi, Carsten Witt 16:10-16:35

EDAs cannot be Balanced and Stable
Tobias Friedrich, Timo Kötzing, Martin S. Krejca 16:35-17:00

Optimal Parameter Choices via Precise Black-Box Analysis
Benjamin Doerr, Carola Doerr, Jing Yang 17:00-17:25

Optimal Parameter Settings for the $(1 + (\lambda, \lambda))$ Genetic Algorithm
Benjamin Doerr 17:25-17:50

Best Paper: ECOM

(Best Paper nominees are marked with a star)

Saturday, July 23, 10:40-12:20, Chasm Creek A
Chair: Holger H. Hoos (University of British Columbia)

Extension of the CMSA Algorithm: An LP-based Way for Reducing Sub-instances ☆
Christian Blum, Jordi Pereira 10:40-11:05

Multi-objective Neutral Neighbors? What could be the definition(s)? ☆
Marie-Eléonore Marmion, Hernan E. Aguirre, Clarisse Dhaenens, Laetitia Jourdan, Kiyoshi Tanaka 11:05-11:30

On the Impact of the Renting Rate for the Unconstrained Nonlinear Knapsack Problem ☆
Junhua Wu, Sergey Polyakovskiy, Frank Neumann 11:30-11:55

Communities of Local Optima as Funnels in Fitness Landscapes
Sebastian Herrmann, Gabriela Ochoa, Franz Rothlauf 11:55-12:20

CO2

Saturday, July 23, 10:40-12:20, Wind River B
Chair: Youhei Akimoto (Shinshu University)

Experimental Investigation of Recombination Operators for Differential Evolution
Felipe Campelo, Moisés Botelho 10:40-11:05

Low-Budget Exploratory Landscape Analysis on Multiple Peaks Models
Pascal Kerschke, Mike Preuss, Simon Wessing, Heike Trautmann 11:05-11:30

Projection-Based Restricted Covariance Matrix Adaptation for High Dimension
Youhei Akimoto, Nikolaus Hansen 11:30-11:55

Analysis of Different Types of Regret in Continuous Noisy Optimization
Sandra Astete-Morales, Marie-Liesse Cauwet, Olivier Teytaud 11:55-12:20

GP1

Saturday, July 23, 10:40-12:20, Mesa Verde B
Chair: Una-May O'Reilly (CSAIL, Massachusetts Institute of Technology)

Improving Generalisation of Genetic Programming for Symbolic Regression with Structural Risk Minimisation
Qi Chen, Bing Xue, Lin Shang, Mengjie Zhang 10:40-11:05

Discovering Rubik's Cube Subgroups using Coevolutionary GP – A Five Twist Experiment
Robert J. Smith, Stephen Kelly, Malcolm I. Heywood 11:05-11:30

Managing Repetition in Grammar-Based Genetic Programming
Miguel Nicolau, Michael Fenton 11:30-11:55

Reducing Antagonism between Behavioral Diversity and Fitness in Semantic Genetic Programming
Marcin Szubert, Anuradha Kodali, Sangram Ganguly, Kamalika Das, Josh C. Bongard 11:55-12:20

HOP2

Saturday, July 23, 10:40-12:20, Wind Star A
Chair: Thomas Stützle (Université Libre de Bruxelles)

neat Genetic Programming: Controlling Bloat Naturally
Leonardo Trujillo, Luis Muñoz, Edgar Galván-López, Sara Silva 10:40-11:05

An Improved Fully Stressed Design Evolution Strategy for Layout Optimization of Truss Structures
Ali Ahrari, Kalyanmoy Deb 11:05-11:30

On the Automatic Construction of Regular Expressions from Examples (GP vs. Humans 1-0)
Alberto Bartoli, Andrea De Lorenzo, Eric Medvet, Fabiano Tarlao 11:30-11:55

Online Discovery of Search Objectives for Test-based Problems
Paweł Liskowski, Krzysztof Krawiec 11:55-12:20

PES1

Saturday, July 23, 10:40-11:55, Chasm Creek B
Chair: Juan Julián Merelo Guervós (U. Granada)

Hardware-Accelerated Parallel Genetic Algorithm for Fitness Functions with Variable Execution Times
Yunfeng Ma, Leandro Soares Indrusiak 10:40-11:05

The Seamless Peer and Cloud Evolution Framework
Guillaume Leclerc, Joshua E. Auerbach, Giovanni Iacca, Dario Floreano 11:05-11:30

Performance for the Masses
Juan J. Merelo, Pedro A. Castillo, Pablo García-Sánchez, Paloma de las Cuevas, Nuria Rico, Mario García Valdez 11:30-11:55

RWA4+IGEC1

Saturday, July 23, 10:40-12:20, Wind River A
Chair: Boris Naujoks (Cologne University of Applied Sciences)

A Sparse Recurrent Neural Network for Trajectory Prediction of Atlantic Hurricanes
Mina Moradi Kordmahalleh, Mohammad Gorji Sefidmazgi, Abdollah Homaifar 10:40-11:05

Selection of a DFO Method for the Efficient Solution of Continuous Constrained Sub-Problems within a Memetic Algorithm for Chemical Process Synthesis
Maren Urselmann, Christophe Foussette, Tim Janus, Stephen Tlatlik, Axel Gottschalk, Michael T.M. Emmerich, Sebastian Engell, Thomas Bäck 11:05-11:30

A Hybrid Multi-Population Genetic Algorithm for UAV Path Planning
Márcio da Silva Arantes, Jesimar da Silva Arantes, Claudio Fabiano Motta Toledo, Brian C. Williams 11:30-11:55

Approximation of (k,t)-robust Equilibria
Tudor Dan Mihoc, Rodica Ioana Lung, Noémi Gaskó, Mihai Suciu 11:55-12:20

ACO-SI1

Saturday, July 23, 14:00-15:40, Wind River B
Chair: Christian Blum (University of the Basque Country)

ACO-inspired Acceleration of Gossip Averaging
Andreas Janecek, Wilfried N. Gansterer 14:00-14:25

A Mixed-Attribute Approach in Ant-Miner Classification Rule Discovery Algorithm
Ayah Helal, Fernando E. B. Otero 14:25-14:50

Geometric Particle Swarm Optimization for Multi-objective Optimization Using Decomposition
Saul Zapotecas-Martinez, Alberto Moraglio, Hernan E. Aguirre, Kiyoshi Tanaka 14:50-15:15

Relaxing Consensus in Distributed Factored Evolutionary Algorithms
Stephyn Butcher, Shane Strasser, Jenna Hoole, Benjamin Demeo, John Sheppard 15:15-15:40

Best Paper: RWA

(Best Paper nominees are marked with a star)

Saturday, July 23, 14:00-15:40, Chasm Creek A
Chair: Enrique Alba (University of Málaga)

A Real World Multi-UAV Evolutionary Planner for Minimum Time Target Detection ☆
Sara Perez-Carabaza, Eva Besada-Portas, Jose A. Lopez-Orozco, Jesus M. de la Cruz 14:00-14:25

Tackling the IFP Problem with the Preference-Based Genetic Algorithm ☆
Sune S. Nielsen, Christof Ferreira Torres, Grégoire Danoy, Pascal Bouvry 14:25-14:50

Planning Inspection Paths through Evolutionary Multi-objective Optimization ☆
Kai Olav Ellefsen, Herman A. Lepikson, Jan C. Albiez 14:50-15:15

Finding Reliable Solutions in Bilevel Optimization Problems Under Uncertainties ☆
Zhichao Lu, Kalyanmoy Deb, Ankur Sinha 15:15-15:40

ECOM2

Saturday, July 23, 14:00-15:40, Wind River A
Chair: Markus Wagner (School of Computer Science, The University of Adelaide)

Population-based vs. Single-solution Heuristics for the Travelling Thief Problem
Mohamed El Yafrani, Belaïd Ahiod 14:00-14:25

Cellular Genetic Algorithm for Solving a Routing On-Demand Transit Problem
Olfa Chebbi, Ezzeddine Fatnassi, Jouhaina Chaouachi, Nouha Nouri 14:25-14:50

HMOBEDA: Hybrid Multi-objective Bayesian Estimation of Distribution Algorithm
Marcella S. R. Martins, Myriam R. B.S. Delgado, Roberto Santana, Ricardo Lüders, Richard Aderbal Gonçalves, Carolina Paula de Almeida 14:50-15:15

Ants can Learn from the Opposite
Nicolás Rojas-Morales, María-Cristina Riff, Elizabeth Montero 15:15-15:40

GA2

Saturday, July 23, 14:00-15:40, Chasm Creek B
Chair: Brian W. Goldman (Colorado State University)

Escaping Local Optima with Diversity Mechanisms and Crossover 14:00-14:25
Duc-Cuong Dang, Tobias Friedrich, Timo Kötzing, Martin S. Krejca, Per Kristian Lehre, Pietro S. Oliveto, Dirk Sudholt, Andrew M. Sutton

Runtime Analysis for the Parameter-less Population Pyramid 14:25-14:50
Brian W. Goldman, Dirk Sudholt

Fast Building Block Assembly by Majority Vote Crossover 14:50-15:15
Tobias Friedrich, Timo Kötzing, Martin S. Krejca, Samadhi Nallaperuma, Frank Neumann, Martin Schirneck

A Parallel Hybrid Genetic Algorithm for the k-Edge-Connected Hop-Constrained Network Design Problem 15:15-15:40
Mohamed Khalil Labidi, Ibrahima Diarrassouba, Ali Ridha Mahjoub, Anissa Omrane

GP2

Saturday, July 23, 14:00-15:40, Mesa Verde B
Chair: Wolfgang Banzhaf (Memorial University of Newfoundland)

A New Wave: A Dynamic Approach to Genetic Programming 14:00-14:25
David Medernach, Jeannie Fitzgerald, R. Muhammad Atif Azad, Conor Ryan

Epsilon-Lexicase Selection for Regression 14:25-14:50
William La Cava, Lee Spector, Kourosh Danai

Automatically Designing More General Mutation Operators of Evolutionary Programming for Groups of Function Classes Using a Hyper-Heuristic 14:50-15:15
Libin Hong, John H. Drake, John R. Woodward, Ender Özcan

Evolving Algebraic Constructions for Designing Bent Boolean Functions 15:15-15:40
Stjepan Picek, Domagoj Jakobovic

HOP3

Saturday, July 23, 14:00-15:15, Wind Star A
Chair: Julia Handl (University of Manchester)

The Smaller, the Better: Selecting Refined SVM Training Sets Using Adaptive Memetic Algorithm 14:00-14:25
Jakub Nalepa, Michal Kawulok

Robots that can adapt like animals 14:25-14:50
Antoine Cully, Jeff Clune, Danesh Tarapore, Jean-Baptiste Mouret

Intelligent On-Line Energy Management System for Plug-in Hybrid Electric Vehicles based on Evolutionary Algorithm 14:50-15:15
Xuewei Qi, Matthew J. Barth, Guoyuan Wu, Kanok Boriboonsomsin

ACO-SI2

Saturday, July 23, 16:10-17:50, Chasm Creek B
Chair: Ruby Moritz (Otto-von-Guericke-Universität Magdeburg)

The Influence of Heredity Models on Adaptability in Evolutionary Swarms
Ruby L. V. Moritz, Sanaz Mostaghim 16:10-16:35

Curvature Flight Path for Particle Swarm Optimisation
Cheng Wai Kheng, Day Chyi Ku, Hui Fuang Ng, Mahmoud Khattab, Siang Yew Chong 16:35-17:00

Using Mutual Information to Build Dynamic Neighbourhoods for Particle Swarm Optimisation
Ángel Arturo Rojas-García, Arturo Hernández-Aguirre 17:00-17:25

A New Discrete Particle Swarm Optimization Algorithm
Shane Strasser, Rollie Goodman, John Sheppard, Stephyn Butcher 17:25-17:50

Best Papers: GA+CS

(Best Paper nominees are marked with a star)
Saturday, July 23, 16:10-17:50, Chasm Creek A
Chair: Alberto Moraglio (University of Exeter); William F. Punch (Michigan State University)

Breaking the Billion-Variable Barrier in Real-World Optimization Using a Customized Evolutionary Algorithm ☆
Kalyanmoy Deb, Christie Myburgh 16:10-16:35

Expanding from Discrete Cartesian to Permutation Gene-pool Optimal Mixing Evolutionary Algorithms ☆
Peter A.N. Bosman, Ngoc Hoang Luong, Dirk Thierens 16:35-17:00

Identifying Core Functional Networks and Functional Modules within Artificial Neural Networks via Subsets Regression ☆
Roby Velez, Jeff Clune 17:00-17:25

Quantifying Deception: A Case Study in the Evolution of Antimicrobial Resistance ☆
Margaret J. Eppstein, C. Brandon Ogbunugafor 17:25-17:50

DETA1

Saturday, July 23, 16:10-17:50, Mesa Verde B
Chair: Julian Togelius (IT University of Copenhagen)

Evotype: From Shapes to Glyphs
Tiago Martins, João Correia, Ernesto Costa, Penousal Machado 16:10-16:35

Discovering Combos in Fighting Games with Evolutionary Algorithms
Gianlucca L. Zuin, Yuri P. A. Macedo, Luiz Chaimowicz, Gisele L. Pappa 16:35-17:00

General Video Game Level Generation
Ahmed Khalifa, Diego Perez-Liebana, Simon M. Lucas, Julian Togelius 17:00-17:25

Two-Dimensional Barcode Decoration Using Module-wise Non-systematic Coding and Cooperative Evolution by User and System
Makoto Kamizono, Kigo Shimomura, Masayuki Tajiri, Satoshi Ono 17:25-17:50

ECOM3+RWA5

Saturday, July 23, 16:10-17:50, Wind River A
Chair: Darrell Whitley (Colorado State University)

Additional Dimensions to the Study of Funnels in Combinatorial Landscapes
Gabriela Ochoa, Nadarajen Veerapen 16:10-16:35

Game theory, Extremal optimization, and Community Structure Detection in Complex Networks
Mihai Suciu, Rodica Ioana Lung, Noémi Gaskó 16:35-17:00

Grammatical Evolutionary Techniques for Prompt Migraine Prediction
Josué Pagán, José L. Risco-Martín, José M. Moya, José L. Ayala 17:00-17:25

New Bounds for Office Space Allocation using Tabu Search
Francisco Castillo, María-Cristina Riff, Elizabeth Montero 17:25-17:50

EML2

Saturday, July 23, 16:10-17:50, Wind River B
Chair: Will Neil Browne (Victoria University of Wellington)

A New Evaluation Function for Clustering: The NK Internal Validation Criterion
Renato Tinós, Zhao Liang, Francisco Chicano, Darrell Whitley 16:10-16:35

Using an Ant Colony Optimization Algorithm for Monotonic Regression Rule Discovery
James Brookhouse, Fernando E. B. Otero 16:35-17:00

Transferable XCS
Xianneng Li, Guangfei Yang 17:00-17:25

A Hybrid Approach for Sleep Stages Classification
Abdelhamid Ouanes, Lilia Rejeb 17:25-17:50

HOP4

Saturday, July 23, 16:10-17:25, Wind Star A
Chair: Andrew M. Sutton (Hasso-Plattner-Institut)

Evolutionary Circuit Design for Fast FPGA-Based Classification of Network Application Protocols
David Grochol, Lukas Sekanina, Martin Zadnik, Jan Korenek, Vlastimil Kosar 16:10-16:35

Unleashing the Potential of Evolutionary Swarm Robotics in the Real World
Miguel Duarte, Vasco Costa, Jorge Gomes, Tiago Rodrigues, Fernando Silva, Sancho Moura Oliveira, Anders Lyhne Christensen 16:35-17:00

Spectrum-Diverse Neuroevolution with Unified Neural Models
Danilo Vasconcellos Vargas, Junichi Murata 17:00-17:25

Best Paper: EML

(Best Paper nominees are marked with a star)

Sunday, July 24, 09:00-10:40, Chasm Creek A
Chair: Julia Handl (University of Manchester)

Simple Evolutionary Optimization Can Rival Stochastic Gradient Descent in Neural Networks ☆
Gregory Morse, Kenneth O. Stanley 09:00-09:25

Evaluation of a Tree-based Pipeline Optimization Tool for Automating Data Science ☆
Randal S. Olson, Nathan Bartley, Ryan J. Urbanowicz, Jason H. Moore 09:25-09:50

Evolving Probabilistically Significant Epistatic Classification Rules for Heterogeneous Big Datasets ☆
John P. Hanley, Margaret J. Eppstein, Jeffrey S. Buzas, Donna M. Rizzo 09:50-10:15

Human-inspired Scaling in Learning Classifier Systems
Isidro M. Alvarez, Will N. Browne, Mengjie Zhang 10:15-10:40

CS3+IGEC2

Sunday, July 24, 09:00-10:15, Mesa Verde B
Chair: Jeff Clune (University of Wyoming)

Inspiration-Triggered Search: Towards Higher Complexities by Mimicking Creative Processes
Milan Rybář, Heiko Hamann 09:00-09:25

Learning Behavior Characterizations for Novelty Search
Elliot Meyerson, Joel Lehman, Risto Miikkulainen 09:25-09:50

Classification of Cardiac Arrhythmia by Random Forests with Features Constructed by Kaizen Programming with Linear Genetic Programming
Léo Françoso Dal Piccol Sotto, Regina C. Coelho, Vinícius Veloso de Melo 09:50-10:15

ECOM4

Sunday, July 24, 09:00-10:40, Chasm Creek B
Chair: Francisco Chicano (University of Malaga)

On the Design of Hard mUBQP Instances
Murilo Zangari, Roberto Santana, Alexander Mendiburu, Aurora T. R. Pozo 09:00-09:25

Evolutionary Approaches to Optimization Problems in Chimera Topologies
Roberto Santana, Zheng Zhu, Helmut G. Katzgraber 09:25-09:50

A Simulated Annealing Algorithm for Maximum Common Edge Subgraph Detection in Biological Networks
Simon J. Larsen, Frederik G. Alkærsig, Henrik J. Ditzel, Igor Jurisica, Nicolas Alcaraz, Jan Baumbach 09:50-10:15

A Population-based Local Search Technique with Random Descent and Jump for the Steiner Tree Problem in Graphs
Angus Kenny, Xiaodong Li, A. K. Qin, Andreas T. Ernst 10:15-10:40

RWA6

Sunday, July 24, 09:00-10:40, Wind River A
Chair: Boris Naujoks (Cologne University of Applied Sciences)

Poster Session

Friday, July 22, 18:30-20:00, Grand Mesa Ballroom DEF

Ant Colony Optimization and Swarm Intelligence (ACO-SI)

Ant Colony Optimization Beats Resampling on Noisy Functions
Tobias Friedrich, Timo Kötzing, Francesco Quinzan, Andrew M. Sutton

Asynchronous Steady State Particle Swarm
Carlos M. Fernandes, Juan J. Merelo, Agostinho C. Rosa

Artificial Immune Systems and Biological and Medical Applications (AIS-BIO)

Using Multiobjective Evolutionary Algorithms to Understand Parkinson's Disease
Marta Vallejo, Jeremy Cosgrove, Jane E. Alty, Stephen L. Smith, David W. Corne, Michael A. Lones

Exploiting the Plasticity of Primary and Secondary Response Mechanisms in Artificial Immune Systems
Julie Greensmith, Andrew M. Jackson, Ian Spendlove

Fitness-Dependent Hybridization of Clonal Selection Algorithm and Random Local Search
Nina Bulanova, Arina Buzdalova, Maxim Buzdalov

Metabolite Overproduction through Engineering and Optimization of Microbiome Composition Dynamics
Stephen Lincoln, Jacquelynn Benjamino, Joerg Graf, Ranjan Srivastava

Continuous Optimization (CO)

Multilevel Evolution Strategies for Multigrid Problems
Ofer M. Shir

QR Mutations Improve Many Evolution Strategies - A Lot On Highly Multimodal Problems
Fabien Teytaud, Olivier Teytaud

Diversity-Based Multi-Population Differential Evolution for Large-Scale Optimization
Yong-Feng Ge, Wei-Jie Yu, Jun Zhang

Contextual Stochastic Search
Abbas Abdolmaleki, Nuno Lau, Luis Paulo Reis, Gerhard Neumann

Complex Systems (CS)

Automatic Evolution of Multimodal Behavior with Multi-Brain HyperNEAT
Jacob Schrum, Joel Lehman, Sebastian Risi

Exploring Conflicting Objectives with MADNS
Davy Smith, Laurissa Tokarchuk, Geraint Wiggins

What Factors Drive the Evolution of Mutualism?
Anya E. Vostinar, Luis Zaman, Charles Ofria

A Multi-objective Optimization Approach for Generating Complex Networks
Viplove Arora, Mario Ventresca

Evolving Novel Cellular Automaton Seeds Using Compositional Pattern Producing Networks (CPPN)
Joshuah Aaron Wolper, George Abraham

A Morphogenetic Design Strategy Using a Composite CA Model
Camilo Cruz, Justyna Karakiewicz, Michael Kirley

An Extended Study of Quality Diversity Algorithms
Justin K. Pugh, L. B. Soros, Kenneth O. Stanley

Digital Entertainment Technologies and Arts (DETA)

Evolutionary Procedural 2D Map Generation using Novelty Search
Andreas Scheibenpflug, Johannes Karder, Susanne Schaller, Stefan Wagner, Michael Affenzeller

An Evo-Devo System for Algorithmic Composition that Actually Works
David Daniel Albarracín-Molina, Juan Carlos Moya, Francisco Jose Vico

Interactive Super Mario Bros Evolution
Patrikk Sørensen, Jeppeh Olsen, Sebastian Risi

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

Efficient Stochastic Local Search for Modularity Maximization
Rafael Santiago, Luís Lamb

Search Space Exploration and an Optimization Criterion for Hard Design Problems
Pierre Bergé, Kaourintin Le Guiban, Joanna Tomasik, Arpad Rimmel

Hybridizing Different Local Search Algorithms with Each Other and Evolutionary Computation: Better Performance on the Traveling Salesman Problem
Yuezhong Wu, Thomas Weise, Weichen Liu

A Coevolution Genetic Algorithm for Conflict Resolution of Multi-user Satellite Observation Activities
Baorong Zhai, Hao Chen, Jun Li, Ning Jing

Solving Maximum Cut Problem with an Incremental Genetic Algorithm
Jinhyun Kim, Yourim Yoon, Byung-Ro Moon

Experimental Study of Automated Parameter Tuning on the Example of irace and the Traveling Salesman Problem
Daniil Chivilikhin

Iterated Local Search Based Heuristic for Scheduling Jobs on Unrelated Parallel Machines with Machine Deterioration Effect
Vívian Ludimila Aguiar Santos, José Elias Claudio Arroyo, Thales Francisco Mota Carvalho

A Novel Co-evolutionary Approach for Constrained Genetic Algorithms
Emmanuel Kieffer, Mateusz Guzek, Grégoire Danoy, Pascal Bouvry, Anass Nagih

Toward the Design of Efficient Pivoting Rules for Local Search
Sara Tari, Matthieu Basseur, Adrien Goëffon

Evolutionary Machine Learning (EML)

Inspecting the Latent Space of Stock Market Data with Genetic Programming
Sungjoo Ha, Sangyeop Lee, Byung-Ro Moon

Directly Constructing Multiple Features for Classification with Missing Data using Genetic Programming with Interval Functions
Cao Truong Tran, Mengjie Zhang, Peter Andreae, Bing Xue

Variance-based Learning Classifier System without Convergence of Reward Estimation
Takato Tatsumi, Takahiro Komine, Masaya Nakata, Hiroyuki Sato, Tim Kovacs, Keiki Takadama

Improving Logistic Regression Classification of Credit Approval with Features Constructed by Kaizen Programming
Vinícius Veloso de Melo, Wolfgang Banzhaf

Evolving Augmented Graph Grammars for Argument Analysis
Collin F. Lynch, Linting Xue, Min Chi

Evolutionary Multiobjective Optimization (EMO)

A CUDA Implementation of an Improved Decomposition Based Evolutionary Algorithm for Multi-Objective Optimization
Md Asafuddoula, Hemant Kumar Singh, Tapabrata Ray

Weighted Optimization Framework for Large-scale Multi-objective Optimization
Heiner Zille, Hisao Ishibuchi, Sanaz Mostaghim, Yusuke Nojima

Multi-objective Optimisation with a Sequence-based Selection Hyper-heuristic
David Walker, Ed Keedwell

Towards a Better Diversity of Evolutionary Multi-Criterion Optimization Algorithms using Local Searches
Haitham Ahmed Seada, Mohamed Abouhawwash, Kalyanmoy Deb

Local Search Move Strategies within MOEA/D
Bilel Derbel, Arnaud Liefooghe, Qingfu Zhang, Hernan E. Aguirre, Kiyoshi Tanaka

Approximate BDD Optimization with Prioritized ε-Preferred Evolutionary Algorithm
Saeideh Shirinzadeh, Mathias Soeken, Daniel Große, Rolf Drechsler

Adaptive Use of Innovization Principles for a Faster Convergence of Evolutionary Multi-Objective Optimization Algorithms
Abhinav Gaur, Kalyanmoy Deb

Genetic Algorithms (GA)

A Homologous Gene Replacement based Genetic Algorithm
Sumaiya Iqbal, Md Tamjidul Hoque

A Novel GA-based Feature Selection Approach for High Dimensional Data
Claudio De Stefano, Francesco Fontanella, Alessandra Scotto di Freca

A GA-Inspired Approach to the Reduction of Edge Crossings in Force-Directed Layouts
Farshad Ghassemi Toosi, Nikola S. Nikolov, Malachy Eaton

