Genetic and Evolutionary Computation Conference 2017

Conference Program

Berlin, Germany
July 15-19, 2017

Association for Computing Machinery
Advancing Computing as a Science & Profession

sigevo

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

Welcome

It is my pleasure and honor to welcome you to the Genetic and Evolutionary Computation Conference (GECCO) 2017 in Berlin, Germany, July 15-19, on behalf of the entire organization committee. GECCO is the main conference of the Special Interest Group on Genetic and Evolutionary Computation (SIGEVO) of the Association for Computing Machinery (ACM). GECCO prides itself in being the top quality conference in the area of genetic and evolutionary computation. This quality is ensured by having a selective and thorough reviewing process. Decisions on the acceptance of papers are made by expert track chairs with strong reputations, covering all the key areas in our field.

This year 464 papers were submitted to 13 different tracks, and 1780 reviews were assigned. Approximately 39% of papers have been accepted as full papers, with a further 36% accepted for poster presentation.

I am thrilled that this year we are able to offer an enticing mix of academic and corporate invited keynote presentations by Francesca Ciccarelli of King's College London and The Francis Crick Institute, Drew Purves and Chrisantha Fernando of Google DeepMind, and, for the SIGEVO Chair plenary lecture, Hod Lipson of Columbia University.

Attending GECCO provides an unparalleled opportunity to listen to and interact with the leading experts in our field, to establish new collaborations, and to reunite with well-known friends. On top of that, GECCO this year offers an amazing plethora of 21 workshops and 33 tutorials at no extra charge. Furthermore, with 7 competitions and the annual Humies event sponsored by John Koza, GECCO is sure to present the edge of modern computational possibilities and the latest human competitive results in our field. Finally, GECCO 2017 also brings a few new items to the table such as a job market, a summer school, and a completely new look and feel for the website.

I would like to thank all authors for submitting their excellent work to GECCO 2017 and all people who contributed to the organization of the conference. I am very much in debt to the organization committee, the track chairs, and the reviewers for their tremendous work. GECCO could not happen without the joint and tireless effort of the amazing people that make up the GECCO community.

I would like to specifically mention and thank the editor-in-chief Gabriela Ochoa for the excellent teamwork and Francisco Chicano for the huge job of getting the proceedings together in time. I would also like to mention and thank the core event organization team Cara Candler and Roxane Rose as well as this year's addition Taylor Vick from Executive Events for handling registrations and logistics, and Franz Rothlauf and Marc Schoenauer from SIGEVO for their in-depth knowledge, experience and advice on how to organize a successful GECCO.

On behalf of GECCO I further want to thank our industry sponsors Sentient, Uber AI Labs as well as Springer, Beacon and ACM SIGEVO for their contribution and support.

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

Peter A.N. Bosman
GECCO 2017 General Chair
Centrum Wiskunde & Informatica (CWI)
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Miller, Julian, *University of York*
Minetti, Gabriela, *Universidad Nacional de La Pampa, Facultad de Ingeniería*
Minku, Leandro, *University of Leicester*
Miramontes Hercog, Luis, *Eclectic Systems*
Miranda, Eduardo Reck, *University of Plymouth*
MISIR, Mustafa, *Nanjing University of Aeronautics and Astronautics*
Montemanni, Roberto, *Dalle Molle Institute for Artificial Intelligence*
Montes de Oca, Marco A., *University of Delaware*
Moore, Jason, *University of Pennsylvania*
Mora, Antonio, *Dpto. Arquitectura y Tecnología de Computadores*
Moraglio, Alberto, *University of Exeter*
Moritz, Ruby, *Otto-von-Guericke-Universität Magdeburg*
Moritz, Steffen, *Technische Hochschule Köln*
Mostaghim, Sanaz, *University of Magdeburg*
Mouret, Jean-Baptiste, *Inria / CNRS / UL*
Musliu, Nysret, *Vienna University of Technology*
Nakata, Masaya, *Yokohama National University*
Nakib, Amir, *Laboratoire LISSI*
Nallaperuma, Samadhi, *School of Computer Science, University of Adelaide*
Naujoks, Boris, *TH Köln - University of Applied Sciences*
Nealen, Andy, *NYU*
Neamatian Monemi, Rahimeh, *IFSTTAR*
Nebro, Antonio, *University of Málaga*
Neruda, Roman, *Institute of Computer Science of ASCR*
Neshatian, Kourosh, *Victoria University of Wellington*
Neumann, Frank, *The University of Adelaide*
Nguyen, Quang Uy, *University College Dublin*
Nguyen Xuan, Hoai, *Hanoi University, Vietnam*
Nicolau, Miguel, *University College Dublin*
Nievola, Julio Cesar, *PUCPR*

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, *CSAIL, Massachusetts Institute of Technology*
Ochoa, Gabriela, *University of Stirling*
Ofria, Charles, *Michigan State University*
Olhofer, Markus, *Honda Research Institute Europe GmbH*
Oliveto, Pietro S., *The University of Sheffield*
Oliwa, Tomasz, *University of Chicago*
Olson, Randal S., *University of Pennsylvania*
Ombuki-Berman, Beatrice, *Brock University*
Omidvar, Mohammad Nabi, *University of Birmingham*
Ong, Yew-Soon, *Nanyang Technological University*
Ono, Isao, *Tokyo Institute of Technology*
Ortega, Julio, *University of Granada*
Otero, Fernando, *University of Kent*
Ouni, Ali, *Osaka University*
Özcan, Ender, *University of Nottingham*
Paechter, Ben, *Edinburgh Napier University*
Pagnozzi, Federico, *Université Libre de Bruxelles*
Paixão, Tiago, *IST Austria*
Pang, Wei, *University of Aberdeen*
Panichella, Annibale, *University of Luxembourg*
Papa, Gregor, *Jozef Stefan Institute*
Paquete, Luis, *University of Coimbra*
Parkes, Andrew J., *University of Nottingham*
Parque, Victor, *Waseda University*
Parsopoulos, Konstantinos, *University of Ioannina*
Pasquier, Philippe, *SIAT - Simon Fraser University*
Pawlak, Tomasz, *Poznan University of Technology*
Pearce, Michael, *University of Warwick*
Pedemonte, Martín, *Instituto de Computación, Facultad de Ingeniería, Universidad de la República*
Pereira, Francisco Baptista, *Instituto Superior de Engenharia de Coimbra, Portugal*
Pereira, Jordi, *Universidad Adolfo Ibáñez*
Perez, Diego, *University of Essex*
Perez Caceres, Leslie, *Iridia - ULB*
Perez Heredia, Jorge, *University of Sheffield*
Petke, Justyna, *University College London*
Pilát, Martin, *Charles University, Faculty of Mathematics And Physics*
Pillay, Nelishia, *University of KwaZulu-Natal*
Pizzuti, Clara, *Institute for High Performance Computing and Networking - ICAR National Research Council of Italy - CNR*
Platos, Jan, *VSB - Technical University of Ostrava*
Polani, Daniel, *University of Hertfordshire*
Poles, Silvia, *EnginSoft*
Pop, Petrica, *Technical University of Cluj-Napoca, North University Center at Baia Mare, Romania*
Portalés, Cristina, *Universitat de València*
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Pošík, Petr, *Czech Technical University in Prague*
Poulding, Simon, *Blekinge Institute of Technology*
Powers, Simon, *School of Computing, Edinburgh Napier University*
Prandtstetter, Matthias, *AIT Austrian Institute of Technology GmbH*
Prestwich, Steve, *University College Cork*
Preuss, Mike, *WWU Muenster*
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*
Pushinger, Jakob, *SystemX-CentraleSupélec*
Qin, A. K., *RMIT University*
Qiu, Xin, *National University of Singapore*
Quagliarella, Domenico, *CIRA — Italian Center for Aerospace Research*
Rahat, Alma A. M., *University of Exeter*
Raidl, Günther R., *Vienna University of Technology*
Raja, Adil, *University of the Punjab*
Randall, Marcus Christian, *School of Information Technology, Bond University*
Rasheed, Khaled, *University of Georgia*
Ray, Tapabrata, *School of Aerospace, Civil and Mechanical Engineering*
Ray, Tom, *University of Oklahoma*
Read, Mark, *University of Sydney*
Reynolds, Robert, *Wayne State University*
Rhyd, Lewis, *Cardiff University*
Richter, Neal, *The Rubicon Project*
Rieffel, John, *Tufts University*
Riff, Maria Cristina, *UTFSM*
Risi, Sebastian, *IT University of Copenhagen*
Robert, Wille, *University of Bremen*
Robilliard, Denis, *LISIC, ULCO, Univ Lille-Nord de France*
Rockett, Peter, *Dept of Electronic & Electrical Engineering*
Rodriguez-Tello, Eduardo, *CINVESTAV,Tamaulipas*
Rohlfshagen, Philipp, *Paradyn Systems*
Rojas, José Miguel, *University of Sheffield*
Roli, Andrea, *Alma Mater Studiorum Universita' di Bologna*
Roper, Marc, *University of Strathclyde*
Ross, Brian J., *Brock University*
Rothlauf, Franz, *University of Mainz*
Rowe, Jonathan, *University of Birmingham*
Rudolph, Guenter, *TU Dortmund University*
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, *DIRO, Univ. de Montreal*
Salem, Ziad, *Karl-Franzens-University Graz*
Salto, Carolina, *Fac. de Ingeniería - UNLPam - Argentina*
Samothrakis, Spyridon, *University of Essex*

Sanchez, Luciano, *Universidad de Oviedo*
Sanchis, Javier, *Universitat Politècnica de València*
Santana, Roberto, *University of the Basque Country (UPV/EHU)*
Santibanez Koref, Ivan, *Technical Univ. Berlin*
Sarro, Federica, *University College London*
Sato, Hiroyuki, *The University of Electro-Communications*
Sato, Yuji, *Hosei University*
Saubion, Fredéric, *University of Angers, France*
Schmitt, Manuel, *University of Erlangen-Nuremberg*
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Schuetze, Oliver, *CINVESTAV-IPN*
Scully, Peter, *Aberystwyth University*
Segovia-Dominguez, Ignacio, *Center for Research in Mathematics*
Segredo, Eduardo, *Edinburgh Napier University*
Segura, Carlos, *Centro de Investigación en Matemática*
Sekanina, Lukas, *Brno University of Technology, Czech Republic*
Seppi, Kevin, *Brigham Young University*
Sevaux, Marc, *Université de Bretagne-Sud - Lab-STICC*
Shaheen, Fatima, *Loughborough University*
Shamshiri, Sina, *University of Sheffield*
Shir, Ofer M., *Tel-Hai College*
Shukla, Pradyumn Kumar, *KIT*
Siarry, Patrick, *University of Paris-Est Créteil*
Silva, Arlindo, *Polytechnic Institute of Castelo Branco*
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Silva, Sara, *BioISI / FCUL*
Sim, Kevin, *Edinburgh Napier University*
Simões, Anabela, *DEIS/ISEC - Coimbra Polytechnic*
Simons, Christopher L., *University of the West of England*
Singh, Hemant K., *University of New South Wales*
Sipper, Moshe, *Ben-Gurion University*
Skurikhin, Alexei N., *Los Alamos National Laboratory*
Smith, Jim, *University of the West of England*
Smyth, Tamara, *University of Califronia San Diego*
Solnon, Christine, *LIRIS, INSA de Lyon*
Solteiro Pires, Eduardo J., *UTAD University*
song, Andy, *RMIT University*
Sosa Hernandez, Victor Adrian, *CINVESTAV-IPN*
Soule, Terence, *University of Idaho*
Spector, Lee, *Hampshire College*
Squillero, Giovanni, *ALIFE Chair*
Srinivasan, Dipti, *National University of Singapore*
Stanley, Kenneth O., *University of Central Florida*
Stich, Sebastian, *École polytechnique fédérale de Lausanne*
Stolfi, Daniel H., *University of Malaga*
Stonedahl, Forrest, *Northwestern University*
Stork, Jörg, *SPOTSeven Lab, TH Köln*
Straccia, Umberto, *ISTI-CNR, Italy*
Stützle, Thomas, *Université Libre de Bruxelles*
Sudholt, Dirk, *University of Sheffield*
Suganthan, Ponnuthurai, *NTU*
Sun, Chaoli, *Taiyuan University of Science and Technology*
Sutton, Andrew Michael, *Hasso-Plattner-Institut*
Suzuki, Reiji, *Nagoya University*
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Takahashi, Ricardo, *Universidade Federal de Minas Gerais*
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Tan, KC, *NUS*
Tanabe, Ryoji, *The University of Tokyo*
Tanev, Ivan, *Faculty of Engineering, Doshisha University*
Tang, Ke, *University of Science and Technology of China*
Tarantino, Ernesto, *ICAR - CNR*
Tarapore, Danesh, *University of York*
Tauritz, Daniel R., *Missouri University of Science and Technology*
Tavares, Jorge, *Microsoft*
Tavares, Roberto, *UFSCAR*
Taylor, Tim, *University of London International Academy*
Teich, Jürgen, *University of Erlangen-Nuremberg*
Tettamanzi, Andrea G. B., *Université Nice Sophia Antipolis*
Teuscher, Christof, *Portland State University*
Textor, Johannes, *University of Utrecht*
Thawonmas, Ruck, *Ritsumeikan University*
Thiele, Lothar, *ETH Zurich*
Thierens, Dirk, *Utrecht University*
Timmis, Jonathan, *University of York*
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Tino, Peter, *University of Birmingham*
Tinos, Renato, *University of São Paulo*
Togelius, Julian, *IT University of Copenhagen*
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Toutouh, Jamal, *University of Malaga*
Tran, Binh, *Victoria University of Wellington*
Trautmann, Heike, *University of Münster*
Trefzer, Martin, *University of York*
Trojanowski, Krzysztof, *Fac. of Mathematics and Natural Sciences. School of Exact Sciences. Cardinal Stefan Wyszyński University in Warsaw*
Trubenova, Barbora, *IST Austria*
Trujillo, Leonardo, *Instituto Tecnológico de Tijuana*
Tusar, Tea, *Jozef 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*
Urli, Tommaso, *CSIRO Data61*
Urquhart, Neil, *Edinburgh Napier University*
Vanneschi, Leonardo, *NOVA-IMS*
Vasicek, Zdenek, *Brno University Of Technology*
Vatolkin, Igor, *TU 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, *INESC TEC/Polytechnic of Porto*
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Volz, Vanessa, *TU Dortmund University*
Von Zuben, Fernando J., *Unicamp*
Vos, Tanja, *Universidad Politecnica de Valencia*
Vrahatis, Michael N., *University of Patras*
Vukasinovic, Vida, *JSI*
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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*
Whitley, Darrell, *Colorado State University*
Wilkerson, Josh, *NAVAIR*
Wilson, Garnett, *Memorial University of Newfoundland*
Wimmer, Manuel, *Vienna University of Technology*
Wineberg, Mark, *University of Guelph*
Winfield, Alan F. T., *University of the West of England*
Winkler, Stephan, *University Of Applied Sciences Upper Austria*
Witt, Carsten, *Technical University Of Denmark*
Wong, M. L. Dennis, *Heriot-Watt University Malaysia*
Wong, Man Leung, *Lingnan University, Hong Kong*
Woodward, John R., *University of Stirling*
Wrobel, Borys, *Adam Mickiewicz University*
Wu, Annie S., *University of Central Florida*
Xie, Huayang, *Oracle New Zealand*
Xue, Bing, *Victoria University of Wellington*
Yamada, Takeshi, *NTT Communication Science Labs.*
Yang, Shengxiang, *De Montfort Unviersity*
Yannakakis, Georgios N., *Institute of Digital Games, University of Malta, Malta*
Yeh, Wei-Chang, *National Tsing Hua University*
Yen, Gary G., *Oklahoma State University*
Yoo, Shin, *Korea Advanced Institute of Science and Technology*
Yu, Yang, *Nanjing University*
Zaefferer, Martin, *TH Köln*
Zafra, Amelia, *University of Cordoba*
Zaharie, Daniela, *West University of Timisoara*
Zambetta, Fabio, *RMIT University*
Zamuda, Alez, *University of Maribor*
Zapotecas Martínez, Saúl, *CINVESTAV-IPN*
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Zexuan, Zhu, *Shenzhen University*
Zhan, Zhi-Hui, *South China University of Technology*
Zhang, Byoung-Tak, *Seoul National University*
Zhang, Mengjie, *Victoria University of Wellington*
Zhang, Qingfu, *City University of Hong Kong*
Zhong, Yanfei, *Wuhan university*
Zhou, Aimin, *Department of Computer Science, East China Normal University*
Zincir-Heywood, Nur, *Dalhousie University*

Proceedings

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user:	gecco2017
password:	berlin

Schedule and Floor Plans

BEST 2017

Schedule at a Glance

Saturday, July 15	Sunday, July 16	Monday, July 17	Tuesday, July 18	Wednesday, July 19
Tutorials and Workshops 08:30-10:20	Tutorials and Workshops 08:30-10:20	Opening 08:45-09:00		
		Invited Keynote Francesca Ciccarelli 09:00-10:10	Invited Keynote D. Purves C. Fernando 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 and ECiP 10:40-12:20	Paper Sessions and HOP 10:40-12:20	Coffee Break
				SIGEVO Keynote Hod Lipson 11:10-12:00
Lunch on Your Own	Lunch on Your Own	Lunch on Your Own Job Market	Lunch on Your Own	SIGEVO Meeting/Awards Closing 12:00-13:30
Tutorials and Workshops 14:00-15:50	Tutorials, Workshops, and Competitions 14:00-15:50	Paper Sessions, ECiP and HUMIES 14:00-15:40	Paper Sessions and HOP 14:00-15:40	
Coffee Break	Coffee Break	Coffee Break	Coffee Break	
Tutorials and Workshops 16:10-18:00	Tutorials, Workshops, and LBA 16:10-18:00	Paper Sessions and ECiP 16:10-17:50	Paper Sessions and HOP 16:10-17:50	
Women @ GECCO 18:00-20:00		Poster Session 17:50-20:00	Social Event 19:00-23:00	

Registration desk hours: Saturday, 7:45-16:10
Sunday and Monday, 8:00-16:10
Tuesday, 8:30-16:10
Wednesday, 8:30-11:10
Closed during lunch

Coffee breaks: Foyer

Keynotes, posters, and SIGEVO meeting: Saphir

Social event: Pirates Berlin (`http://piratesberlin.com/`). The participants will have to go to the site by their own. One suggested route (including S-Bahn) can be checked at this link.

Workshop and Tutorial Sessions, Saturday, July 15

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
Saphir 1	**Introductory Statistics for EC: A Visual Approach** Wineberg	**Industrial Applications of Metaheuristics (IAM)** p. 27	**Generative and Developmental Systems Tutorial** Stanley	
Saphir 2+3	**Evolutionary Computation Software Systems (EvoSoft)** p. 26		**Measuring and Promoting Diversity in Evolutionary Algorithms (MPDEA)** p. 29	**Tutorial on Evolutionary Multi-objective Optimization** Brockhoff
Opal	**Automated Offline Design of Algorithms** López-Ibáñez, Stützle	**Hyper-heuristics** Tauritz	**Next Generation Genetic Algorithms** Whitley	**Evolutionary Robotics** Bredeche, Doncieux, Mouret
Jade	**Introduction to Randomized Continuous Optimization** Auger, Hansen	**A Practical Guide to Benchmarking and Experimentation** Hansen	**Evolutionary Computation in Network Management and Security** Zincir-Heywood	**Introducing Rule-Based Machine Learning: Capturing Complexity** Urbanowicz
Amethyst	**Genetic Programming** O'Reilly	**Fitness Landscape Characterisation of Optimisation Problems** Malan, Moser, Aleti	**Exploratory Landscape Analysis** Kerschke, Preuss	**Funding Sources** p. 30
Bernstein	**Parallel and Distributed Evolutionary Inspired Methods (PDEIM)** p. 26			**Visualisation Methods in Genetic and Evolutionary Computation (VizGEC)** p. 30
Smaragd	**Introduction to Gene Regulatory Networks** Cussat-Blanc, Banzhaf	**Theory for Non-Theoreticians** B. Doerr	**Runtime Analysis of Population-based Evolutionary Algorithms** Lehre, Oliveto	**Theory of Swarm Intelligence** Sudholt
Diamant		**Workshop on Medical Applications of Genetic and Evolutionary Computation (MedGEC)** p. 28	**Evolutionary Computation for the Automated Design of Algorithms (ECADA)** p. 30	
Topas 1	**Evolutionary Computation and Cryptology** Picek	**Student Workshop** p. 28		

Tutorials Workshops

Women @ GECCO
Saphir 2+3
18:00-20:00
p. 30

Workshop and Tutorial Sessions, Sunday, July 16

	08:30-10:20	10:40-12:30	14:00-15:50	16:10-18:00
Saphir 1	**Recent Advances in Evolutionary Multi-Criterion Optimization** Deb	**Sequential Experimentation by Evolutionary Algorithms** Shir, Bäck, Knowles, Allmendinger	**Solving Complex Problems with Coevolutionary Algorithms** Krawiec, Heywood	**Evolution of Neural Networks** Miikkulainen
Saphir 2+3		**Multiagent Systems and Agent-based Modeling and Simulation** Bazzan	**Constraint-Handling Techniques used with EAs** Coello Coello	**Model-based Evolutionary Algorithms (MBEA)** p. 36
Opal	**Evolutionary Large-Scale Global Optimization: An Introduction** Omidvar, Li	**Representations for Evolutionary Algorithms** Rothlauf	**Non-Static Parameter Choices in Evolutionary Computation** C. Doerr	**CMA-ES and Advanced Adaptation Mechanisms** Akimoto, Hansen
Jade	**Model-Based Evolutionary Algorithms** Thierens, Bosman	**Genetic Improvement Workshop (GI)** p. 34		
Amethyst	**Blackbox Optimization Benchmarking (BBOB)** p. 32		**New Standards for Benchmarking in Evolutionary Computation Research (ECR)** p. 35	**Surrogate-Assisted Evolutionary Optimization (SAEOpt)** p. 37
Bernstein	**Intelligent Systems for Smart Cities** Alba	**20th International Workshop on Evolutionary Rule-Based Machine Learning (ERBML)** p. 33	**Evolutionary Methods for Smart Grid Applications (EMSGA)** p. 35	
Smaragd	**Exploration of inaccessible environments through hardware/software co-evolution (EIEHS)** p. 31	**Simulation in Evolutionary Robotics (SimER)** p. 33	**Evolving collective behaviors in robotics (ECBR)** p. 34	**Evolution in Cognition (EiC)** p. 36
Diamant	**Landscape-Aware Heuristic Search (LAHS)** p. 31	**Expressive Genetic Programming: Concepts and Applications** Spector, McPhee	**Evolutionary Computation: A Unified Approach** De Jong	**Genetic and Evolutionary Computation in Defense, Security, and Risk Management (SecDef)** p. 37
Topas 1	**Evolutionary Computation in Computational Biology (ECCB)** p. 32		**Competitions** p. 55	**Late-Breaking Abstracts** p. 37

Tutorials Workshops Competitions LBA session

Parallel Sessions, Monday, July 17 through Wednesday, July 19

	Monday July 17 10:40-12:20	Monday July 17 14:00-15:40	Monday July 17 16:10-17:50	Tuesday July 18 10:40-12:20	Tuesday July 18 14:00-15:40	Tuesday July 18 16:10-17:50	Wednesday July 19 09:00-10:40
Saphir	GA1 ☆ p. 63	Hotel Poster Setup	Authors Poster Setup	GP4 ☆ p. 70	EMO4 ☆ p. 73	RWA7 ☆ p. 76	ECOM6 ☆ p. 79
Opal	ECOM1 p. 62	GECH1 +DETA1 ☆ p. 65	EML3 ☆ p. 67	SBSE1 +ACO-SI1 ☆ p. 71	CS3 ☆ p. 72	THEORY3 +ENUM3 ☆ p. 77	EML5 p. 79
Jade	EML1 p. 62	RWA2 p. 66	ECOM2 p. 67	ECOM3 p. 69	SBSE2 +ECOM4 p. 74	ECOM5 p. 75	RWA8 p. 80
Amethyst	RWA1 p. 64	EML2 p. 65	RWA3 p. 68	EMO3 +RWA5 p. 69	EML4 p. 72	GA3 p. 75	GA4 p. 79
Bernstein	GP1 p. 63	GP2 p. 65	GP3 p. 68	RWA4 p. 71	RWA6 p. 74	GP5 p. 76	CS4 p. 78
Smaragd	CS1 p. 62	THEORY1 p. 66	EMO2 p. 68	ENUM1 p. 69	ENUM2 p. 73	GECH3 p. 75	ACO-SI2 p. 78
Diamant	EMO1 p. 63	HUMIES p. 54	CS2 p. 67	GECH2 p. 70	GA2 +THEORY2 p. 73	SBSE3 p. 77	THEORY4 p. 80
Topas 1	ECiP1 p. 58	ECiP2 p. 58	ECiP3 p. 58	HOP1 p. 70	HOP2 p. 74	HOP3 p. 76	DETA2 p. 78

☆ *Sessions with best paper nominees* — *HUMIES* — *ECiP* — *HOP*

Track List and Abbreviations

ACO-SI: Ant Colony Optimization and Swarm Intelligence

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

DETA: Digital Entertainment Technologies and Arts

ECiP: Evolutionary Computation in Practice

ECOM: Evolutionary Combinatorial Optimization and Metaheuristics

EML: Evolutionary Machine Learning

EMO: Evolutionary Multiobjective Optimization

ENUM: Evolutionary Numerical Optimization

GA: Genetic Algorithms

GECH: General Evolutionary Computation and Hybrids

GP: Genetic Programming

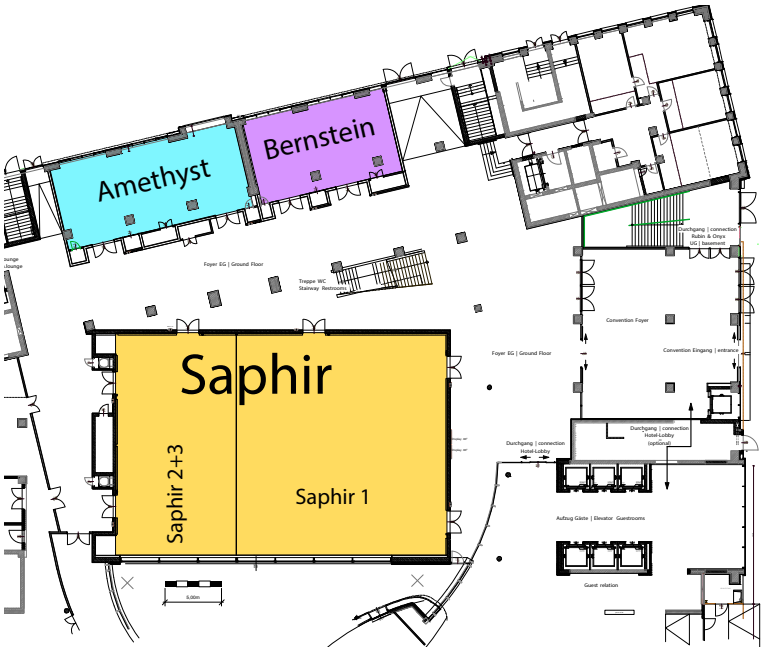
HOP: Hot Off the Press

RWA: Real World Applications

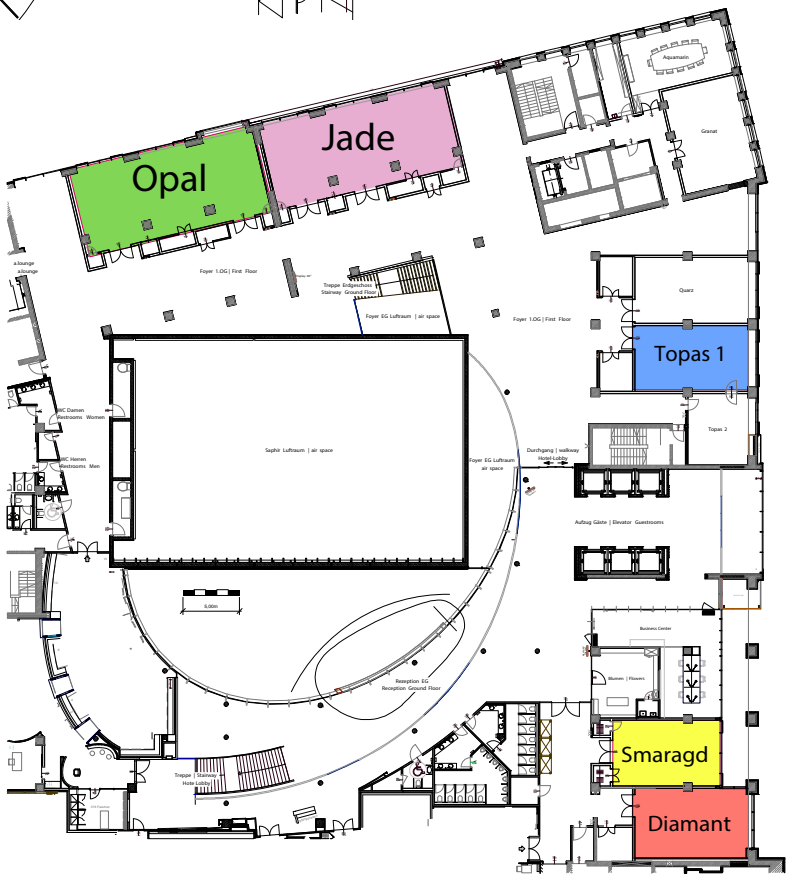
SBSE: Search-Based Software Engineering

THEORY: Theory

Floor Plans



Ground floor



First floor

Tutorials

Introductory Tutorials

Genetic Programming
Una-May O'Reilly, *MIT*
Saturday, July 15, 08:30-10:20
Amethyst

Introductory Statistics for EC: A Visual Approach
Mark Wineberg, *Univeristy of Guelph*
Saturday, July 15, 08:30-10:20
Saphir 1

Introduction to Randomized Continuous Optimization
Anne Auger, *Inria*
Nikolaus Hansen, *Inria*
Saturday, July 15, 08:30-10:20
Jade

Introduction to Gene Regulatory Networks
Sylvain Cussat-Blanc, *University of Toulouse*
Wolfgang Banzhaf, *Memorial University of Newfoundland*
Saturday, July 15, 08:30-10:20
Smaragd

Fitness Landscape Characterisation of Optimisation Problems
Katherine Malan, *University of Pretoria*
Irene Moser, *Swinburne University of Technology*
Aldeida Aleti, *Monash University*
Saturday, July 15, 10:40-12:30
Amethyst

Hyper-heuristics
Daniel R. Tauritz, *Missouri University of Science and Technology*
John R. Woodward, *University of Stirling*
Saturday, July 15, 10:40-12:30
Opal

Theory for Non-Theoreticians
Benjamin Doerr, *Ecole Polytechnique*
Saturday, July 15, 10:40-12:30
Smaragd

A Practical Guide to Benchmarking and Experimentation
Nikolaus Hansen, *Inria*
Saturday, July 15, 10:40-12:30
Jade

Runtime Analysis of Population-based Evolutionary Algorithms
Per Kristian Lehre, *University of Birmingham*
Pietro Simone Oliveto, *University of Sheffield*
Saturday, July 15, 14:00-15:50
Smaragd

Tutorial on Evolutionary Multiobjective Optimization
Dimo Brockhoff, *Inria Saclay - Ile-de-France and CMAP, Ecole Polytechnique*
Saturday, July 15, 16:10-18:00
Saphir 2+3

Introducing Rule-Based Machine Learning: Capturing Complexity
Ryan Urbanowicz, *University of Pennsylvania*
Saturday, July 15, 16:10-18:00
Jade

Model-Based Evolutionary Algorithms
Dirk Thierens, *Utrecht University*
Peter A.N. Bosman, *CWI*
Sunday, July 16, 08:30-10:20
Jade

Representations for Evolutionary Algorithms
Franz Rothlauf, *Universität Mainz*
Sunday, July 16, 10:40-12:30
Opal

Evolutionary Computation: A Unified Approach
Kenneth A. De Jong, *George Mason University*
Sunday, July 16, 14:00-15:50
Diamant

Evolution of Neural Networks
Risto Miikkulainen, *The University of Texas at Austin*
Sunday, July 16, 16:10-18:00
Saphir 1

Advanced Tutorials

Generative and Developmental Systems Tutorial
Kenneth O. Stanley, *University of Central Florida and Uber AI Labs*
Saturday, July 15, 14:00-15:50
Saphir 1

Exploratory Landscape Analysis
Pascal Kerschke, *University of Münster*
Mike Preuss, *University of Münster*
Saturday, July 15, 14:00-15:50
Amethyst

Next Generation Genetic Algorithms
Darrell Whitley, *Colorado State University*
Saturday, July 15, 14:00-15:50
Opal

Theory of Swarm Intelligence
Dirk Sudholt, *University of Sheffield*
Saturday, July 15, 16:10-18:00
Smaragd

Evolutionary Large-Scale Global Optimization: An Introduction
Mohammad Nabi Omidvar, *University of Birmingham*
Xiaodong Li, *RMIT University*
Sunday, July 16, 08:30-10:20
Opal

Recent Advances in Evolutionary Multi-Criterion Optimization
Kalyanmoy Deb, *Michigan Stare University*
Sunday, July 16, 08:30-10:20
Saphir 1

Sequential Experimentation by Evolutionary Algorithms
Ofer M. Shir, *Tel-Hai College*
Thomas Bäck, *Leiden University*
Joshua Knowles, *University of Birmingham*
Richard Allmendinger, *University of Manchester*
Sunday, July 16, 10:40-12:30
Saphir 1

Expressive Genetic Programming: Concepts and Applications
Lee Spector, *Hampshire College*
Nicholas Freitag McPhee, *University of Minnesota, Morris*
Sunday, July 16, 10:40-12:30
Diamant

Constraint-Handling Techniques used with Evolutionary Algorithms
Carlos A. Coello Coello, *CINVESTAV-IPN*
Sunday, July 16, 14:00-15:50
Saphir 2+3

Non-Static Parameter Choices in Evolutionary Computation
Carola Doerr, *CNRS and Univ. Sorbonnes Paris 6*
Sunday, July 16, 14:00-15:50
Opal

Solving Complex Problems with Coevolutionary Algorithms
Krzysztof Krawiec, *Poznan University of Technology*
Malcolm I. Heywood, *Dalhousie University*
Sunday, July 16, 14:00-15:50
Saphir 1

CMA-ES and Advanced Adaptation Mechanisms
Youhei Akimoto, *Shinshu University*
Nikolaus Hansen, *Inria*
Sunday, July 16, 16:10-18:00
Opal

Specialized Tutorials

Automated Offline Design of Algorithms
Manuel López-Ibáñez, *Decision and Cognitive Sciences Research Centre, University of Manchester*
Thomas Stützle, *IRIDIA, Université libre de Bruxelles*
Saturday, July 15, 08:30-10:20
Opal

Evolutionary Computation and Cryptology Stjepan Picek, *CSAIL, MIT*	Saturday, July 15, 08:30-10:20 Topas 1
Evolutionary Computation in Network Management and Security Nur Zincir-Heywood, *Dalhousie University*	Saturday, July 15, 14:00-15:50 Jade
Evolutionary Robotics Nicolas Bredeche, *Université Pierre et Marie Curie* Stéphane Doncieux, *Université Pierre et Marie Curie* Jean-Baptiste Mouret, *Inria*	Saturday, July 15, 16:10-18:00 Opal
Intelligent Systems for Smart Cities Enrique Alba, *University of Malaga*	Sunday, July 16, 08:30-10:20 Bernstein
Multiagent Systems and Agent-based Modeling and Simulation Ana Lucia C. Bazzan, *UFRGS*	Sunday, July 16, 10:40-12:30 Saphir 2+3