Maintaining Genetic Diversity in Multimodal Evolutionary Algorithms using Population Injection
Robin Mueller-Bady, Martin Kappes, Inmaculada Medina-Bulo, Francisco Palomo-Lozano

mpEAd: Multi-Population EA Diagrams
Sebastian Lenartowicz, Mark Wineberg

Investigation on Parameterless Schemes for DSMGA-II
Chia-hua Chang, Tian-Li Yu

Genetic Programming (GP)

A Semantics based Symbolic Regression Framework for Mining Explicit and Implicit Equations from Data
Quang Nhat Huynh, Hemant Kumar Singh, Tapabrata Ray

Niching Genetic Programming based Hyper-heuristic Approach to Dynamic Job Shop Scheduling: An Investigation into Distance Metrics
John Park, Yi Mei, Gang Chen, Mengjie Zhang

Finding Nonlinear Relationships in fMRI Time Series with Symbolic Regression
James Alexander Hughes, Mark Daley

Grammar-based Selection Hyper-heuristics for Solving Irregular Bin Packing Problems
Alejandro Sosa-Ascencio, Hugo Terashima-Marín, José Carlos Ortiz-Bayliss, Santiago Enrique Conant-Pablos

Evolving Attackers against Wireless Sensor Networks
Kinga Mrugala, Nilufer Tuptuk, Stephen Hailes

Simultaneous Synthesis of Multiple Functions using Genetic Programming with Scaffolding
Iwo Bladek, Krzysztof Krawiec

Arbitrarily Close Alignments in the Error Space: a Geometric Semantic Genetic Programming Approach
Ivo Gonçalves, Sara Silva, Carlos M. Fonseca, Mauro Castelli

On Heuristics for Seeding the Initial Population of Cartesian Genetic Programming Applied to Combinational Logic Circuits
Francisco A.L. Manfrini, Heder S. Bernardino, Helio J.C. Barbosa

Solving the Lawn Mower problem with Kaizen Programming and λ-Linear Genetic Programming for Module Acquisition
Léo Françoso Dal Piccol Sotto, Vinícius Veloso de Melo

Integrative Genetic and Evolutionary Computation (IGEC)

Recombination Hotspots Promote the Evolvability of Modular Systems
Ari Larson, Anton Bernatskiy, Collin Cappelle, Ken Livingston, Nicholas Livingston, John Long, Jodi Schwarz, Marc Smith, Josh C. Bongard

Parallel Evolutionary Systems (PES)

Parallel Differential Evolution Based on Distributed Cloud Computing Resources for Power Electronic Circuit Optimization
Xiao-Fang Liu, Zhi-Hui Zhan, Jun-Hao Lin, Jun Zhang

A New Hybrid GPU-PSO Approach for Solving Max-CSPs
Dali Narjess, Bouamama Sadok

Develop, Deploy and Execute Parallel Genetic Algorithms in the Cloud
Pasquale Salza, Filomena Ferrucci, Federica Sarro

Real World Applications (RWA)

A Graph-based QoS-Aware Method for Web Service Composition with Branching
Alexandre Sawczuk da Silva, Hui Ma, Mengjie Zhang

Optimum Design of Artificial Lateral Line Systems for Object Tracking under Uncertain Conditions
Ali Ahrari, Hong Lei, Montassar Aidi Sharif, Kalyanmoy Deb, Xiaobo Tan

Mechanical Modeling with Particle Swarm Optimization Algorithm for Braided Bicomponent Ureteral Stent
Xiaoyan Liu, Feng Li, Yongsheng Ding, Lu Wang, Kuangrong Hao

Evolutionary Dynamic Optimization of Control Trajectories for the Catalytic Transformation of the Bioethanol-To-Olefins Process using Neural Networks
Gorka Sorrosal, Cruz E. Borges, Martin Holeňa, Ana M. Macarulla, Cristina Martin, Ainhoa Alonso-Vicario

Co-evolution of Sensor Morphology and Behavior
Terence Soule, Barrie D. Robison, Robert B. Heckendorn

Introducing Pareto-based MOEA to Neurosurgery Preoperative Path Planning
Noura Hamze, Pierre Collet, Caroline Essert

Improving Classification of Patterns in Ultra-High Frequency Time Series with Evolutionary Algorithms
Piotr Lipinski, Krzysztof Michalak, Adrian Lancucki

Search Based Software Engineering and Self-* Search (SBS-SS)

Configuring a Stigmergy-based Traffic Light Controller
Jérémie Dubois-Lacoste, Thomas Stützle

Exploiting Antipheromone in Ant Colony Optimisation for Interactive Search-Based Software Design and Refactoring
Chris Simons, Jim Smith

Adaptive Parameter Selection in Evolutionary Algorithms by Reinforcement Learning with Dynamic Discretization of Parameter Range
Arkady Rost, Irina Petrova, Arina Buzdalova

Selection and Generation Hyper-heuristics for Solving the Vehicle Routing Problem with Time Windows
David Espinoza-Nevárez, José Carlos Ortiz-Bayliss, Hugo Terashima-Marín, Gustavo Gatica

Curious: Searching for Unknown Regions of Space with a Subpopulation-based Algorithm
Danilo Vasconcellos Vargas, Junichi Murata

Theory (THEORY)

On the Capacity of Evolution Strategies to Statistically Learn the Landscape
Ofer M. Shir, Jonathan Roslund, Amir Yehudayoff

Principled Evolutionary Algorithm Design and the Kernel Trick
Fergal Lane, R. Muhammad Atif Azad, Conor Ryan

An Algorithm for Computing Lower Bounds for Unrestricted Black-Box Complexities
Maxim Buzdalov

Abstracts by Track

Hot Off the Press

Session: HOP1
Thursday, July 21, 16:10-17:50, Wind Star A

Evolution of Complex Emergent Behaviour in Multi-State Cellular Automata

Michal Bidlo, *Brno University of Technology*

The paper presents a special technique, called conditionally matching rules, for the representation of transition functions of cellular automata and its application to the evolutionary design of complex emergent behaviour. The square calculation in one-dimensional cellular automata and the problem of designing replicating loops in two-dimensional cellular automata will be treated as case studies. It will be shown that the evolutionary algorithm in combination with the conditionally matching rules is able to successfully solve these tasks and provide some innovative results in comparison with the existing solutions. The results represent successful solutions of problems in cellular automata discovered using conditionally matching rules, for which the utilisation of conventional techniques has failed. Original publication: M. Bidlo, "On Routine Evolution of Complex Cellular Automata," in IEEE Transactions on Evolutionary Computation, vol.PP, no.99.

Neural Modularity Helps Organisms Evolve to Learn New Skills without Forgetting Old Skills

Kai Olav Ellefsen, *Norwegian University of Science and Technology*, Jean-Baptiste Mouret, *INRIA*, Jeff Clune, *University of Wyoming*

A long-standing goal in artificial intelligence (AI) is creating computational brain models (neural networks) that learn what to do in new situations. An obstacle is that agents typically learn new skills only by losing previously acquired skills. We tested whether such forgetting is reduced by evolving modular neural networks, meaning networks with many distinct subgroups of neurons. Modularity intuitively should help because learning can be selectively turned on only in the module learning the new task. We confirm this hypothesis: modular networks have higher overall performance because they learn new skills faster while retaining old skills more. Another reason for the improved performance of modular networks is that they frequently have a reinforcement learning module separate from sensory processing modules, allowing learning to happen only in response to a positive or negative reward. Our results suggest that one benefit of modularity in natural animal brains may be allowing learning without forgetting. The cite for this paper is "K.O. Ellefsen, J-B Mouret, and J Clune. Neural modularity helps organisms evolve to learn new skills without forgetting old skills. PLoS Computational Biology 11.4 (2015): e1004128."

The Benefit of Recombination in Noisy Evolutionary Search

Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Martin S. Krejca, *Hasso Plattner Institute*, Andrew M. Sutton, *Hasso Plattner Institute*

Practical optimization problems frequently include uncertainty about the quality measure, for example due to noisy evaluations. Thus, they do not allow for a straightforward application of traditional optimization techniques. In these settings, randomized search heuristics such as evolutionary algorithms are a popular choice because they are often assumed to exhibit some kind of resistance to noise. Empirical evidence suggests that some algorithms, such as estimation of distribution algorithms (EDAs) are robust against a scaling of the noise intensity, even without resorting to explicit noise-handling techniques such as resampling. In this paper, we want to support such claims with mathematical rigor. We introduce the concept of *graceful scaling* in which the run time of an algorithm scales polynomially with noise intensity. We study a monotone fitness function over binary strings with additive noise taken from a Gaussian distribution. We show that myopic heuristics cannot efficiently optimize the function under arbitrarily intense noise without any explicit noise-handling. Furthermore, we prove that using a population does not help. Finally we show that a simple EDA called the Compact Genetic Algorithm can overcome the shortsightedness of mutation-only heuristics to scale gracefully with noise. We conjecture that recombinative genetic algorithms also have this property. This extended abstract summarizes our work "The Benefit of Recombination in Noisy Evolutionary Search," which appeared in *Proceedings of International Symposium on Algorithms and Computation (ISAAC)*, 2015, pp. 140–150.

Model-Based Relative Entropy Stochastic Search

Abbas Abdolmaleki, *IEETA*

Stochastic search algorithms are general black-box optimizers. Due to their ease of use and their generality, they have recently also gained a lot of attention in operations research, machine learning and policy search. In this paper we introduce a new surrogate-based stochastic search approach. We learn simple, quadratic surrogate models of the objective function. As the quality of such a quadratic approximation is limited, we do not greedily exploit the learned models. The algorithm can be misled by an inaccurate optimum introduced by the surrogate. Instead, we use information theoretic constraints to bound the 'distance' between the new and old data distribution while maximizing the objective function. Additionally the new method is able to sustain the exploration of the search distribution to avoid premature convergence. Original publication: Abdolmaleki, A.; Lioutikov, R.; Peters, J.; Lau, N.; Reis, L.; Neumann, G. (2015). Model-Based Relative Entropy Stochastic Search, Advances in Neural Information Processing Systems (NIPS), MIT Press.

Session: HOP2
Saturday, July 23, 10:40-12:20, Wind Star A

neat Genetic Programming: Controlling Bloat Naturally

Leonardo Trujillo, *Instituto Tecnológico de Tijuana*, Luis Muñoz, *Instituto Tecnológico de Tijuana*, Edgar Galván-López, *Trinity College Dublin*, Sara Silva, *FCUL*

Bloat is still one of the most studied phenomena in Genetic Programming (GP), with several successful bloat control strategies, such as performing a multi-objective search or using specialized search operators. This work presents a bloat control approach that is based on the Flat Operator Equalization bloat control method, that explicitly shapes the program size distributions towards a uniform or flat shape. However, the size distribution is indirectly controlled by applying the general principles of the NeuroEvolution of Augmenting Topologies algorithm (NEAT), a metaheuristic that was originally developed to evolve neural networks. The proposed algorithm is referred to as neat-GP, with results indicating that it can curtail the effects of bloat without sacrificing performance, outperforming both standard GP and the Flat-OE method. We will also presents the benefits of combining this approach with a local search method. This work is based on "Leonardo Trujillo, Luis Muñoz, Edgar Galván-López, Sara Silva. neat Genetic Programming: Controlling Bloat Naturally, Information Sciences 333:21-43 (2016)".

An Improved Fully Stressed Design Evolution Strategy for Layout Optimization of Truss Structures

Ali Ahrari, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*

In the recent decades, the field of structural optimization has undergone a detectable shift from optimality criteria and mathematical programming based methods toward metaheuristic approaches. This trend is usually justified by global search capability of metaheuristics; however, their required evaluation budget grows fast with respect to the number of design parameters, which practically limits the complexity of problems to which they can be applied. As an alternative, a recent study advocated a bi-level approach for structural optimization, called fully stressed design evolution strategy (FSD-ES), in which global search performs in the upper level while problem specific knowledge is utilized in the lower level. This study proposes an improved version of this method, called FSD-ES-II, which follows the concept of contemporary evolution strategies in the upper level and can explicitly handle displacement constraints in the lower level. Some complicated truss optimization problems are also proposed to overcome shortcomings in the complexity of available test problems. Performance of FSD-ES-II is compared with the best available methods in the literature, which usually demonstrates a significant superiority. The details of the method and results can be found in [Ahrari, A., & Deb, K. (2016). An improved fully stressed design evolution strategy for layout optimization of truss structures. Computers & Structures, 164, 127-144].

On the Automatic Construction of Regular Expressions from Examples (GP vs. Humans 1-0)

Alberto Bartoli, *DIA - University of Trieste*, Andrea De Lorenzo, *DIA - University of Trieste*, Eric Medvet, *DIA - University of Trieste*, Fabiano Tarlao, *DIA - University of Trieste*

Regular expressions are systematically used in a number of different application domains. Writing a regular expression for solving a specific task is usually quite difficult, requiring significant technical skills and creativity. We have developed a tool based on Genetic Programming capable of constructing regular expressions for text extraction automatically, based on examples of the text to be extracted. We have recently demonstrated that our tool is human-competitive in terms of both accuracy of the regular expressions and time required for their construction. We base this claim on a large-scale experiment involving more than 1700 users on 10 text extraction tasks of realistic complexity. The F-measure of the expressions constructed by our tool was almost always higher than the average F-measure of the expressions constructed by each of the three categories of users involved in our experiment (Novice, Intermediate, Experienced). The time required by our tool was almost always smaller than the average time required by each of the three categories of users. The experiment is described in full detail in "Can a machine replace humans? A case study. IEEE Intelligent Systems, 2016"

Online Discovery of Search Objectives for Test-based Problems

Paweł Liskowski, *Poznan University of Technology*, Krzysztof Krawiec, *Poznan University of Technology*

In [13], we proposed disco, a method that automatically identifies the groups of tests for which the candidate solutions behave similarly. Each such group gives rise to a derived objective, which together guide the search algorithm in multi-objective fashion. When applied to several well-known test-based problems, the proposed approach significantly outperforms the conventional two-population coevolution. This opens the door to efficient and generic countermeasures to premature convergence for both coevolutionary and evolutionary algorithms applied to problems featuring aggregating fitness functions.

Session: HOP3
Saturday, July 23, 14:00-15:15, Wind Star A

The Smaller, the Better: Selecting Refined SVM Training Sets Using Adaptive Memetic Algorithm

Jakub Nalepa, *Silesian University of Technology*, Michal Kawulok, *Silesian University of Technology*

Support vector machine (SVM) is a supervised classifier which has been applied for solving a wide range of pattern recognition

problems. However, training of SVMs may easily become a bottleneck, because of its time and memory requirements. Enduring this issue is a vital research topic, especially in the era of big data. In this abstract, we present our adaptive memetic algorithm for selection of refined (significantly smaller) SVM training sets. The algorithm - being a hybrid of an adaptive genetic algorithm and some refinement procedures - exploits the knowledge about the training set vectors extracted before the evolution, and attained dynamically during the search. The results obtained for several real-life, benchmark, and artificial datasets showed that our approach outperforms the other state-of-the-art techniques, and is able to extract very high-quality SVM training sets.

Robots that can adapt like animals

Antoine Cully, *Imperial College*, Jeff Clune, *University of Wyoming*, Danesh Tarapore, *University of York*, Jean-Baptiste Mouret, *INRIA*

While animals can quickly adapt to a wide variety of injuries, current robots cannot "think outside the box" to find a compensatory behavior when damaged: they are limited to their prespecified self-sensing abilities and can diagnose only anticipated failure modes. Here we introduce an intelligent trial and error algorithm that allows robots to adapt to damage in less than 2 minutes, without requiring self-diagnosis or pre-specified contingency plans. Before deployment, a robot exploits a novel evolutionary algorithm to create a detailed map of the space of high-performing behaviors. If the robot is damaged, it uses this map to guide a trial-and-error learning algorithm that conducts experiments to rapidly discover a compensatory behavior that works in spite of the damage. Experiments reveal successful adaptations for a legged robot injured in five different ways, including damaged, broken, and missing legs, and for a robotic arm with joints broken in 14 different ways. This new technique will enable more robust, effective, autonomous robots and suggests principles that animals may use to adapt to injury. Original publication: Cully, A., Clune, J., Tarapore, D., & Mouret, J.-B. (2015). Robots that can adapt like animals. Nature, 521(7553).

Intelligent On-Line Energy Management System for Plug-in Hybrid Electric Vehicles based on Evolutionary Algorithm

Xuewei Qi, *UCR CECERT*, Matthew J. Barth, *UCR CECERT*, Guoyuan Wu, *UCR CECERT*, Kanok Boriboonsomsin, *UCR CERT*

Energy management system (EMS) is crucial to a plug-in hybrid electric vehicle (PHEV) in reducing its fuel consumption and pollutant emissions. The EMS determines how energy flows in a hybrid powertrain should be managed in response to a variety of driving conditions. In the development of an EMS, the battery state-of-charge (SOC) control strategy plays a critical role. This paper proposes a novel evolutionary algorithm (EA)-based EMS with a self-adaptive SOC control strategy for PHEVs, which can significantly improve the fuel efficiency without knowing the trip length (in time). Numerical studies show that this proposed system can save up to 13% fuel, compared to other online EMS with different SOC control strategies. Further analysis indicates that the proposed system is less sensitive to the errors in predicting propulsion power demand in real-time, which is favorable for on-line implementation. Original publication: X. Qi, G. Wu, K. Boriboonsomsin and M. J. Barth, Evolutionary algorithm based on-line PHEV energy management system with self-adaptive SOC control, Intelligent Vehicles Symposium (IV), 2015 IEEE, Seoul, 2015, pp. 425-430.

Session: HOP4
Saturday, July 23, 16:10-17:25, Wind Star A

Evolutionary Circuit Design for Fast FPGA-Based Classification of Network Application Protocols

David Grochol, *Brno University of Technology*, Lukas Sekanina, *Brno University of Technology*, Martin Zadnik, *Brno University of Technology*, Jan Korenek, *Brno University of Technology*, Vlastimil Kosar, *Brno University of Technology*

The evolutionary design can produce fast and efficient implementations of digital circuits. It is shown in this paper how evolved circuits, optimized for the latency and area, can increase the throughput of a manually designed classifier of application protocols. The classifier is intended for high speed networks operating at 100 Gbps. Because a very low latency is the main design constraint, the classifier is constructed as a combinational circuit in a field programmable gate array (FPGA). The classification is performed using the first packet carrying the application payload. The improvements in latency (and area) obtained by Cartesian genetic programming are validated using a professional FPGA design tool. The quality of classification is evaluated by means of real network data. All results are compared with commonly used classifiers based on regular expressions describing application protocols. Original publication: D. Grochol, L. Sekanina, M. Zadnik, J. Korenek, V. Kosar. Evolutionary circuit design for fast FPGA-based classification of network application protocols. Applied Soft Computing 38 (2016) 933–941.

Unleashing the Potential of Evolutionary Swarm Robotics in the Real World

Miguel Duarte, *BioMachines Lab*, Vasco Costa, *BioMachines Lab*, Jorge Gomes, *BioMachines Lab*, Tiago Rodrigues, *BioMachines Lab*, Fernando Silva, *BioMachines Lab*, Sancho Moura Oliveira, *BioMachines Lab*, Anders Lyhne Christensen, *BioMachines Lab*

We provide a summary of our real-world experiments with a swarm of aquatic surface robots with evolved control. Robotic control was synthesized in simulation, using of- fline evolutionary robotics techniques, and then successfully transferred to a real swarm. Our study presents one of the first demonstrations of evolved control in a swarm robotics system outside of controlled laboratory conditions. Original publication: M. Duarte,

V. Costa, J. Gomes, T. Rodrigues, F. Silva, S. M. Oliveira, and A. L. Christensen. Evolution of collective behaviors for a real swarm of aquatic surface robots. PLoS ONE, 11(3):e0151834, 2016.

Spectrum-Diverse Neuroevolution with Unified Neural Models

Danilo Vasconcellos Vargas, *Kyushu University*, Junichi Murata, *Kyushu University*

Current learning systems behave sometimes erratically when facing new problems or require a lot of trial and error to set their parameters as well as prior knowledge to work. We propose a new neuroevolution based method that can cope with all these problems. The algorithm demonstrates its capability by learning 5 completely different control problems without changing any parameters. This achievement was made possible by two contributions: (1) Unified Neural Model and (2) Spectrum-Diverse Neuroevolution. (1) Unified Neural Model - To learn a wide variety of problem classes, learning systems need a greater representation power. Therefore, a novel neural model called Unified Neural Model is proposed that unifies most neural network features from the literature into one representation. (2) Spectrum-Diverse Neuroevolution - To develop such complex representations, neuroevolution is used with a new concept that calculates the spectrum of candidate solutions based on their characteristics and uses it to keep the diversity. This enables high dimensional structures to be compared efficiently and scales well with their size. Original publication: Danilo Vasconcellos Vargas and Junichi Murata. "Spectrum-Diverse Neuroevolution with Unified Neural Models", IEEE Transactions on Neural Networks and Learning Systems.

Ant Colony Optimization and Swarm Intelligence

Session: Best Papers: CO+THEORY+ACO-SI
Friday, July 22, 10:40-11:55, Chasm Creek A

Update Strength in EDAs and ACO: How to Avoid Genetic Drift

Dirk Sudholt, *University of Sheffield*, Carsten Witt, *Technical University of Denmark*

We provide a rigorous runtime analysis concerning the update strength, a vital parameter in probabilistic model-building GAs such as the step size $1/K$ in the compact Genetic Algorithm (cGA) and the evaporation factor ρ in ACO. While a large update strength is desirable for exploitation, there is a general trade-off: too strong updates can lead to genetic drift and poor performance. We demonstrate this trade-off for the cGA and a simple MMAS ACO algorithm on the OneMax function. More precisely, we obtain lower bounds on the expected runtime of $\Omega(K\sqrt{n}+n\log n)$ and $\Omega(\sqrt{n}/\rho+n\log n)$, respectively, showing that the update strength should be limited to $1/K, \rho = O(1/(\sqrt{n}\log n))$. In fact, choosing $1/K, \rho \sim 1/(\sqrt{n}\log n)$ both algorithms efficiently optimize OneMax in expected time $O(n\log n)$. Our analyses provide new insights into the stochastic behavior of probabilistic model-building GAs and propose new guidelines for setting the update strength in global optimization.

Session: ACO-SI1
Saturday, July 23, 14:00-15:40, Wind River B

ACO-inspired Acceleration of Gossip Averaging

Andreas Janecek, *University of Vienna*, Wilfried N. Gansterer, *University of Vienna*

Gossip ("epidemic") algorithms can be used for computing aggregation functions of local values across a distributed system without the need to synchronize participating nodes. Although several (theoretical) studies have proven that these algorithms scale well with the number of nodes n, most of these studies are restricted to fully connected networks and based on rather strong assumptions, e.g., it is often assumed that all messages are sent at exactly the same time on different nodes. Applying gossip algorithms on non-fully connected networks significantly increases the number of messages/rounds, especially on weakly connected networks without a regular structure. We present new acceleration strategies for gossip-based averaging algorithms based on ant colony optimization, which specifically target weakly connected networks with irregular structure, where existing gossip averaging algorithms tend to be slow. The proposed acceleration strategies reduce the message and time complexity of standard gossip algorithms without any additional communication cost. The overhead only consists of additional local computation which is proportional to the node degree. All findings are confirmed experimentally for different types of network topologies and for different network sizes.

A Mixed-Attribute Approach in Ant-Miner Classification Rule Discovery Algorithm

Ayah Helal, *University of Kent*, Fernando E. B. Otero, *University of Kent*

In this paper, we introduce Ant-MinerMA to tackle mixed-attribute classification problems. Most classification problems involve continuous, ordinal and categorical attributes. The majority of Ant Colony Optimization (ACO) classification algo-

rithms have the limitation of being able to handle categorical attributes only, with few exceptions that use a discretisation procedure when handling continuous attributes either in a preprocessing stage or during the rule creation. Using a solution archive as a pheromone model, inspired by the ACO for mixed-variable optimization (ACO-MV), we eliminate the need for a discretisation procedure and attributes can be treated directly as continuous, ordinal, or categorical. We compared the proposed Ant-MinerMA against cAnt-Miner, an ACO-based classification algorithm that uses a discretisation procedure in the rule construction process. Our results show that Ant-MinerMA achieved significant improvements on computational time due to the elimination of the discretisation procedure without affecting the predictive performance.

Geometric Particle Swarm Optimization for Multi-objective Optimization Using Decomposition

Saul Zapotecas-Martinez, *Shinshu University*, Alberto Moraglio, *University of Exeter*, Hernan E. Aguirre, *Shinshu University*, Kiyoshi Tanaka, *Shinshu University*

Multi-objective evolutionary algorithms (MOEAs) based on decomposition are aggregation-based algorithms which transform a multi-objective optimization problem (MOP) into several single-objective subproblems. Being effective, efficient, and easy to implement, Particle Swarm Optimization (PSO) has become one of the most popular single-objective optimizers for continuous problems, and recently it has been successfully extended to the multi-objective domain. However, no investigation on the application of PSO within a multi-objective decomposition framework exists in the context of combinatorial optimization. This is precisely the focus of the paper. More specifically, we study the incorporation of Geometric Particle Swarm Optimization (GPSO), a discrete generalization of PSO that has proven successful on a number of single-objective combinatorial problems, into a decomposition approach. We conduct experiments on many-objective 1/0 knapsack problems i.e. problems with more than three objectives functions, substantially harder than multi-objective problems with fewer objectives. The results indicate that the proposed multi-objective GPSO based on decomposition is able to outperform two version of the well-know MOEA based on decomposition (MOEA/D) and the most recent version of the non-dominated sorting genetic algorithm (NSGA-III), which are state-of-the-art multi-objective evolutionary approaches based on decomposition.