Workshops and Late Breaking Abstracts

BERLIN 2017

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: Saturday, July 15, 08:30-12:30, Saphir 2+3

Design and Architecture of the jMetalSP Framework
Antonio J. Nebro

In Hypercubo Nigrae Capsulae Optimum
Arnaud Berny

evospace-js: Asynchronous Pool-Based Execution of Heterogeneous Metaheuristics
Mario García-Valdez, Juan Julian Merelo-Guervos

PyshGP: PushGP in Python
Edward Pantridge, Lee Spector

flaccogui: Exploratory Landscape Analysis for Everyone
Pascal Kerschke, Christian Hanster

PonyGE2: Grammatical Evolution in Python
Michael Fenton, James McDermott, David Fagan, Stefan Forstenlechner, Erik Hemberg, Michael O'Neill

Multijob: A Framework for efficient Distribution of Evolutionary Algorithms for Parameter Tuning
Robin Mueller-Bady, Martin Kappes, Lukas Atkinson, Inmaculada Medina-Bulo

ecr 2.0: A Modular Framework for Evolutionary Computation in R
Jakob Bossek

Towards Evolutionary Machine Learning Comparison, Competition, and Collaboration with a Multi-Cloud Platform
Pasquale Salza, Erik Hemberg, Filomena Ferrucci, Una-May O'Reilly

Towards the Design and Implementation of Optimization Networks in HeuristicLab
Johannes Karder, Stefan Wagner, Andreas Beham, Michael Kommenda, Michael Affenzeller

MYRA: A Java Ant Colony Optimization Framework for Classification Algorithms
Fernando E. B. Otero

ECJ Then and Now
Sean Luke

Parallel and Distributed Evolutionary Inspired Methods (PDEIM)

Organizers: Ernesto Tarantino, *National Research Council of Italy (CNR) - Institute of High-Performance Computing and Networking (ICAR)*
Ivanoe De Falco, *National Research Council of Italy (CNR) - Institute of High-Performance Computing and Networking (ICAR)*
Antonio Della Cioppa, *Natural Computation Lab, DIEM, University of Salerno*
Umberto Scafuri, *National Research Council of Italy (CNR) - Institute of High-Performance Computing and Networking (ICAR)*

Time and Location: Saturday, July 15, 08:30-15:50, Bernstein

Hyper-Parameter Selection in Deep Neural Networks Using Parallel Particle Swarm Optimization
Pablo Ribalta Lorenzo, Jakub Nalepa, Luciano Sanchez Ramos, José Ranilla Pastor

A Parallel Multi-objective Cooperative Co-evolutionary Algorithm with Changing Variables
Biao Xu, Dunwei Gong, Yong Zhang, Ling Wang

Parallel Optimization of Transistor Level Circuits using Cartesian Genetic Programming
Vojtech Mrazek, Zdenek Vasicek

A Distributed Framework for Cooperation of Many-Objective Evolutionary Algorithms
Gian Maurício Fritsche, Aurora Trinidad Ramirez Pozo

Island-Cellular Model Differential Evolution for Large-Scale Global Optimization
Rodolfo A. Lopes, Alan R. R. Freitas

TensorFlow Enabled Genetic Programming
Kai Staats, Edward Pantridge, Marco Cavaglia, Iurii Milovanov, Arun Aniyan

Designing Bent Boolean Functions With Parallelized Linear Genetic Programming
Jakub Husa, Roland Dobai

Asynchronous Parallel Cartesian Genetic Programming
Adam Harter, Daniel R. Tauritz, William M. Siever

Integrating Surrogate Evaluation Model and Asynchronous Evolution in Multi-Objective Evolutionary Algorithm for Expensive and Different Evaluation Time
Misaki Kaidan, Tomohiro Harada, Ruck Thawonmas

Multi-Objective Parallel Extremal Optimization in Processor Load Balancing for Distributed Programs
Ivanoe De Falco, Eryk Laskowski, Richard Olejnik Richard Olejnik, Ernesto Tarantino, Marek Tudruj

Large Scale Optimization of Computationally Expensive Functions: an approach based on Parallel Cooperative Coevolution and Fitness Metamodeling
Ivanoe De Falco, Antonio Della Cioppa, Giuseppe A. Trunfio

A Distributed Implementation Using Apache Spark Of A Genetic Algorithm Applied To Test Data Generation
Ciprian Paduraru, Marius-Constantin Melemciuc, Alin Stefanescu

Exploiting Diversity in an Asynchronous Migration Model for Distributed Differential Evolution
Ernesto Tarantino, Ivanoe De Falco, Antonio Della Cioppa, Umberto Scafuri

A Study of Self-Adaptive Semi-Asynchronous Evolutionary Algorithm on Multi-Objective Optimization Problem
Tomohiro Harada, Keiki Takadama

2nd Workshop on Industrial Applications of Metaheuristics (IAM)

Organizers: Silvino Fernandez Alzueta, *ArcelorMittal*
Pablo Valledor Pellicer, *ArcelorMittal*
Thomas Stützle, *IRIDIA laboratory, ULB, Belgium*

Time and Location: Saturday, July 15, 10:40-12:30, Opal

Artificial Bee Colony Framework to Non-convex Economic Dispatch Problem with Valve Point Effects: A Case Study
Dogan Aydin, Gurcan Yavuz, Serdar Ozyon, Celal Yasar, Thomas Stützle

Multiobjective Discovery of Human-like Driving Strategies
Erik Dovgan, Jaka Sodnik, Ivan Bratko, Bogdan Filipic

Identifying a Robust Waste Heat Recovery System for Varying Hot Water Temperature Demand
Maizura Mokhtar

Combining Parallel Coordinates with Multi-Objective Evolutionary Algorithms in a Real-World Optimisation Problem
Neil Urquhart

Workshop on Medical Applications of Genetic and Evolutionary (MedGEC)

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

Time and Location: Saturday, July 15, 10:40-12:30, Diamant

Forecasting Glucose Levels in Patients with Diabetes Mellitus using Semantic Grammatical Evolution and Symbolic Aggregate Approximation
Jose Manuel Velasco, Oscar Garnica, Sergio Contador, Marta Botella, Juan Lanchares, Jose Ignacio Hidalgo

Evolutionary learning-based modeling for warfarin dose prediction in Chinese
Yanyun Tao, Yuzhen Zhang, Bin Jiang

Efficient, Effective, and Insightful Tackling of the High-Dose-Rate Brachytherapy Treatment Planning Problem for Prostate Cancer using Evolutionary Multi-Objective Optimization Algorithms
Ngoc Hoang Luong, Anton Bouter, Marjolein C. van der Meer, Yury Niatsetski, Cees Witteveen, Arjan Bel, Tanja Alderliesten, Peter A.N. Bosman

Going Through Directional Changes: Evolving Human Movement Classifiers Using an Event Based Encoding
Michael A. Lones, Jane E. Alty, Jeremy Cosgrove, Stuart Jamieson, Stephen L. Smith

A Comparative Study of the EEG Signals Big Optimization Problem using Evolutionary, Swarm and Memetic Computation Algorithms
Mohamed Amine El Majdouli, Saad Bougrine, Ismail Rbouh, Abdelhakim Ameur El Imrani

Student Workshop

Organizers: Vanessa Volz, *TU Dortmund University*
Boris Naujoks, *Cologne University of Applied Sciences, Germany*

Time and Location: Saturday, July 15, 10:40-18:00, Topas 1

An Investigation of Topological Choices in FS-NEAT and FD-NEAT on XOR-based Problems of Increased Complexity
Evgenia Papavasileiou, Bart Jansen

Hybridisation of Artificial Bee Colony algorithm on Four Classes of Real-valued Optimisation Functions
Mudita Sharma, Dimitar Kazakov

Econometric Genetic Programming Outperforms Traditional Econometric Algorithms for Regression Tasks
André Novaes, Ricardo Tanscheit, Douglas Mota Dias

Hierarchical Surrogate Modeling for Illumination Algorithms
Alexander Hagg

Variable Selection as a Non-Completely Decomposable Problem: A Case Study in Multivariate Calibration
Lauro de Paula, Anderson Soares

Ant Colony Optimization with Human-computer Cooperative Strategy for Two-echelon Vehicle Routing Problem
Xueming Yan, Zhifeng Hao, Han Huang, Hongyue Wu

Reinforcement Learning Based Dynamic Selection of Auxiliary Objectives with Preservation of the Best Found Solution
Irina Petrova, Arina Buzdalova

Evaluation of a Genetic Representation for Outline Shapes
Paul Lapok, Alistair Lawson, Ben Paechter

Genetic Programming meets Linear Algebra How genetic programming can be used to find improved iterative numerical methods
Reza Gholami M., Harald Köstler

Amplitude-oriented Mixed-type CGP Classification
Karlo Knezevic, Stjepan Picek, Julian Francis Miller

Optimization Networks for Real-World Production and Logistics Problems
Viktoria A. Hauder, Andreas Beham, Stefan Wagner, Michael Affenzeller

Evaluation of Heavy-tailed Mutation Operator on Maximum Flow Test Generation Problem
Vladimir Mironovich, Maxim Buzdalov

On Binary Unbiased Operators Returning Multiple Offspring
Nina Bulanova, Maxim Buzdalov

Measuring and Promoting Diversity in Evolutionary Algorithms (MPDEA)

Organizers: Giovanni Squillero, *Politecnico di Torino*
Alberto Tonda, *UMR 782 GMPA, INRA, Thiverval-Grignon, France*

Time and Location: Saturday, July 15, 14:00-15:50, Saphir 2+3

A comparison of illumination algorithms in unbounded spaces
Vassilis Vassiliades, Konstantinos Chatzilygeroudis, Jean-Baptiste Mouret

A Multi-Objective Decomposition-based Evolutionary Algorithm with Enhanced Variable Space Diversity Control
Joel Chacón, Carlos Segura, Arturo Hernández Aguirre, Gara Miranda, Colomoto León

A Simple Bucketing Based Approach to Diversity Maintenance
Amit Benbassat, Yuri Shafet

Dynamic Observation of Genotypic and Phenotypic Diversity for Different Symbolic Regression GP variants
Michael Affenzeller, Stephan Winkler, Bogdan Burlacu, Gabriel Kronberger, Michael Kommenda, Stefan Wagner

Genealogical Distance as a Diversity Estimate in Evolutionary Algorithms
Thomas Gabor, Lenz Belzner

Evolutionary Computation for the Automated Design of Algorithms (ECADA)

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

Time and Location: Saturday, July 15, 14:00-18:00, Diamant

Evaluating random forest models for irace
Leslie Pérez Cáceres, Bernd Bischl, Thomas Stützle

Evolutionary Computation for the Automated Design of Category Functions for Fuzzy ART: An Initial Exploration
Islam Elnabarawy, Daniel R. Tauritz, Donald C. Wunsch

Comparing Hyper-heuristics with Blackboard Systems
Kevin Graham, Leslie Smith

Recent Developments in Autoconstructive Evolution
Lee Spector, Eva Moscovici

Towards a Method for Automatically Selecting and Configuring Multi-Label Classification Algorithms
Alex Guimarães Cardoso de Sá, Gisele Lobo Pappa, Alex Alves Freitas

Design of An Efficient Hyper-heuristic Algorithm CMA-VNS for Combinatorial Black-box Optimization Problems
Fan Xue, Geoffrey Q. Shen

Visualisation Methods in Genetic and Evolutionary Computation (VizGEC)

Organizers: David Walker, *University of Exeter, UK*
Richard M. Everson, *University of Exeter, UK*
Jonathan E. Fieldsend, *University of Exeter, UK*
Bogdan Filipic, *Jozef Stefan Institute, Slovenia*
Tea Tušar, *Jožef Stefan Institute, Ljubljana, Slovenia*

Time and Location: Saturday, July 15, 16:10-18:00, Bernstein

Interactive tool for analyzing multiobjective optimization results with Level Diagrams
Xavier Blasco, Juan Manuel Herrero, Gilberto Reynoso-Meza, Miguel A. Martínez Iranzo

The DU Map: A Visualization to Gain Insights into Genotype-Phenotype Mapping and Diversity
Eric Medvet, Tea Tušar

On the Role of Aesthetics in Genetic Algorithms Applied to Graph Drawing
Evgheni Polisciuc, António Cruz, Penousal Machado, Joel P. Arrais

Spatial Redistribution of Irregularly-Spaced Pareto Fronts for More Intuitive Navigation and Solution Selection
Anton Bouter, Kleopatra Pirpinia, Tanja Alderliesten, Peter A.N. Bosman

Funding Sources

Organizers: Carlos Gálvez, *European Commission*

Time and Location: Saturday, July 15, 16:10-18:00, Amethyst

Women@GECCO

Organizers: Amarda Shehu, *George Mason University, Fairfax, VA*
Tea Tušar, *Jožef Stefan Institute, Ljubljana, Slovenia*

Time and Location: Saturday, July 15, 18:00-20:00, Saphir 2+3

Challenges of a PhD student and early stage researcher
Vanessa Volz, *TU Dortmund University*

A road to becoming an independent researcher
Justyna Petke, *University College London*

Learn from my mistakes: what NOT to do to become a world leading researcher
Anna I Esparcia-Alcázar, *Universidad Politecnica de Valencia*

Landscape-Aware Heuristic Search (LAHS)

Organizers: Nadarajen Veerapen, *University of Stirling, UK*
Fabio Daolio, *University of Stirling, UK*
Arnaud Liefooghe, *Université de Lille, France*
Sébastien Verel, *Univ. Littoral Côte d'Opale*
Gabriela Ochoa, *University of Stirling, UK*

Time and Location: Sunday, July 16, 08:30-10:20, Diamant

Exploiting Active Subspaces in Global Optimization: How Complex is your Problem?
Pramudita Satria Palar, Koji Shimoyama

The Effect of Landscape Funnels in QAPLIB Instances
Sarah L. Thomson, Gabriela Ochoa, Fabio Daolio, Nadarajen Veerapen

Instance-Based Algorithm Selection on Quadratic Assignment Problem Landscapes
Andreas Beham, Michael Affenzeller, Stefan Wagner

Analyzing Deception, Evolvability, and Behavioral Rarity in Evolutionary Robotics
Joel Lehman

Long-Term Stability of Genetic Programming Landscapes
William B. Langdon

Exploration of inaccessible environments through hardware/software co-evolution (EIEHS)

Organizers: P.G.M. Baltus, *Eindhoven University of Technology*
Giovanni Iacca, *RWTH Aachen University*
Martin Andraud, *TU Eindhoven - KU Leuven*

Time and Location: Sunday, July 16, 08:30-10:20, Smaragd

Acquiring Moving Skills in Robots with Evolvable Morphologies: Recent Results and Outlook
Milan Jelisavcic, Evert Haasdijk, A. E. Eiben, Evert Haasdijk, A. E. Eiben

Instinct-Driven Dynamic Hardware Reconfiguration: Evolutionary Algorithm Optimized Compression for Autonomous Sensory Agents
Ahmed Hallawa, Jaro De Roose, Martin Andraud, Gerd Ascheid, Marian Verhelst

Energy-Efficient Environment Mapping via Evolutionary Algorithm Optimized Multi-Agent Localization
Ahmed Hallawa, Stephan Schlupkothen, Giovanni Iacca, Gerd Ascheid

Evolutionary Computation in Computational Biology (ECCB)

Organizers: José Santos, *University of A Coruña, Spain*
Julia Handl, *University of Manchester, UK*
Amarda Shehu, *George Mason University, Fairfax, VA*
Mostafa Ellabaan, *Technical University of Denmark, Denmark*

Time and Location: Sunday, July 16, 08:30-12:30, Topas 1

On heuristic bias in fragment-assembly methods for protein structure prediction
Julia Handl, Mario Garza-Fabre, Shaun Kandathil, Simon C. Lovell

Optimisation and Landscape Analysis of Computational Biology Models: A Case Study
Kevin Doherty, Khulood Alyahya, Jonathan E. Fieldsend, Ozgur Akman

Toward Self-Adapting Computation in Cells: Building Spiking Neural Network with Cell Signaling Pathways
Katherine H. Chiang

Identification of Robust Strain Designs via Tandem pFBA/LMOMA phenotype prediction
Paulo Maia, Isabel Rocha, Miguel Rocha

Genetic Improvement of Computational Biology Software
William B. Langdon, Karina Zile

A protein folding model using the Face-Centered Cubic lattice model
Daniel Varela, José Santos

An Evolutionary Algorithm to Model Structural Excursions of a Protein
Amarda Shehu

Blackbox Optimization Benchmarking (BBOB)

Organizers: Anne Auger, *Inria Saclay-Ile-de-France*
Dimo Brockhoff, *Inria Saclay - Ile-de-France and CMAP, Ecole Polytechnique, France*
Nikolaus Hansen, *INRIA Saclay, France*
Tea Tušar, *Jožef Stefan Institute, Ljubljana, Slovenia*
Dejan Tušar, *Inria Saclay*

Time and Location: Sunday, July 16, 08:30-12:30, Amethyst

Comparison of Ordinal and Metric Gaussian Process Regression as Surrogate Models for CMA Evolution Strategy
Zbyněk Pitra, Lukáš Bajer, Jakub Repický, Martin Holeňa

Benchmarking a Pool-Based Execution with GA and PSO Workers on the BBOB Noiseless Testbed
Mario García-Valdez, Juan Julian Merelo-Guervos

Benchmarking CMAES-APOP on the BBOB Noiseless Testbed
Duc Manh Nguyen, Nikolaus Hansen

Benchmarking the SMS-EMOA with Self-adaptation on the bbob-biobj Test Suite
Simon Wessing

Self-adaptive Search Equation-Based Artificial Bee Colony Algorithm with CMA-ES on the Noiseless BBOB Testbed
Dogan Aydin, Gurcan Yavuz

Benchmarking the Novel CMA-ES Restart Strategy Using the Search History on the BBOB Noiseless Testbed
Takahiro Yamaguchi, Youhei Akimoto

Simulation in Evolutionary Robotics (SimER)

Organizers: Jared M. Moore, *School of Computing and Information Systems, Grand Valley State University*
Anthony J. Clark, *Missouri State University*

Time and Location: Sunday, July 16, 10:40-12:30, Smaragd

Simulating the Evolution of Soft and Rigid-Body Robots
Sam Kriegman, Collin Kovach Cappelle, Francesco Corucci, Anton Bernatskiy, Nick Cheney, Josh Bongard

20 Years of Reality Gap: A few Thoughts About Simulators in Evolutionary Robotics
Jean-Baptiste Mouret, Konstantinos Chatzilygeroudis

A Baseline-Realistic Objective Open-Ended Kinematics Simulator for Evolutionary Robotics
Riley Konsella, Frank Chiarulli, John Peterson, John Rieffel

20th International Workshop on Evolutionary Rule-Based Machine Learning (ERBML)

Organizers: Ryan Urbanowicz, *University of Pennsylvania, USA*
Kuber Karthik, *Microsoft, Redmond, Washington, USA*
Danilo Vasconcellos Vargas, *Kyushu University*

Time and Location: Sunday, July 16, 10:40-12:30, Bernstein

Toward Curious Learning Classifier Systems: Combining XCS with Active Learning Concepts
Anthony Stein, Roland Maier, Jörg Hähner

Classifier Systems with Native Fuzzy Logic Control Operation
Nugroho Fredivianus, Kurt Geihs

Genetic Improvement Workshop (GI)

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

Time and Location: Sunday, July 16, 10:40-18:00, Jade

Deep Parameter Optimisation on Android Smartphones for Energy Minimisation - A Tale of Woe and a Proof-of-Concept
Mahmoud A. Bokhari, Bobby R. Bruce, Bradley James Alexander, Markus Wagner

Embedding Genetic Improvement into Programming Languages
Shin Yoo

Evolving Software Building Blocks with FINCH
Michael Orlov

Modelling Genetic Improvement Landscapes with Local Optima Networks
Nadarajen Veerapen, Fabio Daolio, Gabriela Ochoa

Fixing Bugs in Your Sleep: How Genetic Improvement Became an Overnight Success
Saemundur Oskar Haraldsson, John R. Woodward, Alexander E.I. Brownlee, Kristin Siggeirsdottir

From Problem Landscapes to Language Landscapes: Questions in Genetic Improvement
Brendan Cody-Kenny, Michael Fenton, Michael O'Neill

Gaining Insights into Road Traffic Data through Genetic Improvement
Aniko Ekart, Alina Patelli, Victoria Lush, Elisabeth Ilie-Zudor

Learning from Super-Mutants
Jason Landsborough, Stephen Harding, Sunny Fugate

Improving SSE Parallel Code with Grow and Graft Genetic Programming
William B. Langdon, Ronny Lorenz

GI in No Time
David R. White

New Operators for Non-functional Genetic Improvement
Justyna Petke

Genetic Improvement of Runtime and its Fitness Landscape in a Bioinformatics Application
Saemundur Oskar Haraldsson, John R. Woodward, Alexander E.I. Brownlee, Albert V. Smith, Vilmundur Gudnason

Evolving collective behaviors in robotics (ECBR)

Organizers: Nicolas Bredeche, *Université Pierre et Marie Curie*
Evert Haasdijk, *Vrije University, Amsterdam*
Abraham Prieto, *University of A Coruña, Spain*
Heiko Hamann, *University of Paderborn*

Time and Location: Sunday, July 16, 14:00-15:50, Smaragd

Benefits of Proportionate Selection in Embodied Evolution: a Case Study with Behavioural Specialization
Nicolas Bredeche, Jean-Marc Montanier, Simon Carrignon

Validation of a Learning and Evolving Robot Swarm
Rasmus Munk, Emma Hart, Ben Paechter

Phylogeny of Embodied Evolutionary Robotics
Amine Boumaza

Incorporating User Feedback in Embodied Evolution
Micha Kemeling, Evert Haasdijk

Evolving Robot Swarm Behaviors by Minimizing Surprise: Results of Simulations in 2-d on a Torus
Richard Borkowski, Heiko Hamann

New Standards for Benchmarking in Evolutionary Computation Research (ECR)

Organizers: William La Cava, *University of Massachusetts Amherst*
Ryan Urbanowicz, *University of Pennsylvania, USA*
Randal S. Olson, *University of Pennsylvania*
Patryk Orzechowski, *University of Pennsylvania*

Time and Location: Sunday, July 16, 14:00-15:50, Amethyst

Generating custom classification datasets by targeting the instance space
Mario Andrés Muñoz, Kate Smith-Miles

CryptoBench: Benchmarking Evolutionary Algorithms with Cryptographic Problems
Stjepan Picek, Domagoj Jakobovic, Una-May O'Reilly

On the Difficulty of Benchmarking Inductive Program Synthesis Methods
Edward Pantridge, Thomas Helmuth, Nicholas Freitag McPhee, Lee Spector

Performance Testing of Automated Modeling for Industrial Applications
Dylan Sherry, Michael Schmidt

Evolutionary Methods for Smart Grid Applications (EMSGA)

Organizers: Frank Neumann, *University of Adelaide, Australia*
Markus Wagner, *University of Adelaide*
Paul Kaufmann, *Paderborn University*
Oliver Kramer, *University of Oldenburg, Germany*

Time and Location: Sunday, July 16, 14:00-18:00, Bernstein

Evolving Multi-Objective Neural Networks using Differential Evolution for Dynamic Economic Emission Dispatch
Karl J. Mason, Jim Duggan, Enda Howley

Differential Evolution Strategies for Large-Scale Energy Resource Management in Smart Grids
Fernando Lezama, Joao Soares, Enrique Munoz de Cote, Luis Enrique Sucar, Zita Vale

Optimizing Booster Stations
Jonas Benjamin Weber, Ulf Lorenz

Restoration of Power Distribution Networks - A Fast Evolutionary Approach based on Practical Perspectives
Carlos E. R. Nogueira, Wallace C. Boaventura, Ricardo H. C. Takahashi, Eduardo G. Carrano

Towards Coding Strategies for Forecasting-Based Scheduling in Smart Grids and the Energy Lab 2.0
Wilfried Jakob, Jorge Ángel González Ordiano, Nicole Ludwig, Ralf Mikut, Veit Hagenmeyer

Model-based Evolutionary Algorithms (MBEA)

Organizers: John McCall, *Robert Gordon University*
Dirk Thierens, *Utrecht University, The Netherlands*

Time and Location: Sunday, July 16, 16:10-18:00, Saphir 2+3

Introduction
Dirk Thierens

Dealing with constraints in estimation of distribution algorithms
Josu Cebeiro

Gene-pool Optimal Mixing Evolutionary Algorithms: A Growing Family of Fast, Scalable and Practical Model Building EAs
Peter A.N. Bosman

DSMGA-II: pros and cons
Tian-Li Yu

Seeing the Wood for the Trees: Essential Structure in Model-based Search
John McCall

Close

Evolution in Cognition (EiC)

Organizers: Stéphane Doncieux, *Université Pierre et Marie Curie*
Joshua E. Auerbach, *École Polytechnique Fédérale de Lausanne (EPFL)*
Richard J. Duro, *Universidade da Coruna, Spain*
Harold de Vladar, *Parmenides Foundation*

Time and Location: Sunday, July 16, 16:10-18:00, Smaragd

Cognitive Cultural Dynamics
Harold de Vladar

Context Nodes in the Operation of a Long Term Memory Structure for an Evolutionary Cognitive Architecture
Richard J. Duro, Jose Antonio Becerra, Juan Monroy, Luis Calvo

Learning Highly Diverse Robot Throwing Movements through Quality Diversity Search
Seungsu Kim, Stéphane Doncieux

Genetic and Evolutionary Computation in Defense, Security, and Risk Management (SecDef)

Organizers: Frank Moore, *University of Alaska Anchorage, USA*
Gunes Kayacik, *Qualcomm Research Silicon Valley, USA*
Nur Zincir-Heywood, *Dalhousie University, Canada*
Anna I. Esparcia-Alcázar, *Universitat Politècnica de València, Spain*

Time and Location: Sunday, July 16, 16:10-18:00, Diamant

Investigating Coevolutionary Archive Based Genetic Algorithms on Cyber Defense Networks
Dennis Alberto Garcia, Anthony Edward Erb Lugo, Erik Hemberg, Una-May O'Reilly

Return-Oriented Programme Evolution with ROPER: A proof of concept
Olivia Lucca Fraser, Nur Zincir-Heywood, Malcolm I. Heywood, John T. Jacobs

Administrating Role-Based Access Control by Genetic Algorithms
Igor Saenko, Igor Kotenko

Surrogate-Assisted Evolutionary Optimization (SAEOpt)

Organizers: Alma A. M. Rahat, *University of Exeter*
Richard M. Everson, *University of Exeter, UK*
Jonathan E. Fieldsend, *University of Exeter, UK*
Handing Wang, *University of Surrey*
Yaochu Jin, *University of Surrey*

Time and Location: Sunday, July 16, 16:10-18:00, Amethyst

Enabling High-Dimensional Surrogate-Assisted Optimization by Using Sliding Windows
Bernhard Werth, Erik Pitzer, Michael Affenzeller

Bayesian Optimization Approach of General Bi-level Problems
Emmanuel Kieffer, Grégoire Danoy, Pascal Bouvry, Anass Nagih

A Surrogate-Based Evolutionary Algorithm For Highly Constrained Design Problems
Charlotte Beauthier, Paul Beaucaire, Caroline Sainvitu

Overview of Surrogate-model Versions of Covariance Matrix Adaptation Evolution Strategy
Zbyněk Pitra, Lukáš Bajer, Jakub Repický, Martin Holeňa

Late-Breaking Abstracts

Organizers: Ngoc Hoang Luong, *Centrum Wiskunde & Informatica (CWI)*

Time and Location: Sunday, July 16, 16:10-18:00, Topas 1

Late-Breaking Abstracts will be presented as posters with a short introduction of each poster by the LBA Chair.

A Novel Iterative Improvement Pivoting Rule for Local Search Heuristics
Saad Bougrine, Mohamed Amine El Majdouli, Abdelhakim Ameur El Imrani

Solving Order/Degree Problems by Using EDA-GK
Hisashi Handa, Ryoichi Hasegawa

An Approach of Satellite Periodic Continuous Observation Task Scheduling Based on Evolutionary Computation
Hao Chen, Chun Du, Jun Li, Ning Jing, Lingfeng Wang

Evaluating Island-based EAs on Unstable Networks with Complex Failure Patterns
Rafael Nogueras, Carlos Cotta

Discovering Weekly Seasonality for Water Demand Prediction using Evolutionary Algorithms
Piotr Lipinski, Patryk Filipiak, Pawel Rychlikowski, Justyna Stanczyk, Joanna Kajewska-Szkudlarek, Janusz Lomotowski, Tomasz Konieczny

Exploring the (Efficient) Frontiers of Portfolio Optimization
Matthew J. Craven, David I. Graham

Social Trends in the Iterated Prisoner's Dilemma
Jessica Finocchiaro, H. David Mathias

BBIOS: A Characterization of Evolutionary Algorithm Stability
Matthew J. Craven, Simon P. Martin

Hierarchical Pattern Mining Based On Swarm Intelligence
Kazuaki Tsuboi, Satoshi Suga, Satoshi Kurihara

Utilization of Infeasible Solutions in MOEA/D for Solving Constrained Many-objective Optimization Problems
Minami Miyakawa, Hiroyuki Sato, Yuji Sato

Melody Composition Using Geometric Crossover for Variable-length Encoding
Yong-Wook Nam, Yong-Hyuk Kim

Solving A Large Sudoku by Co-evolving Numerals
Jeffrey Horn

Optimization of Solid Waste Collection: Two ACO Approaches
Katya Rodríguez-Vázquez, Beatriz Garro-Licón, Elizabeth Mancera-Galván

General Aspect-based Selection Concept for Multi- and Many-objective Molecular Optimization
Susanne Rosenthal, Markus Borschbach

An Efficient Vector-Growth Decomposition Algorithm for Cooperative Coevolution in Solving Large Scale Problems
Zhigang Ren, An Chen, Lin Wang, Yongsheng Liang, Beibei Pang

A Bi-objective memetic algorithm proposal for solving the minimum sum coloring problem
Olfa Harrabi, Ezzeddine Fatnassi, Hend Bouziri, Jouhaina Chaouachi

Multi-document Summarization using Evolutionary Multi-objective Optimization
Chihoon Jung, Rituparna Datta, Aviv Segev

Optimizing LSTM RNNs Using ACO to Predict Turbine Engine Vibration
AbdElRahman ElSaid, Travis Desell, Fatima El Jamiy, James Higgins, Brandon Wild

Keynotes

BER 2017

GECCO Keynote

Computational Approaches in Cancer Genomics

Monday, July 17, 9:00-10:10
Saphir

Francesca Ciccarelli, *King's College London and The Francis Crick Institute, London UK*

Large-scale cancer genome projects provide an extraordinary mine of molecular information on a vast range of cancer types and samples and offer the exciting potential of understanding the molecular mechanisms of cancer. Much knowledge is however still hidden in the data and this significantly reduces the effective contribution of cancer molecular profiling to the personalised medicine agenda. In my lecture I will review some of the technical, analytical and scientific challenges in cancer genomic data analysis. I will also provide examples of how this type of analysis can contribute effectively to unravel cancer driver mechanisms and potential targets for anti-cancer therapy.

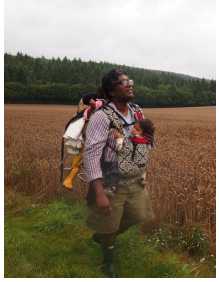
Biosketch: Francesca Ciccarelli is Associate Professor of Genomics and Bioinformatics at King's College London and Group Leader of the Cancer Systems Biology Group at The Francis Crick Institute in London. Francesca graduated in pharmaceutical chemistry at the University of Bologna and was awarded with a PhD in Natural Science from the University of Heidelberg. She was trained as a computational biologist under the supervision of Peer Bork at the EMBL. In 2005, she started her research group at the European Institute on Oncology in Milan focusing on cancer genomics, with a particular interest in gastrointestinal cancer. In 2014, she moved to London to work in the Cancer Division of King's College, where she also coordinates the qGEB (quantitative Genomics, Epigenomics and Biobank) programme. Francesca's group uses a combination of computational and experimental approaches to analyse cancer genomic data and predict patient-specific cancer drivers, identify cancer vulnerability, and rebuild tumour evolution in space and time.

GECCO Keynote

Evolving Brains in Evolving Environments

Tuesday, July 18, 9:00-10:10
Saphir

Drew Purves, *Google DeepMind, London, UK*
Chrisantha Fernando, *Google DeepMind, London, UK*



The spectacular and headline-grabbing recent successes in deep learning have made little or no use of evolutionary algorithms. Has this left Darwin turning in his grave, like one of the Earthworms he was so fond of studying? Or is he flying high, like a Galapagos Finch, safe in the knowledge that the inferior land-borne creatures below him will soon reach the edge of their harsh island and realize that, to go any further without drowning, they will need evolution?
We will discuss and illustrate two ways in which evolution may be on the critical path to Artificial General Intelligence, AGI. On the environment side, highly connected ecosystems of evolving agents — such as the environments within which our own intelligence evolved — may provide a 'natural curriculum' that naturally optimizes the nature and magnitude of the learning challenge presented to each of the agents in those ecosystems. If so, simulations of virtual ecosystems could become an efficient engine of innovation in AI. On the brain side, evolutionary algorithms and deep learning interact in various ways, e.g. searching over hyperparameters, copying weights in neural networks can contribute to continual learning, evolution can control which parts of giant neural networks learn, neural networks can learn mutation operators, reward functions can be evolved, and diversity maintenance mechanisms can be applied to reinforcement learning.

Biosketch: Dr. Drew Purves' research journey began in his teenage years when he became interested in the then nascent field of Artificial Life. This led him to study real Ecology at Cambridge, before doing a PhD in Ecological Modelling at the University

of York, and a postdoc at Princeton, before moving on to lead the Computational Ecology and Environmental Science group at Microsoft Research, Cambridge. Along the way, Drew became increasingly obsessed with developing complex ecological models that were nonetheless constrained rigorously against data using Bayesian methods. Many models, papers and software prototypes later, he jumped at the chance to join DeepMind, where is attempting to draw on all his experience to help create Artificial General Intelligence.

Dr. Chrisantha Fernando studied medicine at Oxford before realizing it was more fun to do evolutionary and adaptive systems at COGS in Sussex. He did his PhD mainly on the origin of life, which culminated many years later in a nice paper about soap bubbles ("Evolution before Genes"). In 2008 Chrisantha and Eors Szathmary started working on the crazy idea of things replicating in the brain, and in 2015 Chrisantha joined DeepMind to work on combining evolution and learning at the algorithmic level. He is interested in continual learning in giant neural networks that combine the population based search principles of evolutionary computation with gradient based deep learning, which he believes is one of the keys of artificial general intelligence.

SIGEVO Plenary Lecture

Wednesday, July 19,
11:10-12:00
Saphir

Curious and Creative Machines

Hod Lipson, *Columbia University, New York, USA*

Can machines ask questions and generate hypotheses? Despite the prevalence of big data, the process of distilling data into scientific laws has resisted automation. Particularly challenging are situations with small amounts of data that is difficult or expensive to collect, such as in robotics and other physical sciences. This talk will outline a series of recent research projects, starting with self-reflecting robotic systems, and ending with machines that can formulate hypotheses, design experiments, and interpret the results, to discover new scientific laws. We will see examples from geology to cosmology, from classical physics to modern physics, from big science to small science.

Biosketch: Hod Lipson is a professor of Engineering and Data Science at Columbia University in New York, and a co-author of the award winning book “Fabricated: The New World of 3D printing” and “Driverless: Intelligent cars and the road ahead”. His work on self-aware and self-replicating robots challenges conventional views of robotics, and has enjoyed widespread media coverage. Lipson has co-authored over 300 publications that received over 14,000 citations to date. He has co-founded four companies, and is frequent keynoter both in industry and academic events. Hod directs the Creative Machines Lab, which pioneers new ways to make machines that create, and machines that are creative.

Best Paper Nominations

BES 2017

Best Paper Nominations

Ant Colony Optimization and Swarm Intelligence (ACO-SI)

Analysis of Independent Roulette Selection in Parallel Ant Colony Optimization
Huw Lloyd, Martyn Amos
Tuesday, July 18, 10:40-11:05, Opal

Complex Systems (CS)

Discovering Evolutionary Stepping Stones through Behavior Domination
Elliot Meyerson, Risto Miikkulainen
Tuesday, July 18, 15:15-15:40, Opal

Data-Efficient Exploration, Optimization, and Modeling of Diverse Designs through Surrogate-Assisted Illumination
Adam Gaier, Alexander Asteroth, Jean-Baptiste Mouret
Tuesday, July 18, 14:50-15:15, Opal

On Self-Adaptive Mutation Restarts for Evolutionary Robotics with Real Rotorcraft
Gerard David Howard
Tuesday, July 18, 14:00-14:25, Opal

Evolutionary Optimization of Self-Assembly in a Swarm of Bio-microrobots
Nathanael Y. I. Aubert-Kato, Charles Fosseprez, Guillaume Gines, Ibuki Kawamata, Huy Q. Dinh, Leo Cazenille, Andre Estevez-Torres, Masami Hagiya, Yannick Rondelez, Nicolas Bredeche
Tuesday, July 18, 14:25-14:50, Opal

Digital Entertainment Technologies and Arts (DETA)

Multi-Task Learning in Atari Video Games with Emergent Tangled Program Graphs
Stephen Kelly, Malcolm I. Heywood
Monday, July 17, 14:25-14:50, Opal

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

Automatic Design of Multi-Objective Local Search Algorithms
Aymeric Blot, Laetitia Jourdan, Marie-Éléonore Kessaci
Wednesday, July 19, 09:25-09:50, Saphir

Configuring irace using surrogate configuration benchmarks
Nguyen Dang, Leslie Pérez Cáceres, Thomas Stützle, Patrick De Causmaecker
Wednesday, July 19, 09:50-10:15, Saphir

Distributed Evolutionary k-way Node Separators
Peter Sanders, Christian Schulz, Darren Strash, Robert Williger
Wednesday, July 19, 09:00-09:25, Saphir

Evolutionary Machine Learning (EML)

A Genetic Programming Approach to Designing Convolutional Neural Network Architectures
Masanori Suganuma, Shinichi Shirakawa, Tomoharu Nagao
Monday, July 17, 17:25-17:50, Opal

Toward the automated analysis of complex diseases in genome-wide association studies using genetic programming
Andrew M. Sohn, Randal S. Olson, Jason H. Moore
Monday, July 17, 16:10-16:35, Opal

Accelerating Coevolution with Adaptive Matrix Factorization
Paweł Liskowski, Wojciech Jaśkowski
Monday, July 17, 16:35-17:00, Opal

Evolving Memory-Augmented Neural Architecture for Deep Memory Problems
Shauharda Khadka, Jen Jen Chung, Kagan Tumer
Monday, July 17, 17:00-17:25, Opal

Evolutionary Multiobjective Optimization (EMO)

Reference Point Specification in Hypervolume Calculation for Fair Comparison and Efficient Search
Hisao Ishibuchi, Ryo Imada, Yu Setoguchi, Yusuke Nojima
Tuesday, July 18, 14:00-14:25, Saphir

Improved Incremental Non-dominated Sorting for Steady-State Evolutionary Multiobjective Optimization
Ilya Yakupov, Maxim Buzdalov
Tuesday, July 18, 14:25-14:50, Saphir

Progressively Adding Objectives: A Case Study in Anomaly Detection
Luis Martí, Arsene Fansi-Tchango, Laurent Navarro, Marc Schoenauer
Tuesday, July 18, 14:50-15:15, Saphir

Evolutionary Numerical Optimization (ENUM)

Exploiting Linkage Information in Real-Valued Optimization with the Real-Valued Gene-Pool Optimal Mixing Evolutionary Algorithm
Anton Bouter, Tanja Alderliesten, Cees Witteveen, Peter A.N. Bosman
Tuesday, July 18, 17:00-17:25, Opal

TPAM: A Simulation-Based Model for Quantitatively Analyzing Parameter Adaptation Methods
Ryoji Tanabe, Alex Fukunaga
Tuesday, July 18, 16:10-16:35, Opal

Deriving and Improving CMA-ES with Information Geometric Trust Regions
Abbas Abdolmaleki, Bob Price, Nuno Lau, Luis Paulo Reis, Gerhard Neumann
Tuesday, July 18, 16:35-17:00, Opal

Genetic Algorithms (GA)

Fast Genetic Algorithms
Benjamin Doerr, Huu Phuoc Le, Regis Makhmara, Ta Duy Nguyen
Monday, July 17, 11:05-11:30, Saphir

Optimizing One Million Variable NK Landscapes by Hybridizing Deterministic Recombination and Local Search
Francisco Chicano, Darrell Whitley, Gabriela Ochoa, Renato Tinós
Monday, July 17, 10:40-11:05, Saphir

General Evolutionary Computation and Hybrids (GECH)

Investigating Uncertainty Propagation in Surrogate-Assisted Evolutionary Algorithms
Vanessa Volz, Günter Rudolph, Boris Naujoks
Monday, July 17, 14:00-14:25, Opal

Genetic Programming (GP)

How Noisy Data Affects Geometric Semantic Genetic Programming
Luis Fernando Miranda, Luiz Otavio Vilas Boas Oliveira, Joao Francisco Barreto da Silva Martins, Gisele Lobo Pappa
Tuesday, July 18, 11:05-11:30, Saphir

Improving Generalization of Evolved Programs through Automatic Simplification
Thomas Helmuth, Nicholas Freitag McPhee, Edward Pantridge, Lee Spector
Tuesday, July 18, 10:40-11:05, Saphir

Counterexample-Driven Genetic Programming
Krzysztof Krawiec, Iwo Błądek, Jerry Swan
Tuesday, July 18, 11:30-11:55, Saphir

Real World Applications (RWA)

Heuristic Allocation of Computational Resources
Silviu Tofan, Richard Allmendinger, Manuela Zanda, Olly Stephens
Tuesday, July 18, 16:10-16:35, Saphir

Evolutionary Decomposition for 3D Printing
Eric A. Yu, Jin Yeom, Cem C. Tutum, Etienne Vouga, Risto Miikkulainen
Tuesday, July 18, 16:35-17:00, Saphir

Search-Based Software Engineering (SBSE)

Active Coevolutionary Learning of Requirements Specifications from Examples
Marcel Wever, Lorijn van Rooijen, Heiko Hamann
Tuesday, July 18, 11:05-11:30, Opal

Theory (THEORY)

Runtime Analysis of the $(1 + (\lambda, \lambda))$ Genetic Algorithm on Random Satisfiable 3-CNF Formulas
Maxim Buzdalov, Benjamin Doerr
Tuesday, July 18, 17:25-17:50, Opal

SIGEVO Summer School

SIGEVO Summer School (S3)

Organizer: Enrique Alba, *University of Malaga*
Dates: July 14-21
Mentors: Anne Auger, *INRIA*
Jürgen Branke, *University of Warwick*
Carlos Coello, *CINVESTAV-IPN*
Carola Doerr, *CNRS and Université Pierre et Marie Curie - Paris 6*
Manuel López-Ibáñez, *University of Manchester*
John McCall, *Robert Gordon University*
Justyna Petke, *University College London*
Mike Preuss, *University of Münster*
Thomas Stützle, *Université Libre de Bruxelles*
Una-May O'Reilly, *Massachusetts Institute of Technology*

SIGEVO is a special interest group of ACM always looking for new ways to improve the research and learning on genetic and evolutionary computation. In this quest for disseminating the knowledge and making activities in this domain we will organize, for the first time, a Summer School around GECCO 2017 in Berlin: S3 (SIGEVO Summer School). We seek for PhD students to participate in this event (only 30 students accepted), offering:

- One day before GECCO (July 14th), with lectures and interactions to world class researchers in this domain.
- Two days after GECCO (July 20th and 21st) of discussions, presentations, and joint works.
- Oriented interactions and learning in tutorials and sessions of GECCO.
- Great networking opportunities and up to 6 awards to recognize outstanding performance.

The many appealing activities during S3 will include:

- A first day (get together) where students will meet each other and listen to short lessons. An assignment will be done to students and links for a close interaction to mentors will be created for the whole school and conference duration.
- Questions, competitions, and awards (economic plus diploma prizes) will be offered to the students who perform the best, granted at the end of the summer school. We have up to 6 awards in different categories: come and participate!
- Opportunities to attend a big number of high quality GECCO tutorials plus continuous interaction to the summer school staff and the school mentors, what will raise the abilities and vision of students: don't miss this.
- The first day after GECCO, students will discuss with their mentors, so as to finish their assignments. Also, mentors will evaluate during this day the solution to the questions made the first day. The last day of the school, the results and winners will be announced.
- The first and second days after GECCO students will present their assignments to mentors. Enjoy this boosting to your knowledge, your PhD thesis, and your networking to this community!

STUDENTS ARE EXPECTED TO:

- Attend **ALL** the 1+2 days of S3, plus attending some tutorials and sessions of GECCO 2017.
- Have a valid registration to GECCO itself, plus a small fee of 100 euros to participate in the school.
- Fulfill an assignment, participate in the school challenges, and follow the standards of proper social and research behavior.

SIGEVO SUMMER SCHOOL: S3 2017

Dates 1: July 14-20-21 2017 (just activities of the school)
Dates 2: July 15-19 (soft merged activities with GECCO)
Participants: 30 students, 10 mentors, school organizers
Venue: Andel's by Vienna House Hotel in Berlin (like GECCO)

Activities of S3

Friday July 14th (before GECCO)

1. Mentor's Master Lesson

Ten mentors will make a short self-contained lesson with several topics (connected or not between them). The expected duration will be 30m, plus 15m to present three scientific assignments to students.

An assignment for a student could be of any of these three types: (1) make a written report, (2) program, (3) numerical study, involving a preliminary search in literature plus using a mentor's own paper presented in past GECCO's. These are just suggestions!

2. Mentor's Challenge Proposal

Every mentor will also present one challenge for all students, consisting in attending to one concrete paper (or tutorial) presentation at this GECCO. Students are expected to make an answer to 8 mentor's questions. The three students with more correct answers will win an award (500, 300, 150 euros) plus a diploma. Ties will be broken by those presenting more one-page summaries of (three) associated papers given by mentors.

Saturday July 15th to Wednesday July 19th (GECCO time)

3. Mentor's Assignments Working Time

The first day after GECCO students get together with seniors, in a free private arrangement –place and time- between the three students and their mentor. The goal of this short meeting is to ask potential questions for understanding their assignments.

In case that students need an additional meeting we suggest they consult their mentor's availability in advance to arrange additional (short) meetings.

4. Mentor's Challenge Working Time

During the five days of GECCO, students will attend to the defined paper/tutorial presentations looking for an answer to the proposed mentor's challenge.

Students can prepare a sound summary of one page on the paper/tutorial for potential ties in the challenge. This is voluntary. Summaries do not replace correct answers to the challenge, but are just used for breaking ties on equal number of answers. On July 19th students will send their answers (and maybe summaries) to every mentor.

Thursday July 20th (after GECCO)

5. Mentor's Assignment and Challenge Resolution

In the morning, mentors will meet with every one of the three students to discuss the results of the assignments initiated the first day of the school. This will finish the assignment part for students: they should deliver to their mentors any document or program resulting from the assignment before 12h.

During the morning, mentors will be evaluating answers to their challenges, and quality of the summary received from students.

This is a private time where mentors do this activity on their own. A shared document will be available to evaluate answers and summaries. An overall evaluation of all the answers to the challenge will be done so as to define the first three students making the higher quality answers (ties broken by number and quality of summaries).

A shared document will be available to include student's grades.

6. Mentor's Assignments Oral Presentations (Part I)

We will here start a series of presentations (10 m presentation plus 5 m debate with mentors) of the assignments, where every student will summarize his/her work to the mentor panels. Mentors will grade students as they present, to give feedback to students and to allow the identification of the three best works.

Friday July 21st (after GECCO)

7. Mentor's Assignments Oral Presentations (Part II)

This last day of the summer school, students will continue to present (10 m presentation plus 5 m debate with mentors) their assignments to the mentor panels.

At the end of all presentations, mentors will meet to make a global decision on the three best assignments (quality, difficulty, relevance, presentation…).

The day will finish with a closing ceremony, where two awards will be granted:

1. The award to the best assignments (500, 300, 150 euros plus diploma).
2. The award to the best challenge (500, 300, 150 euros plus diploma).

Important comments:

- Mentors will consider at all times the high variety of students in terms of research maturity, culture, and research preferences (i.e., will offer assorted assignments).
- Students will participate in every activity of the school. All activities are mandatory with the exception of making the one-page summaries.
- There will be a room linked to the school on 14-20-21 for all activities. The interaction of mentor and his/her students can be carried out of the room if easier.

PROGRAM OF THE SIGEVO SUMMER SCHOOL (S3) 2017

July 14th	July 15th – 19th	July 20th	July 21st
8:30h: Opening & Games 09:00h *Manuel López-Ibáñez* 09:45h *Mike Preuss* 10:30h *Carola Doerr* **11:15h Coffee Break** 11:45h *Una-May O'Reilly* 12:30h *Justyna Petke* 13:15h *Thomas Stützle* **14:00h LUNCH TOGETHER** 15:30h *John McCall* 16:15h *Juergen Branke* **17:00h Coffee Break** 17:30h *Anne Auger* 18:15h *Carlos Coello* **19h:00 End** *Students can select an assignment anytime during the day by sending an email to eat@lcc.uma.es*	GECCO **Students:** - Work on assignments - Solve challenges - Make paper summaries (voluntary) - Send challenge answers and paper summaries before 19h - Interact with mentors **Mentors:** - Interact with students 19:00h Deliver challenges to mentors	**MORNING - free agreed timing** **Students:** - Interview with mentors for assignment and oral presentation - Deliver assignments before 12h **Mentors:** - Interview with students for assignment and oral presentation - Grade student answers to own challenge and own assignments **12h Deadline for any student submission** **13:00h LUNCH TOGETHER** - 15:00h..16:45h 7 students (15m each) Mentor Panel 1 **- 16:45h..17:15h** **Coffee Break** - 17:15h..19:15h 8 students (15m each) Mentor Panel 2	**Oral presentation: student assignments** - 08:00h..10:00h 8 students (15m each) Mentor Panel 1 **- 10:00h..10:30h** **Coffee Break** - 10:30..12:15 7 students (15m each) Mentor Panel 2 - 12:15h..12:45h Evaluations **12:45h Closing of the S3** - Diplomas of participation for all students - Public decision on 3 awards for assignments - Public decision on 3 awards for challenge - Farewell

Mentor Panel 1: Una-May O'Reilly, Justyna Petke, Thomas Stützle, John McCall, Carlos Coello

Mentor Panel 2: Juergen Branke, Manuel López-Ibáñez, Anne Auger, Mike Preuss, Carola Doerr

Humies, Competitions, Evolutionary Computation in Practice, and Job Market

Human Competitive Results: 14th Annual Humies Awards

Presentations: Monday, July 17, 14:00-15:50
Diamant

Announcement of Awards: Wednesday, July 19, 12:00-13:30
Saphir

On-location chair: Erik D. Goodman

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

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: Sunday, July 16, 14:00-15:50, Topas 1

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 aims at attacking a growing impact of over-fitting of optimization algorithms to a narrow set of existing benchmark problems. The competition was run three times with a total of 100 submissions.

Industrial Challenge: Monitoring of drinking-water quality

Organizers: Martina Friese, Andreas Fischbach, Thomas Bartz-Beielstein

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

Water covers 71% of the Earth's surface and is vital for all known forms of life. The holistic consideration of water as an important means of nourishment as well as the general protection of lakes and rivers are a central basis for the growth and further development of human civilization. At the same time, the civilization itself, with its steady growth, is a menace to the purity of water resources used for drinking water supply and its distribution network. They are highly sensible to any kinds of contaminations. The provision of clean and safe drinking-water is an essential task for water supply companies all over the world.
To deal with this scenario, highly sensible sensors monitor relevant water- and environmental data at several measuring points, on a regular basis. The monitored data can be analyzed to discover any kinds of anomalies. This allows for early recognitions of undesirable changes in the drinking water quality and enables the water supply companies to counteract in time.
This year'sindustrial partner is Thüringer Fernwasserversorgung (TFW), which provides the dataset used in this challenge. Goal of the GECCO 2017 Industrial Challenge is to develop an event detector to accurately predict any kinds of changes in a time series of drinking water composition data.

MicroRTS AI Competition

Organizer: Santiago Ontanion

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

Several AI competitions organized around RTS games have been organized in the past (such as the ORTS competitions, and the StarCraft AI competitions), which has spurred a new wave of research in to RTS AI. However, as it has been reported numerous times, developing bots for RTS games such as StarCraft involves a very large amount of engineering, which often relegates the research aspects of the competition to a second plane. The microRTS competition has been created to motivate research in the basic research questions underlying the development of AI for RTS games, while minimizing the amount of engineering required to participate. Also, a key difference with respect to the StarCraft competition is that the AIs have access to a "forward model" (i.e., a simulator), with which they can simulate the effect of actions or plans, thus allowing for planning and game-tree search techniques to be developed easily. Although we acknowledge that planning in domains for which the agent does not have a forward model is a very important problem, this is left out of this competition, in order to focus on other core RTS problems.

Niching Methods for Multimodal Optimization

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

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

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 2017 (i.e., submitting via the online submission system of GECCO 2017). 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.

Optimisation of Problems with Multiple Interdependent Components

Organizers: Markus Wagner, Wanru Gao

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

Real-world optimization problems often consist of several NP-hard combinatorial optimization problems that interact with each other. Such multi-component optimization problems are difficult to solve not only because of the contained hard optimization problems, but in particular, because of the interdependencies between the different components. Interdependence complicates a decision making by forcing each sub-problem to influence the quality and feasibility of solutions of the other sub-problems. This influence might be even stronger when one sub-problem changes the data used by another one through a solution construction process. Examples of multi-component problems are vehicle routing problems under loading constraints, the maximizing material utilization while respecting a production schedule, and the relocation of containers in a port while minimizing idle times of ships.
The goal of this competition is to provide a platform for researchers in computational intelligence working on multi-component optimization problems. The main focus of this competition is on the combination of Traveling Salesperson and Knapsack problems. However, we plan to extend this competition format to more complex combinations of problems (that have typically been dealt with individually in the past decades) in the upcoming years.

The General Video Game AI Competition

Organizers: Diego Perez, Simon M. Lucas, Spyridon Samothrakis, Julian Togelius, Tom Schaul

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

The GVG-AI Competition explores the problem of creating controllers for general video game playing. How would you create a single agent that is able to play any game it is given? Could you program an agent that is able to play a wide variety of games, without knowing which games are to be played?

Virtual Creatures

Organizers: Joel Lehman, Sebastian Risi, Nicholas Cheney

Time and Location: Sunday, July 16, 14:00-15:50, Topas 1

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

Evolutionary Computation in Practice

Organizers: Thomas Bartz-Beielstein, *Cologne University of Applied Sciences*
Anna I. Esparcia-Alcázar, *Universidad Politecnica de Valencia*
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. A panel of experts describes a range of techniques you can use to identify, design, manage, and successfully complete an EA project for a client. If you are working in academia and are interested in managing industrial projects, you will receive valuable hints for your own research projects.

Session 1: Bridging the gap between academia and industry

Monday, July 17, 10:40-12:20
Topas 1

Optimization and Learning Through Evolutionary Computation
Kalyanmoy Deb — Chair: Erik Goodman

A Collaborative Approach to Quality Control in Manufacturing
Bogdan Filipic — Chair: Erik Goodman

Heuristic Optimization Networks in Production and Logistics
Michael Affenzeller — Chair: Erik Goodman

One Decade of Experience in Coupling a Genetic Algorithm with Casting Process Simulation
Volker Kokot — Chair: Thomas Bartz-Beielstein

Session 2: "Real" real-world optimization

Monday, July 17, 14:00-15:40
Topas 1

Evolutionary Computation in the Future of Making Things
Hooman Shayani — Chair: Thomas Bartz-Beielstein

Particle Swarm Optimization Policy (PSO-P) for Industrial Reinforcement Learning Problems
Daniel Hein — Chair: Thomas Bartz-Beielstein

Electrostatic Precipitator Optimization using a model-based Evolutionary Algorithm
Frederik Rehbach, Andre Schagen — Chair: Thomas Bartz-Beielstein

Session 3: Ask the experts / Getting a job

Monday, July 17, 16:10-17:50
Topas 1

Publishing your Research Work
Ronan Nugent — Chair: Jörn Mehnen

Ask the experts / Getting a job
Anna I. Esparcia-Alcázar, Jörn Mehnen, Erik Goodman, Thomas Bartz-Beielstein — Chair: Andreas Fischbach

Job Market

Organizer: Tea Tušar, *Jozef Stefan Institute*
Time and Location: Monday, July 17, 12:20-14:00, Opal

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

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

Papers and Posters

BEST 2017

CS1

Monday, July 17, 10:40-12:20, Smaragd
Chair: Emma Hart (Napier University)

Coupling Novelty and Surprise for Evolutionary Divergence
Daniele Gravina, Antonios Liapis, Georgios N. Yannakakis 10:40-11:05

Minimal Criterion Coevolution: A New Approach to Open-Ended Search
Jonathan C. Brant, Kenneth O. Stanley 11:05-11:30

An Investigation of Environmental Influence on the Benefits of Adaptation Mechanisms in Evolutionary Swarm Robotics
Andreas Steyven, Emma Hart, Ben Paechter 11:30-11:55

Effect of Animat Complexity on the Evolution of Hierarchical Control
Jared M. Moore, Anthony J. Clark, Philip K. McKinley 11:55-12:20

ECOM1

Monday, July 17, 10:40-12:20, Opal
Chair: Tobias Friedrich (Hasso Plattner Institute)

Combining Two Local Searches with Crossover: An Efficient Hybrid Algorithm for the Traveling Salesman Problem
Weichen Liu, Thomas Weise, Yuezhong Wu, Qi Qi 10:40-11:05

Multimodal Truss Structure Design Using Bilevel and Niching Based Evolutionary Algorithms
Md. Jakirul Islam, Xiaodong Li, Kalyanmoy Deb 11:05-11:30

Approximating Optimization Problems using EAs on Scale-Free Networks
Ankit Chauhan, Tobias Friedrich, Francesco Quinzan 11:30-11:55

On Feasible and Infeasible Search for Equitable Graph Coloring
Wen Sun, Jin-Kao Hao, XiangJing Lai, Qinghua Wu 11:55-12:20

EML1

Monday, July 17, 10:40-12:20, Jade
Chair: Mengjie Zhang (Victoria University of Wellington)

Theoretical XCS Parameter Settings of Learning Accurate Classifiers
Masaya Nakata, Will N. Browne, Tomoki Hamagami, Keiki Takadama 10:40-11:05

Particle Swarm Optimization for Hyper-Parameter Selection in Deep Neural Networks
Pablo Ribalta Lorenzo, Jakub Nalepa, Michal Kawulok, Luciano Sanchez Ramos, José Ranilla Pastor 11:05-11:30

Biogeography-Based Rule Mining for Classification
Effat Farhana, Steffen Heber 11:30-11:55

Evolving Parsimonious Networks by Mixing Activation Functions
Alexander Hagg, Maximilian Joseph Mensing, Alexander Asteroth 11:55-12:20

EMO1

Monday, July 17, 10:40-12:20, Diamant
Chair: Dimo Brockhoff (INRIA Lille - Nord Europe)

Multimodal Scalarized Preferences in Multi-objective Optimization
Marlon Alexander Braun, Lars Heling, Pradyumn Shukla, Hartmut Schmeck 10:40-11:05

On the Importance of Isolated Solutions in Constrained Decomposition-based Many-objective Optimization
Maha Elarbi, Slim Bechikh, Lamjed Ben Said 11:05-11:30

A Hyper-Heuristic of Scalarizing Functions
Raquel Hernández Gómez, Carlos A. Coello Coello 11:30-11:55

Speeding Up Evolutionary Multi-objective Optimisation Through Diversity-Based Parent Selection
Edgar Covantes Osuna, Wanru Gao, Frank Neumann, Dirk Sudholt 11:55-12:20

GA1: Best Papers

Monday, July 17, 10:40-12:20, Saphir
Chair: Tian-Li Yu (Department of Electrical Engineering, National Taiwan University)
(Best Paper nominees are marked with a star)

Optimizing One Million Variable NK Landscapes by Hybridizing Deterministic Recombination and Local Search ☆
Francisco Chicano, Darrell Whitley, Gabriela Ochoa, Renato Tinós 10:40-11:05

Fast Genetic Algorithms ☆
Benjamin Doerr, Huu Phuoc Le, Regis Makhmara, Ta Duy Nguyen 11:05-11:30

Automatic Generation of Domain-Specific Genetic Algorithm Operators using the Hierarchical Bayesian Optimization Algorithm
Mark W. Hauschild, Cezary Janikow 11:30-11:55

GP1

Monday, July 17, 10:40-12:20, Bernstein
Chair: Wolfgang Banzhaf (Memorial University of Newfoundland)

Properties of a GP Active Learning Framework for Streaming Data with Class Imbalance
Sara Khanchi, Malcolm I. Heywood, Nur Zincir-Heywood 10:40-11:05

Self-adaptation of Genetic Operators Through Genetic Programming Techniques
Andrés Felipe Cruz Salinas, Jonatan Gomez Perdomo 11:05-11:30

Ensemble representation learning: an analysis of fitness and survival for wrapper-based genetic programming methods
William La Cava, Jason H. Moore 11:30-11:55

A Hybrid Genetic Programming Decision Making System for RoboCup Soccer Simulation
Amir Tavafi, Wolfgang Banzhaf 11:55-12:20

RWA1

Monday, July 17, 10:40-12:20, Amethyst
Chair: Enrique Alba (University of Málaga)

EML2

Monday, July 17, 14:00-15:40, Amethyst
Chair: Bing Xue (Victoria University of Wellington)

GPGC: Genetic Programming for Automatic Clustering using a Flexible Non-Hyper-Spherical Graph-Based Approach
Andrew Lensen, Bing Xue, Mengjie Zhang 14:00-14:25

Solving Test Case Based Problems With Fuzzy Dominance
Jason Zutty, Gregory Rohling 14:25-14:50

Feature Selection Using Stochastic Diffusion Search
Haya Abdullah Alhakbani, Mohammad Majid Al-Rifaie 14:50-15:15

An Evolutionary Algorithm for Discovering Multi-Relational Association Rules in the Semantic Web
Minh Duc Tran, Claudia d'Amato, Binh Thanh Nguyen, Andrea G. B. Tettamanzi 15:15-15:40

GECH1+DETA1: Best Papers

Monday, July 17, 14:00-15:40, Opal
Chair: Juergen Branke (University of Warwick) (Best Paper nominees are marked with a star)

Investigating Uncertainty Propagation in Surrogate-Assisted Evolutionary Algorithms ☆
Vanessa Volz, Günter Rudolph, Boris Naujoks 14:00-14:25

Multi-Task Learning in Atari Video Games with Emergent Tangled Program Graphs ☆
Stephen Kelly, Malcolm I. Heywood 14:25-14:50

Evolution of Artistic Image Variants Through Feature Based Diversity Optimisation
Bradley James Alexander, James Kortman, Aneta Neumann 14:50-15:15

GP2

Monday, July 17, 14:00-15:40, Bernstein
Chair: William B. Langdon (University College London)

Bounding Bloat in Genetic Programming
Benjamin Doerr, Timo Kötzing, J. A. Gregor Lagodzinski, Johannes Lengler 14:00-14:25

Combining Conformal Prediction and Genetic Programming for Symbolic Interval Regression
Thuong Thi Pham, Hoai Xuan Nguyen, Xin Yao 14:25-14:50

Evolvability in Grammatical Evolution
Eric Medvet, Fabio Daolio, Danny Tagliapietra 14:50-15:15

Geometric Semantic Genetic Programming for Recursive Boolean Programs
Alberto Moraglio, Krzysztof Krawiec 15:15-15:40

RWA2

Monday, July 17, 14:00-15:40, Jade
Chair: Neil Urquhart (Edinburgh Napier University)

Solving Structures of Pigment-Protein Complexes as Inverse Optimization Problems using Decomposition
Yigal Lahav, Ofer M. Shir, Dror Noy 14:00-14:25

Monopolies Can Exist in Unmanned Airspace
Scott Stephen Forer, Logan Yliniemi 14:25-14:50

Evolving Solution Choice and Decision Support for a Real-World Optimisation Problem.
Neil Urquhart, Achille Fonzone 14:50-15:15

Searching for Nonlinear Relationships in fMRI Data with Symbolic Regression
James Alexander Hughes, Mark Daley 15:15-15:40

THEORY1

Monday, July 17, 14:00-15:40, Smaragd
Chair: Carola Doerr (CNRS and Univ. Sorbonnes Paris 6)

Upper Bounds on the Runtime of the Univariate Marginal Distribution Algorithm on OneMax
Carsten Witt 14:00-14:25

When is it Beneficial to Reject Improvements?
Samadhi Nallaperuma, Pietro Simone Oliveto, Jorge Perez Heredia, Dirk Sudholt 14:25-14:50

Running Time Analysis of the (1+1)-EA for OneMax and LeadingOnes under Bit-wise Noise
Chao Qian, Chao Bian, Wu Jiang, Ke Tang 14:50-15:15

The (1+λ) Evolutionary Algorithm with Self-Adjusting Mutation Rate
Benjamin Doerr, Christian Gießen, Carsten Witt, Jing Yang 15:15-15:40

CS2

Monday, July 17, 16:10-17:50, Diamant
Chair: Sam Kriegman (University of Vermont)

Vascular Morphogenesis Controller: A Generative Model For Developing Morphology of Artificial Structures
Payam Zahadat, Daniel Nicolas Hofstadler, Thomas Schmickl 16:10-16:35

On the Runtime Analysis of the Opt-IA Artificial Immune System
Dogan Corus, Pietro Simone Oliveto, Donya Yazdani 16:35-17:00

A Minimal Developmental Model Can Increase Evolvability in Soft Robots
Sam Kriegman, Nick Cheney, Francesco Corucci, Josh Bongard 17:00-17:25

ECOM2

Monday, July 17, 16:10-17:50, Jade
Chair: Myriam Delgado (Federal University of Technology (UTFPR))

Comparing Communities of Optima with Funnels in Combinatorial Fitness Landscapes
Sarah L. Thomson, Fabio Daolio, Gabriela Ochoa 16:10-16:35

Just-in-Time Batch Scheduling Problem with Two-dimensional Bin Packing Constraints
Sergey Polyakovskiy, Alexander Makarowsky, Rym M'Hallah 16:35-17:00

Parameter-less Late Acceptance Hill-Climbing
Mosab Bazargani, Fernando G. Lobo 17:00-17:25

HSEDA: A Heuristic Selection Approach Based on Estimation of Distribution Algorithm for the Travelling Thief Problem
Marcella Scoczynski Ribeiro Martins, Mohamed El Yafrani, Markus Wagner, 17:25-17:50
Myriam Regattieri Delgado, Belaïd Ahiod, Ricardo Lüders

EML3: Best Papers

Monday, July 17, 16:10-17:50, Opal
Chair: Will Neil Browne (Victoria University of Wellington) (Best Paper nominees are marked with a star)

Toward the automated analysis of complex diseases in genome-wide association studies using genetic programming ☆
Andrew M. Sohn, Randal S. Olson, Jason H. Moore 16:10-16:35

Accelerating Coevolution with Adaptive Matrix Factorization ☆
Paweł Liskowski, Wojciech Jaśkowski 16:35-17:00

Evolving Memory-Augmented Neural Architecture for Deep Memory Problems ☆
Shauharda Khadka, Jen Jen Chung, Kagan Tumer 17:00-17:25

A Genetic Programming Approach to Designing Convolutional Neural Network Architectures ☆
Masanori Suganuma, Shinichi Shirakawa, Tomoharu Nagao 17:25-17:50

EMO2

Monday, July 17, 16:10-17:50, Smaragd
Chair: Carlos A. Coello Coello (CINVESTAV-IPN)

Benchmarking MOEAs for Multi- and Many-objective Optimization Using an Unbounded External Archive
Ryoji Tanabe, Akira Oyama 16:10-16:35

Closed States Model for Understanding the Dynamics of MOEAs
Hugo Monzón, Hernán Aguirre, Sébastien Verel, Arnaud Liefooghe, Bilel Derbel, Kiyoshi Tanaka 16:35-17:00

Multiobjective Data Mining from Solutions by Evolutionary Multiobjective Optimization
Yusuke Nojima, Yuki Tanigaki, Hisao Ishibuchi 17:00-17:25

Metamodeling for Multimodal Selection Functions in Evolutionary Multi-Objective Optimization
Proteek Roy, Rayan Hussien, Kalyanmoy Deb 17:25-17:50

GP3

Monday, July 17, 16:10-17:50, Bernstein
Chair: Krzysztof Krawiec (Poznan University of Technology)

Coevolving Deep Program Hierarchies to Solve Complex Tasks
Robert Jacob Smith, Malcolm I. Heywood 16:10-16:35

Genetic Programming based Feature Construction for Classification with Incomplete Data
Cao Truong Tran, Mengjie Zhang, Peter Andreae, Bing Xue 16:35-17:00

Scalable Genetic Programming by Gene-Pool Optimal Mixing and Input-Space Entropy-Based Building-Block Learning
Marco Virgolin, Tanja Alderliesten, Cees Witteveen, Peter A.N. Bosman 17:00-17:25

RWA3

Monday, July 17, 16:10-17:50, Amethyst
Chair: Emma Hart (Napier University)

A Hybrid Method for Feature Construction and Selection to Improve Wind-Damage Prediction in the Forestry Sector
Emma Hart, Kevin Sim, Barry Gardiner, Kana Kanimura 16:10-16:35

University Staff Teaching Allocation: Formulating and Optimising a Many-Objective Problem
Jonathan E. Fieldsend 16:35-17:00

Fast Pedestrian Detection Using Multimodal Estimation of Distribution Algorithms
Da-Zhao Tan, Wei-Neng Chen, Jun Zhang, Wei-Jie Yu 17:00-17:25

Towards Solving Large-Scale Precedence Constrained Production Scheduling Problems in Mining
Angus Kenny, Xiaodong Li, Andreas T. Ernst, Dhananjay Thiruvady 17:25-17:50

ECOM3

Tuesday, July 18, 10:40-12:20, Jade
Chair: Franz Rothlauf (University of Mainz)

Automated Heuristic Design Using Genetic Programming Hyper-Heuristic for Uncertain Capacitated Arc Routing Problem
Yuxin Liu, Yi Mei, Mengjie Zhang, Zili Zhang 10:40-11:05

Fragment-based Genetic Programming for Fully Automated Multi-Objective Web Service Composition
Alexandre Sawczuk da Silva, Yi Mei, Hui Ma, Mengjie Zhang 11:05-11:30

Toward Evolving Dispatching Rules for Dyanmic Job Shop Scheduling Under Uncertainty
Deepak Karunakaran, Yi Mei, Gang Chen, Mengjie Zhang 11:30-11:55

Shaping Communities of Local Optima by Perturbation Strength
Sebastian Herrmann, Matthias Herrmann, Franz Rothlauf, Gabriela Ochoa 11:55-12:20

EMO3+RWA5

Tuesday, July 18, 10:40-12:20, Amethyst
Chair: Bogdan Filipic (Jozef Stefan Institute)

The Multi-Objective Real-Valued Gene-Pool Optimal Mixing Evolutionary Algorithm
Anton Bouter, Ngoc Hoang Luong, Cees Witteveen, Tanja Alderliesten, Peter A.N. Bosman 10:40-11:05

Simulation-Based Crossover for the Firefighter Problem
Krzysztof Michalak 11:05-11:30

Robust Multiobjective Optimization using Regression Models and Linear Subproblems
Fillipe Goulart, Silvio Tassini Borges, Fernanda Caldeira Takahashi, Felipe Campelo 11:30-11:55

Optimizing nucleic acid sequences for a molecular data recorder
Jerzy Kozyra, Harold Fellermann, Ben Shirt-Ediss, Annunziata Lopiccolo, Natalio Krasnogor 11:55-12:20

ENUM1

Tuesday, July 18, 10:40-12:20, Smaragd
Chair: Nikolaus Hansen (Inria, research centre Saclay)

Constraint Handling in Efficient Global Optimization
Samineh Bagheri, Wolfgang Konen, Richard Allmendinger, Jürgen Branke, Kalyanmoy Deb, Jonathan E. Fieldsend, Domenico Quagliarella, Karthik Sindhya 10:40-11:05

Analysis of the pcCMSA-ES on the noisy ellipsoid model
Hans-Geog Beyer, Michael Hellwig 11:05-11:30

Per Instance Algorithm Configuration of CMA-ES with Limited Budget
Nacim Belkhir, Johann Dréo, Pierre Savéant, Marc Schoenauer 11:30-11:55

Niching an Estimation-of-Distribution Algorithm by Hierarchical Gaussian Mixture Learning
Stef C. Maree, Tanja Alderliesten, Dirk Thierens, Peter A.N. Bosman 11:55-12:20

GECH2

Tuesday, July 18, 10:40-12:20, Diamant
Chair: Pietro S. Oliveto (The University of Sheffield)

Simulation-based Test Functions for Optimization Algorithms
Martin Zaefferer, Andreas Fischbach, Boris Naujoks, Thomas Bartz-Beielstein 10:40-11:05

Reexpressing Problematic Optimization Data: Creating a Workflow for the Statistical Analysis of Multifactorial EC Experiments
Mark Wineberg, Sebastian Lenartowicz 11:05-11:30

Theoretical results on bet-and-run as an initialisation strategy
Andrei Lissovoi, Dirk Sudholt, Markus Wagner, Christine Zarges 11:30-11:55

On the Runtime Analysis of Generalised Selection Hyper-heuristics for Pseudo-Boolean Optimisation
Andrei Lissovoi, Pietro Simone Oliveto, John Alasdair Warwicker 11:55-12:20

GP4: Best Papers

Tuesday, July 18, 10:40-12:20, Saphir
Chair: Zdenek Vasicek (Brno University Of Technology) (Best Paper nominees are marked with a star)

Improving Generalization of Evolved Programs through Automatic Simplification ☆
Thomas Helmuth, Nicholas Freitag McPhee, Edward Pantridge, Lee Spector 10:40-11:05

How Noisy Data Affects Geometric Semantic Genetic Programming ☆
Luis Fernando Miranda, Luiz Otavio Vilas Boas Oliveira, Joao Francisco Barreto da Silva Martins, Gisele Lobo Pappa 11:05-11:30

Counterexample-Driven Genetic Programming ☆
Krzysztof Krawiec, Iwo Błądek, Jerry Swan 11:30-11:55

HOP1

Tuesday, July 18, 10:40-12:20, Topas 1
Chair: Elena Popovici (Icosystem Corp.)