Relaxing Consensus in Distributed Factored Evolutionary Algorithms

Stephyn Butcher, *Johns Hopkins University*, Shane Strasser, *Montana State University*, Jenna Hoole, *Whitworth University*, Benjamin Demeo, *Williams College*, John Sheppard, *Montana State University*

Factored Evolutionary Algorithms (FEA) have proven to be fast and efficient optimization methods, often outperforming established methods using single populations. One restriction to FEA is that it requires a central communication point between all of the factors, making FEA difficult to use in completely distributed settings. The Distributed Factored Evolutionary Algorithm (DFEA) relaxes this requirement on central communication by having neighboring factors communicate directly with one another. While DFEA has been effective at finding good solutions, there is often an increase in computational complexity due to the communication between factors. In previous work on DFEA, the authors required the algorithm reach full consensus between factors during communication. In this paper, we demonstrate that even without full consensus, the performance of DFEA was not statistically different on problems with low epistasis. Additionally, we found that there is a relationship between the convergence of consensus between factors and the convergence of fitness of DFEA.

Session: ACO-SI2
Saturday, July 23, 16:10-17:50, Chasm Creek B

The Influence of Heredity Models on Adaptability in Evolutionary Swarms

Ruby L. V. Moritz, *Otto-von-Guericke-Universität Magdeburg*, Sanaz Mostaghim, *Otto-von-Guericke-Universität Magdeburg*

Evolutionary systems can be very adaptable to dynamic environments. If the systems input changes, it either has to remember or (re-)invent an efficient behavior fitting to a new or recurring situation. In this study we propose a haplodiploid system where haploid agents have one set of properties and diploid agents have two sets of properties. In the studied system agents process tasks which add to their fitness values. Once their fitness values exceed a certain threshold, they pass a copy of their property set to randomly chosen other agents. The agents property set defines the fitness value it gains by processing a task. Diploid agents apply the property set providing the higher fitness. While haploid agents enforce a fast and straight forwards adaptation and convergence, diploid agents maintain a higher diversity in the system. However, mixed systems are most suitable in highly dynamic environments. The focus of our simulation experiments is the adaptability of systems with specific distributions of haploids and diploids in various dynamic environments.

Curvature Flight Path for Particle Swarm Optimisation

Cheng Wai Kheng, *Universiti Tunku Abdul Rahman*, Day Chyi Ku, *Multimedia University*, Hui Fuang Ng, *Universiti Tunku Abdul Rahman*, Mahmoud Khattab, *University of Nottingham (Malaysia Campus)*, Siang Yew Chong, *University of Nottingham (Malaysia Campus)*

An optimisation is a process of finding maxima or minima of the objective function. Particle Swarm Optimisation (PSO) is a nature-inspired, meta-heuristic, black box optimisation algorithm used to search for global minimum or maximum in the solution space. The sampling strategy in this algorithm mimics

the flying pattern of a swarm, where each sample is generated randomly according to uniform distribution among three different locations, which marks the current particle location, the individual best found location, and the best found location for the entire swam over all generation. The PSO has known disadvantage of premature convergence in problems with high correlated design variables (high epistatis). However, there is limited research conducted in finding the main reason why the algorithm fails to locate better solutions in these problems. In this paper, we propose to change the traditional triangular flight trajectory of PSO to an elliptical flight path. The new flying method is tested and compared with the traditional triangular flight trajectory of PSO on five high epistatis benchmark problems. Our results show that the samples generated from the elliptical flight path are generally better than the traditional triangular flight trajectory of PSO in term of average fitness and the fitness of best found solution.

Using Mutual Information to Build Dynamic Neighbourhoods for Particle Swarm Optimisation

Ángel Arturo Rojas-García, *Center for Research in Mathematics*, Arturo Hernández-Aguirre, *Center for Research in Mathematics*

A proposal to build dynamic neighbourhoods in PSO based on mutual information is presented in this paper. The relationship among the paths the particles follow in the search space along the iterations is measured with mutual information and particles are linked to produce a graph (a tree) with maximum mutual information. Another graph investigated is ring topology. The performance of the approach is tested using a set of thirteen benchmark functions available in the specialised literature. A comparison with canonical PSO (a static fully connected neighbourhood) and two state of the art dynamic neighbourhood PSOs are reported. The results show a fast convergence (a lesser number of function evaluations) in unimodal functions; this convergence speed is more remarkable in high dimensional problems.

A New Discrete Particle Swarm Optimization Algorithm

Shane Strasser, *Montana State University*, Rollie Goodman, *Montana State University*, John Sheppard, *Montana State University*, Stephyn Butcher, *Johns Hopkins University*

Particle Swarm Optimization (PSO) has been shown to perform very well on a wide range of optimization problems. One of the drawbacks to PSO is that the base algorithm assumes continuous variables. In this paper, we present a version of PSO that is able to optimize over discrete variables. This new PSO algorithm, which we call Integer and Categorical PSO (ICPSO), incorporates ideas from Estimation of Distribution Algorithms (EDAs) in that particles represent probability distributions rather than solution values, and the PSO update modifies the probability distributions. In this paper, we describe our new algorithm and compare its performance against other discrete PSO algorithms. In our experiments, we demonstrate that our algorithm outperforms comparable methods on both discrete benchmark functions and NK landscapes, a mathematical framework that generates tunable fitness landscapes for evaluating EAs.

Artificial Immune Systems and Biological and Medical Applications

Session: AIS-BIO1+CO1
Friday, July 22, 14:00-15:15, Chasm Creek B

A Novel EA-based Memetic Approach for Efficiently Mapping Complex Fitness Landscapes

Emmanuel Sapin, *George Mason University*, Kenneth A. De Jong, *George Mason University*, Amarda Shehu, *George Mason University*

Recent work in computational structural biology focuses on modeling intrinsically dynamic proteins important to human biology and health. The energy landscapes of these proteins are rich in minima that correspond to alternative structures with which a dynamic protein binds to molecular partners in the cell. On such landscapes, evolutionary algorithms that switch their objective from classic optimization to mapping are more informative of protein structure function relationships. While techniques for mapping energy landscapes have been developed in computational chemistry and physics, protein landscapes are more difficult for mapping due to their high dimensionality and multimodality. In this paper, we describe a memetic evolutionary algorithm that is capable of efficiently mapping complex landscapes. In conjunction with a hall of fame mechanism, the algorithm makes use of a novel, lineage- and neighborhood-aware local search procedure or better exploration and mapping of complex landscapes. We evaluate the algorithm on several benchmark problems and demonstrate the superiority of the novel local search mechanism. In addition, we illustrate its effectiveness in mapping the complex multimodal landscape of an intrinsically dynamic protein important to human health.

Continuous Optimization

Session: Best Papers: CO+THEORY+ACO-SI
Friday, July 22, 10:40-11:55, Chasm Creek A

Analysis of Linear Convergence of a (1 + 1)-ES with Augmented Lagrangian Constraint Handling

Asma Atamna, *Inria & Universite Paris-Saclay*, Anne Auger, *Inria & Universite Paris-Saclay*, Nikolaus Hansen, *Inria & Universite Paris-Saclay*

We address the question of linear convergence of evolution strategies on constrained optimization problems. In particular, we analyze a $(1 + 1)$-ES with an augmented Lagrangian constraint handling approach on functions defined on a continuous domain, subject to a single linear inequality constraint. We identify a class of functions for which it is possible to construct a homogeneous Markov chain whose stability implies linear convergence. This class includes all functions such that the augmented Lagrangian of the problem, centered with respect to its value at the optimum and the corresponding Lagrange multiplier, is positive homogeneous of degree 2 (thus including convex quadratic functions as a particular case). The stability of the constructed Markov chain is empirically investigated on the sphere function and on a moderately ill-conditioned ellipsoid function.

Session: AIS-BIO1+CO1
Friday, July 22, 14:00-15:15, Chasm Creek B

Population Size Adaptation for the CMA-ES Based on the Estimation Accuracy of the Natural Gradient

Kouhei Nishida, *Shinshu University*, Youhei Akimoto, *Shinshu University*

We propose a novel strategy to adapt the population size, i.e. the number of candidate solutions per iteration, for the rank-mu update covariance matrix adaptation evolution strategy (CMA-ES). Our strategy is based on the interpretation of the rank-mu update CMA-ES as the stochastic natural gradient approach on the parameter space of the sampling distribution. We introduce a measurement of the accuracy of the current estimate of the natural gradient. We propose a novel strategy to adapt the population size according to the accuracy measure. The proposed strategy is evaluated on test functions including rugged functions and noisy functions where a larger population size is known to help to find a better solution. The experimental results show the advantage of the adaptation of the population size over a fixed population size. It is also compared with the state-of-the-art uncertainty handling strategy for the CMA-ES, namely UH-CMA-ES, on noisy test functions.

Permuted Orthogonal Block-Diagonal Transformation Matrices for Large Scale Optimization Benchmarking

Ouassim Ait ElHara, *Université Paris-Sud*, Anne Auger, *Inria Saclay–Ile-de-France*, Nikolaus Hansen, *Inria Saclay–Ile-de-France*

We propose a general methodology to construct large-scale testbeds for the benchmarking of continuous optimization algorithms. Our approach applies an orthogonal transformation on raw functions that involve only a linear number of operations. The orthogonal transformation is sampled from a parametrized family of transformations that are the product of a permutation matrix times a block-diagonal matrix times a permutation matrix. We investigate the impact of the different parameters of the transformation on the difficulty of the problems using the separable CMA-ES. We illustrate the use of the above defined transformation in the BBOB-2009 testbed as replacement for the expensive orthogonal (rotation) matrices. We also show the practicability of the approach by studying the computational cost and its applicability in a large scale setting.

Session: CO2
Saturday, July 23, 10:40-12:20, Wind River B

Experimental Investigation of Recombination Operators for Differential Evolution

Felipe Campelo, *Universidade Federal de Minas Gerais*, Moisés Botelho, *Universidade Federal de Minas Gerais*

This paper presents a systematic investigation of the effects of sixteen recombination operators for real-coded spaces on the performance of Differential Evolution. A unified description of the operators in terms of mathematical operations of vectors is presented, and a standardized implementation is provided in the form of an R package. The objectives are to simplify the examination of similarities and differences between operators as well as the understanding of their effects on the population, and to provide a platform in which future operators can be incorporated and evaluated. An experimental comparison of the recombination operators is conducted using twenty-eight test problems, and the results are used to discuss possibly promising directions in the development of improved operators for differential evolution.

Low-Budget Exploratory Landscape Analysis on Multiple Peaks Models

Pascal Kerschke, *University of Münster*, Mike Preuss, *University of Münster*, Simon Wessing, *TU Dortmund*, Heike Trautmann, *University of Münster*

When selecting the best suited algorithm for an unknown optimization problem, it is useful to possess some a priori knowledge of the problem at hand. In the context of single-objective, continuous optimization problems such knowledge can be retrieved by means of Exploratory Landscape Analysis (ELA), which automatically identifies properties of a landscape, e.g., the so-called funnel structures, based on an initial sample. In this paper, we extract the relevant features (for detecting funnels) out of a large set of landscape features when only given a small initial sample consisting of 50 x D observations, where D is the number of decision space dimensions. This is already in the range of the start population sizes of many evolutionary algorithms. The new Multiple Peaks Model Generator (MPM2) is used for training the classifier, and the approach is then very successfully validated on the Black-Box Optimization Benchmark (BBOB) and a subset of the CEC 2013 niching competition problems.

Projection-Based Restricted Covariance Matrix Adaptation for High Dimension

Youhei Akimoto, *Shinshu University*, Nikolaus Hansen, *Inria & Universite Paris-Saclay*

We propose a novel variant of the covariance matrix adaptation evolution strategy (CMA-ES) using a covariance matrix parameterized with a smaller number of parameters. The motivation of a restricted covariance matrix is twofold. First, it requires less internal time and space complexity that is desired when optimizing a function on a high dimensional search space. Second, it requires less function evaluations to adapt the covariance matrix if the restricted covariance matrix is rich enough to express the variable dependencies of the problem. In this paper we derive a computationally efficient way to update the restricted covariance matrix where the model richness of the covariance matrix is controlled by an integer and the internal complexity per function evaluation is linear in this integer times the dimension, compared to quadratic in the dimension in the CMA-ES. We prove that the proposed algorithm is equivalent to the sep-CMA-ES if the covariance matrix is restricted to the diagonal matrix, it is equivalent to the original CMA-ES if the matrix is not restricted. Experimental results reveal the class of efficiently solvable functions depending on the model richness of the covariance matrix and the speedup over the CMA-ES.

Analysis of Different Types of Regret in Continuous Noisy Optimization

Sandra Astete-Morales, *Inria & Universite Paris-Saclay*, Marie-Liesse Cauwet, *Inria & Universite Paris-Saclay*, Olivier Teytaud, *Inria & Universite Paris-Saclay*

The performance measure of an algorithm is a crucial part of its analysis. The performance can be determined by the study on the convergence rate of the algorithm in question. It is necessary to study some (hopefully convergent) sequence that will measure how "good" is the approximated optimum compared to the real optimum. The concept of *Regret* is widely used in the bandit literature for assessing the performance of an algorithm. The same concept is also used in the framework of optimization algorithms, sometimes under other names or without a specific name. And the numerical evaluation of convergence rate of noisy algorithms often involves *approximations* of regrets. We discuss here two types of approximations of Simple Regret used in practice for the evaluation of algorithms for noisy optimization. We use specific algorithms of different nature and the noisy sphere function to show the following results. The approximation of Simple Regret, termed here Approximate Simple Regret, used in some optimization testbeds, fails to estimate the Simple Regret convergence rate. We also discuss a recent new approximation of Simple Regret, that we term Robust Simple Regret, and show its advantages and disadvantages.

Complex Systems

Session: CS1
Friday, July 22, 10:40-12:20, Wind River A

Does Aligning Phenotypic and Genotypic Modularity Improve the Evolution of Neural Networks?

Joost Huizinga, *University of Wyoming*, Jean-Baptiste Mouret, *University of Lorraine*, Jeff Clune, *University of Wyoming*

Many argue that to evolve artificial intelligence that rivals that of natural animals, we need to evolve neural networks that are *structurally organized* in that they exhibit *modularity*, *regularity*, and *hierarchy*. It was recently shown that a cost for network connections, which encourages the evolution of modularity, can be combined with an indirect encoding, which encourages the evolution of regularity, to evolve networks that are both modular and regular. However, the bias towards regularity from indirect encodings may prevent evolution from independently optimizing different modules to perform different functions, unless modularity in the phenotype is *aligned* with modularity in the genotype. We test this hypothesis on two multi-modal problems—a pattern recognition task and a robotics task—that each require *different* phenotypic modules. In general, we find that performance is improved only when genotypic and phenotypic modularity are encouraged simultaneously, though the role of alignment remains unclear. In addition, intuitive manual decompositions fail to provide the performance benefits of automatic methods on the more challenging robotics problem, em-

phasizing the importance of automatic, rather than manual, decomposition methods. These results suggest encouraging modularity in both the genotype and phenotype as an important step towards solving large-scale multi-modal problems, but also indicate that more research is required before we can evolve structurally organized networks to solve tasks that require multiple, different neural modules.

Neuromodulation Improves the Evolution of Forward Models

Mohammad Sadegh Norouzzadeh, *University of Wyoming*, Jeff Clune, *University of Wyoming*

Many animals predict the outcomes of their actions by internal models. Such "forward models" enable animals to rapidly simulate many actions without performing them to choose an appropriate action. Robots would similarly benefit from forward models. However, such models must change over time to account for changes in the environment or body, such as injury. Thus, forward models must not only be accurate, but also adaptable. Neural networks can learn complex functions with high accuracy, hence they are suitable candidates to build forward models for robots. Generally, neural networks are static, which means once they pass the training phase, their weights remain unchanged and they thus cannot adapt themselves if something about the world or their body changes. Plastic neural networks change their connections over time via local learning rules (e.g. Hebbian rule) and can thus deal with unforeseen changes. A more complex, yet still biologically-inspired, technique is neuromodulation, which can change per-connection learning rates in different contexts. In this paper, we test the hypothesis that neuromodulation may improve the evolution of forward models because it can heighten learning after drastic changes such as injury. We compare forward models evolved with neuromodulation to those evolved with static neural networks and Hebbian plastic neural networks. The results show that neuromodulation produces forward models that can adapt to changes significantly better than the controls. Our findings suggest that neuromodulation is an effective tool for enabling robots (and artificial intelligence agents, more generally) to have more adaptable, effective forward models.

EvoRBC: Evolutionary Repertoire-based Control for Robots with Arbitrary Locomotion Complexity

Miguel Duarte, *BioMachines Lab, Instituto de Telecomunicações & Instituto Universitário de Lisboa (ISCTE-IUL)*, Jorge Gomes, *BioMachines Lab, Instituto de Telecomunicações & BioISI*, Sancho Moura Oliveira, *BioMachines Lab, Instituto de Telecomunicações & Instituto Universitário de Lisboa (ISCTE-IUL)*, Anders Lyhne Christensen, *BioMachines Lab, Instituto de Telecomunicações & Instituto Universitário de Lisboa (ISCTE-IUL)*

The use of evolutionary robotics in robots with complex means of locomotion has, so far, mainly been limited to gait evolution. Increasing the number of degrees of freedom available to a controller significantly enlarges the search space, which in turn makes the evolution of solutions for a given task more challenging. In this paper, we present Evolutionary Repertoire-based Control (EvoRBC), an approach that enables the evolution of control for robots with arbitrary locomotion complexity. EvoRBC separates the synthesis of control into two levels: the generation of a repertoire of behavior primitives through the application of Quality Diversity techniques; and the evolution of a behavior arbitrator that uses the repertoire's primitives to solve a particular task. We evaluate EvoRBC in simulated robots with different numbers of degrees of freedom in two tasks, navigation and foraging. Our results show that while standard evolutionary approaches are highly affected by the locomotion complexity of the robot, EvoRBC is consistently able to evolve high-performing solutions. We also show that EvoRBC allows for the evolution of general controllers, that can be successfully used in robots different than those with which they were evolved.

Evolving Neural Turing Machines for Reward-based Learning

Rasmus Boll Greve, *IT University of Copenhagen*, Emil Juul Jacobsen, *IT University of Copenhagen*, Sebastian Risi, *IT University of Copenhagen*

An unsolved problem in neuroevolution (NE) is to evolve artificial neural networks (ANN) that can store and use information to change their behavior online. While plastic neural networks have shown promise in this context, they have difficulties retaining information over longer periods of time and integrating new information without losing previously acquired skills. Here we build on recent work by Graves et al. [5] who extended the capabilities of an ANN by combining it with an external memory bank trained through gradient descent. In this paper, we introduce an evolvable version of their Neural Turing Machine (NTM) and show that such an approach greatly simplifies the neural model, generalizes better, and does not require accessing the entire memory content at each time-step. The Evolvable Neural Turing Machine (ENTM) is able to solve a simple copy tasks and for the first time, the continuous version of the double T-Maze, a complex reinforcement-like learning problem. In the T-Maze learning task the agent uses the memory bank to display adaptive behavior that normally requires a plastic ANN, thereby suggesting a complementary and effective mechanism for adaptive behavior in NE.

Session: CS2
Friday, July 22, 14:00-15:40, Wind River A

How do Different Encodings Influence the Performance of the MAP-Elites Algorithm?

Danesh Tarapore, *University of York*, Jeff Clune, *University of Wyoming*, Antoine Cully, *Imperial College*, Jean-Baptiste Mouret, *Inria*

The recently introduced Intelligent Trial and Error algorithm (IT&E) both improves the ability to automatically generate controllers that transfer to real robots, and enables robots to creatively adapt to damage in less than 2 minutes. A key component of IT&E is a new evolutionary algorithm called MAP-Elites, which creates a behavior-performance map that is provided as a set of "creative" ideas to an online learning algorithm. To date, all experiments with MAP-Elites have been performed with a directly encoded list of parameters: it is therefore unknown how MAP-Elites would behave with more advanced encodings, like HyperNeat and SUPG. In addition, because we ultimately want robots that respond to their environments via sensors, we investigate the ability of MAP-Elites to evolve closed-loop controllers, which are more complicated, but also more powerful. Our results show that the encoding critically impacts the quality of the results of MAP-Elites, and that the differences are likely linked to the locality of the encoding (the likelihood of generating a similar behavior after a single mutation). Overall, these results improve our understanding of both the dynamics of the MAP-Elites algorithm and how to best harness MAP-Elites to evolve effective and adaptable robotic controllers.

Evolvability Search: Directly Selecting for Evolvability in order to Study and Produce It

Henok Mengistu, *University of Wyoming*, Joel Lehman, *IT University of Copenhagen*, Jeff Clune, *University of Wyoming*

One hallmark of natural organisms is their significant evolvability, i.e.,their increased potential for further evolution. However, reproducing such evolvability in artificial evolution remains a challenge, which both reduces the performance of evolutionary algorithms and inhibits the study of evolvable digital phenotypes. Although some types of selection in evolutionary computation indirectly encourage evolvability, one unexplored possibility is to directly select for evolvability. To do so, we estimate an individual's future potential for diversity by calculating the behavioral diversity of its immediate offspring, and select organisms with increased offspring variation. While the technique is computationally expensive, we hypothesized that direct selection would better encourage evolvability than indirect methods. Experiments in two evolutionary robotics domains confirm this hypothesis: in both domains, such Evolvability Search produces solutions with higher evolvability than those produced with Novelty Search or traditional objective-based search algorithms. Further experiments demonstrate that the higher evolvability produced by Evolvability Search in a training environment also generalizes, producing higher evolvability in a new test environment without further selection. Overall, Evolvability Search enables generating evolvability more easily and directly, facilitating its study and understanding, and may inspire future practical algorithms that increase evolvability without significant computational overhead.

Convolution by Evolution: Differentiable Pattern Producing Networks

Chrisantha Fernando, *Google DeepMind*, Dylan Banarse, *Google DeepMind*, Malcolm Reynolds, *Google DeepMind*, Frederic Besse, *Google DeepMind*, David Pfau, *Google DeepMind*, Max Jaderberg, *Google DeepMind*, Marc Lanctot, *Google DeepMind*, Daan Wierstra, *Google DeepMind*

In this work we introduce a differentiable version of the Compositional Pattern Producing Network, called the DPPN. Unlike a standard CPPN, the topology of a DPPN is evolved but the weights are learned. A Lamarckian algorithm, that combines evolution and learning, produces DPPNs to reconstruct an image. Our main result is that DPPNs can be evolved/trained to compress the weights of a denoising autoencoder from 157684 to roughly 200 parameters, while achieving a reconstruction accuracy comparable to a fully connected network with more than two orders of magnitude more parameters. The regularization ability of the DPPN allows it to rediscover (approximate) convolutional network architectures embedded within a fully connected architecture. Such convolutional architectures are the current state of the art for many computer vision applications, so it is satisfying that DPPNs are capable of discovering this structure rather than having to build it in by design. DPPNs exhibit better generalization when tested on the Omniglot dataset after being trained on MNIST, than directly encoded fully connected autoencoders. DPPNs are therefore a new framework for integrating learning and evolution.

Accelerating the Evolution of Cognitive Behaviors Through Human-Computer Collaboration

Mathias Löwe, *IT Univeristy of Copenhagen*, Sebastian Risi, *IT Univeristy of Copenhagen*

An open problem in *neuroevolution* (i.e. evolving artificial neural networks) is to evolve complex cognitive behaviors that allow robots to adapt and learn from past experience. While previous studies on the evolution of cognitive behaviors have shown that more explorative search methods such as *novelty search*, outperform traditional objective-based approaches, evolving more sophisticated cognitive capabilities remains difficult. In this context, a major challenge is the deceptive nature of learning to learn. Because it is easier at first to improve fitness without evolving the ability to learn, evolution often converges on non-adaptive solutions. The novel hypothesis in this paper is that we can leverage human insights during the search for cognitive behaviors because of our ability to more easily distinguish between adaptive and non-adaptive solutions than novelty or fitness-based approaches. This paper shows that the recently introduced method *novelty-assisted interactive evolution* (NA-IEC), which combines human intuition with novelty search, allows the evolution of cognitive behaviors in a T-Maze domain faster than fully-automated searches by themselves.

Session: Best Papers: GA+CS
Saturday, July 23, 16:10-17:50, Chasm Creek A

Identifying Core Functional Networks and Functional Modules within Artificial Neural Networks via Subsets Regression

Roby Velez, *Univ. of Wyoming*, Jeff Clune, *Univ. of Wyoming*

As the power and capabilities of Artificial Neural Networks (ANNs) grow, so do their size and complexity. To both decipher and improve ANNs, we need to build better tools that help us understand their inner workings. To that end, we introduce an algorithm called Subsets Regression on network Connectivity (SRC). SRC allows us to prune away unimportant nodes and connections in ANNs, revealing a core functional network (CFN) that is simpler and thus easier to analyze. SRC can also identify functional modules within an ANN. We demonstrate SRC's capabilities on both directly and indirectly encoded ANNs evolved to solve a modular problem. In many of the cases when evolution produces a highly entangled, non-modular ANN, SRC reveals that a CFN is hidden within these networks that is actually sparse and modular. That finding will substantially impact the sizable and ongoing research into the evolution of modularity and will encourage researchers to revisit previous results on that topic. We also show that the SRC algorithm can more accurately estimate the modularity Q-Score of a network than state-of-the-art approaches. Overall, SRC enables us to greatly simplify ANNs in order to better understand and improve them, and reveals that they often contain hidden modular structures within.