Downscaling near-surface atmospheric fields with multi-objective Genetic Programming
Tanja Zerenner, Victor Venema, Petra Friederichs, Clemens Simmer 10:40-11:05

The Unrestricted Black-Box Complexity of Jump Functions
Maxim Buzdalov, Benjamin Doerr, Mikhail Kever 11:05-11:30

Exploring multi-objective trade-offs in the design space of a waste heat recovery system
Maizura Mokhtar, Ian Hunt, Stephen Burns, Dave Ross 11:30-11:55

A Genetic Algorithm for Learning Parameters in Bayesian Networks using Expectation Maximization
Priya Krishnan Sundararajan, Ole Jakob Mengshoel 11:55-12:20

RWA4

Tuesday, July 18, 10:40-12:20, Bernstein
Chair: Hernan Aguirre (Shinshu University)

An Adaptive Prioritized ε-Preferred Evolutionary Algorithm for Approximate BDD Optimization
Saeideh Shirinzadeh, Mathias Soeken, Daniel Große, Rolf Drechsler 10:40-11:05

Multi-Objective Optimization of Level of Service in Urban Transportation
Rolando Armas, Hernán Aguirre, Kiyoshi Tanaka 11:05-11:30

Evolving a Real-time Evacuation for Urban Disaster Management
Keith J. Drew, Robert B. Heckendorn, Ahmed Abdel-Rahim, Homaja Pydi Kumar Marisetty, Anton Stalick 11:30-11:55

Optimization of Monitoring in Dynamic Communication Networks using a Hybrid Evolutionary Algorithm
Robin Mueller-Bady, Martin Kappes, Inmaculada Medina-Bulo, Francisco Palomo-Lozano 11:55-12:20

SBSE1+ACO-SI1: Best Papers

Tuesday, July 18, 10:40-12:20, Opal
Chair: Xiaodong Li (RMIT University) (Best Paper nominees are marked with a star)

Analysis of Independent Roulette Selection in Parallel Ant Colony Optimization ☆
Huw Lloyd, Martyn Amos 10:40-11:05

Active Coevolutionary Learning of Requirements Specifications from Examples ☆
Marcel Wever, Lorijn van Rooijen, Heiko Hamann 11:05-11:30

A Multi-UAV Minimum Time Search Planner based on ACO-R
Sara Perez-Carabaza, Julian Bermudez-Ortega, Eva Besada-Portas, Jose Antonio Lopez-Orozco, Jesus Manuel de la Cruz 11:30-11:55

Estimating Stop Conditions of Swarm Based Stochastic Metaheuristic Algorithms
Peter Frank Perroni, Daniel Weingaertner, Myriam Regattieri Delgado 11:55-12:20

CS3: Best Papers

Tuesday, July 18, 14:00-15:40, Opal
Chair: Risto Miikkulainen (The University of Texas at Austin) (Best Paper nominees are marked with a star)

On Self-Adaptive Mutation Restarts for Evolutionary Robotics with Real Rotorcraft ☆
Gerard David Howard 14:00-14:25

Evolutionary Optimization of Self-Assembly in a Swarm of Bio-microrobots ☆
Nathanael Y. I. Aubert-Kato, Charles Fosseprez, Guillaume Gines, Ibuki Kawamata, Huy Q. Dinh, Leo Cazenille, Andre Estevez-Torres, Masami Hagiya, Yannick Rondelez, Nicolas Bredeche 14:25-14:50

Data-Efficient Exploration, Optimization, and Modeling of Diverse Designs through Surrogate-Assisted Illumination ☆
Adam Gaier, Alexander Asteroth, Jean-Baptiste Mouret 14:50-15:15

Discovering Evolutionary Stepping Stones through Behavior Domination ☆
Elliot Meyerson, Risto Miikkulainen 15:15-15:40

EML4

Tuesday, July 18, 14:00-15:40, Amethyst
Chair: Keiki Takadama (The University of Electro-Communications)

Automatic Adjustment of Selection Pressure based on Range of Reward in Learning Classifier System
Takato Tatsumi, Hiroyuki Sato, Keiki Takadama 14:00-14:25

Multiple Imputation and Genetic Programming for Classification with Incomplete Data
Cao Truong Tran, Mengjie Zhang, Peter Andreae, Bing Xue 14:25-14:50

Towards the Evolution of Multi-Layered Neural Networks: A Dynamic Structured Grammatical Evolution Approach
Filipe Assunção, Nuno Lourenço, Penousal Machado, Bernardete Ribeiro 14:50-15:15

Neuroevolution on the Edge of Chaos
Filip Matzner 15:15-15:40

EMO4: Best Papers

Tuesday, July 18, 14:00-15:40, Saphir
Chair: Tea Tusar (Jozef Stefan Institute) (Best Paper nominees are marked with a star)

Reference Point Specification in Hypervolume Calculation for Fair Comparison and Efficient Search ☆
Hisao Ishibuchi, Ryo Imada, Yu Setoguchi, Yusuke Nojima 14:00-14:25

Improved Incremental Non-dominated Sorting for Steady-State Evolutionary Multiobjective Optimization ☆
Ilya Yakupov, Maxim Buzdalov 14:25-14:50

Progressively Adding Objectives: A Case Study in Anomaly Detection ☆
Luis Martí, Arsene Fansi-Tchango, Laurent Navarro, Marc Schoenauer 14:50-15:15

Adaptive Weights Generation for Decomposition-Based Multi-Objective Optimization Using Gaussian Process Regression
Mengyuan Wu, Sam Kwong, Yuheng Jia, Ke Li, Qingfu Zhang 15:15-15:40

ENUM2

Tuesday, July 18, 14:00-15:40, Smaragd
Chair: Jose A. Lozano (University of the Basque Country)

Reconsidering Constraint Release for Active-Set Evolution Strategies
Dirk V. Arnold 14:00-14:25

Effect of the Mean Vector Learning Rate in CMA-ES
Hidekazu Miyazawa, Youhei Akimoto 14:25-14:50

A Cooperative Co-evolutionary Algorithm for solving Large-Scale Constrained Problems with Interaction Detection
Julien Blanchard, Charlotte Beauthier, Timoteo Carletti 14:50-15:15

Algorithm Configuration Data Mining for CMA Evolution Strategies
Sander van Rijn, Hao Wang, Bas van Stein, Thomas Bäck 15:15-15:40

GA2+THEORY2

Tuesday, July 18, 14:00-15:40, Diamant
Chair: Dirk Thierens (Utrecht University)

Speeding Up DSMGA-II on CUDA Platform
Sung Chi Li, Tian-Li Yu 14:00-14:25

Two-edge Graphical Linkage Model for DSMGA-II
Ping-Lin Chen, Chun-Jen Peng, Chang-Yi Lu, Tian-Li Yu 14:25-14:50

Sorting by Swaps with Noisy Comparisons
Tomas Gavenciak, Barbara Geissmann, Johannes Lengler 14:50-15:15

Improved Runtime Bounds for the Univariate Marginal Distribution Algorithm via Anti-Concentration
Per Kristian Lehre, Phan Trung Hai Nguyen 15:15-15:40

HOP2

Tuesday, July 18, 14:00-15:40, Topas 1
Chair: William B. Langdon (University College London)

Trading Between Quality and Non-functional Properties of Median Filter in Embedded Systems
Zdenek Vasicek, Vojtech Mrazek 14:00-14:25

Design of Power-Efficient Approximate Multipliers for Approximate Artificial Neural Networks
Vojtech Mrazek, Syed Shakib Sarwar, Lukas Sekanina, Zdenek Vasicek, Kaushik Roy 14:25-14:50

Multilayer Optimization of Heterogeneous Networks using Grammatical Genetic Programming
Michael Fenton, David Lynch, Stepan Kucera, Holger Claussen, Michael O'Neill 14:50-15:15

Evolutionary Multi-Path Routing for Network Lifetime and Robustness in Wireless Sensor Networks
Alma A. M. Rahat, Richard M. Everson, Jonathan E. Fieldsend 15:15-15:40

RWA6

Tuesday, July 18, 14:00-15:40, Bernstein
Chair: Erik Goodman (Michigan State University)

Solving a Supply-Chain Management Problem Using a Bilevel Approach
Zhichao Lu, Kalyanmoy Deb, Erik Goodman, John Wassick 14:00-14:25

Handling Practicalities in Agricultural Policy Optimization for Water Quality Improvements
Bradley Barnhart, Zhichao Lu, Moriah Bostian, Ankur Sinha, Kalyanmoy Deb, Luba Kurkalova, Manoj Jha, Gerald Whittaker 14:25-14:50

Protein Design by Multiobjective Optimization: Evolutionary and Non-Evolutionary Approaches
Sandeep V. Belure, Ofer M. Shir, Vikas Nanda 14:50-15:15

Accurate Mixed Weibull Distribution Fitting by Differential Evolution
Pavel Krömer, Jana Heckenbergerova, Petr Musilek 15:15-15:40

SBSE2+ECOM4

Tuesday, July 18, 14:00-15:40, Jade
Chair: Federica Sarro (University College London)

Hybrid Metaheuristic for Combinatorial Optimization based on Immune Network for Optimization and VNS
Rodney O. M. Diana, Sérgio R. de Souza, Elizabeth Fialho Wanner, Moacir F. de França Filho 14:00-14:25

Empirical Evaluation of Conditional Operators in GP Based Fault Localisation
Dahyun Kang, Jeongju Sohn, Shin Yoo 14:25-14:50

A penalty-based Tabu search for constrained covering arrays.
Philippe Galinier, Sègla Kpodjedo, Giuliano Antoniol 14:50-15:15

A Context-Based Refactoring Recommendation Approach Using Simulated Annealing: Two Industrial Case Studies
Marouane Kessentini, Troh-Josselin Dea, Ali Ouni 15:15-15:40

ECOM5

Tuesday, July 18, 16:10-17:50, Jade
Chair: Domagoj Jakobovic (Faculty of Electrical Engineering and Computing, Zagreb)

Community structure detection for multipartite networks
Noémi Gaskó, Florentin Bota, Mihai Alexandru Suciu, Rodica Ioana Lung 16:10-16:35

Improving an Exact Solver for the Traveling Salesman Problem using Partition Crossover
Danilo Sipoli Sanches, Darrell Whitley, Renato Tinós 16:35-17:00

Building a Better Heuristic for the Traveling Salesman Problem: Combining Edge Assembly Crossover and Partition Crossover.
Danilo Sipoli Sanches, Darrell Whitley, Renato Tinós 17:00-17:25

Evolutionary Algorithms for the Design of Orthogonal Latin Squares based on Cellular Automata
Luca Mariot, Stjepan Picek, Domagoj Jakobovic, Alberto Leporati 17:25-17:50

GA3

Tuesday, July 18, 16:10-17:50, Amethyst
Chair: Alberto Moraglio (University of Exeter)

Different scenarios for survival analysis of evolutionary algorithms
Roberto Santana, Jose A. Lozano 16:10-16:35

A Diversity Preservation Scheme for DSMGA-II to Conquer the Hierarchical Difficulty
Jheng-Ying Yu, I-Ting Chen, Tian-Li Yu 16:35-17:00

Evolutionary Image Composition Using Feature Covariance Matrices
Aneta Neumann, Zygmunt Ladyslaw Szpak, Wojciech Chojnacki, Frank Neumann 17:00-17:25

EGAC: A Genetic Algorithm to Compare Chemical Reaction Networks
Stefano Tognazzi, Mirco Tribastone, Max Tschaikowski, Andrea Vandin 17:25-17:50

GECH3

Tuesday, July 18, 16:10-17:50, Smaragd
Chair: Jonathan Edward Fieldsend (University of Exeter)

Parallel Evolutionary Algorithm with Interleaving Generations
Martin Pilát, Roman Neruda 16:10-16:35

Time Complexity Reduction in Efficient Global Optimization using Cluster Kriging
Hao Wang, Bas van Stein, Michael Emmerich, Thomas Bäck 16:35-17:00

Alternative Infill Strategies for Expensive Multi-Objective Optimisation
Alma A. M. Rahat, Richard M. Everson, Jonathan E. Fieldsend 17:00-17:30

GP5

Tuesday, July 18, 16:10-17:50, Bernstein
Chair: Mauro Castelli (NOVA IMS, Universidade Nova de Lisboa)

A Probabilistic Linear Genetic Programming with Stochastic Context-Free Grammar for solving Symbolic Regression problems
Léo Françoso Dal Piccol Sotto, Vinícius Veloso de Melo 16:10-16:35

Discovery of Search Objectives in Continous Domains
Paweł Liskowski, Krzysztof Krawiec 16:35-17:00

Unsure When to Stop? Ask Your Semantic Neighbors
Ivo Gonçalves, Sara Silva, Carlos M. Fonseca, Mauro Castelli 17:00-17:25

HOP3

Tuesday, July 18, 16:10-17:50, Topas 1
Chair: Christine Zarges (Department of Computer Science, Aberystwyth University)

Evolutionary algorithm with a directional local search for multiobjective optimization in combinatorial problems
Krzysztof Michalak 16:10-16:35

On Constructing Ensembles for Combinatorial Optimisation
Emma Hart, Kevin Sim 16:35-17:00

Co-optimization Free Lunches: Tractability of Optimal Black-box Algorithms for Maximizing Expected Utility. Bridging Supervised Learning and Test-Based Co-optimization.
Elena Popovici 17:00-17:25

Interval Type-2 Mutual Subsethood Fuzzy Neural Inference System (IT2MSFuNIS)
Sumati Vuppuluri, Patvardhan Chellapilla 17:25-17:50

RWA7: Best Papers

Tuesday, July 18, 16:10-17:50, Saphir
Chair: Anna Isabel Esparcia-Alcazar (Universidad Politecnica de Valencia); Boris Naujoks (TH Köln - University of Applied Sciences) (Best Paper nominees are marked with a star)

Heuristic Allocation of Computational Resources ☆
Silviu Tofan, Richard Allmendinger, Manuela Zanda, Olly Stephens 16:10-16:35

Evolutionary Decomposition for 3D Printing ☆
Eric A. Yu, Jin Yeom, Cem C. Tutum, Etienne Vouga, Risto Miikkulainen 16:35-17:00

Enhanced Genetic Path Planning for Autonomous Flight
Vincent R. Ragusa, H. David Mathias, Vera A. Kazakova, Annie S. Wu 17:00-17:25

An Embedded System Architecture based on Genetic Algorithms for Mission and Safety Planning with UAV
Jesimar da Silva Arantes, Márcio da Silva Arantes, Claudio Fabiano Motta Toledo, Onofre Trindade Júnior, Brian Charles Williams 17:25-17:50

SBSE3

Tuesday, July 18, 16:10-17:50, Diamant
Chair: Shin Yoo (Korea Advanced Institute of Science and Technology)

An Adaptive Fitness Function Based on Branch Hardness for Search Based Testing
Xiong Xu, Ziming Zhu, Li Jiao 16:10-16:35

Multi-Objective Black-Box Test Case Selection for System Testing
Remo Lachmann, Michael Felderer, Manuel Nieke, Sandro Schulze, Christoph Seidl, Ina Schaefer 16:35-17:00

A Search for Improved Performance in Regular Expressions
Brendan Cody-Kenny, Michael Fenton, Adrian Ronayne, Eoghan Considine, Thomas McGuire, Michael O'Neill 17:00-17:25

Mining Cross Product Line Rules with Multi-Objective Search and Machine Learning
Safdar Aqeel Safdar, Hong Lu, Tao Yue, Shaukat Ali 17:25-17:50

THEORY3+ENUM3: Best Papers

Tuesday, July 18, 16:10-17:50, Opal
Chair: Dirk Sudholt (University of Sheffield) (Best Paper nominees are marked with a star)

TPAM: A Simulation-Based Model for Quantitatively Analyzing Parameter Adaptation Methods ☆
Ryoji Tanabe, Alex Fukunaga 16:10-16:35

Deriving and Improving CMA-ES with Information Geometric Trust Regions ☆
Abbas Abdolmaleki, Bob Price, Nuno Lau, Luis Paulo Reis, Gerhard Neumann 16:35-17:00

Exploiting Linkage Information in Real-Valued Optimization with the Real-Valued Gene-Pool Optimal Mixing Evolutionary Algorithm ☆
Anton Bouter, Tanja Alderliesten, Cees Witteveen, Peter A.N. Bosman 17:00-17:25

Runtime Analysis of the $(1 + (\lambda, \lambda))$ **Genetic Algorithm on Random Satisfiable 3-CNF Formulas** ☆
Maxim Buzdalov, Benjamin Doerr 17:25-17:50

ACO-SI2

Wednesday, July 19, 09:00-10:40, Smaragd
Chair: Andries P. Engelbrecht (University of Pretoria)

PSO-based Parameters Selection for the Bilateral Filter in Image Denoising
Chengyan Wang, Bing Xue, Lin Shang 09:00-09:25

CycloAnt: Sequencing Cyclic Peptides Using Hybrid Ants
Sujata Baral, Swakkhar Shatabda, Rashid A. Mahmood 09:25-09:50

Fitness-Distance-Ratio Particle Swarm Optimization: Stability Analysis
Christopher Wesley Cleghorn, Andries P. Engelbrecht 09:50-10:15

Coordinating a Team of Searchers: Of Ants, Swarms, and Slime Molds
Silja Meyer-Nieberg 10:15-10:40

CS4

Wednesday, July 19, 09:00-10:40, Bernstein
Chair: Ivan I. Garibay (University of Central Florida)

A Comparison of Genetic Regulatory Network Dynamics and Encoding
Jean Disset, Dennis Wilson, Sylvain Cussat-Blanc, Stephane Sanchez, Hervé Luga, Yves Duthen 09:00-09:25

Alternate Social Theory Discovery Using Genetic Programming: Towards Better Understanding the Artificial Anasazi
Chathika Gunaratne, Ivan Garibay 09:25-09:50

Evolution and Analysis of Embodied Spiking Neural Networks Reveals Task-Specific Clusters of Effective Networks
Madhavun Candadai Vasu, Eduardo J. Izquierdo 09:50-10:15

DETA2

Wednesday, July 19, 09:00-10:40, Topas 1
Chair: Sebastian Risi (IT University of Copenhagen)

Multi-segment Evolution of Dungeon Game Levels
Antonios Liapis 09:00-09:25

Comparing Direct and Indirect Encodings Using Both Raw and Hand-Designed Features in Tetris
Lauren E. Gillespie, Gabriela R. Gonzalez, Jacob Schrum 09:25-09:50

Continual Online Evolutionary Planning for In-Game Build Order Adaptation in StarCraft
Niels Justesen, Sebastian Risi 09:50-10:15

Can you feel it? Evaluation of affective expression in music generated by MetaCompose
Marco Scirea, Peter Eklund, Julian Togelius, Sebastian Risi 10:15-10:40

ECOM6: Best Papers

Wednesday, July 19, 09:00-10:40, Saphir
Chair: Sebastien Verel (Université du Littoral Côte d'Opale) (Best Paper nominees are marked with a star)

Distributed Evolutionary k-way Node Separators ☆
Peter Sanders, Christian Schulz, Darren Strash, Robert Williger 09:00-09:25

Automatic Design of Multi-Objective Local Search Algorithms ☆
Aymeric Blot, Laetitia Jourdan, Marie-Éléonore Kessaci 09:25-09:50

Configuring irace using surrogate configuration benchmarks ☆
Nguyen Dang, Leslie Pérez Cáceres, Thomas Stützle, Patrick De Causmaecker 09:50-10:15

Heuristic rope team : a parallel algorithm for graph coloring
Laurent Moalic, Alexandre Gondran 10:15-10:40

EML5

Wednesday, July 19, 09:00-10:40, Opal
Chair: Grant Dick (University of Otago)

Automatic Design of Ant-Miner Mixed Attributes for Classification Rule Discovery
Ayah M. Helal, Fernando E. B. Otero 09:00-09:25

PAC models in stochastic multi-objective multi-armed bandits
Madalina Drugan 09:25-09:50

Sensitivity-Like Analysis for Feature Selection in Genetic Programming
Grant Dick 09:50-10:15

GA4

Wednesday, July 19, 09:00-10:40, Amethyst
Chair: Penousal Machado (University of Coimbra)

A genetic algorithm for fair land allocation
Alex Gliesch, Marcus Ritt, Mayron César de Oliveira Moreira 09:00-09:25

Real-Polarized Genetic Algorithm for the Three-Dimensional Bin Packing Problem
André Homem Dornas, Flávio Vinícius Cruzeiro Martins, João Fernando Machry Sarubbi, Elizabeth Fialho Wanner 09:25-09:50

The Role of Crossover Operator in Bayesian Network Structure Learning Performance: a Comprehensive Comparative Study and New Insights
Carlo Contaldi, Fatemeh Vafaee, Peter C. Nelson 09:50-10:15

Genetic Algorithm for Epidemic Mitigation by Removing Relationships
Fernando Concatto, Wellington Zunino, Luigi A. Giancoli, Rafael de Santiago, Luís C. Lamb 10:15-10:40

RWA8

Wednesday, July 19, 09:00-10:40, Jade
Chair: Risto Miikkulainen (The University of Texas at Austin)

Exploring Trade-Offs between Target Coverage, Healthy Tissue Sparing, and the Placement of Catheters in HDR Brachytherapy for Prostate Cancer using a Novel Multi-Objective Model-Based Mixed-Integer Evolutionary Algorithm
Krzysztof Leszek Sadowski, Marjolein C. van der Meer, Ngoc Hoang Luong, Tanja Alderliesten, Dirk Thierens, Rob van der Laarse, Yury Niatsetski, Arjan Bel, Peter A.N. Bosman 09:00-09:25

Conversion Rate Optimization through Evolutionary Computation
Risto Miikkulainen, Neil Iscoe, Aaron Shagrin, Ron Cordell, Sam Nazari, Cory Schoolland, Myles Brundage, Jonathan Epstein, Randy Dean, Gurmeet Lamba 09:25-09:50

A Knee Point based Evolutionary Multi-objective Optimization for Mission Planning Problems
Cristian Ramirez-Atencia, Sanaz Mostaghim, David Camacho 09:50-10:15

Evolutionary Approach to Optimization of Data Representation for Classification of Patterns in Financial Ultra-High Frequency Time Series
Piotr Lipinski 10:15-10:40

THEORY4

Wednesday, July 19, 09:00-10:40, Diamant
Chair: Dirk Sudholt (University of Sheffield)

Unknown Solution Length Problems With No Asymptotically Optimal Run Time
Benjamin Doerr, Carola Doerr, Timo Kötzing 09:00-09:25

Reoptimization Times of Evolutionary Algorithms on Linear Functions Under Dynamic Uniform Constraints
Feng Shi, Martin Schirneck, Tobias Friedrich, Timo Kötzing, Frank Neumann 09:25-09:50

Island Models Meet Rumor Spreading
Benjamin Doerr, Philipp Fischbeck, Clemens Frahnow, Tobias Friedrich, Timo Kötzing, Martin Schirneck 09:50-10:15

Poster Session

Monday, July 17, 17:50-20:00, Saphir

Ant Colony Optimization and Swarm Intelligence (ACO-SI)

Parallel Ant Colony Optimization for Evacuation Planning
Manel Hajjem, Hend Bouziri, El-Ghazali Talbi, Khaled Mellouli

Particle Swarm Optimization based on Island Models
Houda Abadlia, Nadia Smairi, Khaled Ghedira

Complex Systems (CS)

The EMeRGE modular robot, an open platform for quick testing of evolved robot morphologies
Rodrigo Moreno, Ceyue Liu, Andres Faina, Henry Hernandez, Jonatan Gomez

Exploiting Environmental Differentiation to Promote Evolvability in Artificial Evolution
Jonata Tyska Carvalho, Stefano Nolfi

Evolving Cost Functions For Model Predictive Control of Multi-Agent UAV Combat Swarms
David D. Fan, Evangelos Theodorou, John Reeder

GP-Based Motion Control Design for the Double-Integrator System Subject to Velocity Constraint
Ollin Peñaloza-Mejía, Eddie Clemente, Marlen Meza-Sánchez, Cynthia Beatriz Pérez, Francisco Chávez

Precomputation for Rapid Hypothesis Generation in Evolutionary Robotics
Joel Lehman

A developmental artificial neural network model for solving multiple problems
Julian Francis Miller, Dennis Wilson

Balancing Selection Pressures, Multiple Objectives, and Neural Modularity to Coevolve Cooperative Agent Behavior
Alex C. Rollins, Jacob Schrum

Automated Pattern Identification and Classification: Anomaly Detection Case Study
Ryan Goss, Geoff Nitschke

Exploring Divergence for Soft Robot Evolution
Daniele Gravina, Antonios Liapis, Georgios N. Yannakakis

Embodied Evolution versus Cooperative Coevolution in Multi-Robot Optimization: a practical comparison
Pedro Trueba, Abraham Prieto, Francisco Bellas

Evolutionary Search For Paths on Protein Energy Landscapes
Emmanuel Sapin, Kenneth A. De Jong, Amarda Shehu

Ecological Modularity as a Means to Reduce Necessary Training Environments in Evolutionary Robotics
Collin Kovach Cappelle, Josh Bongard, Anton Bernatskiy

Increasing the Complexity of Solutions Produced by an Evolutionary Developmental System
Heather Goldsby, Rebecca L. Young, Hans A. Hofmann, Arend Hintze

Benefits of Lamarckian Evolution for Morphologically Evolving Robots
Milan Jelisavcic, Rafael Kiesel, Kyrre Glette, Evert Haasdijk, A. E. Eiben

An Evolutionary Approach to Behavioural Morphometrics
Sebastian von Mammen, Melanie Däschinger, Andreas Knote

Is Social Learning More Than Parameter Tuning?
Jacqueline Heinerman, Jörg Stork, Margarita Alejandra Rebolledo Coy, Julien Hubert, Thomas Bartz-Beielstein, A. E. Eiben, Evert Haasdijk

Digital Entertainment Technologies and Arts (DETA)

A Deep Learning / Neuroevolution Hybrid for Visual Control
Andreas Precht Poulsen, Mark Thorhauge, Mikkel Hvilshøj Funch, Sebastian Risi

Procedural Level Design using an Interactive Cellular Automata Genetic Algorithm
Chad M. Adams, Hirav P. Parekh, Sushil J. Louis

Comparing multimodal optimization and illumination
Vassilis Vassiliades, Konstantinos Chatzilygeroudis, Jean-Baptiste Mouret

Speeding up Genetic Algorithm-based Game Balancing using Fitness Predictors
Mihail Morosan, Riccardo Poli

Gamification Techniques in Collaborative Interactive Evolutionary Computation
Mario Garcia Valdez, Juan Julian Merelo-Guervos, José Christian Romero, Francisco Fernández de Vega, Alejandra Mancilla

Voxelbuild: A Minecraft-Inspired Domain for Experiments in Evolutionary Creativity
Lisa B. Soros, Justin K. Pugh, Kenneth O. Stanley

Escher-like Tiling Design Using Hierarchical Optimization
Asuka Hisatomi, Hitomi Koba, Makoto Kamizono, Kazunori Mizuno, Satoshi Ono

Evolutionary Combinatorial Optimization and Metaheuristics (ECOM)

A Model-Based Genetic Algorithm Framework for Constrained Optimisation Problems
Mark Lawrenson, Tommaso Urli, Philip Kilby

Modeling Optimization Algorithm Runtime Behavior and its Applications
Qi Qi, Thomas Weise, Bin Li

Efficient Quantitative Heuristics for Graph Clustering
Rafael de Santiago, Luís C. Lamb

A memetic algorithm for computing multicriteria shortest paths in stochastic multimodal networks
Omar Dib, Alexandre Caminada, Marie-Ange Manier, Laurent Moalic

Multi-objectiveness in the Single-objective Traveling Thief Problem
Mohamed El Yafrani, Shelvin Chand, Markus Wagner, Aneta Neumann, Belaïd Ahiod

Parameter-less Population Pyramid with Feedback
Marcin Michal Komarnicki, Michal Witold Przewozniczek

How to Get More from Your Model: The Role of Constructive Selection in Estimation of Distribution Algorithms
Jamie R. Caldwell, Richard A. Watson

Clustering of Hyper-heuristic Selections using the Smith-Waterman Algorithm for Offline Learning
William Brian Yates, Edward Chrisotopher Keedwell

A Novel Reduction Algorithm for the Generalized Traveling Salesman Problem
Mehdi El Krari, Belaïd Ahiod, Bouazza El Benani

A fast heuristic algorithm for the critical node problem
Yangming Zhou, Jin-Kao Hao

A New Evolutionary Approach Using Pre-Post Testing to Trigger Exploration and Exploitation in DOPs
Hajer Ben-Romdhane, Enrique Alba, Saoussen Krichen

The Menu Planning Problem: a MultiObjective Approach for the Brazilian Schools Context
Rafaela Priscila Cruz Moreira, Elizabeth Fialho Wanner, Flávio Vinícius Cruzeiro Martins, João Fernando Machry Sarubbi

Evolutionary Machine Learning (EML)

Linear Combinations of Features as Leaf Nodes in Symbolic Regression
Jan Žegklitz, Petr Pošík

cCube: A Cloud Microservices Architecture for Evolutionary Machine Learning Classification
Pasquale Salza, Erik Hemberg, Filomena Ferrucci, Una-May O'Reilly

An Upgraded Bat Algorithm for Tuning Extreme Learning Machines for Data Classification
Adis Alihodzic, Eva Tuba, Milan Tuba

Large Scale Evolution of Convolutional Neural Networks Using Volunteer Computing
Travis Desell

Autonomous Intersection Driving with Neuro-Evolution
Geoff Nitschke, Aashiq Parker

Evidential Learning Classifier System
Chedi Abdelkarim, Lilia Rejeb, Lamjed Ben Said, Maha Elarbi

Evolutionary Learning of Meta-Rules for Text Classification
Juan Carlos Gomez, Stijn Hoskens, Marie-Francine Moens

The Role of Conditional Independence in the Evolution of Intelligent Systems
Jory Schossau, Larissa Albantakis, Arend Hintze

Revisiting Interval Arithmetic for Regression Problems in Genetic Programming
Grant Dick

Stability Selection using a Genetic Algorithm and Logistic Linear Regression on Healthcare Records
Ales Zamuda, Christine Zarges, Gregor Stiglic, Goran Hrovat

Low-power FSM synthesis using a fuzzy c-mean clustering-based decomposition
Yanyun Tao, Yuzhen Zhang, Qinyu Wang

Automated State Feature Learning for Actor-Critic Reinforcement Learning through NEAT
Yiming Peng, Gang Chen, Scott Holdaway, Yi Mei, Mengjie Zhang

Evolutionary Multiobjective Optimization (EMO)

Set-SMAA for Finding Preferable Multi-Objective Solutions
Rotem Dror, Amir Kantor, Michael Masin, Segev Shlomov

Distributed NSGA-II with Migration using Compensation on Many-core Processors for Improving Performance and Accuracy
Yuji Sato, Mikiko Sato, Minami Miyakawa

Multiple Reference Points MOEA/D for Feature Selection
Bach Hoai Nguyen, Bing Xue, Hisao Ishibuchi, Peter Andreae, Mengjie Zhang

Solving electoral zone design problems with NSGA-II. Application to redistricting in Mexico
Antonin Ponsich, Eric Alfredo Rincón García, Roman Anselmo Mora Gutiérrez, Sergio Gerardo de-los-Cobos Silva, Miguel Angel Gutiérrez Andrade, Pedro Lara Velázquez

An Improved MOEA/D Utilizing Variation Angles for Multi-Objective Optimization
Hiroyuki Sato, Minami Miyakawa, Keiki Takadama

A Multi-Objective Continuous Genetic Algorithm for Financial Portfolio Optimization Problem
Yacine Kessaci

The MOEA/D Algorithm with Gaussian Neighbourhoods for the Multiobjective Travelling Salesman Problem
Krzysztof Michalak

Towards an Epigenetics-Inspired Control System for Power Dispatch Problem
Daniel Joel Couvertier, Kalyanmoy Deb, Erik Goodman

Hybridizing Non-dominated Sorting Algorithms: Divide-and-Conquer Meets Best Order Sort
Margarita Markina, Maxim Buzdalov

Evolutionary Numerical Optimization (ENUM)

Ordinal versus Metric Gaussian Process Regression in Surrogate Modelling for CMA Evolution Strategy
Zbyněk Pitra, Lukáš Bajer, Jakub Repický, Martin Holeňa

Adaptiveness of CMA based Samplers
Nixon Ronoh, Edna Milgo, Peter Waiganjo, Bernard Manderick

Analysis of Scaling for Fitness Landscape Learning Evolutionary Computation based on CMA-ES
Naoki Mori, Kento Tsukada, Taku Hasegawa, Keinosuke Matsumoto

Non-parametric model of the space of continuous black-box optimization problems
Mario Andres Munoz Acosta, Kate Smith-Miles

A Computationally Efficient Gravitational Search Algorithm
Alex Rothwell, Aldeida Aleti

A Two-Stage Coevolution Approach for Constrained Optimization
Jing-Yu Ji, Wei-Jie Yu, Jun Zhang

On the Mutual Information as a Fitness Landscape Measure
Rebeka Coric, Stjepan Picek, Domagoj Jakobovic, Carlos A. Coello Coello

Interpolated Continuous Optimisation Problems with Tunable Landscape Features
Benjamin Lacroix, Lee Ashley Christie, John McCall

Modified Box Constraint Handling for the Covariance Matrix Adaptation Evolution Strategy
Naoki Sakamoto, Youhei Akimoto

A New Grouping Strategy-Based Hybrid Algorithm for Large Scale Global Optimization Problems
Haiyan Liu, Yuping Wang, Liwen Liu, Xiao-Zhi Gao, Yiu-ming Cheung

Genetic Algorithms (GA)

On the Exploitation of Search History and Accumulative Sampling in Robust Optimisation
Khulood Alyahya, Kevin Doherty, Jonathan E. Fieldsend, Ozgur Akman

Introducing the Cumulation to the Population Based Incremental Learning and the Compact GA to Relax Genetic Drift
Keigo Tanaka, Youhei Akimoto

A Computationally Fast Multimodal Optimization with Push Enabled Genetic Algorithm
Yashesh Dhebar, Kalyanmoy Deb

A Hybrid Genetic Algorithm for Deploying RSUs in VANETs Based on Inter-Contact Time
Marcelo Fonseca Faraj, João Fernando Machry Sarubbi, Cristiano Maciel da Silva, Flávio Vinícius Cruzeiro Martins

Automated Case Generation Using a Genetic Algorithm
Hayley Borck, Mark Boddy

Overlapping community detection in social networks using a quantum-based genetic algorithm
Alireza Saleh Sedgh Pour, Amin Nikanjam

A Two-Phase Genetic Algorithm for Image Registration
Sarit Chicotay, Eli (Omid) David, Nathan S. Netanyahu

A Genetic Algorithm with randomly shifted Gray codes and local optimizations based on quadratic approximations of the fitness
Alexandre Mayer

General Evolutionary Computation and Hybrids (GECH)

Randomized Parameter Settings for a Pool-based Particle Swarm Optimization Algorithm
Amaury Hernandez-Aguila, Mario Garcia-Valdez, Juan Julian Merelo-Guervos, Oscar Castillo

Synergies Between Evolutionary Computation and Multiagent Reinforcement Learning: the Benefits of Exchanging Solutions
Ana Lucia C. Bazzan

A Parallel hybrid GA-PSO Approach with Dynamic Rule Based Parameter Setting
Abtin Nourmohammadzadeh, Sven Hartmann, Hui Ma

Load Balance Aware Distributed Differential Evolution for Computationally Expensive Optimization Problems
Xiao-Fang Liu, Zhi-Hui Zhan, Jun Zhang, Ning Ma, Jing-Hui Zhong

Indicator-Based Multi-Objective Genetic Programming for Workflow Scheduling Problem
Qin-zhe Xiao, Jinghui Zhong, Wei-Neng Chen, Zhi-Hui Zhan, Jun Zhang

The Baldwin Effect on a Memetic Differential Evolution for Constrained Numerical Optimization Problems
Saul Dominguez-Isidro, Efren Mezura-Montes

Neural Network Topology and Weight Optimization through Neuro Differential Evolution
Karl J. Mason, Jim Duggan, Enda Howley

Design choices for adapting bio-hybrid systems with evolutionary computation
Pedro Mariano, Ziad Salem, Rob Mills, Payam Zahadat, Luís Correia, Thomas Schmickl

A multi-objective approach for the $(\alpha, \beta) - k$ Feature Set Problem using Memetic Algorithms
Francia Jimenez, Claudio Sanhueza, Regina Berretta, Pablo Moscato

Genetic Programming (GP)

Multitask Evolution with Cartesian Genetic Programming
Eric O. Scott, Kenneth A. De Jong

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Tiantian Dou, Peter I. Rockett

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Andrew Lensen, Bing Xue, Mengjie Zhang

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Stjepan Picek, Luca Mariot, Domagoj Jakobovic, Alberto Leporati

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Nicholas Freitag McPhee, Thomas Helmuth, Lee Spector

Long-Term Evolution of Genetic Programming Populations
William B. Langdon

Evolving Texture Image Descriptors Using A Multitree Genetic Programming Representation
Harith Al-Sahaf, Bing Xue, Mengjie Zhang

Late-Acceptance and Step-Counting Hill-Climbing GP for Anomaly Detection
Van Loi Cao, Miguel Nicolau, James McDermott

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Gustavo Henrique Rosa, Luciene Patrici Papa, Joao Paulo Papa

Late-acceptance hill-climbing with a grammatical program representation
James McDermott, Miguel Nicolau

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Yuyu Liang, Mengjie Zhang, Will N. Browne

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Qi Chen, Mengjie Zhang, Bing Xue

Visualizing genetic programming ancestries using graph databases
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Eric Medvet

An Effective Diversity Promotion Mechanism in Grammatical Evolution
Eric Medvet, Alberto Bartoli, Giovanni Squillero

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Michael Francis Korns

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Community detection in power grids by an evolutionary method
Manuel Guerrero, Consolación Gil, Francisco G. Montoya, Alfredo Alcayde, Raúl Baños

A Genetic Algorithm for Hybrid VANETs with Synchronous Communication
João Fernando Machry Sarubbi, Flávio Vinícius Cruzeiro Martins, Cristiano Maciel da Silva, Elizabeth Fialho Wanner

Developing Proactive Defenses for Computer Networks with Coevolutionary Genetic Algorithms
Anthony Edward Erb Lugo, Dennis Alberto Garcia, Erik Hemberg, Una-May O'Reilly

Automatically Difficulty Grading Method of "Instruction System" Question Bank based on Knowledge Tree
Chengcheng Liu, Jin Zhang, Yang Zhou, Shunjian Tian, Xiaoli Gong, Xin Wei

A Hybrid Genetic Algorithm for Climate Input Features and Neural Network Parameters Selection
Ali Haidar, Brijesh Verma

Toward a Smart Mobility System: Integrating Electric Vehicles Within Smart Cities
Ezzeddine Fatnassi, Olfa Harrabi, Jouhaina Chaouachi

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Gara Miranda, Algirdas Lančinskas, Yanira González

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Adetokunbo Makanju, Nur Zincir-Heywood, Shinsaku Kiyomoto

A Fast Hybrid Evolutionary Algorithm with Inexact Fitness Evaluation for Solving Two-Stage Stochastic Scheduling Problems
Thomas Siwczyk, Sebastian Engell

Interactive evolutionary modelling of complex food systems: freeze-drying of lactic acid bacteria
Thomas Chabin, Marc Barnabé, Nadia Boukhelifa, Fernanda Fonseca, Alberto Tonda, Hélène Velly, Nathalie Perrot, Evelyne Lutton

Massive Asynchronous Master-Worker EA for a Nuclear Reactor Optimization : a Fitness Landscape Perspective
Mathieu Muniglia, Sébastien Verel, Jean-Charles Le Pallec, Jean-Michel Do

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Jared Drayton, Eduardo Miranda, Alexis Kirke

Reducing systemic risk in multiplex networks using evolutionary optimization
Krzysztof Michalak

Using Desirability Functions for Many-Objective Optimization of a Hybrid Car Controller
Yuka Ogino, Ryoya Iida, Tobias Rodemann

Fast 3D Path Planning based on Heuristic-aided Differential Evolution
Ning Ma, Xue Yu, Wei-Neng Chen, Jun Zhang

Genetic Algorithms Approaches for the Production Planning in the Glass Container Industry.
Flaviana Moreira de Souza Amorim, Márcio da Silva Arantes, Pierre Eric Frisch, Bernardo Almada-lobo, Claudio Fabiano Motta Toledo, Jesimar da Silva Arantes

Evolutionary Computation at work for the Optimization of Link State Routing Protocols
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Hila Fox, Shimon Ben-Alul, Miri Weiss Cohen

Applying Particle Swarm Optimization to the Motion-Cueing-Algorithm Tuning Problem
Sergio Casas, Cristina Portalés, Inmaculada Coma, Marcos Fernández

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Gilyana Borlikova, Louis Smith, Michael Phillips, Michael O'Neill

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Software Change Prediction using Voting Particle Swarm Optimization based Ensemble Classifier
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Analyzing Search Heuristics with Differential Equations
Tobias Friedrich, Timo Kötzing, Anna Melnichenko

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Abstracts by Track

BES 2017

Ant Colony Optimization and Swarm Intelligence

Session: SBSE1+ACO-SI1: Best Papers
Tuesday, July 18, 10:40-12:20, Opal

Analysis of Independent Roulette Selection in Parallel Ant Colony Optimization

Huw Lloyd, *Manchester Metropolitan University*, Martyn Amos, *Manchester Metropolitan University*

The increased availability of high-performance parallel architectures such as the Graphics Processing Unit (GPU) has led to significant interest in modified versions of metaheuristics that take advantage of their capabilities. Parallel Ant Colony Optimization (ACO) algorithms are now widely-used, but these often present a challenge in terms of maximizing the potential for parallelism. One common bottleneck for parallelization of ACO occurs during the *tour construction* phase, when edges are probabilistically selected. Independent Roulette (I-Roulette) is an alternative to the standard Roulette Selection method used during this phase, and this achieves significant performance improvements on the GPU. In this paper we provide the first in-depth study of *how* I-Roulette works. We establish that, even though I-Roulette works in a qualitatively different way to Roulette Wheel selection, its use in two popular ACO variants does not affect the *quality* of the solutions obtained. However, I-Roulette *significantly accelerates* convergence to a solution. Our theoretical analysis shows that I-Roulette possesses several interesting and non-obvious features, and is capable of a form of *dynamical adaptation* during the tour construction process.

A Multi-UAV Minimum Time Search Planner based on ACO-R

Sara Perez-Carabaza, *Universidad Complutense de Madrid*, Julian Bermudez-Ortega, *Universidad Complutense de Madrid*, Eva Besada-Portas, *Universidad Complutense de Madrid*, Jose Antonio Lopez-Orozco, *Universidad Complutense de Madrid*, Jesus Manuel de la Cruz, *Universidad Complutense de Madrid*

This paper presents a new planner based on Ant Colony Optimization for Real-coded domains (ACOR) for optimizing the trajectories of multiple Unmanned Aircraft Vehicles (UAVs) in Minimum Time Search (MTS) missions, where the UAVs have to shorten the detection time of a given target while avoiding collisions and Non-Flying Zones (NFZ). Therefore, the planner has to identify the UAV trajectories that minimize the Expected Time of Target Detection (ETTD) and nullify the total of NFZ overflights and of UAV collisions. To achieve it, the planner is backed by an ACOR that 1) ensures the feasibility of the trajectories by encoding them as a sequence of input UAV control commands and by decoding them through complex UAVs kinematic/dynamic models, 2) handles the uncertainty of the sensor and of the target location in the computation of the ETTD using Bayesian theory, and 3) improves the planning process with a heuristic that has been especially designed to exploit the probability and spatial properties of the problem. All these properties let our ACOR based planner handle successfully minimum time target detection missions in real world scenarios, as the results analyzed in this paper, obtained over different setups, show.

Estimating Stop Conditions of Swarm Based Stochastic Metaheuristic Algorithms

Peter Frank Perroni, *Federal University of Paraná*, Daniel Weingaertner, *Federal University of Paraná*, Myriam Regattieri Delgado, *Federal University of Technology - Paraná*

When dealing with metaheuristics, one important question is how many evaluations are worth spending in the search for better results. This work proposes a method to estimate the best moment to stop swarm iterations based on the analysis of the convergence behavior presented during optimization, aiming to provide an effective balance between saving fitness evaluations and keeping the optimization quality. An automated Convergence Stabilization Modeling operating in Online mode (CSMOn) is proposed based on a sequence of linear regressions using exponential and log-like curves. The method was tested on the CEC13 benchmark with CCPSO2-IP E algorithm and on 30 random Max-Set functions with the swarm algorithms PSO, ABC and CCPSO2-IP E. CEC13 results show that up to 90% less fitness evaluations are performed for functions where CCPSO2-IP E has a steady convergence, and up to 49% for functions where convergence is erratic, while penalties for fitness are kept small. Max-Set results demonstrates the robustness of CSMOn for the search algorithms tested. We conclude that CSMOn is capable of adapting to an optimization in progress, producing a good trade-off between result quality and evaluation savings.

Session: ACO-SI2
Wednesday, July 19, 09:00-10:40, Smaragd

PSO-based Parameters Selection for the Bilateral Filter in Image Denoising

Chengyan Wang, *Department of computer science, Nanjing University*, Bing Xue, *School of Engineering and Computer Science, Victoria University of Wellington*, Lin Shang, *Department of computer science, Nanjing University*

The bilateral filter method is a nonlinear filter with spatial averaging without smoothing edges. It has shown to be an effective image denoising technique. Denoising performance using the bilateral filter is affected by the filter parameters, which is image dependent and requires experimental trials. We propose an automatic and effective PSO-based method of parameters selection

for the bilateral filter in image denoising. Intensity domain parameter δr and the radius parameter d are optimized by the PSO algorithm, in which SSIM(structural similarity index) is employed in fitness function. We firstly compare our approach with other four classical filtering methods at different types and levels of noise. We also compare the denoising performance with different values of the parameter δd. Experimental results on three sets of color images have shown that the proposed method of parameter selection outperformed the other filtering methods in denoising standard test images corrupted by different types and levels of noise.

CycloAnt: Sequencing Cyclic Peptides Using Hybrid Ants

Sujata Baral, *United International University*, Swakkhar Shatabda, *United International University*, Rashid A. Mahmood, *University of the South Pacific*

Non ribosomal cyclic peptides have long been used as effective antibiotics in drug industry. However, reconstruction of these peptide sequences extracted from natural elements remain a challenge till today. Introduction of mass spectrometry in this regard created scope for computer scientists to develop efficient algorithms to interpret a mass spectrum into a peptide sequence. Mass spectrum have a well known limitation of missing peaks which misleads the de novo sequencing process of cyclic peptides. In this paper, we present CycloAnt, a computational method that can reproduce correct cyclic amino acid sequence from distorted mass spectrum in an efficient way. We have used hybrid ants that constructs the solution first and then tries to improve the quality of the solution using subsequent local search. We proposed a set of novel scoring functions which emphasize on the presence of sub-sequences of amino acids rather than approving equal contribution of all partial mass and precursor mass present in the spectrum. Moreover, we proposed a novel set of operators for the local search and refinement. Experiments show the effectiveness of our method on a standard set of benchmark and improvement over other methods.

Fitness-Distance-Ratio Particle Swarm Optimization: Stability Analysis

Christopher Wesley Cleghorn, *University of Pretoria*, Andries P. Engelbrecht, *University of Pretoria*

At present the fitness-distance-ratio particle swarm optimizer (FDRPSO) has undergone no form of theoretical stability analysis. This paper theoretically derives the conditions necessary for order-1 and order-2 stability, under the well known stagnation assumption. Since it has been shown that particle stability has a meaningful impact on PSO's performance, it is important for PSO practitioners to know the actual criteria for particle stability. This paper validates its theoretical findings against an assumption free FDRPSO algorithm. This empirical validation is necessary for a truly accurate representation of FDRPSO's stability criteria.

Coordinating a Team of Searchers: Of Ants, Swarms, and Slime Molds

Silja Meyer-Nieberg, *Universitaet der Bundeswehr Muenchen*

This paper introduces new hybrid coordination techniques for searching mobile targets in dangerous and dynamic environments. Situations like this arise for example during and after natural or human caused disasters. The approach presented combines algorithmic concepts from ant colony and particle swarm optimization with an adaptive network approach that utilizes principles stemming from slime-molds. The objectives are to spread the search team in order to cover and explore the area, to send the searchers towards the suspected position, and to safeguard against passing unsafe areas. In addition, the technique proposed can react fast towards environmental changes. Two main algorithms were developed. They are investigated in a series of experiments showing promising first results.

Complex Systems

Session: CS1
Monday, July 17, 10:40-12:20, Smaragd

Coupling Novelty and Surprise for Evolutionary Divergence

Daniele Gravina, *Institute of Digital Games, University of Malta, Malta*, Antonios Liapis, *Institute of Digital Games, University of Malta, Malta*, Georgios N. Yannakakis, *Institute of Digital Games, University of Malta, Malta*

Divergent search techniques applied to evolutionary computation, such as novelty search and surprise search, have demonstrated their efficacy in highly deceptive problems compared to traditional objective-based fitness evolutionary processes. While novelty search rewards unseen solutions, surprise search rewards unexpected solutions. As a result these two algorithms perform a different form of search since an expected solution can be novel while an already seen solution can be surprising. As novelty and surprise search have already shown much promise individually, the hypothesis is that an evolutionary process that rewards both novel and surprising solutions will be able to handle deception in a better fashion and lead to more successful solutions faster. In this paper we introduce an algorithm that realises both novelty and surprise search and we compare it against the two algorithms

that compose it in a number of robot navigation tasks. The key findings of this paper suggest that coupling novelty and surprise is advantageous compared to each search approach on its own. The introduced algorithm breaks new ground in divergent search as it outperforms both novelty and surprise in terms of efficiency and robustness, and it explores the behavioural space more extensively.

Minimal Criterion Coevolution: A New Approach to Open-Ended Search

Jonathan C. Brant, *University of Central Florida*, Kenneth O. Stanley, *University of Central Florida*

Recent studies have emphasized the merits of search processes that lack overarching objectives, instead promoting divergence by rewarding behavioral novelty. While this less objective search paradigm is more open-ended and divergent, it still differs significantly from nature's mechanism of divergence. Rather than measuring novelty explicitly, nature is guided by a single, fundamental constraint: survive long enough to reproduce. Surprisingly, this simple constraint produces both complexity and diversity in a continual process unparalleled by any algorithm to date. Inspired by the relative simplicity of open-endedness in nature in comparison to recent non-objective algorithms, this paper investigates the extent to which interactions between two coevolving populations, both subject to their own constraint, or minimal criterion, can produce results that are both functional and diverse even without any behavior characterization or novelty archive. To test this new approach, a novel maze navigation domain is introduced wherein evolved agents must learn to navigate mazes whose structures are simultaneously coevolving and increasing in complexity. The result is a broad range of maze topologies and successful agent trajectories in a single run, thereby suggesting the viability of minimal criterion coevolution as a new approach to non-objective search and a step towards genuinely open-ended algorithms.

An Investigation of Environmental Influence on the Benefits of Adaptation Mechanisms in Evolutionary Swarm Robotics

Andreas Steyven, *Edinburgh Napier University*, Emma Hart, *Edinburgh Napier University*, Ben Paechter, *Edinburgh Napier University*

A robotic swarm that is required to operate for long periods in a potentially unknown environment can use both evolution and individual learning methods in order to adapt. However, the role played by the environment in influencing the effectiveness of each type of learning is not well understood. In this paper, we address this question by analysing the performance of a swarm in a range of simulated, dynamic environments where a distributed evolutionary algorithm for evolving a controller is augmented with a number of different individual learning mechanisms. The learning mechanisms themselves are defined by parameters which can be either fixed or inherited. We conduct experiments in a range of dynamic environments whose characteristics are varied so as to present different opportunities for learning. Results enable us to map environmental characteristics to the most effective learning algorithm.

Effect of Animat Complexity on the Evolution of Hierarchical Control

Jared M. Moore, *Grand Valley State University*, Anthony J. Clark, *Missouri State University*, Philip K. McKinley, *Michigan State University*

Animal movements are realized by a combination of high-level control from the nervous system and joint-level movement provided by the musculoskeletal system. The digital muscle model (DMM) emulates the low-level musculoskeletal system and can be combined with a high-level artificial neural network (ANN) controller forming a hybrid control strategy. Previous work has shown that, compared to ANN-only controllers, hybrid ANN/DMM controllers exhibit similar performance with fewer synapses, suggesting that some computation is offloaded to the low-level DMM. An open question is how the complexity of the robot, in terms of the number of joints, affects the evolution of the ANN control structure. We explore this question by evolving both hybrid controllers and ANN-only controllers for worm-like animats of varying complexity. Specifically, the number of joints in the worms ranges from 1 to 12. Consistent with an earlier study, the results demonstrate that, in most cases, hybrid ANN/DMM controllers exhibit equal or better performance than ANN-only controllers. In addition, above a threshold for animat complexity (number of joints), the ANNs for one variant of the hybrid controllers have significantly fewer connections than the ANN-only controllers.

Session: CS2
Monday, July 17, 16:10-17:50, Diamant

Vascular Morphogenesis Controller: A Generative Model For Developing Morphology of Artificial Structures

Payam Zahadat, *University of Graz*, Daniel Nicolas Hofstadler, *University of Graz*, Thomas Schmickl, *University of Graz*

Morphology of an artificial structure can be designed beforehand or it can be developed over time via interactions between different parts of the structure. Since structures are supposed to sustain and act in their surrounding environments, a successful generative process needs to consider both the global and local effects of environment during morphogenesis. As in their biological counterparts, many morphogenesis models are distributed over the growing structure. In this paper, a novel distributed model, called Vascular Morphogenesis Controller (VMC), is introduced by being inspired from branching mechanisms in plants where every branch of a plant acts as an autonomous agent competing with the other agents for a larger share of the resources for growth. To the best of our knowledge, this is the first explicit use of distribution of limited resources in morphogenesis process of artificial structures. The model is implemented for growing a

simulated modular robot that is designed based on a physical robot. The parameters of model are successfully evolved to direct the growth of robots in different environmental condition, i.e., in harsh and calm environments, in various light conditions, and in a layered environment. The results demonstrate usability of the model despite simplicity of its logic.

On the Runtime Analysis of the Opt-IA Artificial Immune System

Dogan Corus, *University of Sheffield*, Pietro Simone Oliveto, *University of Sheffield*, Donya Yazdani, *University of Sheffield*

We present a time complexity analysis of the Opt-IA artificial immune system (AIS). We first highlight the power and limitations of its distinguishing operators (i.e., hypermutations with mutation potential and ageing) by analysing them in isolation. Recent work has shown that ageing combined with local mutations can help escape local optima on a dynamic optimisation benchmark function. We generalise this result by rigorously proving that ageing leads to considerable speed-ups (compared to evolutionary algorithms (EAs)) on the standard Cliff benchmark function both when using local and global mutations. Unless the 'stop at first constructive mutation' (FCM) mechanism is applied, we show that hypermutations require exponential expected runtime to optimise any function with a polynomial number of optima. If instead FCM is used, the expected runtime is at most a linear factor larger than the upper bound achieved for any random local search algorithm using the artificial fitness levels method. Nevertheless, we prove that algorithms using hypermutations can be considerably faster than EAs at escaping local optima. An analysis of the complete Opt-IA reveals that it is efficient on the previously considered functions and highlights problems where the use of the full algorithm is crucial.

A Minimal Developmental Model Can Increase Evolvability in Soft Robots

Sam Kriegman, *University of Vermont*, Nick Cheney, *Cornell University*, Francesco Corucci, *Scuola Superiore Sant'Anna*, Josh Bongard, *University of Vermont*

Different subsystems of organisms adapt over many time scales, such as rapid changes in the nervous system (learning), slower morphological and neurological change over the life time of the organism (postnatal development), and change over many generations (evolution). Much work has focused on instantiating learning or evolution in robots, but relatively little on development. Although many theories have been forwarded as to how development can aid evolution, it is difficult to isolate each such proposed mechanism. Thus, here we introduce a minimal yet embodied model of development: the body of the robot changes over its lifetime, yet growth is not influenced by the environment. We show that even this simple developmental model confers evolvability because it allows evolution to sweep over a larger range of body plans than an equivalent non-developmental system, and subsequent heterochronic mutations 'lock in' this body plan in more morphologically-static descendants. Future work will involve gradually complexifying the developmental model to determine when and how such added complexity increases evolvability.

Session: CS3: Best Papers
Tuesday, July 18, 14:00-15:40, Opal

On Self-Adaptive Mutation Restarts for Evolutionary Robotics with Real Rotorcraft

Gerard David Howard, *CSIRO*

Self-adaptive parameters are increasingly used in the eld of Evolutionary Robotics, as they allow key evolutionary rates to vary autonomously in a context-sensitive manner throughout the optimisation process. A significant limitation to self-adaptive mutation is that rates can be set unfavourably, which hinders convergence. Rate restarts are typically employed to remedy this, but thus far have only been applied in Evolutionary Robotics for mutation-only algorithms. This paper focuses on the level at which evolutionary rate restarts are applied in population-based algorithms with >1 evolutionary operator. After testing on a real hexacopter hovering task, we conclude that individual-level restarting results in higher fitness solutions without fitness stagnation, and population restarts provide a more stable rate evolution. Without restarts, experiments can become stuck in suboptimal controller/rate combinations which can be difficult to escape from.

Evolutionary Optimization of Self-Assembly in a Swarm of Bio-microrobots

Nathanael Y. I. Aubert-Kato, *Tokyo Institute of Tech./Ochanomizu University*, Charles Fosseprez, *ESPCI/MNHN*, Guillaume Gines, *ESPCI*, Ibuki Kawamata, *Tohoku University*, Huy Q. Dinh, *The University of Tokyo*, Leo Cazenille, *UPMC/UPD*, Andre Estevez-Torres, *UPMC*, Masami Hagiya, *The University of Tokyo*, Yannick Rondelez, *ESPCI*, Nicolas Bredeche, *UPMC*

This paper deals with the programmability of a swarm of bio-micro-robots in order to display self-assembling behaviors into a specific shape. We consider robots that are DNA-functionalized micro-beads capable of sensing and expressing signal as well as self-assembling. We describe an *in vitro* experimentation with a million of micro-beads conditionally aggregating into clusters. We then address the question of how to automatically design the reaction networks that define the micro-robots' behavior, to self-assemble into a specific shape at a specific location. We use bioNEAT, an instantiation of the famous NEAT algorithm capable of handling chemical reaction networks, to optimize the behavior of each micro-bead. As in swarm robotics, each micro-bead shares the same behavioral rules and the general outcome depends on interactions between neighbors and with the environment. Results obtained on four different target functions show that evolved chemical reaction networks display efficient self-

assembling behaviors, even when compared to hand-designed networks provided by an expert after a week-long trials&errors search. In addition, we show that evolved solutions are able to self-repair after damage, a critical property for smart materials.

Data-Efficient Exploration, Optimization, and Modeling of Diverse Designs through Surrogate-Assisted Illumination

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

The MAP-Elites algorithm produces a set of high-performing solutions that vary according to features defined by the user. This technique to 'illuminate' the problem space through the lens of chosen features has the potential to be a powerful tool for exploring design spaces, but is limited by the need for numerous evaluations. The Surrogate-Assisted Illumination (SAIL) algorithm, introduced here, integrates approximative models and intelligent sampling of the objective function to minimize the number of evaluations required by MAP-Elites. The ability of SAIL to efficiently produce both accurate models and diverse high-performing solutions is illustrated on a 2D airfoil design problem. The search space is divided into bins, each holding a design with a different combination of features. In each bin SAIL produces a better performing solution than MAP-Elites, and requires several orders of magnitude fewer evaluations. The CMA-ES algorithm was used to produce an optimal design in each bin: with the same number of evaluations required by CMA-ES to and a near-optimal solution in a single bin, SAIL finds solutions of similar quality in every bin.

Discovering Evolutionary Stepping Stones through Behavior Domination

Elliot Meyerson, *The University of Texas at Austin; and Sentient Technologies, Inc.*, Risto Miikkulainen, *The University of Texas at Austin; and Sentient Technologies, Inc.*

Behavior domination is proposed as a tool for understanding and harnessing the power of evolutionary systems to discover and exploit useful stepping stones. Novelty search has shown promise in overcoming deception by collecting diverse stepping stones, and several algorithms have been proposed that combine novelty with a more traditional fitness measure to refocus search and help novelty search scale to more complex domains. However, combinations of novelty and fitness do not necessarily preserve the stepping stone discovery that novelty search affords. In several existing methods, competition between solutions can lead to an unintended loss of diversity. Behavior domination defines a class of algorithms that avoid this problem, while inheriting theoretical guarantees from multiobjective optimization. Several existing algorithms are shown to be in this class, and a new algorithm is introduced based on fast non-dominated sorting. Experimental results show that this algorithm outperforms existing approaches in domains that contain useful stepping stones, and its advantage is sustained with scale. The conclusion is that behavior domination can help illuminate the complex dynamics of behavior-driven search, and can thus lead to the design of more scalable and robust algorithms.

Session: CS4
Wednesday, July 19, 09:00-10:40, Bernstein

A Comparison of Genetic Regulatory Network Dynamics and Encoding

Jean Disset, *University of Toulouse*, Dennis Wilson, *University of Toulouse*, Sylvain Cussat-Blanc, *University of Toulouse*, Stephane Sanchez, *University of Toulouse*, Hervé Luga, *University of Toulouse*, Yves Duthen, *University of Toulouse*

Genetic Regulatory Networks (GRNs) implementations have a high degree of variability in their details. Parameters, encoding methods, and dynamics formulas all differ in the literature, and some GRN implementations have a high degree of model complexity. In this paper, we present a comparative study of different implementations of a GRN and introduce new variants for comparison. We use a modified Genetic Algorithm (GA) to evaluate GRN performance on a number of common benchmark tasks, with a focus on real-time control problems. We propose an encoding scheme and set of dynamics equations that simplifies implementation and evaluate the evolutionary fitness of this proposed method. Lastly, we use the comparative modifications study to demonstrate overall enhancements for GRN models.

Alternate Social Theory Discovery Using Genetic Programming: Towards Better Understanding the Artificial Anasazi

Chathika Gunaratne, *University of Central Florida*, Ivan Garibay, *University of Central Florida*

A pressing issue with agent-based model (ABM) replicability is the ambiguity behind micro-behavior rules of the agents. In practice, modelers choose between competing theories, each describing separate candidate solutions. Pattern-oriented modeling (POM) and stylized facts matching recommend testing theories against patterns extracted from real-world data. Yet, manually, POM is tedious and prone to human error. In this study, we present a genetic programming strategy to evolve debatable assumptions on agent micro-behaviors. After proper modularization of the candidate micro-behaviors, genetic programming can discover candidate micro-behaviors which reproduce patterns found in real-world data. We illustrate this strategy by evolving the decision tree representing the farm-seeking strategy of agents in the Artificial Anasazi ABM. Through evolutionary theory discovery, we obtain multiple candidate decision trees for farm-seeking which fit the archaeological data better than the calibrated original model in the literature. We emphasize the necessity to explore a range of components that influence the agents' decision making process and demonstrate that this is achievable through an evolutionary process if the rules are modularized as required. The end result is a set of plausible candidate solutions that closely fit the real-world data, which can then be nominated by domain experts.

Evolution and Analysis of Embodied Spiking Neural Networks Reveals Task-Specific Clusters of Effective Networks

Madhavun Candadai Vasu, *Indiana University*, Eduardo J. Izquierdo, *Indiana University*

Elucidating principles that underlie computation in neural networks is currently a major research topic of interest in neuroscience. Transfer Entropy (TE) is increasingly used as a tool to bridge the gap between network structure, function, and behavior in fMRI studies. Computational models allow us to bridge the gap even further by directly associating individual neuron activity with behavior. However, most computational models that have analyzed embodied behaviors have employed non-spiking neurons. On the other hand, computational models that employ spiking neural networks tend to be restricted to disembodied tasks. We show for the first time the artificial evolution and TE-analysis of embodied spiking neural networks to perform a cognitively-interesting behavior. Specifically, we evolved an agent controlled by an Izhikevich neural network to perform a visual categorization task. The smallest networks capable of performing the task were found by repeating evolutionary runs with different network sizes. Informational analysis of the best solution revealed task-specific TE-network clusters, suggesting that within-task homogeneity and across-task heterogeneity were key to behavioral success. Moreover, analysis of the ensemble of solutions revealed that task-specificity of TE-network clusters correlated with fitness. This provides an empirically testable hypothesis that links network structure to behavior.

Digital Entertainment Technologies and Arts

Session: GECH1+DETA1: Best Papers
Monday, July 17, 14:00-15:40, Opal

Multi-Task Learning in Atari Video Games with Emergent Tangled Program Graphs

Stephen Kelly, *Dalhousie University*, Malcolm I. Heywood, *Dalhousie University*

The Atari 2600 video game console provides an environment for investigating the ability to build artificial agent behaviours for a variety of games using a common interface. Such a task has received attention for addressing issues such as: 1) operation directly from a high-dimensional game screen; and 2) partial observability of state. However, a general theme has been to assume a common machine learning algorithm, but completely retrain the model for each game title. Success in this respect implies that agent behaviours can be identified without hand crafting game specific attributes/actions. This work advances current state-of-the-art by evolving solutions to play multiple titles from the same run. We demonstrate that in evolving solutions to multiple game titles, agent behaviours for an individual game as well as single agents capable of playing all games emerge from the same evolutionary run. Moreover, the computational cost is no more than that used for building solutions for a single title. Finally, while generally matching the skill level of controllers from neuro-evolution/deep learning, the genetic programming solutions evolved here are several orders of magnitude simpler, resulting in real-time operation at a fraction of the cost.

Evolution of Artistic Image Variants Through Feature Based Diversity Optimisation

Bradley James Alexander, *University of Adelaide*, James Kortman, *University of Adelaide*, Aneta Neumann, *University of Adelaide*

Measures aimed to improve the diversity of images and image features in evolutionary art help to direct search toward more novel and creative parts of the artistic search domain. To date such measures have not focused on selecting from all individuals based on their contribution to diversity of feature metrics. In recent work on TSP problem instance classification, selection based on a direct measure of each individual's contribution to diversity was successfully used to generate hard and easy TSP instances. In this work we use this search framework to evolve diverse variants of a source image in one and two feature dimensions. The resulting images show the spectrum of effects from transforming images to score across the range of each feature. The results also reveal interesting correlations between feature values in two dimensions.

Session: DETA2
Wednesday, July 19, 09:00-10:40, Topas 1

Multi-segment Evolution of Dungeon Game Levels

Antonios Liapis, *Institute of Digital Games*

This paper presents a generative technique for game levels, focusing on expansive dungeon levels. The proposed two-step evolutionary process creates a high-level overview of the map, which is then used to specify constraints and objectives on multiple constrained optimization algorithms which generate the high-resolution segments of the map. Results show how different types of segments are possible, and how the different connectivity constraints and objectives affect the performance of the algorithm. The modular approach, which allows for a high-level specification of the level first and the subsequent compartmentalized generation of the final map's components, is both scalable and more computationally efficient than a direct encoding, while it allows for more control and user intervention on either level of detail.