Quantifying Deception: A Case Study in the Evolution of Antimicrobial Resistance

Margaret J. Eppstein, *University of Vermont*, C. Brandon Ogbunugafor, *University of Vermont*

The concept of "deception" in fitness landscapes was introduced in the genetic algorithm (GA) literature to characterize problems where sign epistasis can mislead a GA away from the global optimum. Evolutionary geneticists have long recognized that sign epistasis is the source of the ruggedness of fitness landscapes, and the recent availability of a growing number of empirical fitness landscapes may make it possible for evolutionary biologists to study how deception affects adaptation in a variety of organisms. However, existing definitions of deception are categorical and were developed to characterize landscapes independent of population distributions on the landscape. Here we propose two metrics that quantify deception as continuous functions of the locations of replicators on a given landscape. We develop a discrete population model to simulate within-host evolution on 19 empirical fitness landscapes of Plasmodium falciparum (the most common and deadly form of malaria) under different dosage levels of two anti-malarial drugs. We demonstrate varying levels of deception in malarial evolution, and show that the proposed metrics of deception are predictive of some important aspects of evolutionary dynamics. Our approach can be readily applied to other fitness landscapes and toward an improved understanding of the evolution of antimicrobial drug resistance.

Session: CS3+IGEC2
Sunday, July 24, 09:00-10:15, Mesa Verde B

Inspiration-Triggered Search: Towards Higher Complexities by Mimicking Creative Processes

Milan Rybář, *University of Paderborn*, Heiko Hamann, *University of Paderborn*

Open-ended evolution is still an unachieved goal in evolutionary computation. Evolution guided by objective functions can easily be trapped on local optima. Our approach is inspired by evolutionary paths along stepping stones, as observed in user behaviors of Picbreeder. We propose a general framework, inspiration-triggered search, which tries to roughly mimic the creative design process of a human being. Instead of using a fixed objective function, the search algorithm itself is free to switch between objectives within certain constraints but inspired by features of the currently evolved artifacts. The overall optimization task is to generate complex artifacts that cannot be generated by a direct optimization approach. In contrast to other approaches that make extensive use of external knowledge (e.g., Innovation Engines), we try to approach the ambitious goal of virtually bootstrapping a creative process from scratch. The proposed method is tested in the domain of images, that is to find complex and aesthetically pleasant images, and is compared to novelty search.

Learning Behavior Characterizations for Novelty Search

Elliot Meyerson, *The University of Texas at Austin and Sentient Technologies, Inc.*, Joel Lehman, *IT University of Copenhagen*, Risto Miikkulainen, *The University of Texas at Austin and Sentient Technologies, Inc.*

Novelty search and related diversity-driven algorithms provide a promising approach to overcoming deception in complex domains. The behavior characterization (BC) is a critical choice in the application of such algorithms. The BC maps each evaluated individual to a behavior, i.e., some vector representation of what the individual is or does during evaluation. Search is then driven towards diversity in a metric space of these behaviors. BCs are built from hand-designed features that are limited by human expertise, or upon generic descriptors that cannot exploit domain nuance. The main contribution of this paper is an approach that addresses these shortcomings. Generic behaviors are recorded from evolution on several training tasks, and a new BC is learned from them that funnels evolution towards successful behaviors on any further tasks drawn from the domain. This approach is tested in increasingly complex simulated maze-solving domains, where it outperforms both hand-coded and generic BCs, in addition to outperforming objective-based search. The conclusion is that adaptive BCs can improve search in many-task domains with little human expertise.

Digital Entertainment Technologies and Arts

Session: Best Papers: DETA+PES+SBS-SS
Friday, July 22, 10:40-12:20, Chasm Creek B

Demonstrating the Feasibility of Automatic Game Balancing

Vanessa Volz, *TU Dortmund University*, Günter Rudolph, *TU Dortmund University*, Boris Naujoks, *TH Köln*

Game balancing is an important part of the (computer) game design process, in which designers adapt a game prototype so that the resulting gameplay is as entertaining as possible. In industry, the evaluation of a game is often based on costly playtests with human players. It suggests itself to automate this process using artificial players for the prediction of gameplay and outcome. In this paper, the feasibility of automatic balancing is investigated for the card game top trumps using simulation- and deck-based objectives. Additionally, the necessity of a multi-objective approach is asserted by assessing the only published (single-objective) method. We apply a multi-objective evolutionary algorithm to obtain decks that optimise objectives developed to express the fairness and the excitement of a game of top trumps, e.g. win rate and average number of tricks. The results are compared with decks from published top trumps games using the aforementioned objectives. The possibility to generate decks better or at least as good as decks from published top trumps decks in terms of these objectives is demonstrated. Our results indicate that automatic balancing with the presented approach is feasible even for more complex games such as real-time strategy games.

Session: DETA1
Saturday, July 23, 16:10-17:50, Mesa Verde B

Evotype: From Shapes to Glyphs

Tiago Martins, *University of Coimbra*, João Correia, *University of Coimbra*, Ernesto Costa, *University of Coimbra*, Penousal Machado, *University of Coimbra*

Typography plays a key communication role in the contemporary information-dense culture. Type design is a central, complex, and time consuming task. In this work we develop the generative system to type design based on an evolutionary algorithm. The key novel contributions are twofold. First, in terms of representation it relies on the use of assemblages of shapes to form glyphs. There are no limitations to the types of shapes that can be used. Second, we explore a compromise between legibility and expressiveness, testing different automatic fitness assignment schemes. The attained results show that we are able to evolve a wide variety of alternative glyphs, making the proposed system a viable alternative for real-world applications in the field of type design.

Discovering Combos in Fighting Games with Evolutionary Algorithms

Gianlucca L. Zuin, *Universidade Federal de Minas Gerais*, Yuri P. A. Macedo, *Universidade Federal de Minas Gerais*, Luiz Chaimowicz, *Universidade Federal de Minas Gerais*, Gisele L. Pappa, *Universidade Federal de Minas Gerais*

In fighting games, players can perform many different actions at each instant of time, leading to an exponential number of possible sequences of actions. Some of these combinations can lead to unexpected behaviors, which can compromise the game design. One example of these unexpected behaviors is the occurrence of long or infinite combos, a long sequence of actions that does not allow any reactions from the opponent. Finding these sequences is essential to ensure fairness in fighting games, but evaluating all possible sequences is a time consuming task. In this paper, we propose the use of an evolutionary algorithm to find combos on a fighting game. The main idea is to use a genetic algorithm to evolve a population composed of sequences of inputs and, using an adequate fitness function, select the ones that are more suitable to be considered combos. We performed a series of experiments and the results show that the proposed approach was not only successful in finding combos, managing to find unexpected sequences, but also superior to previous methods.

General Video Game Level Generation

Ahmed Khalifa, *New York University*, Diego Perez-Liebana, *University of Essex*, Simon M. Lucas, *University of Essex*, Julian Togelius, *New York University*

This paper presents a framework and an initial study in general video game level generation, the problem of generating levels for not only a single game but for any game within a specified range. While existing level generators are tailored to a particular game, this new challenge requires generators to take into account the constraints and affordances of games that might not even have been designed when the generator was constructed. The framework presented here builds on the General Video Game AI framework (GVG-AI) and the Video Game Description Language (VGDL), in order to reap synergies from research activities connected to the General Video Game Playing Competition. The framework will also form the basis for a new track of this competition. In addition to the framework, the paper presents three general level generators and an empirical comparison of their qualities.

Two-Dimensional Barcode Decoration Using Module-wise Non-systematic Coding and Cooperative Evolution by User

and System

Makoto Kamizono, *Kagoshima University*, Kigo Shimomura, *Kagoshima University*, Masayuki Tajiri, *Kagoshima University*, Satoshi Ono, *Kagoshima University*

QR code, a kind of two-dimensional barcode, is used as shortcuts from physical media to online information in addition to object recognition purpose. However, QR code has become visually unpleasant with the global popularization of QR code. This paper proposes a method to decorate QR code by arranging module (black and white cell) patterns to be similar to a target image. The proposed method takes a hierarchical approach; upper layer solver using Cooperative Evolution by User and System (CEUS) arranges input images, i.e., location, pose, and scale to form the target image, and lower layer solver based on greedy search controls module pattern of QR code according to the target. A QR code designed by the proposed method completely satisfies QR code specifications and has visual meaning for human. Unlike the previous work controlling module patterns by codewords, the proposed method controls module patterns by modules without being influenced codeword region shape. In addition, CEUS allows users to obtain the most desirable solution with less manual operation.

Evolutionary Combinatorial Optimization and Metaheuristics

Session: ECOM1
Friday, July 22, 10:40-12:20, Wind Star A

Efficient Hill Climber for Constrained Pseudo-Boolean Optimization Problems

Francisco Chicano, *University of Malaga*, Darrell Whitley, *Colorado State University*, Renato Tinós, *University of Sao Paulo*

Efficient hill climbers have been recently proposed for single- and multi-objective pseudo-Boolean optimization problems. For k-bounded pseudo-Boolean functions where each variable appears in at most a constant number of subfunctions, it has been theoretically proven that the neighborhood of a solution can be explored in constant time. These hill climbers, combined with a high-level exploration strategy, have shown to improve state of the art methods in experimental studies and open the door to the so-called Gray Box Optimization, where part, but not all, of the details of the objective functions are used to better explore the search space. One important limitation of all the previous proposals is that they can only be applied to unconstrained pseudo-Boolean optimization problems. In this work, we address the constrained case for multi-objective k-bounded pseudo-Boolean optimization problems. We find that adding constraints to the pseudo-Boolean problem has a linear computational cost in the hill climber.

Feature Selection in Evolving Job Shop Dispatching Rules with Genetic Programming

Yi Mei, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*, Su Nyugen, *Hoa Sen University*

Genetic Programming (GP) has been successfully used to automatically design dispatching rules in job shop scheduling. The goal of GP is to evolve a priority function that will be used to order the waiting jobs at each decision point, and decide the next job to be processed. To this end, the proper terminals (i.e. job shop features) have to be decided. When evolving the priority function, various job shop features can be included in the terminal set. However, not all the features are helpful, and some features are irrelevant to the rule. Including irrelevant features into the terminal set enlarges the search space, and makes it harder to achieve promising areas. Thus, it is important to identify the important features and remove the irrelevant ones to improve the GP-evolved rules. This paper proposes a domain-knowledge-free feature ranking and selection approach. As a result, the terminal set is significantly reduced and only the most important features are selected. The experimental results show that using only the selected features can lead to significantly better GP-evolved rules on both training and unseen test instances.

Fast Heuristics for the Multiple Traveling Thieves Problem

Shelvin Chand, *University of New South Wales*, Markus Wagner, *The University of Adelaide*

The traveling thief problem (TTP) is fast gaining attention for being a challenging combinatorial optimization problem. A number of algorithms have been proposed for solving this problem in the recent past. Despite being a challenging problem, it is often argued if TTP is realistic enough because of its formulation, which only allows a single thief to travel across hundreds or thousands of cities to collect (steal) items. In addition, the thief is required to visit all cities, regardless of whether an item is stolen there or not. In this paper we discuss the shortcomings of the current formulation and present a relaxed version of the problem which allows multiple thieves to travel across different cities with the aim of maximizing the group's collective profit. A number of fast heuristics for solving the newly proposed multiple traveling thieves problem (MTTP) are also proposed and evaluated.

Multi-hard Problems in Uncertain Environment

Michal Roman Przybylek, *Polish-Japanese Academy of Information Technology*, Adam Wierzbicki, *Polish-Japanese Academy of Information Technology*, Zbigniew Michalewicz,

The University of Adelaide

Real-world problems are usually composed of two or more (potentially NP-Hard) problems that are interdependent on each other. Such problems have been recently identified as "multi-hard problems" and various strategies for solving them have been proposed. One of the most successful of the strategies is based on a decomposition approach, where each of the components of a multi-hard problem is solved separately (by state-of-the-art solver) and then a negotiation protocol between the sub-solutions is applied to mediate a global solution. Multi-hardness is, however, not the only crucial aspect of real-world problems. Many real-world problems operate in a dynamically-changing, uncertain environment. Special approaches such as risk analysis and minimization may be applied in cases when we know the possible variants of constraints and criteria, as well as their probabilities. On the other hand, adaptive algorithms may be used in the case of uncertainty about criteria variants or probabilities. While such approaches are not new, their application to multi-hard problems has not yet been studied systematically. In this paper we extend the benchmark problem for multi-hardness with the aspect of uncertainty. We adapt the decomposition-based approach to this new setting, and compare it against another promising heuristic (Monte-Carlo Tree Search) on a large publicly available dataset. Our comparisons show that the decomposition-based approach outperforms the other heuristic in most cases.

Session: Best Paper: ECOM
Saturday, July 23, 10:40-12:20, Chasm Creek A

Extension of the CMSA Algorithm: An LP-based Way for Reducing Sub-instances

Christian Blum, *Ikerbasque and University of the Basque Country UPV/EHU*, Jordi Pereira, *Universidad Adolfo Ibáñez*

Construct, Merge, Solve & Adapt (CMSA) is a recently proposed hybrid algorithm for combinatorial optimization. At each iteration, the algorithm solves a sub-instance of the original problem instance by means of an exact technique. The incumbent sub-instance is adapted at each iteration, first, by adding solution components present in probabilistically constructed solutions; and, second, by removing solution components that have reached a certain age limit and that do not appear in the optimal solution to the current sub-instance. In this work we propose a refined way for selecting the solution components to be removed from the current sub-instance in those cases in which the exact method employed is an integer linear programming solver. More specifically, the information on the reduced costs of the solution components with respect to the linear programming solution is used for this purpose. Experimental results for the chosen test case, the multidimensional knapsack problem, demonstrate the usefulness of this extension of CMSA.

Multi-objective Neutral Neighbors? What could be the definition(s)?

Marie-Eléonore Marmion, *Univ. Lille, CNRS, Centrale Lille & Inria*, Hernan E. Aguirre, *Shinshu University*, Clarisse Dhaenens, *Univ. Lille, CNRS, Centrale Lille & Inria*, Laetitia Jourdan, *Univ. Lille, CNRS, Centrale Lille & Inria*, Kiyoshi Tanaka, *Shinshu University*

There is a significant body of research on neutrality and its effects in single-objective optimization. Particularly, the neutrality concept has been precisely defined and the neutrality between neighboring solutions efficiently exploited in local search algorithms. The extension of neutrality to multi-objective optimization is not straightforward and its effects on the dynamics of multi-objective optimization methods are not clearly understood. In order to develop strategies to exploit neutral neighbors in multi-objective local search algorithms, it is important and necessary to clearly define neutrality in the multi-objective context. In this paper, we propose several definitions of the neutrality property between neighboring solutions. A natural definition comes from the Pareto-dominance, widely used in multi-objective optimization. In addition, definitions derived from epsilon and hypervolume indicators are also proposed as such indicators are usually used to compare sets of solutions. We analyze permutation problems under the proposed definitions of neutrality and show that each definition of neutrality leads to a particular structure of the problem.

On the Impact of the Renting Rate for the Unconstrained Nonlinear Knapsack Problem

Junhua Wu, *University of Adelaide*, Sergey Polyakovskiy, *University of Adelaide*, Frank Neumann, *University of Adelaide*

Multi-component problems combine several combinatorial optimisation problems that occur frequently in real-word applications such as logistics and supply chain management. In order to study the impact of the combination of such problems, the traveling thief problem [Bonyadi, Michalewicz, and Barone, 2013], which combines the traveling salesman problem and the 0-1 knapsack problem, has been introduced. Recently, it has been shown that the non-linear knapsack problem constituting the packing component of the traveling thief problem is NP-hard even when the capacity constraint is not imposed. We investigate the role of the renting rate R which is an important parameter in combining the total profit of selected items and the associated transportation costs in this non-linear knapsack problem. Our theoretical and experimental investigations show how the values of the renting rate influence the difficulty of a given problem instance through the items that can be excluded by a simple but very effective pre-processing scheme. Our further investigations show how to create instances that are hard to be solved by simple evolutionary algorithms.

Communities of Local Optima as Funnels in Fitness Landscapes

Sebastian Herrmann, *Johannes Gutenberg-Universität*, Gabriela Ochoa, *University of Stirling*, Franz Rothlauf, *Johannes*

Gutenberg-Universität

We conduct an analysis of local optima networks extracted from fitness landscapes of the Kauffman NK model under iterated local search. Applying the Markov Cluster Algorithm for community detection to the local optima networks, we find that the landscapes consist of multiple clusters. This result complements recent findings in the literature that landscapes often decompose into multiple funnels, which increases their difficulty for iterated local search. Our results suggest that the number of clusters as well as the size of the cluster in which the global optimum is located are correlated to the search difficulty of landscapes. We conclude that clusters found by community detection in local optima networks offer a new way to characterize the multi-funnel structure of fitness landscapes.

Session: ECOM2
Saturday, July 23, 14:00-15:40, Wind River A

Population-based vs. Single-solution Heuristics for the Travelling Thief Problem

Mohamed El Yafrani, *Mohammed V University in Rabat*, Belaïd Ahiod, *Mohammed V University in Rabat*

The Travelling Thief Problem (TTP) is an optimization problem introduced in order to provide a more realistic model for real-world optimization problems. The problem combines the Travelling Salesman Problem and the Knapsack Problem and introduces the notion of interdependence between sub-problems. In this paper, we study and compare different approaches for solving the TTP from a metaheuristics perspective. Two heuristic algorithms are proposed. The first is a Memetic Algorithm, and the second is a single-solution heuristic empowered by Hill Climbing and Simulated Annealing. Two other state-of-the-art algorithms are briefly revisited, analyzed, and compared to our algorithms. The obtained results prove that our algorithms are very efficient for many TTP instances.

Cellular Genetic Algorithm for Solving a Routing On-Demand Transit Problem

Olfa Chebbi, *Higher Institute of Management of Tunis*, Ezzeddine Fatnassi, *Higher Institute of Management of Tunis*, Jouhaina Chaouachi, *IHEC*, Nouha Nouri, *Higher Institute of Management of Tunis*

To provide sustainable and efficient urban logistics and transportation services, urban mobility tools are facing challenges on reducing carbon emission, waiting time for passengers and transit time. The emergence of many new intelligent and electric transportation system offers many new possible solutions to achieve urban sustainability. This paper proposes to treat the Personal Rapid Transit System (PRT) as an efficient sustainable transportation tool for urban areas. This paper proposes to deal with static problem of routing PRT' vehicles to minimize total energy consumption while considering the battery capacity of vehicles. For that purpose, we describe a multiple crossover Cellular Genetic Algorithm combined with a local search. Numerical experiments on 1320 instances show that our hybrid algorithm is efficient in which the average percent deviations relative to the lower bound over 1320 instances is about 1.632%, and the average running time is about 26.3 seconds.

HMOBEDA: Hybrid Multi-objective Bayesian Estimation of Distribution Algorithm

Marcella S. R. Martins, *Federal University of Technology - Paraná (UTFPR)*, Myriam R. B.S. Delgado, *Federal University of Technology - Paraná (UTFPR)*, Roberto Santana, *University of the Basque Country (UPV/EHU)*, Ricardo Lüders, *Federal University of Technology - Paraná (UTFPR)*, Richard Aderbal Gonçalves, *Midwest State University of Parana (UNICENTRO)*, Carolina Paula de Almeida, *Midwest State University of Parana (UNICENTRO)*

Probabilistic modeling of selected solutions and incorporation of local search methods are approaches that can notably improve the results of multi-objective evolutionary algorithms (MOEAs). In the past, these approaches have been jointly applied to multi-objective problems (MOPs) with excellent results. In this paper, we introduce for the first time a joint probabilistic modeling of (1) local search methods with (2) decision variables and (3) the objectives in a framework named HMOBEDA. The proposed approach is compared with six evolutionary methods (including a modified version of NSGA-III, adapted to solve combinatorial optimization) on instances of the multi-objective knapsack problem with 3, 4, and 5 objectives. Results show that HMOBEDA is a competitive approach. It outperforms the other methods according to the hypervolume indicator.

Ants can Learn from the Opposite

Nicolás Rojas-Morales, *Universidad Técnica Federico Santa María*, María-Cristina Riff, *Universidad Técnica Federico Santa María*, Elizabeth Montero, *Universidad Técnica Federico Santa María*

In this work we present different learning strategies focused on detecting candidate solutions that are not interesting to be explored by a metaheuristic, in terms of evaluation function. We include a first step before the metaheuristic. The information obtained from this step is given to the metaheuristic, for visiting candidate solutions that are more promising in terms of their quality. The goal of using these strategies is to learn about candidate solutions that can be discarded from the search space, and thus to improve the search of the metaheuristic. We present two new strategies that differ on how the solutions can be constructed in an opposite way. Our approach is evaluated using Ant Solver, a well-known ant based algorithm for solving Constraint Satisfaction Problems. We show promising results that make our solution as good approach to apply in other metaheuristics.

Session: ECOM3+RWA5
Saturday, July 23, 16:10-17:50, Wind River A

Additional Dimensions to the Study of Funnels in Combinatorial Landscapes

Gabriela Ochoa, *University of Stirling*, Nadarajen Veerapen, *University of Stirling*

The global structure of travelling salesman's fitness landscapes has recently revealed the presence of multiple 'funnels'. This implies that local optima are organised into several clusters, so that a particular local optimum largely belongs to a particular funnel. Such a global structure can increase search difficulty, especially, when the global optimum is located in a deep, narrow funnel. Our study brings more precision (and dimensions) to the notion of funnels with a data-driven approach using Local Optima Networks and the Chained Lin-Kernighan heuristic. We start by exploring the funnel 'floors', characterising them using the notion of communities from complex networks. We then analyse the more complex funnel 'basins'. Since their depth is relevant to search, we visualise them in 3D. Our study, across a set of TSP instances, reveals a multi-funnel structure in most of them. However, the specific topology varies across instances and relates to search difficulty. Finally, including a stronger perturbation into Chained Lin-Kernighan proved to smooth the funnel structure, reducing the number of funnels and enlarging the valley leading to global optima.

Game theory, Extremal optimization, and Community Structure Detection in Complex Networks

Mihai Suciu, *Babes-Bolyai University*, Rodica Ioana Lung, *Babes-Bolyai University*, Noémi Gaskó, *Babes-Bolyai University*

The network community detection problem consists in identifying groups of nodes that are more densely connected to each other than to the rest of the network. The lack of a formal definition for the notion of community led to the design of various solution concepts and computational approaches to this problem, among which those based on optimization and, more recently, on game theory, received a special attention from the heuristic community. The former ones define the community structure as an optimum value of a fitness function, while the latter as a game equilibrium. Both are appealing as they allowed the design and use of various heuristics. This paper analyses the behavior of such a heuristic that is based on extremal optimization, when used either as an optimizer or within a game theoretic setting. Numerical results, while significantly better than those provided by other state-of-art methods, for some networks show that differences between tested scenarios do not indicate any superior behavior when using game theoretic concepts; moreover, those obtained without using any selection for survival suggest that the search is actually guided by the inner mechanism of the extremal optimization method and by the fitness function used to evaluate and compare components within an individual.

Session: ECOM4
Sunday, July 24, 09:00-10:40, Chasm Creek B

On the Design of Hard mUBQP Instances

Murilo Zangari, *Federal University of Parana*, Roberto Santana, *University of the Basque Country (UPV/EHU)*, Alexander Mendiburu, *University of the Basque Country (UPV/EHU)*, Aurora T. R. Pozo, *Federal University of Parana*

This paper proposes a new method for the design and analysis of multi-objective unconstrained binary quadratic programming (mUBQP) instances, commonly used for testing discrete multi-objective evolutionary algorithms (MOEAs). These instances are usually generated considering the sparsity of the matrices and the correlation between objectives but randomly selecting the values for the matrix cells. Our hypothesis is that going beyond the use of objective correlations by considering different types of variables interactions in the generation of the instances can help to obtain more diverse problem benchmarks, comprising harder instances. We propose a parametric approach in which small building blocks of deceptive functions are planted into the matrices that define the mUBQP. The algorithm for creating the new instances is presented, and the difficulty of the functions is tested using variants of a decomposition-based MOEA. Our experimental results confirm that the instances generated by planting deceptive blocks require more function evaluations to be solved than instances generated using other methods.

Evolutionary Approaches to Optimization Problems in Chimera Topologies

Roberto Santana, *University of the Basque Country (UPV/EHU)*, Zheng Zhu, *Texas A&M University. College Station*, Helmut G. Katzgraber, *Texas A&M University. College Station*

Chimera graphs define the topology of one of the first commercially available quantum computers. A variety of optimization problems have been mapped to this topology to evaluate the behavior of quantum enhanced optimization heuristics in relation to other optimizers, being able to efficiently solve problems classically to use them as benchmarks for quantum machines. In this paper we investigate for the first time the use of Evolutionary Algorithms (EAs) on Ising spin glass instances defined on the Chimera topology. Three genetic algorithms (GAs) and three estimation of distribution algorithms (EDAs) are evaluated over 1000 hard instances of the Ising spin glass constructed from Sidon sets. We focus on determining whether the information about the topology of the graph can be used to improve the results of EAs and on identifying which are the characteristics of the Ising instances that influence the success rate of GAs and EDAs. Chimera graphs define the topology of one of the first commercially available quantum computers. A variety of optimization problems have been mapped to this topology to evaluate the behavior of quantum enhanced optimization heuristics in

relation to other optimizers, being able to efficiently solve problems classically to use them as benchmarks for quantum machines. In this paper we investigate for the first time the use of Evolutionary Algorithms (EAs) on Ising spin glass instances defined on the Chimera topology. Three genetic algorithms (GAs) and three estimation of distribution algorithms (EDAs) are evaluated over 1000 hard instances of the Ising spin glass constructed from Sidon sets. We focus on determining whether the information about the topology of the graph can be used to improve the results of EAs and on identifying the characteristics of the Ising instances that influence the success rate of GAs and EDAs.

A Simulated Annealing Algorithm for Maximum Common Edge Subgraph Detection in Biological Networks

Simon J. Larsen, *University of Southern Denmark*, Frederik G. Alkærsig, *University of Southern Denmark*, Henrik J. Ditzel, *University of Southern Denmark*, Igor Jurisica, *Princess Margaret Cancer Centre*, Nicolas Alcaraz, *University of Southern Denmark*, Jan Baumbach, *University of Southern Denmark*

Network alignment is a challenging computational problem that identifies node or edge mappings between two or more networks, with the aim to unravel common patterns among them. Pairwise network alignment is already intractable, making multiple network comparison even more difficult. Here, we introduce a heuristic algorithm for the multiple maximum common edge subgraph problem that is able to detect large common substructures shared across multiple, real-world size networks efficiently. Our algorithm uses a combination of iterated local search, simulated annealing and a pheromone-based perturbation strategy. We implemented multiple local search strategies and annealing schedules, that were evaluated on a range of synthetic networks and real protein-protein interaction networks. Our method is parallelized and well-suited to exploit current multi-core CPU architectures. While it is generic, we apply it to unravel a biochemical backbone inherent in different species, modeled as multiple maximum common subgraphs.

A Population-based Local Search Technique with Random Descent and Jump for the Steiner Tree Problem in Graphs

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

The Steiner tree problem in graphs (STPG) is a well known NP-hard combinatorial problem with various applications in transport, computational biology, network and VLSI design. Exact methods have been developed to solve this problem to proven optimality, however the exponential nature of these algorithms mean that they become intractable with large-scale instances of the problem. Because of this phenomenon, there has been considerable research into using metaheuristics to obtain good quality solutions in a reasonable time. This paper presents a hybrid local search technique which is an extension of techniques from the literature with an added random jump operator which prevents the algorithm from becoming stuck in local minima. It is compared against greedy local search, the hybrid local search technique it extends and two metaheuristic techniques from the current literature and is shown to outperform them in nearly all cases.

Evolutionary Machine Learning

Session: EML1
Friday, July 22, 16:10-17:50, Chasm Creek B

A Wavelet-based Encoding for Neuroevolution

Sjoerd van Steenkiste, *Maastricht University*, Jan Koutník, *IDSIA, USI & SUPSI*, Kurt Driessens, *Maastricht University*, Jürgen Schmidhuber, *IDSIA, USI & SUPSI*

A new indirect scheme for encoding neural network connection weights as sets of wavelet-domain coefficients is proposed in this paper. It exploits spatial regularities in the weight-space to reduce the gene-space dimension by considering the low-frequency wavelet coefficients only. The wavelet-based encoding builds on top of a frequency-domain encoding, but unlike when using a Fourier-type transform, it offers gene locality while preserving continuity of the genotype-phenotype mapping. We argue that this added property allows for more efficient evolutionary search and demonstrate this on the octopus-arm control task, where superior solutions were found in fewer generations. The scalability of the wavelet-based encoding is shown by evolving networks with many parameters to control game-playing agents in the Arcade Learning Environment.

Evolving Deep LSTM-based Memory Networks using an Information Maximization Objective

Aditya Rawal, *University of Texas at Austin*, Risto Miikkulainen, *University of Texas at Austin*

Reinforcement Learning agents with memory are constructed in this paper by extending neuroevolutionary algorithm NEAT to incorporate LSTM cells, i.e. special memory units with gating logic. Initial evaluation on POMDP tasks indicated that memory solutions obtained by evolving LSTMs outperform traditional RNNs. Scaling neuroevolution of LSTM to deep memory problems is challenging because: (1) the fitness landscape is deceptive, and (2) a large number of associated parameters need to

be optimized. To overcome these challenges, a new secondary optimization objective is introduced that maximizes the information (Info-max) stored in the LSTM network. The network training is split into two phases. In the first phase (unsupervised phase), independent memory modules are evolved by optimizing for the info-max objective. In the second phase, the networks are trained by optimizing the task fitness. Results on two different memory tasks indicate that neuroevolution can discover powerful LSTM-based memory solution that outperform traditional RNNs.

Fast Bi-Objective Feature Selection Using Entropy Measures and Bayesian Inference

Yi Mei, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

The entropy measures have been used in feature selection for decades, and showed competitive performance. In general, the problem aims at minimizing the conditional entropy of the class label on the selected features. However, the generalization of the entropy measures has been neglected in literature. Specifically, the use of conditional entropy has two critical issues. First, the empirical conditional distribution of the class label may have a low confidence and thus is unreliable. Second, there may not be enough training instances for the selected features, and it is highly likely to encounter new examples in the test set. To address these issues, a bi-objective optimization model with a modified entropy measure called the Bayesian entropy is proposed. This model considers the confidence of the optimized conditional entropy value as well as the conditional entropy value itself. As a result, it produces multiple feature subsets with different trade-offs between the entropy value and its confidence. The experimental results demonstrate that by solving the proposed optimization model with the new entropy measure, the number of features can be dramatically reduced within a much shorter time than the existing algorithms. Furthermore, similar or even better classification accuracy was achieved for most test problems.

Improving the Canny Edge Detector Using Automatic Programming: Improving Non-Max Suppression

Lars Vidar Magnusson, *Østfold University College*, Roland Olsson, *Østfold University College*

In this paper, we employ automatic programming, a relatively unknown evolutionary computation strategy, to improve the non-max suppression step in the popular Canny edge detector. The new version of the algorithm has been tested on a dataset widely used to benchmark edge detection algorithms. The performance has increased by 1.9%, and a pairwise student-t comparison with the original algorithm gives a p-value of 6.45×10^{-9}. We show that the changes to the algorithm have made it better at detecting weak edges, without increasing the computational complexity or changing the overall design. Previous attempts have been made to improve the filter stage of the Canny algorithm using evolutionary computation, but, to our knowledge, this is the first time it has been used to improve the non-max suppression algorithm. The fact that we have found a heuristic improvement to the algorithm with significantly better performance on a dedicated test set of natural images suggests that our method should be used as a standard part of image analysis platforms, and that our methodology could be used to improve the performance of image analysis algorithms in general.

Session: EML2
Saturday, July 23, 16:10-17:50, Wind River B

A New Evaluation Function for Clustering: The NK Internal Validation Criterion

Renato Tinós, *University of São Paulo*, Zhao Liang, *University of São Paulo*, Francisco Chicano, *University of Málaga*, Darrell Whitley, *Colorado State University*

The use of good evaluation functions is essential when evolutionary algorithms are employed for clustering. The NK internal clustering validation measure is proposed for hard partitional clustering. The evaluation function is composed of N subfunctions, where N is the number of objects in the dataset. Each subfunction is influenced by a group of K+1 objects. By using neighbourhood relations among connected small groups, density-based regions can be identified. The NK internal clustering validation measure allows the application of partition crossover (PX). PX for hard partitional clustering is also proposed in this work. By using PX, the evaluation function can be decomposed in q partial evaluations. As a consequence, PX deterministically finds the best of 2^q possible offspring at the cost of evaluating 2 solutions. In the experiments, the application of PX resulted in a high number of successful recombinations. It was able to improve partitions defined by the best parents.

Using an Ant Colony Optimization Algorithm for Monotonic Regression Rule Discovery

James Brookhouse, *University of Kent*, Fernando E. B. Otero, *University of Kent*

Many data mining algorithms do not make use of existing domain knowledge when constructing their models. This can lead to model rejection as users may not trust models that behave contrary to their expectations. Semantic constraints provide a way to encapsulate this knowledge which can then be used to guide the construction of models. One of the most studied semantic constraints in the literature is monotonicity, however current monotonically-aware algorithms have focused on ordinal classification problems. This paper proposes an extension to an ACO-based regression algorithm in order to extract a list of monotonic regression rules. We compared the proposed algorithm against a greedy regression rule induction algorithm that preserves monotonic constraints and the well-known M5' Rules. Our experiments using eight publicly available data sets show

that the proposed algorithm successfully creates monotonic rules while maintaining predictive accuracy.

Transferable XCS

Xianneng Li, *Dalian University of Technology*, Guangfei Yang, *Dalian University of Technology*

Traditional accuracy-based XCS classifier system generally learns and evolves classifiers from scratch when facing each particular problem. Inspired by humans with the ability to learn new skills by inducing knowledge from related problems, transfer learning (TL) focuses on leveraging the knowledge of source domains to help the problem solving of another different but related domain. This paper attempts to combine XCS and TL to propose a novel extension transferable XCS (tXCS). tXCS utilizes the inherent characteristics of XCS, that naturally discovers expressive classifiers as the generalized knowledge of domains, to realize the classifier transfer from source domains to a target domain that makes it learn faster, which is conceptually different from the previous integrations between XCS and TL. The systematic study is presented to verify the ability of knowledge transfer between domains with different degrees of similarity, which has been pointed out to be the challenge of TL. We demonstrate that tXCS can significantly speed up the learning efficiency of canonical XCS in both of single-step and multi-step benchmark problems.

A Hybrid Approach for Sleep Stages Classification

Abdelhamid Ouanes, *University of Tunis*, Lilia Rejeb, *University of Tunis*

Healthy sleep is essential for human well-being. Sleep analysis is a necessary process for the majority of sleep disorders diagnosis. In this work we propose to analyze brain activity through Electroencephalogram analysis in order to identify sleep stages variation. We focus on the classification phase. Most works in sleep stages classification are based on prior experts signal scoring which is a hard task. So many available unlabeled data remain unused. To explore more these data and enrich the study of sleep classification, we propose a hybrid approach based on learning classifier systems and artificial neural networks. The effectiveness of the proposed approach was investigated using real electroencephalography data. Good results were reached comparing to supervised learning methods usually used. The proposed approach provides also, an explicit model that could be analyzed a posteriori by experts.

Session: Best Paper: EML
Sunday, July 24, 09:00-10:40, Chasm Creek A

Simple Evolutionary Optimization Can Rival Stochastic Gradient Descent in Neural Networks

Gregory Morse, *University of Central Florida*, Kenneth O. Stanley, *University of Central Florida*

While evolutionary algorithms (EAs) have long offered an alternative approach to optimization, in recent years backpropagation through stochastic gradient descent (SGD) has come to dominate the fields of neural network optimization and deep learning. One hypothesis for the absence of EAs in deep learning is that modern neural networks have become so high dimensional that evolution with its inexact gradient cannot match the exact gradient calculations of backpropagation. Furthermore, the evaluation of a single individual in evolution on the big data sets now prevalent in deep learning would present a prohibitive obstacle towards efficient optimization. This paper challenges these views, suggesting that EAs can be made to run significantly faster than previously thought by evaluating individuals only on a small number of training examples per generation. Surprisingly, using this approach with only a simple EA (called the limited evaluation EA or LEEA) is competitive with the performance of the state-of-the-art SGD variant RMSProp on several benchmarks with neural networks with over 1,000 weights. More investigation is warranted, but these initial results suggest the possibility that EAs could be the first viable training alternative for deep learning outside of SGD, thereby opening up deep learning to all the tools of evolutionary computation.

Evaluation of a Tree-based Pipeline Optimization Tool for Automating Data Science

Randal S. Olson, *University of Pennsylvania*, Nathan Bartley, *University of Chicago*, Ryan J. Urbanowicz, *University of Pennsylvania*, Jason H. Moore, *University of Pennsylvania*

As the field of data science continues to grow, there will be an ever-increasing demand for tools that make machine learning accessible to non-experts. In this paper, we introduce the concept of tree-based pipeline optimization for automating one of the most tedious parts of machine learning–pipeline design. We implement an open source Tree-based Pipeline Optimization Tool (TPOT) in Python and demonstrate its effectiveness on a series of simulated and real-world benchmark data sets. In particular, we show that TPOT can design machine learning pipelines that provide a significant improvement over a basic machine learning analysis while requiring little to no input nor prior knowledge from the user. We also address the tendency for TPOT to design overly complex pipelines by integrating Pareto optimization, which produces compact pipelines without sacrificing classification accuracy. As such, this work represents an important step toward fully automating machine learning pipeline design.

Evolving Probabilistically Significant Epistatic Classification Rules for Heterogeneous Big Datasets

John P. Hanley, *University of Vermont*, Margaret J. Eppstein, *University of Vermont*, Jeffrey S. Buzas, *University of Vermont*, Donna M. Rizzo, *University of Vermont*

We develop an algorithm to evolve sets of probabilistically significant multivariate feature interactions, with co-evolved feature ranges, for classification in large, complex datasets. The datasets may include nominal, ordinal, and/or continuous fea-

tures, missing data, imbalanced classes, and other complexities. Our age-layered evolutionary algorithm generates conjunctive clauses to model multivariate interactions in datasets that are too large to be analyzed using traditional methods such as logistic regression. Using a novel hypergeometric probability mass function for fitness evaluation, the algorithm automatically archives conjunctive clauses that are probabilistically significant at a given threshold, thus identifying strong complex multivariate interactions. The method is validated on two synthetic epistatic datasets and applied to a complex real-world survey dataset aimed at determining the drivers of household infestation for an insect that transmits Chagas disease. We identify a set of 178,719 predictive feature interactions that are associated with household infestation, thus dramatically reducing the size of the search space for future analysis.

Human-inspired Scaling in Learning Classifier Systems

Isidro M. Alvarez, *Victoria University of Wellington*, Will N. Browne, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Learning classifier systems (LCSs) originated from artificial cognitive systems research, but migrated such that LCS became powerful classification techniques. Modern LCSs can be used to extract building blocks of knowledge in order to solve more difficult problems in the same or a related domain. The past work showed that the reuse of knowledge through the adoption of code fragments, GP-like sub-trees, into the XCS learning classifier system framework could provide advances in scaling. However, unless the pattern underlying the complete domain can be described by the selected LCS representation of the problem, a limit of scaling will eventually be reached. This is due to LCSs' 'divide and conquer' approach utilizing rule-based solutions, which entails an increasing number of rules (subclauses) to describe a problem as it scales. Inspired by human problemsolving abilities, the novel work in this paper seeks to reuse learned knowledge and learned functionality to scale to complex problems by transferring them from simpler problems. Progress is demonstrated on the benchmark Multiplexer (Mux) domain, albeit the developed approach is applicable to other scalable domains. The fundamental axioms necessary for learning are proposed. The methods for transfer learning in LCSs are developed. Also, learning is recast as a decomposition into a series of subproblems. Results show that from a conventional tabula rasa, with only a vague notion of what subordinate problems might be relevant, it is possible to learn a general solution to any n-bit Mux problem for the first time. This is verified by tests on the 264, 521 and 1034 bit Mux problems.

Evolutionary Multiobjective Optimization

Session: EMO1
Friday, July 22, 10:40-12:20, Wind River B

Runtime Analysis of Evolutionary Diversity Maximization for OneMinMax

Benjamin Doerr, *École Polytechnique*, Wanru Gao, *The University of Adelaide*, Frank Neumann, *The University of Adelaide*

Diversity mechanisms are key to the working behaviour of evolutionary multi-objective algorithms. With this paper, we contribute to the theoretical understanding of such mechanisms by means of rigorous runtime analysis. We consider the OneMinMax problem for which it has been shown in [Nguyen, Sutton, and Neumann, 2015] that a standard benchmark algorithm called (μ+1) SIBEA is not able to obtain a population with optimal hypervolume distribution in expected polynomial time if the population size is relatively small. We investigate the same setting as in [Nguyen, Sutton, and Neumann, 2015] and show that (μ+1) SIBEA is able to achieve a good approximation of the optimal hypervolume distribution very efficiently. Furthermore, we study OneMinMax in the context of search-based diversity optimization and examine the time until (μ+1) SIBEA with a search-based diversity mechanism has obtained a population of maximal diversity covering the whole Pareto front.

A Toolkit for Generating Scalable Stochastic Multiobjective Test Problems

Shaul Salomon, *University of Sheffield*, Robin Charles Purshouse, *University of Sheffield*, Ioannis Giaghiozis, *University of Sheffield*, Peter John Fleming, *University of Sheffield*

Real-world optimization problems typically include uncertainties over various aspects of the problem formulation. Some existing algorithms are designed to cope with stochastic multiobjective optimization problems, but in order to benchmark them, a proper framework still needs to be established. This paper presents a novel toolkit that generates scalable, stochastic, multiobjective optimization problems. A stochastic problem is generated by transforming the objective vectors of a given deterministic test problem into random vectors. All random objective vectors are bounded by the feasible objective space, defined by the deterministic problem. Therefore, the global solution for the deterministic problem can also serve as a reference for the stochastic problem. A simple parametric distribution for the random objective vector is defined in a radial coordinate system, allowing for direct control over the dual challenges of convergence towards the true Pareto front and diversity across the front. An example for a stochastic test problem, generated by the toolkit, is provided.

Tuning of Multiple Parameter Sets in Evolutionary Algorithms

Martin Andersson, *University of Skövde*, Sunith Bandaru, *University of Skövde*, Amos H.C. Ng, *University of Skövde*

Evolutionary optimization algorithms typically use one or more parameters that control their behavior. These parameters, which are often kept constant, can be tuned to improve the performance of the algorithm on specific problems. However, past studies have indicated that the performance can be further improved by adapting the parameters during runtime. A limitation of these studies is that they only control, at most, a few parameters, thereby missing potentially beneficial interactions between them. Instead of finding a direct control mechanism, the novel approach in this paper is to use different parameter sets in different stages of an optimization. These multiple parameter sets, which remain static within each stage, are tuned through extensive bi-level optimization experiments that approximate the optimal adaptation of the parameters. The algorithmic performance obtained with tuned multiple parameter sets is compared against that obtained with a single parameter set. For the experiments in this paper, the parameters of NSGA-II are tuned when applied to the ZDT, DTLZ and WFG test problems. The results show that using multiple parameter sets can significantly increase the performance over a single parameter set.

A Correlation Analysis of Set Quality Indicator Values in Multiobjective Optimization

Arnaud Liefooghe, *Univ. Lille, CNRS, Inria Lille – Nord Europe*, Bilel Derbel, *Univ. Lille, CNRS, Inria Lille – Nord Europe*

A large spectrum of quality indicators has been proposed so far to assess the performance of discrete Pareto set approximations in multiobjective optimization. Such indicators assign, to any solution set, a real-value reflecting a given aspect of approximation quality. This is an important issue in multiobjective optimization, not only to compare the performance and assets of different approximate algorithms, but also to improve their internal selection mechanisms. In this paper, we adopt a statistical analysis to experimentally investigate by how much a selection of state-of-the-art quality indicators agree with each other for a wide range of Pareto set approximations from well-known two- and three-objective continuous benchmark functions. More particularly, we measure the correlation between the ranking of low-, medium-, and high-quality limited-size approximation sets with respect to inverted generational distance, additive epsilon, multiplicative epsilon, R2, R3, as well as hypervolume indicator values. Since no pair of indicators obtains the same ranking of approximation sets, we confirm that they emphasize different facets of approximation quality. More importantly, our statistical analysis allows the degree of compliance between these indicators to be quantified.

Session: Best Paper: EMO
Friday, July 22, 14:00-15:40, Chasm Creek A

Active Learning in Multi-objective Evolutionary Algorithms for Sustainable Building Design

Siamak Safarzadegan Gilan, *Georgia Institute of Technology*, Naman Goyal, *Georgia Institute of Technology*, Bistra Dilkina, *Georgia Institute of Technology*

Residential and commercial buildings are responsible for about 40% of primary energy consumption in the US. The design of a building has tremendous effect on its energy profile, and recently there has been an increased interest in developing optimization methods that support the design of high performance buildings. Previous approaches are either based on simulation optimization or on training an accurate predictive model to replace expensive energy simulations during the optimization. We propose a method, suitable for expensive multiobjective optimization in very large search spaces. In particular, we use a Gaussian Process (GP) model for the prediction and devise an active learning scheme in a multi-objective genetic algorithm to preferentially simulate only solutions that are very informative to the model's predictions for the current generation. We develop a comprehensive and publicly available benchmark for building design optimization. We show that the GP model is highly competitive as a surrogate for building energy simulations, in addition to being well-suited for the active learning setting. Our results show that our approach clearly outperforms surrogate-based optimization, and produces solutions close in hypervolume to simulation optimization, while using only a fraction of the simulations and time.

A Multi-Objective Evolutionary Algorithm based on Parallel Coordinates

Raquel Hernández Gómez, *CINVESTAV-IPN*, Carlos A. Coello Coello, *CINVESTAV-IPN*, Enrique Alba Torres, *University of Málaga*

Multi-Objective Evolutionary Algorithms (MOEAs) are powerful tools for solving a wide range of real-world applications that involve the simultaneous optimization of several objective functions. However, their scalability to many-objective problems remains as an important issue since, due to the large number of non-dominated solutions, the search is guided solely by the diversity criterion. In this paper, we propose a novel MOEA that incorporates a density estimator based on a visualization technique called Parallel Coordinates. Using this approach, a graph is represented by a digital image, where a pixel identifies the level of overlapping line segments and those individuals covering a wide area of the image have a high probability of survival. Experimental results indicate that our proposed approach, called Multi-objective Optimizer based on Value Path (MOVAP), outperforms existing algorithms based on clustering (SPEA2), crowding distance (NSGA-II), reference points (NSGA-III) and the hypervolume indicator (HypE) on most of

the problems of the WFG test suite for five and seven objectives, while its performance in low dimensionality remains competitive.

A Generative Kriging Surrogate Model for Constrained and Unconstrained Multi-objective Optimization

Rayan Hussein, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*

Surrogate models are effective in reducing the computational time required for solving optimization problems. However, there have been a lukewarm interest in finding multiple trade off solutions for multi-objective optimization problems using surrogate models. The literature on surrogate modeling for constrained optimization problems is also rare. The difficulty lies in the requirement of building and solving multiple surrogate models, one for each Pareto-optimal solution. In this paper, we first provide a brief introduction of the past studies and suggest a computationally fast, Kriging-based, and generative procedure for finding multiple near Pareto optimal solutions in a systematic manner. The expected improvement metric is maximized using a real-parameter genetic algorithm for finding new solutions for high-fidelity evaluations. The approach is computationally fast due to the interlinking of building multiple surrogate models and in its systematic sequencing methodology for assisting one model with another. In standard two and three-objective test problems with and without constraints, our proposed methodology takes only a few hundreds of high-fidelity solution evaluations to find a widely distributed near Pareto optimal solutions compared to the standard EMO methods requiring tens of thousands of high-fidelity solution evaluations. The framework is generic and can be extended to utilize other surrogate modeling methods easily.

Bio-inspired Multi-objective Optimization Design of a Highly Efficient Squirrel Cage Induction Motor

Sergio F. Contreras, *Universidad Nacional de Colombia*, Camilo A. Cortés, *Universidad Nacional de Colombia*, María A. Guzmán, *Universidad Nacional de Colombia*

Although three-phase squirrel cage induction motors are commonly considered a mature technology, their design has always been a challenge for engineering; therefore, new techniques and methodologies are continually being proposed. The growth in the relevance of efficiency has set it as part of the design objectives. However, increased efficiency is in conflict with the manufacturing cost, not only because of the cost of improved materials, but also because of the dimensional modifications. Therefore, a true multi-objective optimization methodology turns out to be attractive for this engineering problem. On the other hand, bio-inspired methods have become an important tool for induction motor optimal design because this involves many variables and parameters, and it is in general a complex optimization problem by nature. Thus, a methodology for the design of highly efficient three-phase squirrel cage induction motors, based on the non-dominated sorting genetic algorithm II (NSGA-II) and the non-dominated sorting particle swarm optimization (NSPSO), together with a true multi-objective optimization problem of manufacturing cost and operation efficiency, is proposed in this paper. The methods are evaluated and compared in order to be used with this type of engineering problems.

Session: EMO2
Friday, July 22, 16:10-17:50, Wind River B

Karush-Kuhn-Tucker Proximity Measure for Multi-Objective Optimization Based on Numerical Gradients

Mohamed Abouhawwash, *Mansoura University*, Kalyanmoy Deb, *Michigan State University*

A measure for estimating the convergence characteristics of a set of non-dominated points obtained by a multi-objective optimization algorithm was developed recently. The idea of the measure was developed based on the Karush-Kuhn-Tucker (KKT) optimality conditions which require the gradients of objective and constraint functions. In this paper, we extend the scope of the proposed KKT proximity measure by computing gradients numerically and evaluating the accuracy of the numerically computed KKT proximity measure with the same computed using the exact gradient computation. The results are encouraging and open up the possibility of using the proposed KKTPM to non-differentiable problems as well.

A Faster Algorithm for the Binary Epsilon Indicator Based on Orthant Minimum Search

Andrey Vasin, *ITMO University*, Maxim Buzdalov, *ITMO University*

The binary ϵ-indicator is often used to assess the quality of solutions in multiobjective optimization, and to perform optimization as well. It is normally evaluated using a straightforward $\Theta(nmk)$ algorithm, where n and m are the number of solutions in the arguments, and k is the number of objectives. This is considered to be fast compared to, for example, the hypervolume indicator, which is #P-hard. However, there are efficient algorithms for the latter, especially for small values of k, while the ϵ-indicator evaluation is too slow already for $n, m > 10^4$ and for any k. We present an efficient algorithm to compute the value of the binary ϵ-indicator. It reduces the problem to a series of orthant minimum searches, which are solved by an appropriate algorithm. For the latter, we consider two implementations: the one based on a dynamic tree data structure, and the one based on the divide-and-conquer technique. In both cases, evaluation of the binary ϵ-indicator takes $O((n+m)k(\log(n+m))^{\max(1,k-2)})$ time. Empirical evaluation shows that the second implementation has a better performance than the first one, and both of them outperform the naive algorithm for large enough values of n.