Comparing Direct and Indirect Encodings Using Both Raw and Hand-Designed Features in Tetris

Lauren E. Gillespie, *Southwestern University*, Gabriela R. Gonzalez, *Southwestern University*, Jacob Schrum, *Southwestern University*

Intelligent agents have a wide range of applications in robotics, video games, and computer simulations. However, fully general agents should function with as little human guidance as possible. Specifically, agents should learn from large collections of raw state variables instead of small collections of hand-designed features. Learning from raw state variables is difficult, but can be easier when agents are aware of the geometry of the input space. Indirect encodings allow agents to take advantage of the geometry of the task, and scale up to large input spaces. This research demonstrates the relative benefits of a direct and indirect encoding using raw or hand-designed features in Tetris, a challenging video game. Specifically, the direct encoding NEAT is compared against the indirect encoding HyperNEAT. Both algorithms create neural networks to play the game, but HyperNEAT makes better use of raw screen inputs, due to its ability to generate large networks that take advantage of the domain's geometry. However, hand-designed features lead to higher scores with both algorithms. HyperNEAT makes better use of hand-designed features early in evolution, but NEAT eventually overtakes it. Since each method succeeds in different circumstances, approaches combining the strengths of both should be explored.

Continual Online Evolutionary Planning for In-Game Build Order Adaptation in StarCraft

Niels Justesen, *IT University of Copenhagen*, Sebastian Risi, *IT University of Copenhagen*

The real-time strategy game StarCraft has become an important benchmark for AI research as it poses a complex environment with numerous challenges. An important strategic aspect in this game is to decide what buildings and units to produce. StarCraft bots playing in AI competitions today are only able to switch between predefined strategies, which makes it hard to adapt to new situations. This paper introduces an evolutionary-based method to overcome this challenge, called Continual Online Evolutionary Planning (COEP), which is able to perform in-game adaptive build order planning. COEP was added to an open source StarCraft bot called UAlbertaBot and is able to outperform the built-in bots in the game as well as being competitive against a number of scripted opening strategies. The COEP augmented bot can change its build order dynamically and quickly adapt to the opponent's strategy.

Can you feel it? Evaluation of affective expression in music generated by MetaCompose

Marco Scirea, *IT University of Copenhagen*, Peter Eklund, *IT University of Copenhagen*, Julian Togelius, *New York University*, Sebastian Risi, *IT University of Copenhagen*

This paper describes an evaluation conducted on the MetaCompose music generator, which is based on evolutionary computation and uses a hybrid evolutionary technique that combines FI-2POP and multi-objective optimization. The main objective of MetaCompose is to create music in real-time that can express different mood-states. The experiment presented here aims to evaluate: (i) if the perceived mood experienced by the participants of a music score matches intended mood the system is trying to express and (ii) if participants can identify transitions in the mood expression that occur mid-piece. Music clips including transitions and with static affective states were produced by MetaCompose and a quantitative user study was performed. Participants were tasked with annotating the perceived mood and moreover were asked to annotate in real-time changes in valence. The data collected confirms the hypothesis that people can recognize changes in music mood and that MetaCompose can express perceptibly different levels of arousal. In regards to valence we observe that, while it is mainly perceived as expected, changes in arousal seems to also influence perceived valence, suggesting that one or more of the music features MetaCompose associates with arousal has some effect on valence as well.

Evolutionary Combinatorial Optimization and Metaheuristics

Session: ECOM1
Monday, July 17, 10:40-12:20, Opal

Combining Two Local Searches with Crossover: An Efficient Hybrid Algorithm for the Traveling Salesman Problem

Weichen Liu, *University of Science and Technology of China*, Thomas Weise, *Hefei University*, Yuezhong Wu, *University of Science and Technology of China*, Qi Qi, *University of Science and Technology of China*

The Traveling Salesman Problem (TSP) is one of the most well-known optimization problems. Ejection Chain Methods (ECM) and the Lin-Kernighan (LK) heuristic are the state-of-art local search (LS) algorithms for solving the TSP. Multi-Neighborhood Search (MNS) is known to be especially suitable for hybridization with Evolutionary Computation (EC). Hybridizing two different LS algorithms with each other (LS-LS) can combine their mutual advantages and lead to better performance. We introduce the new concept of LS-LS-X hybrids, which combines two different LS algorithms with a crossover operator. We enhance the two best LS-LS hybrids, ECM-LK and LK-MNS, with Order

Based Crossover and Heuristic Crossover. We hybridize these LS-LS-X algorithms with an Evolutionary Algorithm, the most prominent EC method, and obtain highly-efficient (memetic) EC-LS-LS-X algorithms. We conduct a large-scale experimental study with many different algorithm setups on all 110 symmetric instances of the TSPLib benchmark set. We find that the LS-LS-X hybrids have significantly better performance than the original LS-LS and their component algorithms. They even outperform several memetic EC-LS-LS and EC-LS algorithm setups. The EC-LS-LS-X hybrids are the best hybrid EA-based TSP solvers by a large margin in our experiment and the wide range of algorithms available in the popular TSP Suite.

Multimodal Truss Structure Design Using Bilevel and Niching Based Evolutionary Algorithms

Md. Jakirul Islam, *RMIT University*, Xiaodong Li, *RMIT University*, Kalyanmoy Deb, *Michigan State University*

Finding an optimal design for a truss structure involves optimizing its topology, size, and shape. A truss design problem is usually multimodal, meaning that the problem offers multiple optimal designs in terms of topology and/or size of the members, but they are evaluated to have similar or equally good objective function values. From a practical standpoint, it is desirable to find as many alternative designs as possible, rather than finding a single design, as often practiced. A few metaheuristics based methods with niching techniques have been used for finding multiple topologies for the truss design problem, but these studies have ignored any emphasis in finding multiple solutions in terms of size. To overcome this issue, this paper proposes to formulate the truss problem as a bilevel optimization problem, where stable topologies can be found in the upper level and the optimized sizes of the members of these topologies can be found in the lower level. As a result, a new bilevel niching method is proposed to find multiple optimal solutions for topology level as well as for the size level simultaneously. The proposed method is shown to be superior over the state-of- the-art methods on several benchmark truss-structure design problems.

Approximating Optimization Problems using EAs on Scale-Free Networks

Ankit Chauhan, *Hasso Plattner Institute*, Tobias Friedrich, *Hasso Plattner Institute*, Francesco Quinzan, *Hasso Plattner Institute*

It has been experimentally observed that real-world networks follow certain topological properties, such as small-world, power-law etc. To study these networks, many random graph models, such as Preferential Attachment, have been proposed. In this paper, we consider the deterministic properties which capture power-law degree distribution and degeneracy. Networks with these properties are known as scale-free networks in the literature. Many interesting problems remain NP-hard on scale-free networks. We study the relationship between scale-free properties and the approximation-ratio of some commonly used evolutionary algorithms. For the Vertex Cover, we observe experimentally that the (1+1)-EA always gives the better result than a greedy local search, even when it runs for only $O(nlog(n))$ steps. We give the construction of a scale-free network in which a multi-objective algorithm and a greedy algorithm obtain optimal solutions, while the (1+1)-EA obtains the worst possible solution with constant probability. We prove that for the Dominating Set, Vertex Cover, Connected Dominating Set and Independent Set, the (1+1)-EA obtains constant-factor approximation in expected run time $O(nlog(n))$ and $O(n^4)$ respectively. Whereas, GSEMO gives even better approximation than the (1+1)-EA in expected run time $O(n^3)$ for Dominating Set, Vertex Cover and Connected Dominating Set on such networks.

On Feasible and Infeasible Search for Equitable Graph Coloring

Wen Sun, *Université d'Angers*, Jin-Kao Hao, *Université d'Angers*, XiangJing Lai, *Nanjing University of Posts and Telecommunications*, Qinghua Wu, *Huazhong University of Science and Technology*

An equitable legal k-coloring of an undirected graph G = (V,E) is a partition of the vertex set V into k disjoint independent sets, such that the cardinalities of any two independent sets differ by at most one (this is called the equity constraint). As a variant of the popular graph coloring problem (GCP), the equitable coloring problem (ECP) involves finding a minimum k for which an equitable legal k-coloring exists. In this paper, we present a study of searching both feasible and infeasible solutions with respect to the equity constraint. The resulting algorithm relies on a mixed search strategy exploring both equitable and inequitable colorings unlike existing algorithms where the search is limited to equitable colorings only. We present experimental results on 73 DIMACS and COLOR benchmark graphs and demonstrate the competitiveness of this search strategy by showing 9 improved best-known results (new upper bounds).

Session: ECOM2
Monday, July 17, 16:10-17:50, Jade

Comparing Communities of Optima with Funnels in Combinatorial Fitness Landscapes

Sarah L. Thomson, *University of Stirling*, Fabio Daolio, *University of Stirling*, Gabriela Ochoa, *University of Stirling*

The existence of sub-optimal 'funnels' in combinatorial fitness landscapes has been linked to search difficulty. The exact nature of these structures - and how commonly they appear - is not yet fully understood. Improving our understanding of funnels could help with designing effective diversification mechanisms for a 'smoothing' effect, making optimisation easier. We model fitness landscapes as local optima networks. The relationship between 'communities' of local optima found by network clustering algorithms and funnels is explored. Funnels are identi-

fied using the notion of 'monotonic sequences' from the study of energy landscapes in theoretical chemistry. NK Landscapes and the Quadratic Assignment Problem are used as case studies. Our results show that communities are linked to funnels, but they are not the same structures. The analysis exhibits relationships between these landscape structures and the performance of trajectory-based metaheuristics such as Simulated Annealing (SA) and Iterated Local Search (ILS). In particular, ILS gets trapped in funnels, and modular communities of optima slow it down. The funnels contribute to lower success for SA. We show that increasing the strength of ILS perturbation helps to 'smooth' the funnels and improves performance in multi-funnel landscapes.

Just-in-Time Batch Scheduling Problem with Two-dimensional Bin Packing Constraints

Sergey Polyakovskiy, *University of Adelaide,*, Alexander Makarowsky, *University of Adelaide*, Rym M'Hallah, *University of Kuwait*

This paper introduces a multi-component problem where small rectangular items are produced from large rectangular bins via guillotine cuts. An item is characterized by its width, height, due date, earliness and tardiness penalties. Each item induces a cost that depends on its lateness when produced earlier or later than its due date. Items cut from the same bin form a batch, whose processing and completion times depend on its assigned items. The objective is to find a cutting plan that minimizes the weighted sum of earliness and tardiness penalties. We use constraint programming (CP) search and agent based (AB) modelling to find approximate solutions to this problem. The CP approach is an impact-based search strategy, implemented in the general-purpose solver IBM CP Optimizer. The AB is a constructive approach which builds a solution through repeated negotiations between the set of agents representing the items and the set representing the bins. The agents cooperate to minimize the weighted earliness-tardiness penalties. The computational investigation shows that the CP heuristic outperforms the AB heuristic on small-sized instances while the opposite prevails for larger instances.

Parameter-less Late Acceptance Hill-Climbing

Mosab Bazargani, *Queen Mary University of London*, Fernando G. Lobo, *Universidade do Algarve*

The Late Acceptance Hill-Climbing (LAHC) algorithm has been recently introduced by Burke and Bykov. It is a simple, general purpose, one-point search metaheuristic that has similarities with Simulated Annealing (SA) in the sense that worsening moves on a current solution can be accepted. One of its advantages relative to Simulated Annealing is that no cooling schedule is required and its sole parameter, the so-called *history length*, has a more meaningful interpretation from the application point of view and is therefore easier to specify by a user. In this paper we show that even this single parameter can be eliminated, making LAHC simpler to apply in practice. The validity of the method is shown with computational experiments on a number of instances of the Travelling Salesman Problem.

HSEDA: A Heuristic Selection Approach Based on Estimation of Distribution Algorithm for the Travelling Thief Problem

Marcella Scoczynski Ribeiro Martins, *Federal University of Technology - Paraná (UTFPR)*, Mohamed El Yafrani, *Mohammed V University in Rabat*, Markus Wagner, *University of Adelaide*, Myriam Regattieri Delgado, *Federal University of Technology - Paraná (UTFPR)*, Belaïd Ahiod, *Mohammed V University in Rabat*, Ricardo Lüders, *Federal University of Technology - Paraná (UTFPR)*

Hyper-heuristics are high-level search techniques which improve the performance of heuristics operating at a higher heuristic level. Usually, these techniques automatically generate or select new simpler components based on the feedback received during the search. Estimation of Distribution Algorithms (EDAs) have been applied as hyper-heuristics, using a probabilistic distribution model to extract and represent interactions between heuristics and its low-level components to provide high-valued problem solutions. In this paper, we consider an EDA-based hyper-heuristic framework which encompasses a Heuristic Selection approach aiming to find best combinations of different known heuristics. A surrogate assisted model evaluates the new heuristic combinations sampled by the EDA probabilistic model using an approximation function. We compare our proposed approach named Heuristic Selection based on Estimation of Distribution Algorithm (HSEDA) with three state-of-the-art algorithms for the Travelling Thief Problem (TTP). The experimental results show that the approach is competitive, outperforming the other algorithms on most of the medium-sized TTP instances considered in this paper.

Session: ECOM3
Tuesday, July 18, 10:40-12:20, Jade

Automated Heuristic Design Using Genetic Programming Hyper-Heuristic for Uncertain Capacitated Arc Routing Problem

Yuxin Liu, *Southwest University*, Yi Mei, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*, Zili Zhang, *Southwest University; Deakin University*

Uncertain Capacitated Arc Routing Problem (UCARP) is a variant of the well-known CARP. It considers a variety of stochastic factors to reflect the reality where the exact information such as the actual task demand and accessibilities of edges are unknown in advance. Existing works focus on obtaining a robust solution beforehand. However, it is also important to design effective heuristics to adjust the solution in real time. In this paper, we develop a new Genetic Programming-based Hyper-Heuristic (GPHH) for automated heuristic design for UCARP. A

novel effective meta-algorithm is designed carefully to address the failures caused by the environment change. In addition, it employs domain knowledge to filter some infeasible candidate tasks for the heuristic function. The experimental results show that the proposed GPHH significantly outperforms the existing GPHH methods and manually designed heuristics. Moreover, we find that eliminating the infeasible and distant tasks in advance can reduce much noise and improve the efficacy of the evolved heuristics. In addition, it is found that simply adding a slack factor to the expected task demand may not improve the performance of the GPHH.

Fragment-based Genetic Programming for Fully Automated Multi-Objective Web Service Composition

Alexandre Sawczuk da Silva, *Victoria University of Wellington*, Yi Mei, *Victoria University of Wellington*, Hui Ma, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Web services have become increasingly popular in recent years, given their modular nature and reusability potential. A particularly promising application is in Web service composition, where multiple individual services with specific functionalities are composed to accomplish a more complex task. Researchers have proposed evolutionary computing techniques for creating compositions that are not only feasible, but also have the best possible Quality of Service (QoS). Some of these works employed multi-objective techniques to tackle the optimisation of compositions with conflicting QoS attributes, but they are not fully automated, i.e. they assume the composition workflow structure is already known. This assumption is often not satisfied, as the workflow is often unknown. This paper proposes a genetic programming-based method to automatically generate service compositions in a multi-objective context, based on a novel fragmented tree representation. An evaluation using benchmark datasets is carried out, comparing existing methods adapted to the multi-objective composition problem. Results show that the fragmented method has the lowest execution time overall. In terms of quality, its Pareto fronts are equivalent to those of one of the approaches but inferior to those of the other. More importantly, this work provides a foundation for future investigation of multi-objective fully automated service composition.

Toward Evolving Dispatching Rules for Dyanmic Job Shop Scheduling Under Uncertainty

Deepak Karunakaran, *Victoria University of Wellington*, Yi Mei, *Victoria Univeristy of Wellington*, Gang Chen, *Victoria Univeristy of Wellington*, Mengjie Zhang, *Victoria Univeristy of Wellington*

Dynamic job shop scheduling (DJSS) is a complex problem which is an important aspect of manufacturing systems. Even though the manufacturing environment is uncertain, most of the existing research works consider deterministic scheduling problems where the time required for processing any job is known in advance and never changes. In this work, we consider DJSS problems with varied uncertainty configurations of machines in terms of processing times and the total flow time as scheduling objective. With the varying levels of uncertainty, many machines become bottlenecks of the job shop. It is essential to identify these bottleneck machines and schedule the jobs to be performed by them carefully. Driven by this idea, we develop a new effective method to evolve pairs of dispatching rules each for a different bottleneck level of the machines. A clustering approach to classifying the bottleneck level of the machines arising in the system due to uncertain processing times is proposed. Then, a cooperative co-evolution technique to evolve pairs of dispatching rules which generalize well across different uncertainty configurations is presented. We perform empirical analysis to show its generalization characteristic over the different uncertainty configurations and show that the proposed method outperforms the current approaches.

Shaping Communities of Local Optima by Perturbation Strength

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

Recent work discovered that fitness landscapes induced by Iterated Local Search (ILS) may consist of multiple clusters, denoted as funnels or communities of local optima. Such studies exist only for perturbation operators (kicks) with low strength. We examine how different strengths of the ILS perturbation operator affect the number and size of clusters. We present an empirical study based on local optima networks from NK fitness landscapes. Our results show that a properly selected perturbation strength can help overcome the effect of ILS getting trapped in clusters of local optima. This has implications for designing effective ILS approaches in practice, where traditionally only small perturbations or complete restarts are applied, with the middle ground of intermediate perturbation strengths largely unexplored.

Session: SBSE2+ECOM4
Tuesday, July 18, 14:00-15:40, Jade

Hybrid Metaheuristic for Combinatorial Optimization based on Immune Network for Optimization and VNS

Rodney O. M. Diana, *CEFET-MG*, Sérgio R. de Souza, *CEFET-MG*, Elizabeth Fialho Wanner, *CEFET-MG*, Moacir F. de França Filho, *CEFET-MG*

Metaheuristics for optimization based on the immune network theory are often highlighted by being able to maintain the diversity of candidate solutions present in the population, allowing a greater coverage of the search space. This work, however, shows that algorithms derived from the aiNET family for the solution

of combinatorial problems may not present an adequate strategy for search space exploration, leading to premature convergence in local minimums. In order to solve this issue, a hybrid metaheuristic called VNS-aiNET is proposed, integrating aspects of the COPT-aiNET algorithm with characteristics of the trajectory metaheuristic Variable Neighborhood Search (VNS), as well as a new fitness function, which makes it possible to escape from local minima and enables it to a greater exploration of the search space. The proposed metaheuristic is evaluated using a scheduling problem widely studied in the literature. The performed experiments show that the proposed hybrid metaheuristic presents a convergence superior to two approaches of the aiNET family and to the reference algorithms of the literature. In contrast, the solutions present in the resulting immunological memory have less diversity when compared to the aiNET family approaches.

Session: ECOM5
Tuesday, July 18, 16:10-17:50, Jade

Community structure detection for multipartite networks

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

Community structure detection algorithms are used to identify groups of nodes that are more connected to each other than to the rest of the network. Multipartite networks are a special type of network in which nodes are divided into partitions such that there are no links between nodes in the same partition. However, such nodes may belong to the same community, making the identification of the community structure of a multipartite network computationally challenging. In this paper, we propose a new fitness function that takes into account the information induced by existing links in the network by considering shadowed connections between nodes that have a common neighbor. The existence of a correct fitness function, i.e. one whose optimum values correspond to the community structure of the network, enables the design and use of optimization-based heuristics for solving this problem. We use numerical experiments performed on artificial benchmarks to illustrate the effectiveness of this function used within an extremal optimization based algorithm and compared to existing approaches. As a direct application, a multipartite network constructed from a direct marketing database is analyzed.

Improving an Exact Solver for the Traveling Salesman Problem using Partition Crossover

Danilo Sipoli Sanches, *Federal University of Technology of*, Darrell Whitley, *Colorado State University*, Renato Tinós, *University of Sao Paulo*

The best known exact solver for generating provably optimal solutions to the Traveling Salesrep Problem (TSP) is the Concorde algorithm. Concorde uses a branch and bound search strategy, as well at cutting planes to reduce the search space. The first step in using Concorde is to obtain a good initial solution. This can be done in two ways. A good solution can be generated using a heuristic solver outside of Concorde, or Concorde will generate its own initial solution using the Chained Lin Kernighan algorithm. In this paper, we speed up the Concorde algorithm by adding a recombination operator, partition crossover, in order to find a better initial solution. In every instance we examined, the use of recombination resulted in an average speed-up of Concorde, and in the majority of case, the difference in the runtime costs was statistically significant.

Building a Better Heuristic for the Traveling Salesman Problem: Combining Edge Assembly Crossover and Partition Crossover.

Danilo Sipoli Sanches, *Federal University of Technology, Parana*, Darrell Whitley, *Colorado State University*, Renato Tinós, *University of Sao Paulo*

A genetic algorithm using Edge Assemble Crossover (EAX) is one of the best heuristic solvers for generating solutions to large Traveling Salesman problems. We develop a new genetic algorithm that uses both EAX and Partition Crossover. The result is better than using one recombination operator. Partition Crossover is a power form of recombination that is highly exploitive. Given two parents that are locally optimal, when partition crossover decomposes two parents into q recombining components, partition crossover returns the best of 2^q reachable offspring. Given two parents that are locally optimal, all of the offspring are also locally optimal is a hyperplane subspace that contains the two parents. One disadvantage of partition crossover, however, is that it cannot generate new edges. By contrast, the Edge Assemble Crossover operator is highly explorative; it not only inherits edges from parents, it also introduces new edges into the population of a genetic algorithm. Using both EAX and Partition Crossover together produces a better genetic algorithm with improved exploitation and exploration.

Evolutionary Algorithms for the Design of Orthogonal Latin Squares based on Cellular Automata

Luca Mariot, *Università degli Studi di Milano-Bicocca*, Stjepan Picek, *Delft University of Technology*, Domagoj Jakobovic, *University of Zagreb*, Alberto Leporati, *Università degli Studi di Milano-Bicocca*

We investigate the design of Orthogonal Latin Squares (OLS) by means of Genetic Algorithms (GA) and Genetic Programming (GP). Since we focus on Latin squares generated by Cellular Automata (CA), the problem can be reduced to the search of pairs of boolean functions that give rise to OLS when used as CA local rules. As it is already known how to design CA-based OLS with linear boolean functions, we adopt the evolutionary approach to address the nonlinear case, experimenting with different encodings for the candidate solutions. In particular, for GA we consider single bitstring, double bitstring and quaternary string encodings, while for GP we adopt a double tree repre-

sentation. We test the two metaheuristics on the spaces of local rules pairs with $n = 7$ and $n = 8$ variables, using two fitness functions. The results show that GP is always able to generate OLS, even if the optimal solutions found with the first fitness function are mostly linear. On the other hand, GA achieves a remarkably lower success rate than GP in evolving OLS, but the corresponding boolean functions are always nonlinear.

Session: ECOM6: Best Papers
Wednesday, July 19, 09:00-10:40, Saphir

Distributed Evolutionary k-way Node Separators

Peter Sanders, *Karlsruhe Institute of Technology*, Christian Schulz, *University of Vienna*, Darren Strash, *Colgate University*, Robert Williger, *Karlsruhe Institute of Technology*

Computing high quality node separators in large graphs is necessary for a variety of applications, ranging from divide-and-conquer algorithms to VLSI design. In this work, we present a novel distributed evolutionary algorithm tackling the k-way node separator problem. A key component of our contribution includes new k-way local search algorithms based on maximum flows. We combine our local search with a multilevel approach to compute an initial population for our evolutionary algorithm, and further show how to modify the coarsening stage of our multilevel algorithm to create effective combine and mutation operations. Lastly, we combine these techniques with a scalable communication protocol, producing a system that is able to compute high quality solutions in a short amount of time. Our experiments against competing algorithms show that our advanced evolutionary algorithm computes the best result on 94% of the chosen benchmark instances.

Automatic Design of Multi-Objective Local Search Algorithms

Aymeric Blot, *Université de Lille, CRIStAL*, Laetitia Jourdan, *Université de Lille, CRIStAL*, Marie-Éléonore Kessaci, *Université de Lille, CRIStAL*

Multi-objective local search (MOLS) algorithms are efficient metaheuristics, which improve a set of solutions by using their neighbourhood to iteratively find better and better solutions. MOLS algorithms are versatile algorithms with many available strategies, first to select the solutions to explore, then to explore them, and finally to update the archive using some of visited neighbours. In this paper, we propose a new generalisation of MOLS algorithms incorporating new recent ideas and algorithms. To be able to instantiate the many MOLS algorithms of the literature, our generalisation exposes numerous numerical and categorical parameters, raising the possibility of being automatically designed by an automatic algorithm configuration (AAC) mechanism. We investigate the worth of such an automatic design of MOLS algorithms using MO-ParamILS, a multi-objective AAC configurator, on the permutation flowshop scheduling problem, and demonstrate its worth against a traditional manual design.

Configuring irace using surrogate configuration benchmarks

Nguyen Dang, *KU Leuven, CODeS & imec-ITEC*, Leslie Pérez Cáceres, *IRIDIA, CoDE, Universite libre de Bruxelles*, Thomas Stützle, *IRIDIA, CoDE, Universite libre de Bruxelles*, Patrick De Causmaecker, *KU Leuven, CODeS & imec-ITEC*

Over recent years, several tools for the automated configuration of parameterized algorithms have been developed. These tools, also called configurators, have themselves parameters that influence their search behavior and make them malleable to different kinds of configuration tasks. The default values of these parameters are set manually based on the experience of the configurator's developers. Studying the impact of these parameters or tuning them is very expensive as it would require many executions of these tools on configuration tasks, each taking often many hours or days of computation. In this work, we tackle this problem using a meta-configuration process, based on the use of surrogate benchmarks that are much faster to evaluate. This paper studies the feasibility of this process using the popular irace configurator as the method to be meta-configured. We first study the consistency between the real and surrogate benchmarks using three measures: the prediction accuracy of the surrogate models, the homogeneity of the benchmarks and the list of important algorithm parameters. Afterwards, we use irace to configure irace on those surrogates. Experimental results indicate the feasibility of this process and a clear potential improvement of irace over its default configuration.

Heuristic rope team : a parallel algorithm for graph coloring

Laurent Moalic, *Univ. Bourgogne Franche-Comté, UTBM, OPERA*, Alexandre Gondran, *ENAC, French Civil Aviation University*

Optimization problems are often compared to mountain climbing. In particular, the classical Hill Climber is a so used local search. In this paper we propose to explore further the analogy with climbing a mountain, not alone as it is generally the case but in rope. Indeed, for difficult problems a single climber (heuristic) can easily be trapped into a local optimum. This situation can be compared to a crevasse which the heuristic can not escape from. In the proposed approach the leader of the rope bring with him at least one other climber, linked by a rope, in order to help him to escape from a local optimum. This approach has been successfully applied to one of the most studied combinatorial problem: the Graph Coloring Problem. The advantage of this approach is twofold: on one hand, it is able to find the best known solution for most of the difficult graphs coming from the DIMACS benchmark; on the other hand, each climber is autonomous allowing parallelization of the algorithm. Among the significant results of this work we can notice 3 well-studied graphs, DSJC500.5 colored with 47 colors, DSJC1000.5 with 82 colors and flat1000_76_0 with 81 colors.

Evolutionary Machine Learning

Session: EML1
Monday, July 17, 10:40-12:20, Jade

Theoretical XCS Parameter Settings of Learning Accurate Classifiers

Masaya Nakata, *Yokohama National University*, Will N. Browne, *Victoria University of Wellington*, Tomoki Hamagami, *Yokohama National University*, Keiki Takadama, *University of Electro-Communications*

XCS is the most popular type of Learning Classifier System, but setting optimum parameter values is more of an art rather than a science. Early theoretical work required the impractical assumption that classifier parameters had fully converged with infinite update times. The aim of this work is to derive a theoretical condition to mathematically guarantee that XCS identifies maximally accurate classifiers, such that subsequent deletion methods can be used optimally, in as few updates as possible. Consequently, our theory provides a universally usable setup guide for three important parameter settings; the learning rate, the accuracy update and the threshold for subsumption deletion. XCS with our best parameter settings solves the 70-bit multiplexer problem with only 21% of instances that the standard XCS setup needs. On a highly class-imbalanced multiplexer problem with inaccurate classifiers having more than 99.99% classification accuracy, our theory enables XCS to identify only 100% accurate classifiers as accurate and thus obtain the optimal performance.

Particle Swarm Optimization for Hyper-Parameter Selection in Deep Neural Networks

Pablo Ribalta Lorenzo, *Future Processing*, Jakub Nalepa, *Silesian University of Technology*, Michal Kawulok, *Silesian University of Technology*, Luciano Sanchez Ramos, *University of Oviedo*, José Ranilla Pastor, *University of Oviedo*

Deep neural networks (DNNs) have achieved unprecedented success in a wide array of tasks. However, the performance of these systems depends directly on their hyper-parameters which often must be selected by an expert. Optimizing the hyper-parameters remains a substantial obstacle in designing DNNs in practice. In this work, we propose to select them using particle swarm optimization (PSO). Such biologically-inspired approaches have not been extensively exploited for this task. We demonstrate that PSO efficiently explores the solution space, allowing DNNs of a minimal topology to obtain competitive classification performance over the MNIST dataset. We showed that very small DNNs optimized by PSO retrieve promising classification accuracy for CIFAR-10. Also, PSO improves the performance of existing architectures. Extensive experimental study, backed-up with the statistical tests, revealed that PSO is an effective technique for automating hyper-parameter selection and efficiently exploits computational resources.

Biogeography-Based Rule Mining for Classification

Effat Farhana, *North Carolina State University*, Steffen Heber, *North Carolina State University*

Rule-based classification is a popular approach for solving real world classification problems. Once suitable rules have been obtained, rule-based classifiers are easy to deploy and explain. In this paper, we describe an approach that uses biogeography-based optimization (BBO) to compute rule sets that maximize predictive accuracy. BBO is an evolutionary algorithm inspired by the migration patterns of species between the islands of an archipelago. In our implementation, each species corresponds to a classification rule, each island is occupied by multiple species and corresponds to a classifier, and the fitness of an island is computed as the predictive classification accuracy of the corresponding classifier. The archipelago evolves via mutation, selection, and migration of species between islands. Successful islands have a decreased immigration rate and an increased emigration rate. In general, such islands tend to resist invasion and to colonize less successful islands. This results in an evolving set of habitats that corresponds to a population of classifiers. We demonstrate the effectiveness of our approach by comparing it to several traditional and evolutionary based state-of the-art classifiers.

Evolving Parsimonious Networks by Mixing Activation Functions

Alexander Hagg, *Bonn-Rhein-Sieg University of Applied Sciences*, Maximilian Joseph Mensing, *Bonn-Rhein-Sieg University of Applied Sciences*, Alexander Asteroth, *Bonn-Rhein-Sieg University of Applied Sciences*

Neuroevolution methods evolve the weights of a neural network, and in some cases the topology, but little work has been done to analyze the effect of evolving the activation functions of individual nodes on network size, an important factor when training networks with a small number of samples. In this work we extend the neuroevolution algorithm NEAT to evolve the activation function of neurons in addition to the topology and weights of the network. The size and performance of networks produced using NEAT with uniform activation in all nodes, or homogenous networks, is compared to networks which contain a mixture of activation functions, or heterogenous networks. For a number of regression and classification benchmarks it is shown that, (1) qualitatively different activation functions lead to different results in homogeneous networks, (2) the heterogeneous version of NEAT is able to select well performing activation functions, (3) the produced heterogeneous networks are significantly smaller than homogeneous networks.

Session: EML2
Monday, July 17, 14:00-15:40, Amethyst

GPGC: Genetic Programming for Automatic Clustering using a Flexible Non-Hyper-Spherical Graph-Based Approach

Andrew Lensen, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*

Genetic programming (GP) has been shown to be very effective for performing data mining tasks. Despite this, it has seen relatively little use in clustering. In this work, we introduce a new GP approach for performing graph-based (GPGC) non-hyper-spherical clustering where the number of clusters is not required to be set in advance. The proposed GPGC approach is compared with a number of well known methods on a large number of data sets with a wide variety of shapes and sizes. Our results show that GPGC is the most generalisable of the tested methods, achieving good performance across all datasets. GPGC significantly outperforms all existing methods on the hardest ellipsoidal datasets, without needing the user to pre-define the number of clusters. To our knowledge, this is the first work which proposes using GP for graph-based clustering.

Solving Test Case Based Problems With Fuzzy Dominance

Jason Zutty, *Georgia Tech Research Institute*, Gregory Rohling, *Georgia Tech Research Institute*

Genetic algorithms and genetic programming lend themselves well to the field of machine learning, which involves solving test case based problems. However, most traditional multi-objective selection methods work with scalar objectives, such as minimizing false negative and false positive rates, that are computed from underlying test cases. In this paper, we propose a new fuzzy selection operator that takes into account the statistical nature of machine learning problems based on test cases. Rather than use a Pareto rank or strength computed from scalar objectives, such as with NSGA2 or SPEA2, we will compute a probability of Pareto optimality. This will be accomplished through covariance estimation and Markov chain Monte Carlo simulation in order to generate probabilistic objective scores for each individual. We then compute a probability that each individual will generate a Pareto optimal solution. This probability is directly used with a roulette wheel selection technique. Our method's performance is evaluated on the evolution of a feature selection vector for a binary classification on each of eight different activities. Fuzzy selection performance varies, outperforming both NSGA2 and SPEA2 in both speed (measured in generations) and solution quality (measured by area under the curve) in some cases, while underperforming in others.

Feature Selection Using Stochastic Diffusion Search

Haya Abdullah Alhakbani, *Goldsmiths University*, Mohammad Majid Al-Rifaie, *Goldsmiths University*

The method introduced in this paper uses stochastic diffusion search (SDS) to select the most relevant feature subset for the classification task. In this algorithm, SDS is adapted to find a suitable feature subset. Moreover, support vector machine (SVM) is used as a classifier to evaluate the predictive accuracy of the agent. The proposed method exhibits a statistically significant outperformance when compared with the performance of the classifier without the SDS-powered features selections. Additionally, the results have been also compared with other methods from the literature over nine datasets. It is shown that the proposed SDS based feature selection (SDS-FS) offers a competitive performance with other methods on datasets with feature size greater than 10. The behaviour of the proposed algorithm has been investigated in the context of global exploration and local exploitation.

An Evolutionary Algorithm for Discovering Multi-Relational Association Rules in the Semantic Web

Minh Duc Tran, *Université Côte d'Azur*, Claudia d'Amato, *University of Bari*, Binh Thanh Nguyen, *The University of Danang - University of Science and Technology*, Andrea G. B. Tettamanzi, *Université Côte d'Azur*

In the Semantic Web context, OWL ontologies represent the conceptualization of domains of interest while the corresponding assertional knowledge is given by RDF data referring to them. Because of its open, distributed, and collaborative nature, such knowledge can be incomplete, noisy, and sometimes inconsistent. By exploiting the evidence coming from the assertional data, we aim at discovering hidden knowledge patterns in the form of multi-relational association rules while taking advantage of the intensional knowledge available in ontological knowledge bases. An evolutionary search method applied to populated ontological knowledge bases is proposed for finding rules with a high inductive power. The proposed method, EDMAR, uses problem-aware genetic operators, echoing the refinement operators of ILP, and takes the intensional knowledge into account, which allows it to restrict and guide the search. Discovered rules are coded in SWRL, and as such they can be straightforwardly integrated within the ontology, thus enriching its expressive power and augmenting the assertional knowledge that can be derived. Additionally, discovered rules may also suggest new axioms to be added to the ontology. We performed experiments on publicly available ontologies, validating the performances of our approach and comparing them with the main state-of-the-art systems.