A novel Multi-objective Optimization-based Image Registra-

tion Method

Meifeng Shi, *Chongqing University*, Zhongshi He, *Chongqing University*, Ziyu Chen, *Chongqing University*, Hang Zhang, *Chongqing University*

The RANSAC is widely used in image registration algorithms. However, the RANSAC becomes computationally expensive when the number of feature points is large. And also, its high error-matching ratio caused by the large number of iterations always raises the possibility of false registration. To deal with these drawbacks, a novel multi-objective optimization-based image registration method is proposed, named MO-IRM. In MO-IRM, a multi-objective estimation model is built to describe the feature matching pairs (data set), with no need for the precheck process that is necessary in some improved RANSAC algorithms to eliminate the error-matching pairs. Moreover, a full variate Gaussian model-based RM-MEDA without clustering process (FRM-MEDA) is presented to solve the established multi-objective model. FRM-MEDA only requires a few iterations to find out a correct model. FRM-MEDA can not only greatly reduce the computational overhead but also effectively decrease the possibility of false registration. The proposed MO-IRM is compared with RM-MEDA, NSGA-? and the RANSAC based registration algorithm on the Dazu grottoes image database. The experiment results demonstrate that the proposed method achieves ideal registration performances on both two images and multiple images, and greatly outperforms the compared algorithms on the runtime.

Experiments on Greedy and Local Search Heuristics for d–dimensional Hypervolume Subset Selection

Matthieu Basseur, *LERIA, Université d'Angers*, Bilel Derbel, *Univ. Lille - CRIStAL, Inria Lille-Nord Europe*, Adrien Goëffon, *LERIA, Université d'Angers*, Arnaud Liefooghe, *Univ. Lille - CRIStAL, Inria Lille-Nord Europe*

Subset selection constitutes an important stage of any evolutionary multiobjective optimization algorithm when truncating the current approximation set for the next iteration. This appears to be particularly challenging when the number of solutions to be removed is large, and when the approximation set contains many mutually non-dominating solutions. In particular, indicator-based strategies have been intensively used in recent years for that purpose. However, most solutions for the indicator-based subset selection problem are based on a very simple greedy backward elimination strategy. In this paper, we experiment additional heuristics that include a greedy forward selection and a greedy sequential insertion policies, a first-improvement hill-climbing local search, as well as combinations of those. We evaluate the effectiveness and the efficiency of such heuristics in order to maximize the enclosed hypervolume indicator of candidate subsets during a hypothetical evolutionary process, or as a post-processing phase. Our experimental analysis, conducted on randomly generated as well as structured two-, three- and four-objective mutually non-dominated sets, allows us to appreciate the benefit of these approaches in terms of quality, and to highlight some practical limitations and open challenges in terms of computational resources.

Genetic Algorithms

Session: GA1
Friday, July 22, 14:00-15:40, Wind Star A

Exploiting Diverse Distance Metrics for Surrogate-Based Optimisation of Ordering Problems

Jim Smith, *University of the West of England*, Christopher Stone, *University of the West of England*, Martin Serpell, *University of the West of England*

Surrogate-assisted Optimisation has proven success in the continuous domain, but only recently begun to be explored for other representations, in particular permutations. The use of Gaussian kernel-based models has been proposed, but only tested on small problems. This case study considers much larger instances, in the experimental setting of a real-world ordering problem. We also investigate whether creating models using different distance metrics generates a diverse ensemble. Results demonstrate the following effects of use to other researchers: (i) Numerical instability in matrix inversion is a factor across all metrics, regardless of algorithm used. The likelihoood increases significantly once the models are parameterised using evolved solutions as well as the initial random population; (ii) This phase transition is also observed in different indicators of model quality. For example, predictive accuracy typically decreases once models start to include data from evolved samples. We explain this transition in terms of the distribution of samples and Gaussian kernel basis of the models; (iii) Measures of how well models predict rank-orderings are less affected; (iv) Benchmark comparisons show that using surrogate models decreases the number of evaluations required to find good solutions, without affecting quality.

Estimating the Advantage of Age-Layering in Evolutionary Algorithms

Hormoz Shahrzad, *Sentient Technologies, Inc.*, Babak Hodjat, *Sentient Technologies, Inc.*, Risto Miikkulainen, *Sentient Technologies, Inc. & The University of Texas at Austin*

In an age-layered evolutionary algorithm, candidates are evaluated on a small number of samples first; if they seem promising, they are evaluated with more samples, up to the entire training

set. In this manner, weak candidates can be eliminated quickly, and evolution can proceed faster. In this paper, the fitness-level method is used to derive a theoretical upper bound for the runtime of $(k + 1)$ age-layered evolutionary strategy, showing a significant potential speedup compared to a non-layered counterpart. The parameters of the upper bound are estimated experimentally in the 11-Multiplexer problem, verifying that the theory can be useful in configuring age layering for maximum advantage. The predictions are validated in a practical implementation of age layering, confirming that 60-fold speedups are possible with this technique.

Surprise Search: Beyond Objectives and Novelty

Daniele Gravina, *University of Malta*, Antonios Liapis, *University of Malta*, Georgios Yannakakis, *University of Malta*

Grounded in the divergent search paradigm and inspired by the principle of surprise for unconventional discovery in computational creativity, this paper introduces surprise search as a new method of evolutionary divergent search. Surprise search is tested in two robot navigation tasks and compared against objective-based evolutionary search and novelty search. The key findings of this paper reveal that surprise search is advantageous compared to the other two search processes. It outperforms objective search and it is as efficient as novelty search in both tasks examined. Most importantly, surprise search is, on average, faster and more robust in solving the navigation problem compared to objective and novelty search. Our analysis reveals that surprise search explores the behavioral space more extensively and yields higher population diversity compared to novelty search.

Hidden Genes Genetic Algorithms for Systems Architecture Optimization

Ossama Abdelkhalik, *Michigan Tech University*, Shadi Darani, *Michigan Tech University*

The concept of hidden genes was recently introduced in genetic algorithms to handle variable-size design space optimization problems. This paper presents new developments in hidden genes genetic algorithms. Mechanisms for assigning (selecting) the hidden genes in the chromosomes of genetic algorithms are presented. In the proposed mechanisms, a tag is assigned for each gene; this tag determines whether the gene is hidden or not, while they evolve over generations using stochastic operations. These mechanisms are tested on mathematical optimization problems and on a trajectory optimization problem for a space mission to Jupiter. In the conducted tests, one of the proposed hidden genes assignment mechanism has enabled the hidden genes genetic algorithms to find better (lower cost) solutions, while other mechanisms has shown to be able to find close solutions.

Session: GA2
Saturday, July 23, 14:00-15:40, Chasm Creek B

Escaping Local Optima with Diversity Mechanisms and Crossover

Duc-Cuong Dang, *University of Nottingham*, Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Martin S. Krejca, *Hasso Plattner Institute*, Per Kristian Lehre, *University of Nottingham*, Pietro S. Oliveto, *University of Sheffield*, Dirk Sudholt, *University of Sheffield*, Andrew M. Sutton, *Hasso Plattner Institute*

Population diversity is essential for the effective use of any crossover operator. We compare seven commonly used diversity mechanisms and prove rigorous run time bounds for the (μ+1) GA using uniform crossover on the fitness function Jump_k. All previous results in this context only hold for unrealistically low crossover probability $p_c = \mathrm{O}(k/n)$, while we give analyses for the setting of constant $p_c < 1$ in all but one case. Our bounds show a dependence on the problem size n, the jump length k, the population size μ, and the crossover probability p_c. For the typical case of constant $k > 2$ and constant p_c, we can compare the resulting expected optimisation times for different diversity mechanisms assuming an optimal choice of μ:

- $\mathrm{O}(n^{k-1})$ for duplicate elimination/minimisation,
- $\mathrm{O}(n^2 \log n)$ for maximising the convex hull,
- $\mathrm{O}(n \log n)$ for det. crowding (assuming $p_c = k/n$),
- $\mathrm{O}(n \log n)$ for maximising the Hamming distance,
- $\mathrm{O}(n \log n)$ for fitness sharing,
- $\mathrm{O}(n \log n)$ for the single-receiver island model.

This proves a sizeable advantage of all variants of the (μ+1) GA compared to the (1+1) EA, which requires $\Theta(n^k)$. In a short empirical study we confirm that the asymptotic differences can also be observed experimentally.

Runtime Analysis for the Parameter-less Population Pyramid

Brian W. Goldman, *Colorado State University*, Dirk Sudholt, *University of Sheffield*

Runtime analysis of black-box search algorithms provides rigorous performance guarantees, aiding in algorithm design and comparison. Unfortunately, deriving bounds can be challenging and as a result existing literature has focused on simplistic algorithms. The Parameter-less Population Pyramid (P3) is a recently proposed (Goldman and Punch, GECCO 2014) unbiased black-box search algorithm that combines local search, model based mixing, and population layering. In empirical studies P3 has outperformed leading genetic algorithms across a variety of problems. We provide a runtime analysis on n-bit problems to help shed light on the reason for P3's effectiveness. We derive upper runtime bounds of $n + 1$ for linear functions, $n^2 + 1$

for LeadingOnes, and $O(2^k n \log(n/k))$ for Concatenated Traps of size k. For a simplified version of P3 we obtain a bound of $O(n \log^3 n)$ for H-IFF. These results show P3 is competitive with the best known unbiased genetic algorithms on each of these problems, suggesting its performance generalizes well. Furthermore, we find that P3's effectiveness relies on all three of its major components, lending support to the algorithm's design.

Fast Building Block Assembly by Majority Vote Crossover

Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Martin S. Krejca, *Hasso Plattner Institute*, Samadhi Nallaperuma, *The University of Sheffield*, Frank Neumann, *The University of Adelaide*, Martin Schirneck, *Hasso Plattner Institute*

Different works have shown how crossover can help with building block assembly. Typically, crossover might get lucky to select good building blocks from each parent, but these lucky choices are usually rare. In this work we consider a crossover operator which works on three parent individuals. In each component, the offspring inherits the value present in the majority of the parents; thus, we call this crossover operator majority vote. We show that, if good components are sufficiently prevalent in the individuals, majority vote creates an optimal individual with high probability. Furthermore, we show that this process can be amplified: as long as components are good independently and with probability at least $1/2 + \delta$, we require only $O(\log 1/\delta + \log\log n)$ successive stages of majority vote to create an optimal individual with high probability! We show how this applies in two scenarios. The first scenario is the Jump test function. With sufficient diversity, we get an optimization time of $O(n \log n)$ even for jump sizes as large as $O(n^(1/2 - \epsilon))$. Our second scenario is a family of vertex cover instances. Majority vote optimizes this family efficiently, while local searches fail and only highly specialized two-parent crossovers are successful.

A Parallel Hybrid Genetic Algorithm for the k-Edge-Connected Hop-Constrained Network Design Problem

Mohamed Khalil Labidi, *Sciences of Tunis & Paris Dauphine University*, Ibrahima Diarrassouba, *Le Havre University*, Ali Ridha Mahjoub, *Paris Dauphine University*, Anissa Omrane, *Sciences of Tunis*

Network design problems have been largely studied in the last decades due to the ubiquity of IT communication in our daily life. We address in this paper the k-edge-connected hop-constrained network design problem (kHNDP) which is known to be NP-hard. In this paper, we present a hybrid parallel approach for solving the kHNDP based on a Lagrangian relaxation algorithm, a greedy algorithm, and a genetic algorithm. Computational results obtained with our algorithms are compared with those from CPLEX.

Session: Best Papers: GA+CS
Saturday, July 23, 16:10-17:50, Chasm Creek A

Breaking the Billion-Variable Barrier in Real-World Optimization Using a Customized Evolutionary Algorithm

Kalyanmoy Deb, *Michigan State University*, Christie Myburgh, *Maptek Pty Ltd*

Despite three decades of intense studies of evolutionary computation (EC), researchers outside the EC community still have a general impression that EC methods are expensive and are not efficient in solving large-scale problems. In this paper, we consider a specific integer linear programming (ILP) problem which, although comes from a specific industry, is similar to many other practical resource allocation and assignment problems. Based on a population based evolutionary optimization framework, we develop a computationally fast method to arrive at a near-optimal solution repeatedly. Two popular softwares (glpk and CPLEX) are not able to handle around 300 and 2,000 integer variable version of the problem, respectively, even after running for several hours. Our proposed method is able to find a near-optimal solution in less than second on the same computer. Moreover, the main highlight of this study is that our method scales in a sub-quadratic computational complexity in handling 50,000 to one billion variables. We believe that this is the first time such a large-sized real-world constrained problem has ever been handled using any optimization algorithm. The study clearly demonstrates the reasons for such a fast and scale-up application of the proposed method. The work should remain as a successful case study of EC methods for years to come.

Expanding from Discrete Cartesian to Permutation Gene-pool Optimal Mixing Evolutionary Algorithms

Peter A.N. Bosman, *Centrum Wiskunde & Informatica (CWI)*, Ngoc Hoang Luong, *Centrum Wiskunde & Informatica (CWI)*, Dirk Thierens, *Utrecht University*

The recently introduced Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) family, which includes the Linkage Tree Genetic Algorithm (LTGA), has been shown to scale excellently on a variety of discrete, Cartesian-space, optimization problems. This paper shows that GOMEA can quite straightforwardly also be used to solve permutation optimization problems by employing the random keys encoding of permutations. As a test problem, we consider permutation flowshop scheduling, minimizing the total flow time on 120 different problem instances (Taillard benchmark). The performance of GOMEA is compared with the recently published generalized Mallows estimation of distribution algorithm (GM-EDA). Statistical tests show that results of GOMEA variants are almost always significantly better than results of GM-EDA. Moreover, even without using local search, the new GOMEA variants obtained the best-known solution for 30 instances in every run and even new upper bounds for several instances. Finally, the time complexity per solution for building a dependency model to drive variation

is an order of complexity less for GOMEA than for GM-EDA, altogether suggesting that GOMEA also holds much promise for permutation optimization.

Genetic Programming

Session: Best Paper: GP
Friday, July 22, 16:10-17:50, Chasm Creek A

Quantitative Analysis of Evolvability using Vertex Centralities in Phenotype Network

Ting Hu, *Memorial University*, Wolfgang Banzhaf, *Memorial University*

In an evolutionary system, robustness describes the resilience to mutational and environmental changes, whereas evolvability captures the capability of generating novel and adaptive phenotypes. The research literature has not seen an effective quantification of phenotypic evolvability able to predict the evolutionary potential of the search for novel phenotypes. In this study, we propose to characterize the mutational potential among different phenotypes using the phenotype network, where vertices are phenotypes and edges represent mutational connections between them. In the framework of such a network, we quantitatively analyze the evolvability of phenotypes by exploring a number of vertex centrality measures commonly used in complex networks. In our simulation studies we use a Linear Genetic Programming system and a population of random walkers. Our results suggest that the weighted eigenvector centrality serves as the best estimator of phenotypic evolvability.

A Dispersion Operator for Geometric Semantic Genetic Programming

Luiz Otavio V. B. Oliveira, *Federal University of Minas Gerais*, Fernando E. B. Otero, *University of Kent*, Gisele L. Pappa, *Federal University of Minas Gerais*

Recent advances in geometric semantic genetic programming (GSGP) have shown that the results obtained by these methods can outperform those obtained by classical genetic programming algorithms, in particular in the context of symbolic regression. However, there are still many open issues on how to improve their search mechanism. One of these issues is how to get around the fact that the GSGP crossover operator cannot generate solutions that are placed outside the convex hull formed by the individuals of the current population. Although the mutation operator alleviates this problem, we cannot guarantee it will find promising regions of the search space within feasible computational time. In this direction, this paper proposes a new geometric dispersion operator that uses multiplicative factors to move individuals to less dense areas of the search space around the target solution before applying semantic genetic operators. Experiments in sixteen datasets show that the results obtained by the proposed operator are statistically significantly better than those produced by GSGP and that the operator does indeed spread the solutions around the target solution.

The Impact of Hyperselection on Lexicase Selection

Thomas Helmuth, *Washington and Lee University*, Nicholas Freitag McPhee, *University of Minnesota, Morris*, Lee Spector, *Hampshire College*

Lexicase selection is a parent selection method that has been shown to improve the problem solving power of genetic programming over a range of problems. Previous work has shown that it can also produce hyperselection events, in which a single individual is selected many more times than other individuals. Here we investigate the role that hyperselection plays in the problem-solving performance of lexicase selection. We run genetic programming on a set of program synthesis benchmark problems using lexicase and tournament selection, confirming that hyperselection occurs significantly more often and more drastically with lexicase selection, which also performs significantly better. We then show results from an experiment indicating that hyperselection is not integral to the problem-solving performance or diversity maintenance observed when using lexicase selection. We conclude that the power of lexicase selection stems from the collection of individuals that it selects, not from the unusual frequencies with which it sometimes selects them.

Non-negative Matrix Factorization for Unsupervised Derivation of Search Objectives in Genetic Programming

Paweł Liskowski, *Poznan University of Technology*, Krzysztof Krawiec, *Poznan University of Technology*

In genetic programming (GP), the outcomes of the evaluation phase in an evolutionary loop can be represented as an interaction matrix, with rows corresponding to programs in a population, columns corresponding to tests that define a program synthesis task, and ones and zeroes signaling respectively passing a test and failing to do so. The conventional fitness, equivalent to a row sum in that matrix, only crudely reflects program's compliance with desired output, and recent contributions in semantic and behavioral GP point to alternative, multifaceted characterizations that facilitate navigation in the search space. In this paper, we propose DOF, a method that uses the popular machine learning technique of non-negative matrix factorization to heuristically derive a low number of underlying objectives from an interaction matrix. The resulting objectives redefine the original single-objective synthesis problem as a multiobjective opti-

mization problem, and we posit that such characterization fosters diversification of search directions while maintaining useful search gradient. The comparative experiment conducted on 15 problems from discrete domains confirms this claim: DOF outperforms the conventional GP and GP equipped with an alternative method of derivation of search objectives on success rate and convergence speed.

Session: GP1
Saturday, July 23, 10:40-12:20, Mesa Verde B

Improving Generalisation of Genetic Programming for Symbolic Regression with Structural Risk Minimisation

Qi Chen, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Lin Shang, *Nanjing University*, Mengjie Zhang, *Victoria University of Wellington*

Generalisation is one of the most important performance measures for any learning algorithm, no exception to Genetic Programming (GP). A number of works have been devoted to improve the generalisation ability of GP for symbolic regression. Methods based on a reliable estimation of generalisation error of models during evolutionary process are a sensible choice to enhance the generalisation of GP. Structural risk minimisation (SRM), which is based on the VC dimension in the learning theory, provides a powerful framework for estimating the difference between the generalisation error and the empirical error. Despite its solid theoretical foundation and reliability, SRM has seldom been applied to GP. The most important reason is the difficulty in measuring the VC dimension of GP models/programs. This paper introduces SRM, which is based on an empirical method to measure the VC dimension of models, into GP to improve its generalisation performance for symbolic regression. The results of a set of experiments confirm that GP with SRM has a dramatical generalisation gain while evolving more compact/less complex models than standard GP. Further analysis also shows that in most cases, GP with SRM has better generalisation performance than GP with bias-variance decomposition, which is one of the state-of-the-art methods to control overfitting.

Discovering Rubik's Cube Subgroups using Coevolutionary GP – A Five Twist Experiment

Robert J. Smith, *Dalhousie University*, Stephen Kelly, *Dalhousie University*, Malcolm I. Heywood, *Dalhousie University*

This work reports on an approach to direct policy discovery (a form of reinforcement learning) using genetic programming (GP) for the 3 by 3 by 3 Rubik's Cube. Specifically, a synthesis of two approaches is proposed: 1) a previous group theoretic formulation is used to suggest a sequence of objectives for developing solutions to different stages of the overall task; and 2) a hierarchical formulation of GP policy search is utilized in which policies adapted for an earlier objective are explicitly transferred to aid the construction of policies for the next objective. The resulting hierarchical organization of policies explicitly demonstrates task decomposition and policy reuse. Algorithmically, the process makes use of a recursive call to a common approach for maintaining a diverse population of GP individuals and then learns how to reuse subsets of programs (policies) developed against the earlier objective. Other than the two objectives, we do not explicitly identify how to decompose the task or mark specific policies for reuse. Moreover, at the end of evolution we return a population solving 100% of 17,675,698 different initial Cubes for the two objectives currently in use.

Managing Repetition in Grammar-Based Genetic Programming

Miguel Nicolau, *University College Dublin*, Michael Fenton, *University College Dublin*

Grammar-based Genetic Programming systems are capable of generating identical phenotypic solutions, either by creating repeated genotypic representations, or from distinct genotypes, through their many-to-one mapping process. Furthermore, their initialisation process can generate a high number of duplicate individuals, while traditional variation and replacement operators can permit multiple individuals to percolate through generations unchanged. This can lead to a high number of phenotypically identical individuals within a population. This study investigates the frequency and effect of such duplicate individuals on a suite of benchmark problems. Both Grammatical Evolution and the CFG-GP systems are examined. Experimental evidence suggests that these useless evaluations can be instead be used either to speed-up the evolutionary process, or to de- lay convergence.

Reducing Antagonism between Behavioral Diversity and Fitness in Semantic Genetic Programming

Marcin Szubert, *University of Vermont*, Anuradha Kodali, *UC Santa Cruz & NASA Ames Research Center*, Sangram Ganguly, *BAERI & NASA Ames Research Center*, Kamalika Das, *UC Santa Cruz & NASA Ames Research Center*, Josh C. Bongard, *University of Vermont*

Maintaining population diversity has long been considered fundamental to the effectiveness of evolutionary algorithms. Recently, with the advent of novelty search, there has been an increasing interest in sustaining behavioral diversity by using both fitness and behavioral novelty as separate search objectives. However, since the novelty objective explicitly rewards diverging from other individuals, it can antagonize the original fitness objective that rewards convergence toward the solution(s). As a result, fostering behavioral diversity may prevent proper exploitation of the most interesting regions of the behavioral space, and thus adversely affect the overall search performance. In this paper, we argue that an antagonism between behavioral diversity and fitness can indeed exist in semantic genetic programming applied to symbolic regression. Minimizing error draws individuals toward the target semantics but promoting novelty, defined as a distance in the semantic space, scatters them away from it. We introduce a less conflicting novelty metric, defined

as an angular distance between two program semantics with respect to the target semantics. The experimental results show that this metric, in contrast to the other considered diversity promoting objectives, allows to consistently improve the performance of genetic programming regardless of whether it employs a syntactic or a semantic search operator.

Session: GP2
Saturday, July 23, 14:00-15:40, Mesa Verde B

A New Wave: A Dynamic Approach to Genetic Programming

David Medernach, *University of Limerick*, Jeannie Fitzgerald, *University of Limerick*, R. Muhammad Atif Azad, *University of Limerick*, Conor Ryan, *University of Limerick*

Wave is a novel form of semantic genetic programming which operates by optimising the residual errors of a succession of short genetic programming runs, and then producing a cumulative solution. These short genetic programming runs are called periods, and they have heterogeneous parameters. In this paper we leverage the potential of Wave's heterogeneity to simulate a dynamic evolutionary environment by incorporating self adaptive parameters together with an innovative approach to population renewal. We conduct an empirical study comparing this new approach with multiple linear regression (MLR) as well as several evolutionary computation (EC) methods including the well known geometric semantic genetic programming (GSGP) together with several other optimised Wave techniques. The results of our investigation show that the dynamic Wave algorithm delivers consistently equal or better performance than Standard GP (both with or without linear scaling), achieves testing fitness equal or better than multiple linear regression, and performs significantly better than GSGP on five of the six problems studied.

Epsilon-Lexicase Selection for Regression

William La Cava, *University of Massachusetts Amherst*, Lee Spector, *Hampshire College*, Kourosh Danai, *University of Massachusetts Amherst*

Lexicase selection is a parent selection method that considers test cases separately, rather than in aggregate, when performing parent selection. It performs well in discrete error spaces but not on the continuous-valued problems that compose most system identification tasks. In this paper, we develop a new form of lexicase selection for symbolic regression, named ϵ-lexicase selection, that redefines the pass condition for individuals on each test case in a more effective way. We run a series of experiments on real-world and synthetic problems with several treatments of ϵ and quantify how ϵ affects parent selection and model performance. ϵ-lexicase selection is shown to be effective for regression, producing better fit models compared to other techniques such as tournament selection and age-fitness Pareto optimization. We demonstrate that ϵ can be adapted automatically for individual test cases based on the population performance distribution. Our experiments show that ϵ-lexicase selection with automatic ϵ produces the most accurate models across tested problems with negligible computational overhead. We show that behavioral diversity is exceptionally high in lexicase selection treatments, and that ϵ-lexicase selection makes use of more fitness cases when selecting parents than lexicase selection, which helps explain the performance improvement.

Automatically Designing More General Mutation Operators of Evolutionary Programming for Groups of Function Classes Using a Hyper-Heuristic

Libin Hong, *University of Nottingham*, John H. Drake, *University of Nottingham*, John R. Woodward, *University of Stirling*, Ender Özcan, *University of Nottingham*

In this study we use Genetic Programming (GP) as an offline hyper-heuristic to evolve a mutation operator for Evolutionary Programming. This is done using the Gaussian and uniform distributions as the terminal set, and arithmetic operators as the function set. The mutation operators are automatically designed for a specific function class. The contribution of this paper is to show that a GP can not only automatically design a mutation operator for Evolutionary Programming (EP) on functions generated from a specific function class, but also can design more general mutation operators on functions generated from groups of function classes. In addition, the automatically designed mutation operators also show good performance on new functions generated from a specific function class or a group of function classes.

Evolving Algebraic Constructions for Designing Bent Boolean Functions

Stjepan Picek, *KU Leuven & iMinds*, Domagoj Jakobovic, *University of Zagreb*

The evolution of Boolean functions that can be used in cryptography is a topic well studied in the last decades. Previous research, however, has focused on evolving Boolean functions directly, and not on general methods that are capable of generating the desired functions. The former approach has the advantage of being able to produce a large number of functions in a relatively short time, but it directly depends on the size of the search space. In this paper, we present a method to evolve algebraic constructions for generation of bent Boolean functions. To strengthen our approach, we define three types of constructions and give experimental results for them. Our results show that this approach is able to produce a large number of constructions, which could in turn enable the construction of many more Boolean functions with a larger number of variables.

Integrative Genetic and Evolutionary Computation

Session: RWA4+IGEC1
Saturday, July 23, 10:40-12:20, Wind River A

Approximation of (k,t)-robust Equilibria

Tudor Dan Mihoc, *Babes-Bolyai University*, Rodica Ioana Lung, *Babes-Bolyai University*, Noémi Gaskó, *Babes-Bolyai University*, Mihai Suciu, *Babes-Bolyai University*

Game theory models strategic and conflicting situations and offers several solution concepts that are known as game equilibria, among which the Nash equilibrium is probably the most popular one. A less known equilibrium, called the (k,t)-robust equilibrium, has recently been used in the context of distributed computing. The (k,t)-robust equilibrium combines the concepts of k-resiliency and t-immunity: a strategy profile is k-resilient if there is no coalition of k players that can benefit from improving their payoffs by collective deviation, and it is t-immune if any action of any t players does not decrease the payoffs of the others. A strategy profile is (k,t)-robust if it is both k-resilient and t-immune. In this paper an evolutionary approach of approximating (k,t)-robust equilibria is proposed. Numerical experiments are performed on a game that models node behavior in a distributed system.

Session: CS3+IGEC2
Sunday, July 24, 09:00-10:15, Mesa Verde B

Classification of Cardiac Arrhythmia by Random Forests with Features Constructed by Kaizen Programming with Linear Genetic Programming

Léo Françoso Dal Piccol Sotto, *Federal University of São Paulo*, Regina C. Coelho, *Federal University of São Paulo*, Vinícius Veloso de Melo, *Federal University of São Paulo*

Cardiac rhythm disorders may cause severe heart diseases, stroke, and even sudden cardiac death. Some arrhythmias are so serious that can cause injury to other organs, for instance, brain, kidneys, lungs or liver. Therefore, early and correct diagnosis of cardiac arrhythmia is essential to the prevention of serious problems. There are expert systems to classify arrhythmias from electrocardiograms signals. However, it has been shown that not only selecting the correct features from the dataset but also generating combined features could be the key to having real progress in classification. Therefore, this paper investigates a novel hybrid evolutionary technique to perform both tasks at the same time, finding complementary features that cover different characteristics of the data. The new features were tested with a widely-used classifier called Random Forests. The method reduced a dataset with 279 attributes to 26 attributes and achieved accuracies of 86.39% for binary classification and 77.69% for multiclass. Our approach outperformed several popular feature selection, feature generation, and state-of-the-art related work from the literature.

Parallel Evolutionary Systems

Session: Best Papers: DETA+PES+SBS-SS
Friday, July 22, 10:40-12:20, Chasm Creek B

Evaluation-Time Bias in Quasi-Generational and Steady-State Asynchronous Evolutionary Algorithms

Eric O. Scott, *George Mason University*, Kenneth A. De Jong, *George Mason University*

A number of papers have emerged in the last two years that apply and study asynchronous master-slave evolutionary algorithms based on a steady-state model. These efforts are largely motivated by the observation that, unlike traditional (synchronous) EAs, asynchronous EAs are able to make maximal use of many parallel processors, even when some individuals evaluate more slowly than others. Asynchronous EAs do not behave the same as their synchronous counterparts, however, and as of yet there is very little theory that makes it possible to predict how they will perform on new problems. Of some concern is evidence suggesting that the steady-state versions tend to be biased toward regions of the search space where fitness evaluation is cheaper. This has led some authors to suggest a so-called 'quasi-generational' asynchronous EA as an intermediate solution that incurs neither idle time nor significant bias toward fast solutions. We perform experiments with the quasi-generational EA, and show that it does not deliver the promised benefits: it is, in fact, just as biased toward fast solutions as the steady-state approach is, and it tends to converge even more slowly than the traditional, generational EA.

Session: PES1
Saturday, July 23, 10:40-11:55, Chasm Creek B

Hardware-Accelerated Parallel Genetic Algorithm for Fitness Functions with Variable Execution Times

Yunfeng Ma, *University of York*, Leandro Soares Indrusiak, *University of York*

Genetic Algorithms (GAs) following a parallel master-slave architecture can be effectively used to reduce searching time when fitness functions have fixed execution time. This paper presents a parallel GA architecture along with two accelerated GA operators to enhance the performance of masterslave GAs, specially when considering fitness functions with variable execution times. We explore the performance of the proposed approach, and analyse its effectiveness against the state-of-the-art. The results show a significant improvement in search times and fitness function utilisation, thus potentially enabling the use of this approach as a faster searching tool for timing-sensitive optimisation processes such as those found in dynamic real-time systems.

The Seamless Peer and Cloud Evolution Framework

Guillaume Leclerc, *Ecole Polytéchnique Fédérale de Lausanne*, Joshua E. Auerbach, *Ecole Polytéchnique Fédérale de Lausanne*, Giovanni Iacca, *Ecole Polytéchnique Fédérale de Lausanne*, Dario Floreano, *Ecole Polytéchnique Fédérale de Lausanne*

Evolutionary algorithms are increasingly being applied to problems that are too computationally expensive to run on a single personal computer due to costly fitness function evaluations and/or large numbers of fitness evaluations. Here, we introduce the Seamless Peer And Cloud Evolution (SPACE) framework, which leverages bleeding edge web technologies to allow the computational resources necessary for running large scale evolutionary experiments to be made available to amateur and professional researchers alike, in a scalable and cost-effective manner, directly from their web browsers. The SPACE framework accomplishes this by distributing fitness evaluations across a heterogeneous pool of cloud compute nodes and peer computers. As a proof of concept, this framework has been attached to the RoboGen™ open-source platform for the co-evolution of robot bodies and brains, but importantly the framework has been built in a modular fashion such that it can be easily coupled with other evolutionary computation systems.

Performance for the Masses

Juan J. Merelo, *Universidad de Granada*, Pedro A. Castillo, *Universidad de Granada*, Pablo García-Sánchez, *Universidad de Granada*, Paloma de las Cuevas, *Universidad de Granada*, Nuria Rico, *Universidad de Granada*, Mario García Valdez, *Instituto Tecnológico de Tijuana*

Using volunteer's browsers as a computing resource presents several advantages, but it remains a challenge to fully harness the browser's capabilities and to model the user's behavior so that those capabilities can be leveraged optimally. These are the objectives of this paper, where we present the results of several evolutionary computation experiments with different implementations of a volunteer computing framework called NodIO, designed to be easily deployable on freely available cloud resources. We use different implementations to find out which one is able to get the user to lend more computing cycles and test different problems to check the influence it has on said performance, as measured by the time needed to find a solution, but also by the number of users engaged. From these experiments we can already draw some conclusions, besides the fact that volunteer computing can be a valuable computing resource and that it is essential to be as open as possible with software and data: the user has to be kept engaged to obtain as many computing cycles as possible, the client has to be built to use the computer capabilities fully, and, finally, that the user contributions follow a common statistical distribution.

Real World Applications

Session: RWA1
Friday, July 22, 10:40-12:20, Mesa Verde B

A Genetic Algorithm for Rule-based Chart Pattern Search in Stock Market Prices

Myoung Hoon Ha, *Seoul National University*, Sangyeop Lee, *Seoul National University*, Byung-Ro Moon, *Seoul National University*

Chart pattern analysis uses knowledge extracted from graphical information of price movements. There are two representative types of problems in chart pattern analysis: the matching problem and the search problem. There have been extensive studies on chart pattern matching. However, chart pattern search has not yet drawn much interest. Instead of automatic search, most studies use chart patterns manually designed by financial experts. In this paper, we suggest an automatic algorithm that searches a rule-based chart pattern. We formulate rule-based chart pattern search as an optimization problem for a genetic algorithm. The suggested genetic algorithm includes a considerable amount of problem-specific manipulation. The algorithm successfully found attractive patterns working on the Korean stock market. We studied the rules used in the found patterns, noting that they

are rising-support patterns. In addition, the automated pattern generation uses designs at a higher level of abstraction.

Evolutionary Learning of Scheduling Heuristics for Heterogeneous Wireless Communications Networks

David Lynch, *University College Dublin*, Michael Fenton, *University College Dublin*, Stepan Kucera, *Bell Laboratories, Nokia-Ireland*, Holger Claussen, *Bell Laboratories, Nokia-Ireland*, Michael O'Neill, *University College Dublin*

Network operators are struggling to cope with exponentially increasing demand. Capacity can be increased by densifying existing Macro Cell deployments with Small Cells. The resulting two-tiered architecture is known as a Heterogeneous Network or 'HetNet'. Significant inter-tier interference in channel sharing HetNets is managed by resource interleaving in the time domain. A key task in this regard is scheduling User Equipment to receive data at Small Cells. Grammar-based Genetic Programming (GBGP) is employed to evolve models that map measurement reports to schedules on a millisecond timescale. Two different fitness functions based on evaluative and instructive feedback are compared. The former expresses an industry standard utility of downlink rates. Instructive feedback is obtained by computing highly optimised schedules offline using a Genetic Algorithm, which then act as target semantics for evolving models. This paper also compares two schemes for mapping the GBGP parse trees to Boolean schedules. Simulations show that the proposed system outperforms a state of the art benchmark and is within 17% of the estimated theoretical optimum. The impressive performance of GBGP illustrates an opportunity for the further use of evolutionary techniques in software-defined wireless communications networks.

Benchmarks for the Coal Processing and Blending Problem

Sven Schellenberg, *RMIT University*, Xiaodong Li, *RMIT University*, Zbigniew Michalewicz, *University of Adelaide*

In this paper we present a challenging problem that many decision makers in coal mining industry face. The coal processing and blending problem (CPBP) builds upon the traditional blending problem known in operations research (OR) by including decision variables around coal processing, novel constraints as well as arbitrary user-defined profit functions which express price bonuses and penalties. The added complexity turns the traditional blending problem into a challenging black-box optimisation problem. We give an informal and mathematical description of this problem and present nine real-world problem instances as benchmark. Finally, we provide preliminary results for solving the problem by using a Genetic Algorithm (GA) and compare the results with those from a commercial Linear Programming (LP) solver. The results show that the GA significantly outperforms the LP solver in many problem instances while being marginally worse in others.

Fine Tuning of Traffic in our Cities with Smart Panels: The Quito City Case Study

Daniel H. Stolfi, *University of Malaga*, Rolando Armas, *Shinshu University*, Enrique Alba Torres, *University of Malaga*, Hernan E. Aguirre, *Shinshu University*, Kiyoshi Tanaka, *Shinshu University*

In this article we work towards the desired future smart city in which IT and knowledge will hopefully provide a highly livable environment for citizens. To this end, we test a new concept based on intelligent LED panels (the Yellow Swarm) to guide drivers when moving through urban streets so as to finally get rid of traffic jams and protect the environment. This is a minimally invasive, low cost idea for the city that needs advanced simulations with real data coupled with new algorithms which perform well. Our proposal is to use evolutionary computation in the Yellow Swarm, which will finally help alleviate the traffic congestion, improve travel times, and decrease gas emissions, all at the same time and for a real case like the city of Quito (Ecuador).

Session: RWA2
Friday, July 22, 14:00-15:40, Mesa Verde B

Fast and Effective Optimisation of Arrays of Submerged Wave Energy Converters

Junhua Wu, *The University of Adelaide*, Slava Shekh, *The University of Adelaide*, Nataliia Y. Sergiienko, *The University of Adelaide*, Benjamin S. Cazzolato, *The University of Adelaide*, Boyin Ding, *The University of Adelaide*, Frank Neumann, *The University of Adelaide*, Markus Wagner, *The University of Adelaide*

Renewable forms of energy are becoming increasingly important to consider, as the global energy demand continues to grow. Wave energy is one of these widely available forms, but it is largely unexploited. A common design for a wave energy converter is called a point absorber or buoy. The buoy typically floats on the surface or just below the surface of the water, and captures energy from the movement of the waves. It can use the motion of the waves to drive a pump to generate electricity and to create potable water. Since a single buoy can only capture a limited amount of energy, large-scale wave energy production necessitates the deployment of buoys in large numbers called arrays. However, the efficiency of arrays of buoys is affected by highly complex intra-buoy interactions. The contributions of this article are two-fold. First, we present an approximation of the buoy interactions model that results in a 350-fold computational speed-up to enable the use inside of iterative optimisation algorithms, Second, we study arrays of fully submerged three-tether buoys, with and without shared mooring points.

Evolutionary Feature Subset Selection with Compression-based Entropy Estimation

Pavel Krömer, *VSB - Technical University of Ostrava*, Jan Platoš, *VSB - Technical University of Ostrava*

Modern massive data sets often comprise of millions of records and thousands of features. Their efficient processing by traditional methods represents an increasing challenge. Feature selection methods form a family of traditional instruments for data dimensionality reduction. They aim at selecting subsets of data features so that the loss of information, contained in the full data set, is minimized. Evolutionary feature selection methods have shown good ability to identify feature subsets in very-high-dimensional data sets. Their efficiency depends, among others, on a particular optimization algorithm, feature subset representation, and objective function definition. In this paper, two evolutionary methods for fixed-length subset selection are employed to find feature subsets on the basis of their entropy, estimated by a fast data compression algorithm. The reasonability of the fitness criterion, ability of the investigated methods to find good feature subsets, and the usefulness of selected feature subsets for practical data mining, is evaluated using two well-known data sets and several widely-used classification algorithms.

Finding Interactions or Relationships between Customer Orders for Building Better Batches by Means of an Estimation of Distribution Algorithm-based Approach for the Online Order Batching Problem

Ricardo Pérez-Rodríguez, *CIMAT, AC*, Arturo Hernández-Aguirre, *CIMAT, AC*

Order-picking systems are very common in industry. In this warehouse environment an order batching consists of combining customer orders into picking orders. Order batching is a combinatorial issue because many customer orders arrive throughout the scheduling in real-world situations, therefore to find interactions or relationships between orders for building better batches is a difficult task. This paper introduces an estimation of distribution algorithm-based approach for the online order batching problem to guide the overall search process. The results show how the warehouse performance is improved by estimating relationships between orders. This approach is compared with others published in the literature.

Planning Habitat Restoration with Genetic Algorithms

Jana Brotankova, *James Cook University*, Tommaso Urli, *NICTA / CSIRO Data61*, Philip Kilby, *NICTA / CSIRO Data61 & the Australian National University*

Conservation is an ethic of sustainable use of natural resources which focuses on the preservation of biodiversity. The term conservation planning encompasses the set of activities, typically carried out by conservation managers, that contribute to the attainment of this goal. Such activities can be preventive, such as the establishment of conservation reserves, or remedial, such as the displacement (or offsetting) of the species to be protected or the culling of invasive species. This last technique is often referred to as habitat restoration and, because of its lower impact on economic activities, is becoming more and more popular among conservation managers. In this paper we present the original formulation of the habitat restoration planning (HRP) problem, which captures some of the decisions and constraints faced by conservation managers in the context of habitat restoration. Example scenarios are drawn from the insular Great Barrier Reef (QLD) and Pilbara (WA) regions of Australia. In addition to the problem formulation, we describe an optimisation solver for the HRP, based on genetic algorithms (GAs), we discuss the preliminary results obtained by our solver, and we outline the current and future directions for the project.

Session: RWA3
Friday, July 22, 16:10-17:50, Mesa Verde B

Evolutionary Design of Fast High-quality Hash Functions for Network Applications

David Grochol, *Brno University of Technology*, Lukas Sekanina, *Brno University of Technology*

High speed networks operating at 100 Gbps pose many challenges for hardware and software involved in the packet processing. As the time to process one packet is very short the corresponding operations have to be optimized in terms of the execution time. One of them is non-cryptographic hashing implemented in order to accelerate traffic flow identification. In this paper, a method based on linear genetic programming is presented, which is capable of evolving high-quality hash functions primarily optimized for speed. Evolved hash functions are compared with conventional hash functions in terms of accuracy and execution time using real network data.

Multiobjective Neuroevolutionary Control for a Fuel Cell Turbine Hybrid Energy System

Mitchell Colby, *Oregon State University*, Logan Yliniemi, *University of Nevada, Reno*, Paolo Pezzini, *Ames National Laboratory*, David Tucker, *National Energy Technology Laboratories*, Kenneth "Mark","Bryden kmbryden@iastate.edu, *Ames*, Kagan Tumer, *Oregon State University*

Increased energy demands are driving the development of new power generation technologies with high efficient. Direct fired fuel cell turbine hybrid systems are one such development, which have the potential to dramatically increase power generation efficiency, quickly respond to transient loads (and are generally flexible), and offer fast start up times. However, traditional control techniques are often inadequate in these systems because of extremely high nonlinearities and coupling between system parameters. In this work, we develop multi-objective neural network controller via neuroevolution and the Pareto Concavity Elimination Transformation (PaCcET). In order for the training process to be computationally tractable, we develop a computationally efficient plant simulator based on physical plant data, allowing for rapid fitness assignment. Results demonstrate that the multi-objective algorithm is able to develop a Pareto front of control policies which represent tradeoffs between tracking desired turbine speed profiles and minimizing transient operation

of the fuel cell.

Neuroevolution of a Hybrid Power Plant Simulator

Shauharda Khadka, *Oregon State University*, Kagan Tumer, *Oregon State University*, Mitchell Colby, *Oregon State University*, David Tucker, *NETL*, Paolo Pezzini, *AMES Laboratory*, Kenneth Bryden, *AMES Laboratory*

Ever increasing energy demands are driving the development of high-efficiency power generation technologies such as direct-fired fuel cell turbine hybrid systems. Due to lack of an accurate system model, high nonlinearities and high coupling between system parameters, traditional control strategies are often inadequate. To resolve this problem, learning based controllers trained using neuroevolution are currently being developed. In order for the neuroevolution of these controllers to be computationally tractable, a computationally efficient simulator of the plant is required. Despite the availability of real-time sensor data from a physical plant, supervised learning techniques such as backpropagation are deficient as minute errors at each step tend to propagate over time. In this paper, we implement a neuroevolutionary method in conjunction with backpropagation to ameliorate this problem. Furthermore, a novelty search method is implemented which is shown to diversify our neural network based-simulator, making it more robust to local optima. Results show that our simulator is able to achieve an overall average error of 0.39% and a maximum error of 1.26% for any state variable averaged over the time-domain simulation of the hybrid power plant.

Grammatical Evolution Enhancing Simulated Annealing for the Load Balancing Problem in Cloud Computing

Nasser R. Sabar, *RMIT university* , Andy Song, *RMIT university*

Load balancing (LB) is crucial in the field of cloud computing. LB is to find the optimum allocation of services onto a set of machines so the machine usage can be maximised. This paper proposes a new method for LB, simulated annealing (SA) enhanced by grammatical evolution (GE). SA is a well-known stochastic optimisation algorithm that has good performance on a range of problems including loading balancing. However the success of SA often relies on a key parameter known as the cooling schedule and the type of the utilised neighbourhood structure. Both the parameter and the structure of SA are problem specific. They need to be manually adjusted to fit the problem in hand. In addition different stages of the search process may have different optimal parameter values. To address these issues, a grammar evolution approach is introduced to adaptively evolve the cooling schedule parameter and neighbourhood structures. The proposed method can adjust SA parameter and structure based on the landscape of the current search state so high quality solutions can be found more quickly. The effectiveness of the proposed GE method is demonstrated on the Google machine reassignment problem, which is a typical LB problem, proposed for the ROADEF/EURO 2012 challenge. Experimental results show that our GE enhanced SA is highly competitive compared to state-of-the-art algorithms.

Session: RWA4+IGEC1
Saturday, July 23, 10:40-12:20, Wind River A

A Sparse Recurrent Neural Network for Trajectory Prediction of Atlantic Hurricanes

Mina Moradi Kordmahalleh, *North Carolina A&T State University*, Mohammad Gorji Sefidmazgi, *North Carolina A&T State University*, Abdollah Homaifar, *North Carolina A&T State University*

Hurricanes constitute major natural disasters that lead to destruction and loss of lives. Therefore, to reduce economic loss and to save human lives, an accurate forecast of hurricane occurrences is crucial. Despite the availability of data and advanced forecasting techniques, there is a need for effective methods with higher accuracy of prediction. We propose a sparse Recurrent Neural Network (RNN) with flexible topology for trajectory prediction of the Atlantic hurricanes. Topology of the RNN along with the strength of the connections are evolved by a customized Genetic Algorithm. The network is particularly suitable for modeling of hurricanes which have complex systems with unknown dynamics. For prediction of the future trajectories of a target hurricane, the Dynamic Time Warping (DTW) distances between direction of the target hurricane over time, and other hurricanes in the dataset are determined and compared. The most similar hurricanes to the target hurricane are then used for training of the network. Comparisons between the actual tracks of the hurricanes DEAN, SANDY, ISSAC and HUMBERTO, and the generated predictions by the sparse RNN for one and two steps ahead of time show that our approach is quite promising for this aim.

Selection of a DFO Method for the Efficient Solution of Continuous Constrained Sub-Problems within a Memetic Algorithm for Chemical Process Synthesis

Maren Urselmann, *TU Dortmund University*, Christophe Foussette, *divis intelligent solutions GmbH*, Tim Janus, *TU Dortmund University*, Stephen Tlatlik, *SUPREN GmbH*, Axel Gottschalk, *Bremerhaven University of Applied Sciences*, Michael T.M. Emmerich, *LIACS, Leiden University*, Sebastian Engell, *TU Dortmund University*, Thomas Bäck, *LIACS, Leiden University*

In this contribution a derivative-free memetic algorithm (MA) for the design optimization of chemical processes is introduced. Design optimization problems are characterized by nonlinear cost functions and highly constrained and multi-modal search spaces. The MA is a combination of an evolution strategy that addresses the global optimization of discrete and continuous design decisions and a derivative-free optimization method (DFO) that performs a local optimization of the continuous sub-

problems that remain after fixing the discrete decisions. The MA calls a process simulation software to simulate the design alternatives, i.e. the evaluation of the objective and the constraints is a black box. In this contribution, the focus lies on the selection of a suitable DFO solver for efficiently solving the continuous constrained sub-problems. Based on latin-hypercube samplings of sub-problems of two instances of a real-world case study, surrogate models for the objective and the constraints were generated. A set of DFO methods was tested and compared on the surrogate models. The method that showed the best performance was coupled to the MA which was then applied to the real-world case study.

A Hybrid Multi-Population Genetic Algorithm for UAV Path Planning

Márcio da Silva Arantes, *University of São Paulo*, Jesimar da Silva Arantes, *University of São Paulo*, Claudio Fabiano Motta Toledo, *University of São Paulo*, Brian C. Williams, *Massachusetts Institute of Technology*

This paper proposes a hybrid method to define a path planning for unmanned aerial vehicles in a non-convex environment with uncertainties. The environment becomes non-convex by the presence of no-fly zones such as mountains, cities and airports. Due to the uncertainties related to the path planning in real situations, risk of collision can not be avoided. Therefore, the planner must take into account a lower level of risk than one tolerated by the user. The proposed hybrid method combines a multi-population genetic algorithm with visibility graph. This is done by encoding all possible paths as individuals and solving a linear programming model to define the full path to be executed by the aircraft. The hybrid method is evaluated from a set of 50 maps and compared against an exact and heuristic approaches with promising results reported.

Session: Best Paper: RWA
Saturday, July 23, 14:00-15:40, Chasm Creek A

A Real World Multi-UAV Evolutionary Planner for Minimum Time Target Detection

Sara Perez-Carabaza, *Universidad Complutense Madrid*, Eva Besada-Portas, *Universidad Complutense Madrid*, Jose A. Lopez-Orozco, *Universidad Complutense Madrid*, Jesus M. de la Cruz, *Universidad Complutense Madrid*

This paper presents a new evolutionary planner for optimizing the input commands of multiple Unmanned Aircraft Vehicles (UAVs) in target search missions. This planner minimizes the target detection time and maximizes the UAVs performance, given 1) the uncertainty in the target location and sensor information, and 2) the UAV motion and sensorial payload models. On one hand, it calculates the detection time related criteria using Bayesian theory to handle the uncertainty of the problem. On the other hand, it measures the UAVs performance against a real kinematic model that takes into account some environmental effects. Besides, it exploits the typical versatility and good performance of evolutionary algorithms to tackle this search problem as a multi-objective and multi-stepped receding horizon controller, capable of providing acceptable long term (less-myopic) decisions due to a novel optimization criterium that weights the future expected observations with the UAV manoeuvrability constraints. All these properties let it handle successfully the minimum time target detection task in real world scenarios, as the results analyzed in this paper, obtained over different setups, show.

Tackling the IFP Problem with the Preference-Based Genetic Algorithm

Sune S. Nielsen, *University of Luxembourg*, Christof Ferreira Torres, *University of Luxembourg*, Grégoire Danoy, *University of Luxembourg*, Pascal Bouvry, *University of Luxembourg*

In molecular biology, the subject of protein structure prediction is of continued interest, not only to chart the molecular map of living cells, but also to design proteins with new functions. The Inverse Folding Problem (IFP) of finding sequences that fold into a defined structure is in itself an important research problem at the heart of rational protein design. In this work the Preference-Based Genetic Algorithm (PBGA) is employed to find many diversified solutions to the IFP. The PBGA algorithm incorporates a weighted sum model in order to combine fitness and diversity into a single objective function scoring a set of individuals as a whole. By adjusting the sum weights, a direct control of the fitness vs. diversity trade-off in the algorithm population is achieved by means of a selection scheme iteratively removing the least contributing individuals. Experimental results demonstrate the superior performance of the PBGA algorithm compared to other state-of-the-art algorithms both in terms of fitness and diversity.