Session: EML3: Best Papers
Monday, July 17, 16:10-17:50, Opal

Toward the automated analysis of complex diseases in genome-wide association studies using genetic programming

Andrew M. Sohn, *Institute for Biomedical Informatics at the Perelman School of Medicine of the University of Pennsylvania*, Randal S. Olson, *Institute for Biomedical Informatics at the Perelman School of Medicine of the University of Pennsylvania*, Jason H. Moore, *Institute for Biomedical Informatics at the Perelman School of Medicine of the University of Pennsylvania*

Machine learning has been gaining traction in recent years to meet the demand for tools that can efficiently analyze and make sense of the ever-growing databases of biomedical data in health care systems around the world. However, effectively using machine learning methods requires considerable domain expertise, which can be a barrier of entry for bioinformaticians new to computational data science methods. Therefore, off-the-shelf tools that make machine learning more accessible can prove invaluable for bioinformaticians. To this end, we have developed an open source pipeline optimization tool (TPOT-MDR) that uses genetic programming to automatically design machine learning pipelines for bioinformatics studies. In TPOT-MDR, we implement Multifactor Dimensionality Reduction (MDR) as a feature construction method for modeling higher-order feature interactions, and combine it with a new expert knowledge-guided feature selector for large biomedical datasets. We demonstrate TPOT-MDR's capabilities using a combination of simulated and real world data sets from human genetics and find that TPOT-MDR significantly outperforms modern machine learning methods such as logistic regression and eXtreme Gradient Boosting (XGBoost). We further analyze the best pipeline discovered by TPOT-MDR for a real world problem and highlight TPOT-MDR's ability to produce a high-accuracy solution that is also easily interpretable.

Accelerating Coevolution with Adaptive Matrix Factorization

Paweł Liskowski, *Poznan University of Technology/Laboratory of Intelligent Decision Support Systems*, Wojciech Jaśkowski, *IDSIA Dalle Molle Institute for Artificial Intelligence Research*

Among many interaction schemes in coevolutionary settings for interactive domains, the round-robin tournament provides the most precise evaluation of candidate solutions at the expense of computational effort. In order to improve the coevolutionary learning speed, we propose an interaction scheme that computes only a fraction of interactions outcomes between the pairs of coevolving individuals. The missing outcomes in the interaction matrix are predicted using matrix factorization. The algorithm adaptively decides how much of the interaction matrix to compute based on the learning speed statistics. We evaluate our method in the context of coevolutionary covariance matrix adaptation strategy (CoCMAES) for the problem of learning position evaluation in the game of Othello. We show that our adaptive interaction scheme allows to match the state-of-the-art results obtained by the standard round-robin CoCMAES while, at the same time, considerably improves the learning speed.

Evolving Memory-Augmented Neural Architecture for Deep Memory Problems

Shauharda Khadka, *Oregon State University*, Jen Jen Chung, *Oregon State University*, Kagan Tumer, *Oregon State University*

In this paper, we present a new memory-augmented neural network called Gated Recurrent Unit with Memory Block (GRU-MB). Our architecture builds on the gated neural architecture of a Gated Recurrent Unit (GRU) and integrates an external memory block, similar to a Neural Turing Machine (NTM). GRU-MB interacts with the memory block using independent read and write gates that serve to decouple the memory from the central feedforward operation. This allows for regimented memory access and update, administering our network the ability to choose when to read from memory, update it, or simply ignore it. This capacity to act in detachment allows the network to shield the memory from noise and other distractions, while simultaneously using it to effectively retain and propagate information over an extended period of time. We evolve GRU-MB using neuroevolution and perform experiments on two different deep memory tasks. Results demonstrate that GRU-MB performs significantly faster and more accurately than traditional memory-based methods, and is robust to dramatic increases in the depth of these tasks.

A Genetic Programming Approach to Designing Convolutional Neural Network Architectures

Masanori Suganuma, *Yokohama National University*, Shinichi Shirakawa, *Yokohama National University*, Tomoharu Nagao, *Yokohama National University*

The convolutional neural network (CNN), which is one of the deep learning models, has seen much success in a variety of computer vision tasks. However, designing CNN architectures still requires expert knowledge and a lot of trial and error. In this paper, we attempt to automatically construct CNN architectures for an image classification task based on Cartesian genetic programming (CGP). In our method, we adopt highly functional modules, such as convolutional blocks and tensor concatenation, as the node functions in CGP. The CNN structure and connectivity represented by the CGP encoding method are optimized to maximize the validation accuracy. To evaluate the proposed method, we constructed a CNN architecture for the image classification task with the CIFAR-10 dataset. The experimental result shows that the proposed method can be used to automatically find the competitive CNN architecture compared with state-of-the-art models.

Session: EML4
Tuesday, July 18, 14:00-15:40, Amethyst

Automatic Adjustment of Selection Pressure based on Range of Reward in Learning Classifier System

Takato Tatsumi, *The University of Electro-Communications*, Hiroyuki Sato, *The University of Electro-Communications*, Keiki Takadama, *The University of Electro-Communications*

XCS (Accuracy-based learning classifier system) can acquire accurate classifiers on the basis of consistent reward, but it does not always receive the consistent reward in real world problems even if it provides the same output for the same input. Such a situation prevents XCS from reducing the number of overspecific accurate classifiers by the subsumption mechanism. This means that XCS finds it hard to acquire the optimal classifiers. For this issue, our previous research proposed XCS-MR (XCS based on Mean of Reward) which can reduce the number of classifiers even in the environments where the size of the rewards is uncertain. However, XCS-MR requires a large amount of learning data to correctly determine the accuracy of classifiers because XCS-MR needs to record the average and variance of the rewards in all input-output space. To overcome this problem, this paper proposes a new XCS that can reduce the number of the classifiers even in the uncertain reward environments without recording the average and variance of the rewards in all input-output space. This paper shows the effectiveness of the proposed XCS through the experiments.

Multiple Imputation and Genetic Programming for Classification with Incomplete Data

Cao Truong Tran, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*, Peter Andreae, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*

Missing values are an unavoidable in many real-world datasets. Dealing with missing values is a crucial requirement for classification task, because insufficient treatment with missing values often leads to a large classification error. One of the most popular approach to solving classification with incomplete data is to use imputation methods for replacing missing values with plausible values before applying classification algorithms. Multiple imputation is a powerful approach to estimating missing values. However, multiple imputation is often computationally expensive to estimate missing values for every single incomplete instance in the unseen set for classification. Genetic programming (GP) has been successfully used to construct classifiers for complete data, but it has been seldom used to construct classifiers for incomplete data. This paper proposes an effective combination between multiple imputation and GP to construct classifiers for incomplete data. To achieve the goal, multiple imputation is only used to estimate missing values in training data. After that, GP is used to construct a set of classifiers which can directly classify incomplete instances without using imputation methods. Experimental results show that the proposed method not only can achieve better classification accuracy but also can be faster than other common methods for classification with incomplete data.

Towards the Evolution of Multi-Layered Neural Networks: A Dynamic Structured Grammatical Evolution Approach

Filipe Assunção, *University of Coimbra*, Nuno Lourenço, *University of Coimbra*, Penousal Machado, *University of Coimbra*, Bernardete Ribeiro, *University of Coimbra*

Current grammar-based NeuroEvolution approaches have several shortcomings. On the one hand, they do not allow the generation of Artificial Neural Networks (ANNs) composed of more than one hidden-layer. On the other, there is no way to evolve networks with more than one output neuron. To properly evolve ANNs with more than one hidden-layer and multiple output nodes there is the need to know the number of neurons available in previous layers. In this paper we introduce Dynamic Structured Grammatical Evolution (DSGE): a new genotypic representation that overcomes the aforementioned limitations. By enabling the creation of dynamic rules that specify the connection possibilities of each neuron, the methodology enables the evolution of multi-layered ANNs with more than one output neuron. Results in different classification problems show that DSGE evolves effective single and multi-layered ANNs, with a varying number of output neurons.

Neuroevolution on the Edge of Chaos

Filip Matzner, *Charles University in Prague, Faculty of Mathematics and Physics*

Echo state networks represent a special type of recurrent neural networks. Recent papers stated that the echo state networks maximize their computational performance on the transition between order and chaos, the so-called edge of chaos. This work confirms this statement in a comprehensive set of experiments. Furthermore, the echo state networks are compared to networks evolved via neuroevolution. The evolved networks outperform the echo state networks, however, the evolution consumes significant computational resources. It is demonstrated that echo state networks with local connections combine the best of both worlds, the simplicity of random echo state networks and the performance of evolved networks. Finally, it is shown that evolution tends to stay close to the ordered side of the edge of chaos.

Session: EML5
Wednesday, July 19, 09:00-10:40, Opal

Automatic Design of Ant-Miner Mixed Attributes for Classification Rule Discovery

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

Ant-Miner Mixed Attributes (Ant-MinerMA) was inspired and built based on ACOMV, which uses an archive-based pheromone model to cope with mixed attribute types. On the one hand, the use of an archive-based pheromone model improved significantly the runtime of Ant-MinerMA and helped to eliminate the need for discretisation procedure when dealing with continuous attributes. On the other hand, the graph-based pheromone model showed superiority when dealing with datasets containing a large size of attributes, as the graph helps the algorithm to easily identify good attributes. In this paper, we propose an automatic design framework to incorporate the graph-based model along with the archive-based model in the rule creation process. We compared the automatically designed hybrid algorithm against existing ACO-based algorithms: one using a graph-based pheromone model and one using an archive-based pheromone model. Our results show that the hybrid algorithm improves the predictive quality over both the base archive-based and graph-based algorithms.

PAC models in stochastic multi-objective multi-armed bandits

Madalina Drugan, *Technical University of Eindhoven*

Many real-world applications, such as stock markets, energy consumption time series, and scheduling in noisy environments, are characterised by stochastic feedback. In this paper, the evolutionary multi-objective (EMO) techniques, like elitist selection strategies, and the probably approximatively correct (PAC) model are used to analyse the multi-armed bandits (MAB) paradigm that identifies the Pareto front from a finite set of arms with stochastic reward vectors. Each arm is associated with a confidence ball centred in the sampling's mean vector that decreases towards its true vector when the number of samples increases. The Pareto lower upper confidence bound algorithm samples the alternatives for which their confidence ball overlaps with the confidence regions of the Pareto optimal arms. Pareto racing deletes the arms classified with certainty as either suboptimal or Pareto optimal arms. The sample complexity estimates the number of samples required for an accurate approximation of the Pareto front using two different statistics, i.e. empirically determined means or quantiles. The analysed PAC models are empirically compared on realistic datasets with two and three objectives.

Sensitivity-Like Analysis for Feature Selection in Genetic Programming

Grant Dick, *University of Otago*

Feature selection is an important process within machine learning problems. Through pressures imposed on models during evolution, genetic programming performs basic feature selection, and so analysis of the evolved models can provide some insights into the utility of input features. Previous work has tended towards a presence model of feature selection, where the frequency of a feature appearing within evolved models is a metric for its utility. In this paper, we identify some drawbacks with using this approach, and instead propose the integration of importance measures for feature selection that measure the influence of a feature within a model. Using sensitivity-like analysis methods inspired by importance measures used in random forest regression, we demonstrate that genetic programming introduces many features into evolved models that have little impact on a given model's behaviour, and this can mask the true importance of salient features. The paper concludes by exploring bloat control methods and adaptive terminal selection methods to influence the identification of useful features within the search performed by genetic programming, with results suggesting that a combination of adaptive terminal selection and bloat control may help to improve generalisation performance.

Evolutionary Multiobjective Optimization

Session: EMO1
Monday, July 17, 10:40-12:20, Diamant

Multimodal Scalarized Preferences in Multi-objective Optimization

Marlon Alexander Braun, *Karlsruhe Institute of Technology*, Lars Heling, *Karlsruhe Institute of Technology*, Pradyumn Shukla, *Karlsruhe Institute of Technology*, Hartmut Schmeck, *Karlsruhe Institute of Technology*

Scalarization functions represent preferences in multi-objective optimization by mapping the vector of objectives to a single real value. Optimization techniques using scalarized preferences mainly focus on obtaining only a single global preference optimum. Instead, we propose considering all local and global scalarization optima on the global Pareto front. These points represent the best choice in their immediate neighborhood. Additionally, they are usually sufficiently far apart in the objective space to present themselves as true alternatives if the scalarization function cannot capture every detail of the decision maker's true preference. We propose an algorithmic framework for obtaining all scalarization optima of a multi-objective optimization problem. In said framework, an approximation of the global Pareto front is obtained, from which neighborhoods of local optima are identified. Local optimization algorithms are then applied to identify the optimum of every neighborhood. In this way, we have an optima-based approximation of the global

Pareto front based on the underlying scalarization function. A computational study reveals that local optimization algorithms must be carefully configured for being able to find all optima.

On the Importance of Isolated Solutions in Constrained Decomposition-based Many-objective Optimization

Maha Elarbi, *University of Tunis (ISGT-campus)*, Slim Bechikh, *University of Tunis (ISGT-campus)*, Lamjed Ben Said, *University of Tunis (ISGT-campus)*

During the few past years, decomposition has shown a high performance in solving Multi-objective Optimization Problems (MOPs) involving more than three objectives, called as Many-objective Optimization Problems (MaOPs). The performance of most of the existing decomposition-based algorithms has been assessed on the widely used DTLZ and WFG unconstrained test problems. However, the number of works that have been devoted to tackle the problematic of constrained many-objective optimization is relatively very small when compared to the number of works handling the unconstrained case. Recently, there has been some interest to exploit infeasible isolated solutions when solving Constrained MaOPs (CMaOPs). Motivated by this observation, we firstly propose an IS-update procedure (Isolated Solution-based update procedure) that has the ability to: (1) handle CMaOPs characterized with various types of difficulties and (2) favor the selection of not only infeasible solutions associated to isolated sub-regions but also infeasible solutions with smaller CV (Constraint Violation) values. The IS-update procedure is subsequently embedded within the Multi-Objective Evolutionary Algorithm-based on Decomposition (MOEA/D). The new obtained algorithm, named ISC-MOEA/D (Isolated Solution-based Constrained MOEA/D), has been shown to provide competitive and better results when compared against three recent works on the CDTLZ benchmark problems.

A Hyper-Heuristic of Scalarizing Functions

Raquel Hernández Gómez, *CINVESTAV-IPN*, Carlos A. Coello Coello, *CINVESTAV-IPN*

Scalarizing functions have been successfully used by Multi-Objective Evolutionary Algorithms (MOEAs) for the fitness assignment process. Their popularity has to do with their low computational cost, their capability to generate (weakly) Pareto optimal solutions, and their effectiveness in solving many-objective optimization problems. Nevertheless, recent studies indicate that the search behavior of MOEAs strongly depends on the choice of the scalarizing function. Besides, this specification varies according to the Pareto-front geometry of the problem at hand. In this work, we present a novel hyper-heuristic for continuous search spaces, which combines the strengths and compensates for the weaknesses of different scalarizing functions. These heuristics have been proposed within the evolutionary multi-objective optimization and mathematical programming communities. Furthermore, the selection of heuristics is conducted through the s-energy, which measures the even distribution of a set of points in k-dimensional manifolds. Experimental results indicate that our proposed approach outperforms the use of a single heuristic as well as other state-of-the-art algorithms in the majority of the ZDT, DTLZ and WFG test problems.

Speeding Up Evolutionary Multi-objective Optimisation Through Diversity-Based Parent Selection

Edgar Covantes Osuna, *University of Sheffield*, Wanru Gao, *The University of Adelaide*, Frank Neumann, *The University of Adelaide*, Dirk Sudholt, *University of Sheffield*

Parent selection in evolutionary algorithms for multi-objective optimization is usually performed by dominance mechanisms or indicator functions that prefer non-dominated points, while the reproduction phase involves the application of diversity mechanisms or other methods to achieve a good spread of the population along the Pareto front. We propose to refine the parent selection on evolutionary multi-objective optimization with diversity-based metrics. The aim is to focus on individuals with a high diversity contribution located in poorly explored areas of the search space, so the chances of creating new non-dominated individuals are better than in highly populated areas. We show by means of rigorous runtime analyses that the use of diversity-based parent selection mechanisms in the Simple Evolutionary Multi-objective Optimiser (SEMO) and Global SEMO for the well known bi-objective functions OneMinMax and LOTZ can significantly improve its performance. Our theoretical results are accompanied by additional experiments that show a correspondence between theory and empirical results.

Session: EMO2
Monday, July 17, 16:10-17:50, Smaragd

Benchmarking MOEAs for Multi- and Many-objective Optimization Using an Unbounded External Archive

Ryoji Tanabe, *Japan Aerospace Exploration Agency*, Akira Oyama, *Japan Aerospace Exploration Agency*

While a large number of multi-objective evolutionary algorithms (MOEAs) for many-objective optimization problems (MaOPs) have been proposed in the past few years, an exhaustive benchmarking study has never been performed. Moreover, most previous studies evaluated the performance of MOEAs based on nondominated solutions in the final population at the end of the search. In this paper, we exhaustively investigate the convergence performance of 21 MOEAs using an unbounded external archive that stores all nondominated solutions found during the search process. Surprisingly, the experimental results for the WFG functions with up to six objectives indicate that several recently proposed MOEAs perform significantly worse than classical MOEAs. Moreover, the performance rank among the 21 MOEAs significantly depends on the number of function evaluations. Thus, the previously reported performance of MOEAs on MaOPs as well as the widely used benchmarking methodology must be carefully reconsidered.

Closed States Model for Understanding the Dynamics of MOEAs

Hugo Monzón, *Shinshu University*, Hernán Aguirre, *Shinshu University*, Sébastien Verel, *Univ. Littoral Cote d'Opale*, Arnaud Liefooghe, *Université Lille - CRIStAL*, Bilel Derbel, *Université Lille - CRIStAL*, Kiyoshi Tanaka, *Shinshu University*

This work proposes the use of simple closed state models to capture, analyze and compare the dynamics of multi- and many-objective evolutionary algorithms. Two- and three-state models representing the composition of the instantaneous population are described and learned for representatives of the major approaches to multi-objective optimization, i.e. dominance, extensions of dominance, decomposition, and indicator algorithms. The model parameters are trained from data obtained running the algorithms with various population sizes on enumerable MNK-landscapes with 3, 4, 5 and 6 objectives. We show ways to interpret and use the model parameter values in order to analyze the population dynamics according to selected features. For example, we are interested in knowing how parameter values change for a given population size with the increase of the number of objectives. We also show a graphical representation capturing in one graph how the parameters magnitude and sign relate to the connections between states.

Multiobjective Data Mining from Solutions by Evolutionary Multiobjective Optimization

Yusuke Nojima, *Osaka Prefecture University*, Yuki Tanigaki, *Osaka Prefecture University*, Hisao Ishibuchi, *Osaka Prefecture University*

One research direction in the field of evolutionary multiobjective optimization (EMO) is a post-analytical process of non-dominated solutions in order to analyze the relationship between design variables and objective functions for optimization problems. For this purpose, data mining techniques have been used in some studies. From a practical point of view, this process itself should be considered as a multiobjective optimization problem. In this paper, multiobjective genetic fuzzy rule selection is applied to the post-analytical process of solutions obtained by EMO algorithms. First, multiple regions of interest are specified in the objective space. Each region with a number of solutions is handled as a different class. A set of patterns is generated by the labeled solutions. Second, a number of fuzzy if-then rules are generated by classification rule mining. Finally, an EMO algorithm is applied to combinatorial optimization of fuzzy if-then rules in order to obtain a number of non-dominated fuzzy classifiers with respect to accuracy and complexity. Through computational experiments using two engineering problems, we show that we can obtain various classifiers with a variety of complexity-accuracy tradeoff.

Metamodeling for Multimodal Selection Functions in Evolutionary Multi-Objective Optimization

Proteek Roy, *Michigan State University*, Rayan Hussien, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*

Most real-world optimization problems involve computationally expensive simulations for evaluating a solution. Despite significant progress in the use of metamodels for single-objective optimization, metamodeling methods have received a lukewarm attention for multi-obejctive optimization. A recent study by authors classified various metamodeling approaches, of which one particular method is interesting, challenging, and novel. In this paper, we study this so-called M6 method in detail. In this approach, a selection operator's assignment function, as it is implemented in an evolutionary multi-objective optimization (EMO) algorithm, is directly metamodeled. Thus, this methodology requires only one selection function to be metamodeled, instead of many objective and constraint functions. However, the flip side is that the resulting function is multimodal having an optimum for each specific Pareto-optimal solution. We have used two different selection functions based on two recent ideas: (i) KKT proximity measure function and (ii) multimodal based multi-objective selection function. The resulting metamodeling methods are applied to a number of standard two and three-objective constraint and unconstraint test problems. Near Pareto-optimal solutions are found using only a fraction of high-fidelity solution evaluation compared to usual EMO applications.

Session: EMO3+RWA5
Tuesday, July 18, 10:40-12:20, Amethyst

The Multi-Objective Real-Valued Gene-Pool Optimal Mixing Evolutionary Algorithm

Anton Bouter, *Centrum Wiskunde & Informatica*, Ngoc Hoang Luong, *Centrum Wiskunde & Informatica*, Cees Witteveen, *Delft University of Technology*, Tanja Alderliesten, *Academic Medical Center*, Peter A.N. Bosman, *Centrum Wiskunde & Informatica*

The recently introduced Multi-Objective Gene-pool Optimal Mixing Evolutionary Algorithm (MO-GOMEA) exhibits excellent scalability in solving a wide range of challenging discrete multi-objective optimization problems. In this paper, we address scalability issues in solving multi-objective optimization problems with continuous variables by introducing the Multi-Objective Real-Valued GOMEA (MO-RV-GOMEA), which combines MO-GOMEA with aspects of the multi-objective estimation-of-distribution algorithm known as MAMaLGaM. MO-RV-GOMEA exploits linkage structure in optimization problems by performing distribution estimation, adaptation, and sampling as well as solution mixing based on an explicitly-defined linkage model. Such a linkage model can be defined a priori when some problem-specific knowledge is available, or it can be learned from the population. The scalability of MO-RV-GOMEA using different linkage models is compared to the state-of-the-art multi-objective evolutionary algorithms NSGA-II and MAMaLGaM on a wide range of benchmark problems. MO-RV-GOMEA is found to retain the excellent scalability of MO-GOMEA through the successful ex-

ploitation of linkage structure, scaling substantially better than NSGA-II and MAMaLGaM. This scalability is even further improved when partial evaluations are possible, achieving strongly sub-linear scalability in terms of the number of evaluations.

Simulation-Based Crossover for the Firefighter Problem

Krzysztof Michalak, *Wrocław University of Economics*

The Firefighter Problem (FFP) is a combinatorial optimization problem in which the goal is to find the best way of protecting nodes in a graph from spreading fire or other threat given limited resources. Because of high computational complexity the FFP is often solved using metaheuristic methods such as evolutionary algorithms (EAs). The problem that arises is that many crossover operators used in EAs were developed with problems such as the TSP or the flowshop problem in mind and are therefore not optimized towards the FFP. In this paper a new crossover operator SimX is proposed that determines how to combine information from parent specimens using a simulation of fire spreading and some problem-specific heuristics. The proposed crossover operator was compared to a set of ten permutation-based crossover operators in experiments performed using a multipopulation algorithm with operator autoadaptation. In the experiments it was observed that the proposed simulation-based crossover operator produced good offspring more often than the other operators.

Robust Multiobjective Optimization using Regression Models and Linear Subproblems

Fillipe Goulart, *Graduate Program in Electrical Engineering, Universidade Federal de Minas Gerais*, Silvio Tassini Borges, *Graduate Program in Electrical Engineering, Universidade Federal de Minas Gerais*, Fernanda Caldeira Takahashi, *Graduate Program in Electrical Engineering, Universidade Federal de Minas Gerais*, Felipe Campelo, *Department of Electrical Engineering, Universidade Federal de Minas Gerais*

We propose a technique for incorporating robustness as part of the search process of evolutionary multiobjective optimization algorithms. The proposed approach calculates the sensitivity of candidate solutions by solving a linear programming subproblem, defined by regression models fitted using points in the neighborhood of each candidate solution. This sensitivity information is then used as part of the selection process, to drive the search towards solutions that comply with robustness requirements defined a priori by the decision-maker. Preliminary results suggest that this approach is capable of correctly converging to the desired robust fronts.

Session: EMO4: Best Papers
Tuesday, July 18, 14:00-15:40, Saphir

Reference Point Specification in Hypervolume Calculation for Fair Comparison and Efficient Search

Hisao Ishibuchi, *Southern University of Science and Technology*, Ryo Imada, *Osaka Prefecture University*, Yu Setoguchi, *Osaka Prefecture University*, Yusuke Nojima, *Osaka Prefecture University*

Hypervolume has been frequently used as a performance indicator for comparing evolutionary multiobjective optimization (EMO) algorithms. Hypervolume has been also used in indicator-based algorithms. Whereas a reference point is needed for hypervolume calculation, its specification has not been discussed in detail from a viewpoint of fair comparison. This may be because a slightly worse reference point than the nadir point seems to work well. In this paper, we tackle this issue: How to specify a reference point for fair comparison. First we discuss an appropriate specification of a reference point for multiobjective problems. Our discussions are based on the well-known theoretical results about the optimal solution distribution for hypervolume maximization. Next we examine various specifications by computational experiments. Experimental results show that a slightly worse reference point than the nadir point works well only for test problems with triangular Pareto fronts. Then we explain why this specification is not always appropriate for test problems with inverted triangular Pareto fronts. We also report a number of solution sets obtained by SMS-EMOA with various specifications of a reference point.

Improved Incremental Non-dominated Sorting for Steady-State Evolutionary Multiobjective Optimization

Ilya Yakupov, *ITMO University*, Maxim Buzdalov, *ITMO University*

We present an algorithm for incremental non-dominated sorting, a procedure to use with steady-state multiobjective algorithms, with the complexity of $O(N(logN)^(M-2))$ for a single insertion, where N is the number of points and M is the number of objectives. This result generalizes the previously known $O(N)$ algorithm designed for two objectives. Our experimental performance study showed that our algorithm demonstrates a superior performance compared to the competitors, including various modifications of the divide-and-conquer non-dominated sorting algorithm (which significantly improve the performance on their own), and the state-of-the-art Efficient Non-domination Level Update algorithm. Only for $M = 2$ the specialized algorithm for two dimensions outperforms the new algorithm.

Progressively Adding Objectives: A Case Study in Anomaly Detection

Luis Martí, *INRIA/Saclay*, Arsene Fansi-Tchango, *Thales Research*, Laurent Navarro, *Thales Research*, Marc Schoenauer, *INRIA/Saclay*

One of the principles of evolutionary multi-objective optimization is the conjoint optimization of the objective functions. However, in some cases, some of the objectives are easier to attain than others. This causes the population to lose diversity at a high rate and stagnate in early stages of the evolution. This paper presents the progressive addition of objectives (PAO) heuristic. PAO gradually adds objectives to a given problem relying on a perceived measure of complexity. This diversity loss phenomenon caused by the nature of a given objective has been observed when applying the Voronoi diagram-based evolutionary algorithm (VorEAl) in anomaly detection problems. Consequently, PAO has been first directed to address that issue. The experimental studies carried out show that the PAO heuristic manages to yield better results than the direct use of VorEAl on a group of test problems.

Adaptive Weights Generation for Decomposition-Based Multi-Objective Optimization Using Gaussian Process Regression

Mengyuan Wu, *City University of Hong Kong*, Sam Kwong, *City University of Hong Kong*, Yuheng Jia, *City University of Hong Kong*, Ke Li, *University of Exeter*, Qingfu Zhang, *City University of Hong Kong*

By transforming a multi-objective optimization problem into a number of single-objective optimization problems and optimizing them simultaneously, decomposition-based evolutionary multi-objective optimization algorithms have attracted much attention in the field of multi-objective optimization. In decomposition-based algorithms, the population diversity is maintained using a set of predefined weight vectors, which are often evenly sampled on a unit simplex. However, when the Pareto front of the problem is not a hyperplane but more complex, the distribution of the final solution set will not be that uniform. In this paper, we propose an adaptive method to periodically regenerate the weight vectors for decomposition-based multi-objective algorithms according to the geometry of the estimated Pareto front. In particular, the Pareto front is estimated via Gaussian process regression. Thereafter, the weight vectors are reconstructed by sampling a set of points evenly distributed on the estimated Pareto front. Experimental studies on a set of multi-objective optimization problems with different Pareto front geometries verify the effectiveness of the proposed adaptive weights generation method.

Evolutionary Numerical Optimization

Session: ENUM1
Tuesday, July 18, 10:40-12:20, Smaragd

Constraint Handling in Efficient Global Optimization

Samineh Bagheri, *Cologne University of Applied Sciences*, Wolfgang Konen, *Cologne University of Applied Sciences*, Richard Allmendinger, *University of Manchester*, Jürgen Branke, *University of Warwick*, Kalyanmoy Deb, *Michigan State University*, Jonathan E. Fieldsend, *University of Exeter*, Domenico Quagliarella, *CIRA — Italian Center for Aerospace Research*, Karthik Sindhya, *University of Jyväskylä*

Real-world optimization problems are often subject to several constraints which are expensive to evaluate in terms of cost or time. Although a lot of effort is devoted to make use of surrogate models for expensive optimization tasks, not many strong surrogate-assisted algorithms can address the challenging constrained problems. Efficient Global Optimization (EGO) is a Kriging-based surrogate-assisted algorithm. It was originally proposed to address unconstrained problems and later was modified to solve constrained problems. However, these type of algorithms still suffer from several issues, mainly: (1) early stagnation, (2) problems with multiple active constraints and (3) frequent crashes. In this work, we introduce a new EGO-based algorithm which tries to overcome these common issues with Kriging optimization algorithms. We apply the proposed algorithm on problems with dimension $d \leq 4$ from the G-function suite and on an airfoil shape example.

Analysis of the pcCMSA-ES on the noisy ellipsoid model

Hans-Geog Beyer, *FH Vorarlberg University of Applied Sciences*, Michael Hellwig, *FH Vorarlberg University of Applied Sciences*

Regarding the noisy ellipsoid model with additive Gaussian noise, the population control covariance matrix self-adaptation Evolution Strategy (pcCMSA-ES) by Hellwig and Beyer was empirically observed to exhibit a convergence rate (CR) close to the theoretical lower bound of -1 for all comparison-based direct search algorithms. The present paper provides the corresponding theoretical analysis of the pcCMSA-ES long-term behavior. To this end, the analysis from the context of isotropic mutations is transferred to the pcCMSA-ES that uses covariance matrix adaptation until significant noise influence is detected. The results allow for the computation of an upper bound on the number of generations between two consecutive test decisions of the pcCMSA-ES that ensures the observed performance. Further, the empirically observed convergence rate of CR=-1 is theoretically derived.

Per Instance Algorithm Configuration of CMA-ES with Limited Budget

Nacim Belkhir, *Thales Research&Technology*, Johann Dréo, *Thales Research&Technology*, Pierre Savéant, *Thales Research&Technology*, Marc Schoenauer, *inria*

Per Instance Algorithm Configuration (PIAC) relies on features that describe problem instances. It builds an Empirical Performance Model (EPM) from a training set made of (instance, parameter configuration) pairs together with the corresponding performance of the algorithm at hand. This paper presents a case study in the continuous black-box optimization domain, using problem features proposed in the literature. The target algorithm is CMA-ES, and three of its hyper-parameters. Special care is taken to the computational cost of the features. The EPM is learned on the BBOB benchmark, but tested on independent test functions gathered from the optimization literature.The results demonstrate that the proposed approach can outperform the default setting of CMA-ES with as few as 30 or 50 time the problem dimension additional function evaluations for feature computation.

Niching an Estimation-of-Distribution Algorithm by Hierarchical Gaussian Mixture Learning

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

Estimation-of-Distribution Algorithms (EDAs) have been applied with quite some success when solving real-valued optimization problems, especially in the case of Black Box Optimization (BBO). Generally, the performance of an EDA depends on the match between its driving probability distribution and the landscape of the problem being solved. Because most well-known EDAs, including CMA-ES, NES, and AMaLGaM, use a uni-modal search distribution, they have a high risk of getting trapped in local optima when a problem is multi-modal with a (moderate) number of relatively comparable modes. This risk could potentially be mitigated using niching methods that define multiple regions of interest where separate search distributions govern sub-populations. However, a key question is how to determine a suitable number of niches, especially in BBO. In this paper, we present a novel, adaptive niching approach that determines the niches through hierarchical clustering based on the correlation between the probability densities and fitness values of solutions. We test the performance of a combination of this niching approach with AMaLGaM on both new and well-known niching benchmark problems and find that the new approach properly identifies multiple landscape modes, leading to much better performance on multi-modal problems than with a non-niched, uni-modal EDA.

Session: ENUM2
Tuesday, July 18, 14:00-15:40, Smaragd

Reconsidering Constraint Release for Active-Set Evolution Strategies

Dirk V. Arnold, *Dalhousie University*

We consider the problem of solving constrained numerical optimization problems where the objective function is a black box, but the constraint functions are known explicitly. A recently proposed active-set approach implemented in an evolution strategy that interleaves the evolution of the active set with the search for better candidate solutions is able to solve unimodal problems from a commonly used test function set with relatively small numbers of objective function evaluations. We observe that the algorithm may under some conditions exhibit long phases of stagnation and propose a novel policy for considering constraints for release from the active set. The algorithm using the revised policy is seen to be able to avoid the stagnation observed in runs of the original strategy.

Effect of the Mean Vector Learning Rate in CMA-ES

Hidekazu Miyazawa, *Shinshu University*, Youhei Akimoto, *Shinshu University*

We investigate the effect of the mean vector learning rate in variants of CMA-ES. The learning rate is set to one in the standard setting, but it is natural to set it to a lower value from the perspective of the CMA-ES as the natural gradient method. Our experiments show that decreasing the mean vector learning rate has an effect similar to increasing the population size in the rank-mu update CMA-ES, and well structured multimodal functions can be solved with the default population size by introducing a small learning rate. On the contrary, the CMA-ES with the cumulative step-size adaptation (CSA) fails to locate the global optimum on well structured multimodal functions with the default population size even if a small learning rate is introduced. The results are discussed from the viewpoint of KL-divergence in relation with the optimal step-size. A parameter setting for the CMA-ES with CSA is reconsidered and evaluated on test problems. The results show the CMA-ES with CSA can solve well structured multimodal functions on dimension up to 80 with high probability with population size of ten if the mean vector learning rate is set small enough.

A Cooperative Co-evolutionary Algorithm for solving Large-Scale Constrained Problems with Interaction Detection

Julien Blanchard, *University of Namur*, Charlotte Beauthier, *Cenaero*, Timoteo Carletti, *University of Namur*

Cooperative co-evolutionary algorithms have a huge potential in optimizing large-scale problems. In a such divide-and-conquer strategy, the decomposition step plays a crucial part in the performance of the algorithm. Automatic decomposition strate-

gies that can uncover the interaction structure between decision variables have been introduced in recent years. However, such strategies for large-scale constrained problems are quite limited in number so far and yet, they are interesting for at least two reasons. On the one hand, they help to find a feasible region faster. On the other hand, they also improve the convergence rate for the optimization itself. In this paper, we propose a novel cooperative co-evolutionary algorithm, DGD-EA for Differential Grouping Evolutionary algorithm, that performs an automatic decomposition of decision variables and allows to optimize large-scale constrained problems. Its performance is evaluated on a set of 10 benchmark functions specially created for this study.

Algorithm Configuration Data Mining for CMA Evolution Strategies

Sander van Rijn, *LIACS, Leiden University*, Hao Wang, *LIACS, Leiden University*, Bas van Stein, *LIACS, Leiden University*, Thomas Bäck, *LIACS, Leiden University*

In the past years, quite a number of algorithmic extensions of the Covariance Matrix Adaptation Evolution Strategy (CMA-ES) have been proposed. These extensions define a large algorithm design space, but relatively little is known about the performance of most of these variations and the interaction between them. In this paper we investigate how various algorithmic extensions interact and what their impact is on objective functions from the Black Box Optimization Benchmark (BBOB). Based on the existing Estimated Running Time (ERT) and Fixed Cost Error (FCE) measures, a novel algorithm quality measure is proposed to quantify an impact-score of the variants studied. Using performance data from running 4,608 available algorithmic variations in the configurable CMA-ES framework published previously, decision trees and other data mining methods are used to analyze this data. Analysis identifies algorithmic variations required for obtaining best performance and identifies strong differences between objective functions, thereby helping to understand the interaction of algorithmic components for an objective function and, ultimately, for an objective function class. The results also quantitatively confirm that popular variants such as increasing population size and elitism generally have a positive impact on algorithm performance.