Planning Inspection Paths through Evolutionary Multi-objective Optimization

Kai Olav Ellefsen, *SENAI CIMATEC*, Herman A. Lepikson, *SENAI CIMATEC*, Jan C. Albiez, *SENAI CIMATEC & DFKI GmbH*

We propose a new method for planning paths allowing the inspection of complex 3D structures, given a triangular mesh model of the structure. The method differs from previous approaches in its emphasis on generating and considering also plans that result in imperfect coverage of the inspection target. In many practical tasks, one would accept imperfections in coverage if this results in a substantially more energy efficient inspection path. We therefore apply an evolutionary multi-objective optimization algorithm to the problem – which generates a set of solutions exploring the different ways to balance energy usage and coverage degree. To our knowledge, this is the first work that exploits the power of multiobjective evolution to explore the set of inspection plans that result in the most energy-efficient coverage of structures. The performance of the optimizer is

demonstrated on a model of a subsea oilfield installation – a type of structure that has many occluded and hidden parts, and that therefore illustrates the need for a method accepting imperfectly covering solutions.

Finding Reliable Solutions in Bilevel Optimization Problems Under Uncertainties

Zhichao Lu, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*, Ankur Sinha, *Indian Institute of Management*

Bilevel optimization problems are referred to as having a nested inner optimization problem as a constraint to a outer optimization problem in the domain of mathematical programming. It is also known as Stackelberg problems in game theory. In the recent past, bilevel optimization problems have received a growing attention because of its relevance in practice applications. However, the hierarchical structure makes these problems difficult to handle and they are commonly optimized with a deterministic setup. With presence of constrains, bilevel optimization problems are considered for finding reliable solutions which are subjected to a possess a minimum reliability requirement under decision variable uncertainties. Definition of reliable bilevel solution, the effect of lower and upper level uncertainties on reliable bilevel solution, development of efficient reliable bilevel evolutionary algorithm, and supporting simulation results on test and engineering design problems amply demonstrate their further use in other practical bilevel problems.

Session: ECOM3+RWA5
Saturday, July 23, 16:10-17:50, Wind River A

Grammatical Evolutionary Techniques for Prompt Migraine Prediction

Josué Pagán, *University of Madrid*, José L. Risco-Martín, *University of Madrid*, José M. Moya, *University of Madrid*, José L. Ayala, *University of Madrid*

The migraine disease is a chronic headache presenting symptomatic crisis that causes high economic costs to the national health services, and impacts negatively on the quality of life of the patients. Even if some patients can feel unspecific symptoms before the onset of the migraine, these only happen randomly and cannot predict the crisis precisely. In our work, we have proved how migraine crisis can be predicted with high accuracy from the physiological variables of the patients, acquired by a non-intrusive Wireless Body Sensor Network. In this paper, we derive alternative models for migraine prediction using Grammatical Evolution techniques. We obtain prediction horizons around 20 minutes, which are sufficient to advance the drug intake and avoid the symptomatic crisis. The robustness of the models with respect to sensor failures has also been tackled to allow the practical implementation in the ambulatory monitoring platform. The achieved models are non linear mathematical expressions with low computing overhead during the run-time execution in the wearable devices.

New Bounds for Office Space Allocation using Tabu Search

Francisco Castillo, *Universidad Tecnica Federico Santa Maria*, María-Cristina Riff, *Universidad Tecnica Federico Santa Maria*, Elizabeth Montero, *Universidad Tecnica Federico Santa Maria*

The Office Space Allocation problem is a combinatorial optimization problem which focuses into determining the way to assign spaces to entities in order to optimize the use of available space in an organization. This allocation process considers a set of preferences, constraints and requirements. In this paper we propose a metaheuristic approach that includes a construction step and an improvement step, based on Greedy and Tabu Search techniques respectively. Here, we propose a construction method specially designed to deal with the misused space and hard/soft constraints of the problem. Then, Tabu Search performs a fast analysis that allows it to find good quality neighborhoods to analyze. We used an automated tuning method to determine the best parameter values for the entire set of benchmarks. Results show that our approach was able to obtain new lower bounds for seven problem instances.

Session: RWA6
Sunday, July 24, 09:00-10:40, Wind River A

Measuring Source Code Similarity by Finding Similar Subgraph with an Incremental Genetic Algorithm

Jinhyun Kim, *Seoul National University*, HyukGeun Choi, *Seoul National University*, Hansang Yun, *Seoul National University*, Byung-Ro Moon, *Seoul National University*

Measuring similarity between source codes has lots of applications, such as code plagiarism detection, code clone detection, and malware detection. A variety of methods for the measurement have been developed and program-dependence-graph based methods are known to be well working against disguise techniques. But these methods usually rely on solving NP-hard problems which cause a scalability issue. In this paper, we propose a genetic algorithm to measure the similarity between two codes by solving an error correcting subgraph isomorphism problem on dependence graphs. We propose a new cost function for this problem, which reflects the characteristic of the source codes. An incremental genetic algorithm is used to solve the problem. The size of the graph to be searched is gradually increasing during the evolutionary process. We developed new operators for the algorithm, and the overall system is tested on some real world data. Experimental results showed that the system successfully works on code plagiarism detection and malware detection. The similarity computed by the system turned out to reflect the similarity between the codes properly.

Artificial Multi-Bee-Colony Algorithm for k-Nearest-

Neighbor Fields Search

Yunhai Wang, *Shandong University*, Yiming Qian, *University of Alberta*, Yang Li, *Memorial University* , Minglun Gong, *Memorial University* , Wolfgang Banzhaf, *Memorial University*

Searching the k-nearest matching patches for each patch in an input image, i.e., computing the k-nearest-neighbor fields (k-NNF), is a core part of various computer vision/graphics algorithms. In this paper, we show that k-NNF can be efficiently computed using a novel artificial multi-bee-colony (AMBC) algorithm, where each patch uses a dedicated bee colony to search for its k-nearest matches. As a population-based algorithm, AMBC is capable of escaping local optima. The added communication among different colonies further allows good matches to be quickly propagated across the image. In addition, AMBC makes no assumption about the neighborhood structure or communication direction, making it directly applicable to image sets and suitable for parallel processing. Quantitative evaluations show that AMBC can find solutions that are much closer to the ground truth than the generalized PatchMatch algorithm does. It also outperforms the PatchMatch Graph over image sets.

Evolutionary Multiobjective Optimization of Winglets

Mateus A. M. Teixeira, *Duke University*, Fillipe Goulart, *Universidade Federal de Minas Gerais*, Felipe Campelo, *Universidade Federal de Minas Gerais*

Evolutionary multiobjective optimization is employed for designing the geometric configurations of winglets adapted to a base wing. Seven decision variables are employed for the winglet parameterization, and the wing-winglet transition region is modeled using Bézier surfaces. A case study is presented to illustrate the application of this technique to the design of wingtip devices. The optimization model includes two objectives: the ratio of drag-lift coefficients, and the wing root bending moment coefficient. The solutions obtained are discussed, and a Monte Carlo sensitivity analysis is performed to test the robustness of the results to uncertainties in the variables. Finally, a winglet geometry is suggested to be retrofitted to the base wing, providing an increased lift to drag ratio at the expense of increasing the root bending moment of the wing.

A Genetic Decomposition Algorithm for Predicting Rainfall within Financial Weather Derivatives

Sam Cramer, *University of Kent*, Michael Kampouridis, *University of Kent*, Alex Freitas, *University of Kent*

Regression problems provide some of the most challenging research opportunities, where the predictions of such domains are critical to a specific application. Problem domains that exhibit large variability and are of chaotic nature are the most challenging to predict. Rainfall being a prime example, as it exhibits very unique characteristics that do not exist in other time series data. Moreover, rainfall is essential for applications that surround financial securities such as rainfall derivatives. This paper is interested in creating a new methodology for increasing the predictive accuracy of rainfall within the problem domain of rainfall derivatives. Currently, the process of predicting rainfall within rainfall derivatives is dominated by statistical models, namely Markov-chain extended with rainfall prediction (MCRP). In this paper, we propose a novel algorithm for decomposing rainfall, which is a hybrid Genetic Programming/Genetic Algorithm (GP/GA) algorithm. Hence, the overall problem becomes easier to solve. We compare the performance of our hybrid GP/GA, against MCRP, Radial Basis Function and GP without decomposition. We aim to show the effectiveness that a decomposition algorithm can have on the problem domain. Results show that in general decomposition has a very positive effect by statistically outperforming GP without decomposition and MCRP.

Search Based Software Engineering and Self-* Search

Session: Best Papers: DETA+PES+SBS-SS
Friday, July 22, 10:40-12:20, Chasm Creek B

Learning Overtime Dynamics Through Multiobjective Optimization

Marcio de O. Barros, *Federal University of the State of Rio de Janeiro*, Luiz Antonio O. de Araujo Jr, *Federal University of the State of Rio de Janeiro*

IT professionals are frequently subject to working overtime, even knowing that excessive overtime has negative effects both on their lives and the software they produce. This contrast creates the need for overtime policies that attend to the demands of a project using as few overtime hours as possible. However, our knowledge about the dynamics of overtime work and the effects of distinct policies on a software project is limited. In this paper we introduce a formulation for the overtime planning problem which extends the state-of-art by considering both the positive effects of overtime on productivity and its negative effects on product quality. We use heuristic search to explore close to optimal overtime allocations under this formulation and report lessons learned by analyzing these allocations. We present an empirical study that compares our approach with practices from the industry and a similar formulation without negative effects. Evidence supports the industrial practice of concentrating overtime in the second half of a project's schedule. Results also show that ignoring the flip-side of the productivity gains brought

by overtime may lead to wrong decisions. For instance, excessive overtime may lead a manager to underestimate project cost and duration by 5.9% and 9.2%, respectively.

Search-Based Cost-Effective Test Case Selection within a Time Budget: An Empirical Study

Dipesh Pradhan, *Simula Research Laboratory*, Shuai Wang, *Simula Research Laboratory*, Shaukat Ali, *Simula Research Laboratory*, Tao Yue, *Simula Research Laboratory/ University of Oslo*

Due to limited time and resources available for execution, test case selection always remains crucial for cost-effective testing. It is even more prominent when test cases require manual steps, e.g., operating physical equipment. Thus, test case selection must consider complicated trade-offs between cost (e.g., execution time) and effectiveness (e.g., fault detection capability). Based on our industrial collaboration within the Maritime domain, we identified a real-world and multi-objective test case selection problem in the context of robustness testing, where test case execution requires human involvement in certain steps, such as turning on the power supply to a device. The high-level goal is to select test cases for execution within a given time budget, where test engineers provide weights for a set of objectives, depending on testing requirements, standards, and regulations. To address the identified test case selection problem, we defined a fitness function including one cost measure, i.e., Time Difference (TD) and three effectiveness measures, i.e., Mean Priority (MPR), Mean Probability (MPO) and Mean Consequence (MC) that were identified together with test engineers. We further empirically evaluated eight multi-objective search algorithms, which include three weight-based search algorithms (e.g., Alternating Variable Method) and five Pareto-based search algorithms (e.g., Strength Pareto Evolutionary Algorithm 2 (SPEA2)) using two weight assignment strategies (WASs). Notice that Random Search (RS) was used as a comparison baseline. We conducted two sets of empirical evaluations: 1) Using a real world case study that was developed based on our industrial collaboration; 2) Simulating the real world case study to a larger scale to assess the scalability of the search algorithms. Results show that SPEA2 with either of the WASs performed the best for both the studies. Overall, SPEA2 managed to improve on average 32.7%, 39% and 33% in terms of MPR, MPO and MC respectively as compared to RS.

Session: SBS-SS1
Friday, July 22, 16:10-17:50, Wind River A

Grammatical Evolution for the Multi-Objective Integration and Test Order Problem

Thainá Mariani, *Federal University of Paraná*, Giovani Guizzo, *Federal University of Paraná*, Silvia R. Vergilio, *Federal University of Paraná*, Aurora T. R. Pozo, *Federal University of Paraná*

Search techniques have been successfully applied for solving different software testing problems. However, choosing, implementing and configuring a search technique can be hard tasks. To reduce efforts spent in such tasks, this paper presents an offline hyper-heuristic named GEMOITO, based on Grammatical Evolution (GE). The goal is to automatically generate a Multi-Objective Evolutionary Algorithm (MOEA) to solve the Integration and Test Order (ITO) problem. The MOEAs are distinguished by components and parameters values, described by a grammar. The proposed hyper-heuristic is compared to conventional MOEAs and to a selection hyper-heuristic used in related work. Results show that GEMOITO can generate MOEAs that are statistically better or equivalent to the compared algorithms.

A Search-based Training Algorithm for Cost-aware Defect Prediction

Annibale Panichella, *Delft University of Technology*, Carol V. Alexandru, *University of Zurich*, Sebastiano Panichella, *University of Zurich*, Alberto Bacchelli, *Delft University of Technology*, Harald C. Gall, *University of Zurich*

Research has yielded approaches to predict future defects in software artifacts based on historical information, thus assisting companies in effectively allocating limited development resources and developers in reviewing each others' code changes. Developers are unlikely to devote the same effort to inspect each software artifact predicted to contain defects, since the effort varies with the artifacts' size (cost) and the number of defects it exhibits (effectiveness). We propose to use Genetic Algorithms (GAs) for training prediction models to maximize their cost-effectiveness. We evaluate the approach on two well-known models, Regression Tree and Generalized Linear Model, and predict defects between multiple releases of six open source projects. Our results show that regression models trained by GAs significantly outperform their traditional counterparts, improving the cost-effectiveness by up to 240%. Often the top 10% of predicted lines of code contain up to twice as many defects.

A Combined Generative and Selective Hyper-heuristic for the Vehicle Routing Problem

Kevin Sim, *Edinburgh Napier University*, Emma Hart, *Edinburgh Napier University*

Hyper-heuristic methods for solving vehicle routing problems (VRP) have proved promising on a range of data. The vast majority of approaches apply selective hyper-heuristic methods that iteratively choose appropriate heuristics from a fixed set of predefined low-level heuristics to either build or perturb a candidate solution. We propose a novel hyper-heuristic called GP-MHH that operates in two stages. The first stage uses a novel Genetic Programming (GP) approach to evolve high quality constructive heuristics; these can be used with any existing method that relies on a candidate solution(s) as its starting point. In the second stage, a perturbative hyper-heuristic is applied to candidate solutions created from the new heuristics. The new constructive heuristics are shown to outperform existing low-level heuristics.

When combined with a naive perturbative hyper-heuristic they provide results which are both competitive with known optimal values and outperform a recent method that also designs new heuristics on some standard benchmarks. Finally, we provide results on a set of rich VRPs, showing the generality of the approach.

Test Case Prioritization of Configurable Cyber-Physical Systems with Weight-Based Search Algorithms

Aitor Arrieta, *Mondragon Unibertsitatea*, Shuai Wang, *Simula Research Laboratory*, Goiuria Sagardui, *Mondragon Unibertsitatea*, Leire Etxeberria, *Mondragon Unibertsitatea*

Cyber-Physical Systems (CPSs) can be found in many sectors (e.g., automotive and aerospace). These systems are usually configurable to give solutions based on different needs. The variability of these systems is large, which implies they can be set into millions of configurations. As a result, different testing processes are needed to efficiently test these systems: the appropriate configurations must be selected and relevant test cases for each configuration must be chosen as well as prioritized. Prioritizing the order in which the test cases are executed reduces the time for detecting faults in these kinds of systems. However, the test suite size is often large and exploring all the possible test case orders is infeasible. Search algorithms can help find optimal solutions from a large solution space. This paper presents an approach based on weight-based search algorithms for prioritizing the test cases for configurable CPSs. We empirically evaluate the performance of the following algorithms with two case studies: Weight-Based Genetic Algorithms, Random Weighted Genetic Algorithms, Greedy, Alternating Variable Method and Random Search (RS). Our results suggest that all the search algorithms outperform RS, which is taken as a baseline. Local search algorithms have shown better performance than global search algorithms.

Theory

Session: Best Papers: CO+THEORY+ACO-SI
Friday, July 22, 10:40-11:55, Chasm Creek A

The (1+1) Elitist Black-Box Complexity of LeadingOnes

Carola Doerr, *CNRS & Univ. Pierre et Marie Curie*, Johannes Lengler, *ETH Zurich*

One important goal of black-box complexity theory is the development of complexity models allowing to derive meaningful lower bounds for whole classes of randomized search heuristics. Complementing classical runtime analysis, black-box models help us understand how algorithmic choices such as the population size, the variation operators, or the selection rules influence the optimization time. One example for such a result is the $\Omega(n \log n)$ lower bound for unary unbiased algorithms on functions with a unique global optimum [Lehre/Witt, GECCO 2010], which tells us that higher arity operators or biased sampling strategies are needed when trying to beat this bound. In lack of analyzing techniques, almost no non-trivial bounds are known for other restricted models. Proving such bounds therefore remains to be one of the main challenges in black-box complexity theory. With this paper we contribute to our technical toolbox for lower bound computations by proposing a new type of information-theoretic argument. We regard the permutation- and bit-invariant version of LEADINGONES and prove that its (1+1) elitist black-box complexity is $\Omega(n^2)$, a bound that is matched by (1+1)-type evolutionary algorithms. The (1+1) elitist complexity of LEADINGONES is thus considerably larger than its unrestricted one, which is known to be of order $n \log \log n$ [Afshani et al., 2013].

Session: THEORY1
Friday, July 22, 14:00-15:40, Wind River B

The Right Mutation Strength for Multi-Valued Decision Variables

Benjamin Doerr, *Ecole Polytechnique*, Carola Doerr, *Université Pierre et Marie Curie - Paris 6*, Timo Kötzing, *Hasso-Plattner-Institut*

The most common representation in evolutionary computation are bit strings. This is ideal to model binary decision variables, but less useful for variables taking more values. With very little theoretical work existing on how to use evolutionary algorithms for such optimization problems, we study the run time of simple evolutionary algorithms on some OneMax-like functions defined over $\Omega = \{0, 1, \dots, r-1\}^n$. More precisely, we regard a variety of problem classes requesting the component-wise minimization of the distance to an unknown target vector $z \in \Omega$. For such problems we see a crucial difference in how we extend the standard-bit mutation operator to these multi-valued domains. While it is natural to select each position of the solution vector to be changed independently with probability $1/n$, there are various ways to then change such a position. If we change each selected position to a random value different from the original one, we obtain an expected run time of $\Theta(nr \log n)$. If we change each selected position by either $+1$ or -1 (random choice), the optimization time reduces to $\Theta(nr + n \log n)$. If we use a random mutation strength $i \in \{0, 1, \dots, r-1\}^n$ with probability inversely proportional to i and change the selected position by either $+i$ or $-i$ (random choice), then the optimization time

becomes $\Theta(n \log(r)(\log(n) + \log(r)))$, bringing down the dependence on r from linear to polylogarithmic. One of our results depends on a new variant of the lower bounding multiplicative drift theorem.

When Non-Elitism Outperforms Elitism for Crossing Fitness Valleys

Pietro S. Oliveto, *University of Sheffield*, Tiago Paixão, *IST Austria*, Jorge Pérez Heredia, *University of Sheffield*, Dirk Sudholt, *University of Sheffield*, Barbora Trubenová, *IST Austria*

Crossing fitness valleys is one of the major obstacles to function optimization. In this paper we investigate how the structure of the fitness valley, namely its depth d and length ℓ, influence the runtime of different strategies for crossing these valleys. We present a runtime comparison between the (1+1) EA and two non-elitist nature-inspired algorithms, Strong Selection Weak Mutation (SSWM) and the Metropolis algorithm. While the (1+1) EA has to jump across the valley to a point of higher fitness because it does not accept decreasing moves, the non-elitist algorithms may cross the valley by accepting worsening moves. We show that while the runtime of the (1+1) EA algorithm depends critically on the length of the valley, the runtimes of the non-elitist algorithms depend crucially only on the depth of the valley. In particular, the expected runtime of both SSWM and Metropolis is polynomial in ℓ and exponential in d while the (1+1) EA is efficient only for valleys of small length. Moreover, we show that both SSWM and Metropolis can also efficiently optimize a rugged function consisting of consecutive valleys.

Optimal Mutation Rates for the (1+λ) EA on OneMax

Christian Gießen, *Technical University of Denmark*, Carsten Witt, *Technical University of Denmark*

We study the (1+λ) EA with mutation probability c/n, where $c > 0$ is a constant, on the OneMax problem. Using an improved variable drift theorem, we show that upper and lower bounds on the expected runtime of the (1+λ) EA obtained from variable drift theorems are at most apart by a small lower order term if the exact drift is known. This reduces the analysis of expected optimization time to finding an exact expression for the drift. We then give an exact closed-form expression for the drift and develop a method to approximate it very efficiently, enabling us to determine approximate optimal mutation rates for the (1+λ) EA for various parameter settings of c and λ and also for moderate sizes of n. This makes the need for potentially lengthy and costly experiments in order to optimize the parameters unnecessary. Interestingly, even for moderate n and not too small λ it turns out that mutation rates up to 10% larger than the asymptotically optimal rate $1/n$ minimize the expected runtime. However, in absolute terms the expected runtime does not change by much when replacing $1/n$ with the optimal mutation rate.

Noisy Optimization: Fast Convergence Rates with Comparison-Based Algorithms

Marie-Liesse Cauwet, *University Paris-Sud*, Olivier Teytaud, *University Paris-Sud*

Derivative Free Optimization is known to be an efficient and robust method to tackle the black-box optimization problem. When it comes to noisy functions, classical comparison-based algorithms are slower than gradient-based algorithms. For quadratic functions, Evolutionary Algorithms without large mutations have a simple regret at best $O(1/\sqrt{N})$ when N is the number of function evaluations, whereas stochastic gradient descent can reach (tightly) a simple regret in $O(1/N)$. It has been conjectured that gradient approximation by finite differences (hence, not a comparison-based method) is necessary for reaching such a $O(1/N)$. We answer this conjecture in the negative, providing a comparison-based algorithm as good as gradient methods, i.e. reaching $O(1/N)$ - under the condition, however, that the noise is Gaussian. Experimental results confirm the $O(1/N)$ simple regret, i.e., squared rate compared to many published results at $O(1/\sqrt{N})$.

Session: THEORY2
Friday, July 22, 16:10-17:50, Wind Star A

The Impact of Migration Topology on the Runtime of Island Models in Dynamic Optimization

Andrei Lissovoi, *University of Sheffield*, Carsten Witt, *Technical University of Denmark*

We introduce a simplified island model with behavior similar to the λ (1+1) islands optimizing the Maze fitness function, and investigate the effects of the migration topology on the ability of the simplified island model to track the optimum of a dynamic fitness function. More specifically, we prove that there exist choices of model parameters for which using a unidirectional ring as the migration topology allows the model to track the oscillating optimum through n Maze-like phases with high probability, while using a complete graph as the migration topology results in the island model losing track of the optimum with overwhelming probability. Additionally, we prove that if migration occurs only rarely, denser migration topologies may be advantageous. This serves to illustrate that while a less-dense migration topology may be useful when optimizing dynamic functions with oscillating behavior, and requires less problem-specific knowledge to determine when migration may be allowed to occur, care must be taken to ensure that a sufficient amount of migration occurs during the optimization process.

EDAs cannot be Balanced and Stable

Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Martin S. Krejca, *Hasso Plattner Institute*

Estimation of Distribution Algorithms (EDAs) work by iteratively updating a distribution over the search space with the help of samples from each iteration. Up to now, theoretical analyses of EDAs are scarce and present run time results for specific

EDAs. We propose a *new framework* for EDAs that captures the idea of several known optimizers, including PBIL, UMDA, λ-MMAS$_{\text{IB}}$, cGA, and $(1, \lambda)$-EA. Our focus is on analyzing two core features of EDAs: a *balanced* EDA is sensitive to signals in the fitness; a *stable* EDA remains uncommitted under a biasless fitness function. We prove that no EDA can be both balanced and stable. The LEADINGONES function is a prime example where, at the beginning of the optimization, the fitness function shows no bias for many bits. Since many well-known EDAs are balanced and thus not stable, they are not well-suited to optimize LEADINGONES. We give a stable EDA which optimizes LEADINGONES within a time of $\mathrm{O}(n \log n)$.

Optimal Parameter Choices via Precise Black-Box Analysis

Benjamin Doerr, *Ecole Polytechnique*, Carola Doerr, *CNRS and Université Pierre et Marie Curie - Paris 6*, Jing Yang, *Ecole Polytechnique*

In classical runtime analysis it has been observed that certain working principles of an evolutionary algorithm cannot be understood by only looking at the asymptotic order of the runtime, but that more precise estimates are needed. In this work we demonstrate that the same observation applies to black-box complexity analysis. We prove that the unary unbiased black-box complexity of the classic OneMax function class is $n \ln(n) - cn \pm o(n)$ for a constant c between 0.2539 and 0.2665. Our analysis yields a simple (1+1)-type algorithm achieving this runtime bound via a fitness-dependent mutation strength. When translated into a fixed-budget perspective, our algorithm with the same budget computes a solution that asymptotically is 13% closer to the optimum (given that the budget is at least $0.2675n$).

Optimal Parameter Settings for the $(1 + (\lambda, \lambda))$ Genetic Algorithm

Benjamin Doerr, *Ecole Polytechnique*

The $(1 + (\lambda, \lambda))$ genetic algorithm is one of the few algorithms for which a super-constant speed-up through the use of crossover could be proven. So far, this algorithm has been used with parameters based also on intuitive considerations. In this work, we rigorously regard the whole parameter space and show that the asymptotic time complexity on the OneMax test function class proven by Doerr and Doerr (GECCO 2015) for the intuitive choice is best possible among all settings for population size, mutation probability, and crossover bias. Our proofs also give some advice on how to choose the parameters for other optimization problems.

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