Session: THEORY3+ENUM3: Best Papers
Tuesday, July 18, 16:10-17:50, Opal

TPAM: A Simulation-Based Model for Quantitatively Analyzing Parameter Adaptation Methods

Ryoji Tanabe, *Southern University of Science and Technology*, Alex Fukunaga, *The University of Tokyo*

While a large number of adaptive Differential Evolution (DE) algorithms have been proposed, their Parameter Adaptation Methods (PAMs) are not well understood. We propose a Target function-based PAM simulation (TPAM) framework for evaluating the tracking performance of PAMs. The proposed TPAM simulation framework measures the ability of PAMs to track predefined target parameters, thus enabling quantitative analysis of the adaptive behavior of PAMs. We evaluate the tracking performance of PAMs of widely used five adaptive DEs (jDE, EPSDE, JADE, MDE, and SHADE) on the proposed TPAM, and show that TPAM can provide important insights on PAMs, e.g., why the PAM of SHADE performs better than that of JADE, and under what conditions the PAM of EPSDE fails at parameter adaptation.

Deriving and Improving CMA-ES with Information Geometric Trust Regions

Abbas Abdolmaleki, *PARC*, Bob Price, *PARC*, Nuno Lau, *IEETA*, Luis Paulo Reis, *LIACC*, Gerhard Neumann, *University of Lincoln*

CMA-ES is one of the most popular stochastic search algorithms. It performs favourably in many tasks without the need of extensive parameter tuning. The algorithm has many beneficial properties, including automatic step-size adaptation, efficient covariance updates that incorporates the current samples as well as the evolution path and its invariance properties. Its update rules are composed of well established heuristics where the theoretical foundations of some of these rules are also well understood. In this paper we will fully derive all CMA-ES update rules within the framework of expectation-maximisation-based stochastic search algorithms using information-geometric trust regions. We show that the use of the trust region results in similar updates to CMA-ES for the mean and the covariance-matrix while it allows for the derivation of an improved update rule for the step-size. Our new algorithm, Trust-Region Covariance Matrix Adaptation Evolution Strategy (TR-CMA-ES) is fully derived from first order optimization principles and performs favourably in compare to standard CMA-ES algorithm.

Exploiting Linkage Information in Real-Valued Optimization with the Real-Valued Gene-Pool Optimal Mixing Evolutionary Algorithm

Anton Bouter, *Centrum Wiskunde & Informatica*, Tanja Alderliesten, *Academic Medical Center*, Cees Witteveen, *Delft University of Technology*, Peter A.N. Bosman, *Centrum Wiskunde & Informatica*

The recently introduced Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) has been shown to be among the state-of-the-art for solving discrete optimization problems. Key to the success of GOMEA is its ability to efficiently exploit the linkage structure of a problem. Here, we introduce the Real-Valued GOMEA (RV-GOMEA), which incorporates several aspects of the real-valued EDA known as AMaLGaM into GOMEA in order to make GOMEA well-suited for real-valued optimization. The key strength of GOMEA to competently exploit linkage structure is effectively preserved in RV-GOMEA, enabling excellent performance on problems that exhibit a linkage structure that is to some de-

gree decomposable. Moreover, the main variation operator of GOMEA enables substantial improvements in performance if the problem allows for partial evaluations, which may be very well possible in many real-world applications. Comparisons of performance with state-of-the-art algorithms such as CMA-ES and AMaLGaM on a set of well-known benchmark problems show that RV-GOMEA achieves comparable, excellent scalability in case of black-box optimization. Moreover, RV-GOMEA achieves unprecedented scalability on problems that allow for partial evaluations, reaching near-optimal solutions for problems with up to millions of real-valued variables within one hour on a normal desktop computer.

Genetic Algorithms

Session: GA1: Best Papers
Monday, July 17, 10:40-12:20, Saphir

Optimizing One Million Variable NK Landscapes by Hybridizing Deterministic Recombination and Local Search

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

In gray-box optimization, the search algorithms have access to the variable interaction graph (VIG) of the optimization problem. For Mk Landscapes (and NK Landscapes) we can use the VIG to identify an improving solution in the Hamming neighborhood in constant time. In addition, using the VIG, deterministic Partition Crossover is able to explore an exponential number of solutions in a time that is linear in the size of the problem. Both methods have been used in isolation in previous search algorithms. We present two new gray-box algorithms that combine Partition Crossover with highly efficient local search. The best algorithms are able to locate the global optimum on Adjacent NK Landscape instances with one million variables. The algorithms are compared with a state-of-the-art algorithm for pseudo-Boolean optimization: Gray-Box Parameterless Population Pyramid. The results show that the best algorithm is always one combining Partition Crossover and highly efficient local search. But the results also illustrate that the best optimizer differs on Adjacent and Random NK Landscapes.

Fast Genetic Algorithms

Benjamin Doerr, *Ecole Polytechnique*, Huu Phuoc Le, *Ecole Polytechnique*, Regis Makhmara, *Ecole Polytechnique*, Ta Duy Nguyen, *Ecole Polytechnique*

For genetic algorithms using a bit-string representation of length n, the general recommendation is to take $1/n$ as mutation rate. In this work, we discuss whether this is really justified for multimodal functions. Taking jump functions and the $(1 + 1)$ evolutionary algorithm as the simplest example, we observe that larger mutation rates give significantly better runtimes. For the $\textsc{Jump}_{m,n}$ function, any mutation rate between $2/n$ and $m \ln(m/2)/n$ leads to a speed-up at least exponential in m compared to the standard choice. The asymptotically best runtime, obtained from using the mutation rate m/n and leading to a speed-up super-exponential in m, is very sensitive to small changes of the mutation rate. Any deviation by a small $(1 \pm \varepsilon)$ factor leads to a slow-down exponential in m. Consequently, any fixed mutation rate gives strongly sub-optimal results for most jump functions. Building on this observation, we propose to use a random mutation rate α/n, where α is chosen from a power-law distribution. We prove that $(1+1)$ EA with this heavy-tailed mutation rate optimizes any $\textsc{Jump}_{m,n}$ function in a time that is only a small polynomial (in m) factor above the one stemming from the for this m optimal rate.

Automatic Generation of Domain-Specific Genetic Algorithm Operators using the Hierarchical Bayesian Optimization Algorithm

Mark W. Hauschild, *University of Missouri-St. Louis*, Cezary Janikow, *University of Missouri-St. Louis*

GAs started with generic mutation and crossover operators, but over the years specialized representations and/or operators designed specifically for a given domain or problem, such as TSP, proved the most effective. In this paper, we define a class of new GA operators which automatically adjust for each problem. The adjustments or instantiations are based on the domain model presented to the operators in the form of Bayesian Network, as generated in the hierarchical Bayesian Optimization Algorithm (hBOA). We then show that these operators outperform standard random operators as long as the models are of sufficient quality.

Session: GA2+THEORY2
Tuesday, July 18, 14:00-15:40, Diamant

Speeding Up DSMGA-II on CUDA Platform

Sung Chi Li, *National Taiwan University*, Tian-Li Yu, *National Taiwan University*

This paper proposes two CUDA based implementations to speed up the model building process for DSMGA-II, which has shown superior optimization ability to hBOA and LT-GOMEA on various benchmark problems. The first implementation is lossless, which is algorithmically identical to the original version.

Thee second implementation is lossy, which sacrifices some accuracy for further speedup. On several commonly used benchmark problems, the proposed implementations are stable. As the problems become larger, the amount of speedup increases accordingly. The lossless scheme speeds up the first part of model building for more than ten times; the lossy implementation further speeds up the second part of model building for more than 400 times on a 600-bit folded-trap problem. The limitation of such implementations are also discussed in detail in this paper.

Two-edge Graphical Linkage Model for DSMGA-II

Ping-Lin Chen, *National Taiwan University*, Chun-Jen Peng, *National Taiwan University*, Chang-Yi Lu, *National Taiwan University*, Tian-Li Yu, *National Taiwan University*

DSMGA-II, a model-based genetic algorithm, is capable of solving optimization problems via exploiting sub-structures of the problem. In terms of number of function evaluations (NFE), DSMGA-II has shown superior optimization ability to LT-GOMEA and hBOA on various benchmark problems as well as real-world problems. This paper proposes a two-edge graphical linkage model, which customizes recombination masks for each receiver according to its alleles, to further improve the performance of DSMGA-II. The new linkage model is more expressive than the original dependency structure matrix (DSM), providing far more possible linkage combinations than the number of solutions in the search space. To reduce unnecessary function evaluations, the two-edge model is used along with the supply bounds from the original DSM. Some new techniques are also proposed to enhance the model selection efficiency. Combining these proposed techniques, the empirical results show an average of 12.2% NFE reduction on eight benchmark problems compared with the original DSMGA-II.

Session: GA3
Tuesday, July 18, 16:10-17:50, Amethyst

Different scenarios for survival analysis of evolutionary algorithms

Roberto Santana, *University of the Basque Country*, Jose A. Lozano, *University of the Basque Country*

Empirical analysis of evolutionary algorithms (EAs) behavior is usually approached by computing relatively simple descriptive statistics like mean fitness and mean number of evaluations to convergence, or more theoretically sound statistical tests for finding significant differences between algorithms. However, these analyses do not consider situations where the EA failed to finish due to numerical errors or excessive computational time. Furthermore, the ability of an EA to continuously make search improvements is usually overlooked. In this paper we propose the use of the theory from survival analysis for empirically investigating the behavior of EAs, even in situations where not all the experiments finish in a reasonable time. We introduce two scenarios for the application of survival analysis in EAs. Survival trees, a machine learning technique adapted to the survival analysis scenario, are applied to automatically identify combinations of EA parameters with similar effect in the behavior of the algorithm.

A Diversity Preservation Scheme for DSMGA-II to Conquer the Hierarchical Difficulty

Jheng-Ying Yu, *National Taiwan University*, I-Ting Chen, *National Taiwan University*, Tian-Li Yu, *National Taiwan University*

DSMGA-II, performing exploration and exploitation properly, requires fewer number of function evaluations on several problems than some well-known evolutionary algorithms such as LTGA and hBOA. However, DSMGA-II does not preserve promising subsolutions to the upper levels in hierarchical problems due to the back mixing operator of DSMGA-II and fail to solve the hierarchical trap problem. Therefore, this paper proposes a diversity preservation scheme for DSMGA-II to conquer hierarchical difficulty by calculating the entropies of subsolutions and determining if the GA performs back mixing. The empirical result shows that our algorithm works well on hierarchical problems and does not decrease the performance a lot on other problems.

Evolutionary Image Composition Using Feature Covariance Matrices

Aneta Neumann, *University of Adelaide*, Zygmunt Ladyslaw Szpak, *University of Adelaide*, Wojciech Chojnacki, *University of Adelaide*, Frank Neumann, *University of Adelaide*

Evolutionary algorithms have recently been used to create a wide range of artistic work. In this paper, we propose a new approach for the composition of new images from existing ones, that retain some salient features of the original images. We introduce evolutionary algorithms that create new images based on a fitness function that incorporates feature covariance matrices associated with different parts of the images. This approach is very flexible in that it can work with a wide range of features and enables targeting specific regions in the images. For the creation of the new images, we propose a population-based evolutionary algorithm with mutation and crossover operators based on random walks. Our experimental results reveal a spectrum of aesthetically pleasing images that can be obtained with the aid of our evolutionary process.

EGAC: A Genetic Algorithm to Compare Chemical Reaction Networks

Stefano Tognazzi, *IMT School for Advanced Studies Lucca*, Mirco Tribastone, *IMT School for Advanced Studies Lucca*, Max Tschaikowski, *IMT School for Advanced Studies Lucca*, Andrea Vandin, *IMT School for Advanced Studies Lucca*

Discovering relations between chemical reaction networks (CRNs) is a relevant problem in computational systems biology

for model reduction, to explain if a given system can be seen as an abstraction of another one; and for model comparison, useful to establish an evolutionary path from simpler networks to more complex ones. This is also related to foundational issues in computer science regarding program equivalence, in light of the established interpretation of a CRN as a kernel programming language for concurrency. Criteria for deciding if two CRNs can be formally related have been recently developed, but these require that a candidate mapping be provided. Automatically finding candidate mappings is very hard in general since the search space essentially consists of all possible partitions of a set. In this paper we tackle this problem by developing a genetic algorithm for a class of CRNs called influence networks, which can be used to model a variety of biological systems including cell-cycle switches and gene networks. An extensive numerical evaluation shows that our approach can successfully establish relations between influence networks from the literature which cannot be found by exact algorithms due to their large computational requirements.

Session: GA4
Wednesday, July 19, 09:00-10:40, Amethyst

A genetic algorithm for fair land allocation

Alex Gliesch, *Federal University of Rio Grande do Sul*, Marcus Ritt, *Federal University of Rio Grande do Sul*, Mayron César de Oliveira Moreira, *Federal University of Lavras*

The goal of the PROTERRA project of the Brazilian National Institute of Colonization and Agrarian reform (INCRA) is to establish settlements of multiple families on land which formerly had a single owner. The main problem which arises in the project is to subdivide the land into lots to be designated to the families. This problem is difficult since several hard and soft constraints stemming from legal or ethical considerations have to be considered. Among the constraints are respecting natural reserves, balancing access to rivers with the size of the lots, and a fair distribution with respect to soil quality. This problem has been mainly solved manually until now. In this paper we propose a genetic algorithm to solve it. We present several algorithmic components including a constructive heuristic and recombination and mutation operators that take into account the specifics of the problem, propose a technique to generate artificial instances for testing, and report on experiments with five real-world and 25 artificial instances.

Real-Polarized Genetic Algorithm for the Three-Dimensional Bin Packing Problem

André Homem Dornas, *Centro Federal de Educação Tecnológica de Minas Gerais*, Flávio Vinícius Cruzeiro Martins, *Centro Federal de Educação Tecnológica de Minas Gerais*, João Fernando Machry Sarubbi, *Centro Federal de Educação Tecnológica de Minas Gerais*, Elizabeth Fialho Wanner, *Aston University*

This article presents a non-deterministic approach to the Three-Dimensional Bin Packing Problem, using a genetic algorithm. To perform the packing, an algorithm was developed considering rotations, size constraints of objects and better utilization of previous free spaces (flexible width). Genetic operators have been implemented based on existing operators, but the highlight is the Real-Polarized crossover operator that produces new solutions with a certain disturbance near the best parent. The proposal presented here has been tested on instances already known in the literature and real instances. A visual comparison using boxplot was done and, in some situations, it was possible to say that the obtained results are statistically superior than the ones presented in the literature. In a given instance class, the presented Genetic Algorithm found solutions reaching up to 70% less bins.

The Role of Crossover Operator in Bayesian Network Structure Learning Performance: a Comprehensive Comparative Study and New Insights

Carlo Contaldi, *University of Illinois at Chicago*, Fatemeh Vafaee, *The University of Sydney*, Peter C. Nelson, *University of Illinois at Chicago*

Bayesian Network (BN) structure learning is a complex search problem, generally characterized by multimodality and epistasis. Genetic Algorithms (GAs) have been extensively used to pursue the BN structure learning task. This paper presents a new approach which incorporates the structural properties of the problem into GA mechanisms. The proposed approach uses a new recombination operator named Parent Set crossover, capable of reducing the disruptive action of the recombination process and enhancing its exploitative power. The new operator has been compared with a comprehensive set of other crossover operators as part of two genetic strategies: a canonical GA and a GA with an adaptive mutation scheme. All examined crossover operators were applied on both canonical and adaptive GAs and then compared in terms of various performance metrics. The experiments involve performance measures at the end of evolution as well as their convergence behavior across generations. The performance of the proposed method was also compared with the state-of-the-art non-evolutionary BN structure learning algorithms. Results show that the proposed recombination method enhances the algorithmic efficiency over a variety of test cases of different size.

Genetic Algorithm for Epidemic Mitigation by Removing Relationships

Fernando Concatto, *University of Vale do Itajaí*, Wellington Zunino, *University of Vale do Itajaí*, Luigi A. Giancoli, *University of Vale do Itajaí*, Rafael de Santiago, *University of Vale do Itajaí*, Luís C. Lamb, *Federal University of Rio Grande do Sul*

Min-SEIS-Cluster is an optimization problem which aims at minimizing the infection spreading in networks. In this problem, nodes can be susceptible to an infection, exposed to an infection, or infectious. One of the main features of this problem

is the fact that nodes have different dynamics when interacting with other nodes from the same community. Thus, the problem is characterized by distinct probabilities of infecting nodes from both the same and from different communities. This paper presents a new genetic algorithm that solves the Min-SEIS-Cluster problem. This genetic algorithm surpassed the current heuristic of this problem significantly, reducing the number of infected nodes during the simulation of the epidemics. The results therefore suggest that our new genetic algorithm is the state-of-the-art heuristic to solve this problem.

General Evolutionary Computation and Hybrids

Session: GECH1+DETA1: Best Papers
Monday, July 17, 14:00-15:40, Opal

Investigating Uncertainty Propagation in Surrogate-Assisted Evolutionary Algorithms

Vanessa Volz, *TU Dortmund University*, Günter Rudolph, *TU Dortmund University*, Boris Naujoks, *TH Köln - University of Applied Sciences*

Uncertainty propagation is a technique to handle individuals with uncertain fitness estimates in evolutionary algorithms. The Surrogate-Assisted Partial Order-Based Evolutionary Optimisation Algorithm (SAPEO) uses uncertainty propagation of fitness predictions from a Kriging model to reduce the number of function evaluations. The fitness predictions are ranked with partial orders and only evaluated if the risk of uncertainty propagation exceeds a steadily decreasing error tolerance threshold. In this paper, we investigate the effects of using uncertainty propagation according to SAPEO on single-objective problems. To this end, we present and apply different ways of measuring the deviations of SAPEO from the underlying CMA-ES. We benchmark the algorithms on the BBOB testbed to assess the effects of uncertainty propagation on performance throughout the runtime of the algorithm on a variety of problems. Additionally, we examine thoroughly the deviations of SAPEO from the CMA-ES evolution path per iteration based on a model for the rank-one update. The BBOB results suggest that the success of SAPEO generally improves the performance but still depends heavily on the function and dimension, which is supported by the analysis of the deviations of the evolution path.

Session: GECH2
Tuesday, July 18, 10:40-12:20, Diamant

Simulation-based Test Functions for Optimization Algorithms

Martin Zaefferer, *TH Köln*, Andreas Fischbach, *TH Köln*, Boris Naujoks, *TH Köln*, Thomas Bartz-Beielstein, *TH Köln*

When designing or developing optimization algorithms, test functions are crucial to evaluate performance. Often, test functions are not sufficiently difficult, diverse, flexible or relevant to real-world applications. Previously, test functions with real-world relevance were generated by training a machine learning model based on real-world data. The model estimation is used as a test function. We propose a more principled approach using simulation instead of estimation. Thus, relevant and varied test functions are created which represent the behavior of real-world fitness landscapes. Importantly, estimation can lead to excessively smooth test functions while simulation may avoid this pitfall. Moreover, the simulation can be conditioned by the data, so that the simulation reproduces the training data but features diverse behavior in unobserved regions of the search space. The proposed test function generator is illustrated with an intuitive, one-dimensional example. To demonstrate the utility of this approach it is applied to a protein sequence optimization problem. This application demonstrates the advantages as well as practical limits of simulation-based test functions.

Reexpressing Problematic Optimization Data: Creating a Workflow for the Statistical Analysis of Multifactorial EC Experiments

Mark Wineberg, *University of Guelph*, Sebastian Lenartowicz, *Azavista*

In current evolutionary computation (EC) praxis, the two most common metrics of success are time to completion and, when completion is not possible, best achieved fitness. As neither commonly produces normally-distributed data, non-parametric statistical analysis techniques are usually employed when performing comparisons and one-way analysis-of-variance (ANOVA). This approach, however, does not incorporate the analysis of interactions when considering multiple factors as is done using a multi-way ANOVA. Unfortunately, stable non-parametric multi-way ANOVA does not yet exist. Furthermore, even non-parametric one-way ANOVA techniques are counter-indicated if the variance around each treatment is not homogeneous, as is often the case for EC data. Instead, statisticians typically employ data reexpression to normalize the dataset, and then apply traditional parametric techniques. In this paper, we introduce the RePOD workflow, which utilizes existing and novel statistical techniques in order to perform more powerful analyses on EC data. By applying this workflow, we find that Box-Cox reexpression is applicable to a variety of EC systems, problems, parameter settings, and performance metrics. We also note that, when time to completion and best

achieved fitness can be defined on the same dataset, subtle differences appear in analysis, which becomes especially apparent when examining factor interactions.

Theoretical results on bet-and-run as an initialisation strategy

Andrei Lissovoi, *University of Sheffield*, Dirk Sudholt, *University of Sheffield*, Markus Wagner, *University of Adelaide*, Christine Zarges, *Aberystwyth University*

Bet-and-run initialisation strategies have been experimentally shown to be beneficial on classical NP-complete problems such as the travelling salesperson problem and minimum vertex cover. We analyse the performance of a bet-and-run restart strategy, where k independent islands run in parallel for t_1 iterations, after which the optimisation process continues on only the best-performing island. We define a family of pseudo-Boolean functions, consisting of a plateau and a slope, as an abstraction of real fitness landscapes with promising and deceptive regions. The plateau shows a high fitness, but does not allow for further progression, whereas the slope has a low fitness initially, but does lead to the global optimum. We show that bet-and-run strategies with non-trivial k and t_1 are necessary to find the global optimum efficiently. We show that the choice of t_1 is linked to properties of the function. Finally, we provide a fixed budget analysis to guide selection of the bet-and-run parameters to maximise expected fitness after $t = k \cdot t_1 + t_2$ fitness evaluations.

On the Runtime Analysis of Generalised Selection Hyper-heuristics for Pseudo-Boolean Optimisation

Andrei Lissovoi, *University of Sheffield*, Pietro Simone Oliveto, *University of Sheffield*, John Alasdair Warwicker, *University of Sheffield*

Selection hyper-heuristics are randomised search methodologies which choose and execute heuristics from a set of low-level heuristics. Recent time complexity analyses for the LeadingOnes benchmark function have shown that the standard simple random, permutation, random gradient, greedy and reinforcement learning selection mechanisms show no effects of learning. The idea behind the learning mechanisms is to continue to exploit the currently selected heuristic as long as it is successful. However, the probability that a promising heuristic is successful in the next step is relatively low when perturbing a reasonable solution to a combinatorial optimisation problem. In this paper we generalise the classical selection-perturbation mechanisms so success can be measured over some fixed period of length τ, rather than in a single iteration. We present a benchmark function where it is necessary to learn to exploit a particular low-level heuristic, rigorously proving that it makes the difference between an efficient and an inefficient algorithm. For LeadingOnes we prove that the generalised random gradient mechanism approaches optimal performance while generalised greedy, although not as fast, still outperforms random local search. An experimental analysis shows that combining the two generalised mechanisms leads to even better performance.

Session: GECH3
Tuesday, July 18, 16:10-17:50, Smaragd

Parallel Evolutionary Algorithm with Interleaving Generations

Martin Pilát, *Charles University, Faculty of Mathematics And Physics*, Roman Neruda, *Institute of Computer Science, The Czech Academy of Sciences*

We present a parallel evolutionary algorithm with interleaving generations. The algorithm uses a careful analysis of genetic operators and selection in order to evaluate individuals from following generations while the current generation is still not completely evaluated. This brings significant advantages in cases where each fitness evaluation takes different amount of time, the evaluations are performed in parallel, and a traditional generational evolutionary algorithm has to wait for all evaluations to finish. The proposed algorithm provides better utilization of computational resources in these cases. Moreover, the algorithm is functionally equivalent to the generational evolutionary algorithm, and thus it does not have any evaluation time bias, which is often present in asynchronous evolutionary algorithms. The proposed algorithm is tested in a series of simple experiments and its effectiveness is compared to the effectiveness of the generational evolutionary algorithm in terms of CPU utilization.

Time Complexity Reduction in Efficient Global Optimization using Cluster Kriging

Hao Wang, *Leiden University*, Bas van Stein, *Leiden Univerisity*, Michael Emmerich, *Leiden University*, Thomas Bäck, *Leiden University*

Efficient Global Optimization (EGO) is an effective method to optimize expensive black-box functions and utilizes Kriging models (or Gaussian process regression) trained on a relatively small design data set. In real-world applications, such as experimental optimization, where a large data set is available, the EGO algorithm becomes computationally infeasible due to the time and space complexity of Kriging. Recently, the so-called Cluster Kriging methods have been proposed to reduce such complexities for the big data, where data sets are clustered and Kriging models are built on each cluster. Furthermore, Kriging models are combined in an optimal way for the prediction. In addition, we analyze the Cluster Kriging landscape to adopt the existing infill-criteria, e.g., the expected improvement. The approach is tested on selected global optimization problems. It is shown by the empirical studies that this approach significantly reduces the CPU time of the EGO algorithm while maintaining the convergence rate of the algorithm.

Alternative Infill Strategies for Expensive Multi-Objective Optimisation

Alma A. M. Rahat, *University of Exeter*, Richard M. Everson, *University of Exeter*, Jonathan E. Fieldsend, *University of Exeter*

Many multi-objective optimisation problems incorporate computationally or financially expensive objective functions. State-of-the-art algorithms therefore construct surrogate model(s) of the parameter space to objective functions mapping to guide the choice of the next solution to expensively evaluate. Starting from an initial set of solutions, an infill criterion – a surrogate-based indicator of quality – is extremised to determine which solution to evaluate next, until the budget on expensive evaluations is exhausted. Many successful infill criteria are dependent on multi-dimensional integration, which may result in infill criteria that are themselves impractically expensive. We propose a computationally cheap infill criterion based on the minimum probability of improvement over the estimated Pareto set. Furthermore, we present a range of set-based scalarisation methods modelling hypervolume contribution, dominance ratio and distance measures. These permit the use of straightforward expected improvement as a cheap infill criterion. We investigated the performance of these novel strategies on standard multi-objective test problems, and compared with the popular SMS-EGO and ParEGO. Unsurprisingly, our experiments show that the best strategy is problem dependent, but in many cases a cheaper strategy is at least as good as more expensive alternatives.

Genetic Programming

Session: GP1
Monday, July 17, 10:40-12:20, Bernstein

Properties of a GP Active Learning Framework for Streaming Data with Class Imbalance

Sara Khanchi, *Dalhousie University*, Malcolm I. Heywood, *Dalhousie University*, Nur Zincir-Heywood, *Dalhousie University*

Active learning algorithms attempt to interactively develop a subset of data from which fitness evaluation is performed. Moreover, the distribution of labeled content within the data subset may adapt over time as genetic programming (GP) individuals improve. The basic goal is therefore to identify the most meaningful subset of data to improve the current model. Under a streaming data context additional challenges exist relative to the non-streaming scenario: non-stationary processes, partial observability, anytime operation. This means that it is not possible to guarantee that the content of the data subset even provides exemplars for each class that could appear in the stream (i.e., different classes appear/disappear at different parts of the stream). With this in mind, an investigation is performed into the impact of adopting different policies for controlling the development of data subset content. To do so, a generic framework is defined in terms of sampling and archiving policies. The resulting evaluation under several large multi-class datasets with class imbalance indicates that adopting random sampling with a biased archiving policy is sufficient for evolving GP classifiers that match or better the current state-of-the-art, particularly when detecting minor classes.

Self-adaptation of Genetic Operators Through Genetic Programming Techniques

Andrés Felipe Cruz Salinas, *Universidad Nacional de Colombia*, Jonatan Gomez Perdomo, *Universidad Nacional de Colombia*

Here we propose an evolutionary algorithm that self modify its operators at the same time candidate solutions are evolved. This tackles convergence and lack of diversity issues leading to better solutions. Operators are represented as trees and are evolved with GP (genetic programming) techniques. The proposed approach is tested with real benchmark functions and an analysis of operators evolution is provided.

Ensemble representation learning: an analysis of fitness and survival for wrapper-based genetic programming methods

William La Cava, *University of Pennsylvania*, Jason H. Moore, *University of Pennsylvania*

Recently we proposed a general, ensemble-based feature engineering wrapper (FEW) that was paired with a number of machine learning methods to solve regression problems. Here, we adapt FEW for supervised classification and perform a thorough analysis of fitness and survival methods within this framework. Our tests demonstrate that two fitness metrics, one introduced as an adaptation of the silhouette score, outperform the more commonly used Fisher criterion. We analyze survival methods and demonstrate that ϵ-lexicase survival works best across our test problems, followed by random survival which outperforms both tournament and deterministic crowding. We conduct a benchmark comparison to several classification methods using a large set of problems and show that FEW can improve the best classifier performance in several cases. We show that FEW generates consistent, meaningful features for a biomedical problem with different ML pairings.

A Hybrid Genetic Programming Decision Making System for RoboCup Soccer Simulation

Amir Tavafi, *Memorial University of Newfoundland*, Wolfgang Banzhaf, *Michigan State University*

In this contribution we propose a hybrid genetic programming approach for evolving a decision making system in the domain of RoboCup Soccer (Simulation League). Genetic programming

has been rarely used in the past in this domain, due to the difficulties and restrictions of the soccer simulation. Mainly, the real-time requirements of robot soccer and the lengthy evaluation time even for simulated games provide a formidable obstacle to the application of evolutionary approaches. The new method uses two evolutionary phases, each of which covering the restrictions and limitations of the other. The first phase produces some evolved GP individuals applying an off-game evaluation system which can be trained on snapshots of game situations as they actually happened in previous games and corresponding decisions tagged as correct or wrong. The second phase uses the best individuals of the first phase as input to run another GP system to evolve players in a real game environment where the quality of decisions is evaluated through winning or losing during real-time runs of the simulator. We benchmark the new system against a baseline system used by most simulation league teams, as well as against winning systems of the 2016 tournament.

Session: GP2
Monday, July 17, 14:00-15:40, Bernstein

Bounding Bloat in Genetic Programming

Benjamin Doerr, *Ecole Polytechnique*, Timo Kötzing, *Hasso Plattner Institute*, J. A. Gregor Lagodzinski, *Hasso Plattner Institute*, Johannes Lengler, *ETH Zurich*

While many optimization problems work with a fixed number of decision variables and thus a fixed-length representation of possible solutions, genetic programming (GP) works on variable-length representations. A naturally occurring problem is that of bloat (unnecessary growth of solutions) slowing down optimization. Theoretical analyses could so far not bound bloat and required explicit assumptions on the magnitude of bloat. In this paper we analyze bloat in mutation-based genetic programming for the two test functions ORDER and MAJORITY. We overcome previous assumptions on the magnitude of bloat and give matching or close-to-matching upper and lower bounds for the expected optimization time. In particular, we show that the (1+1) GP takes (i) $\Theta(T_{init} + n \log n)$ iterations with bloat control on ORDER as well as MAJORITY; and (ii) $O(T_{init} \log T_{init} + n(\log n)^3)$ and $\Omega(T_{init} + n \log n)$ (and $\Omega(T_{init} \log T_{init})$ for $n = 1$) iterations without bloat control on MAJORITY

Combining Conformal Prediction and Genetic Programming for Symbolic Interval Regression

Thuong Thi Pham, *Thai Nguyen University*, Hoai Xuan Nguyen, *Hanoi University*, Xin Yao, *Southern University of Science and Technology*

Symbolic regression has been one of the main learning domains for Genetic Programming. However, most work so far on using genetic programming for symbolic regression only focus on point prediction. The problem of symbolic interval regression is for each input to find a prediction interval containing the output with a given statistical confidence. This problem is important for many risk-sensitive domains (such as in medical and financial applications). In this paper, we propose the combination of conformal prediction and genetic programming for solving the problem of symbolic interval regression. We study two approaches called black-box conformal prediction genetic programming (black-box CPGP) and white-box conformal prediction genetic programming (white-box CPGP) on a number of benchmarks and previously used problems. We compare the performance of these approaches with two popular interval regressors in statistic and machine learning domains, namely, the linear quantile regression and quantile random forrest. The experimental results show that, on the two performance metrics, blackbox CPGP is comparable to the linear quantile regression and not much worse than the quantile random forrest on validity and much better than them on efficiency.

Evolvability in Grammatical Evolution

Eric Medvet, *DIA - University of Trieste*, Fabio Daolio, *University of Stirling*, Danny Tagliapietra, *DIA - University of Trieste*

Evolvability is a measure of the ability of an Evolutionary Algorithm (EA) to improve the fitness of an individual when applying a genetic operator. Other than the specific problem, many aspects of the EA may impact on the evolvability, most notably the genetic operators and, if present, the genotype-phenotype mapping function. Grammatical Evolution (GE) is an EA in which the mapping function plays a crucial role since it allows to map any binary genotype into a program expressed in any user-provided language, defined by a context-free grammar. While GE mapping favored a successful application of GE to many different problems, it has also been criticized for scarcely adhering to the variational inheritance principle, which itself may hamper GE evolvability. In this paper, we experimentally study GE evolvability in different conditions, that is, problems, mapping functions, genotype sizes, and genetic operators. Results suggest that there is not a single factor determining GE evolvability: in particular, the mapping function alone does not deliver better evolvability regardless of the problem. Instead, GE redundancy, which itself is the result of the combined effect of several factors, has a strong impact on the evolvability.

Geometric Semantic Genetic Programming for Recursive Boolean Programs

Alberto Moraglio, *University of Exeter*, Krzysztof Krawiec, *Poznan University of Technology*

Geometric Semantic Genetic Programming (GSGP) induces a unimodal fitness landscape for any problem that consists in finding a function fitting given input/output examples. Most of the work around GSGP to date has focused on real-world applications and on improving the originally proposed search operators, rather than on broadening its theoretical framework to new domains. We extend GSGP to recursive programs, a no-

toriously challenging domain with highly discontinuous fitness landscapes. We focus on programs that map variable-length Boolean lists to Boolean values, and design search operators that are provably efficient in the training phase and attain perfect generalization. Computational experiments complement the theory and demonstrate the superiority of the new operators to the conventional ones. This work provides new insights into the relations between program syntax and semantics, search operators and fitness landscapes, also for more general recursive domains.

Session: GP3
Monday, July 17, 16:10-17:50, Bernstein

Coevolving Deep Program Hierarchies to Solve Complex Tasks

Robert Jacob Smith, *Dalhousie University*, Malcolm I. Heywood, *Dalhousie University*

Scaling genetic programming to organize large complex combinations of programs remains an under investigated topic in general. This work revisits the issue by first demonstrating the respective contributions of coevolution and diversity maintenance. Competitive coevolution is employed to organize a task in such a way that the most informative training cases are retained. Cooperative coevolution helps discover modularity in the solutions discovered and, in this work, is fundamental to constructing complex structures of programs that still execute efficiently (the policy tree). The role of coevolution and diversity maintenance is first independently established under the task of discovering reinforcement learning policies for solving Rubik's Cubes scrambled with 5-twists. With this established, a combined approach is then adopted for building large organizations of code for representing policies that solve 5 to 8-twist combinations of the Cube. The resulting 'deep' policy tree organizes hundreds of programs to provide optimal solutions to tens of millions of test cube configurations.

Genetic Programming based Feature Construction for Classification with Incomplete Data

Cao Truong Tran, *Victoria University of Wellington*, Mengjie Zhang, *Victoria University of Wellington*, Peter Andreae, *Victoria University of Wellington*, Bing Xue, *Victoria University of Wellington*

Missing values are an unavoidable problem in many real-world datasets. Dealing with incomplete data is an crucial requirement for classification because inadequate treatment of missing values often causes large classification error. Feature construction has been successfully applied to improve classification with complete data, but it has been seldom applied to incomplete data. Genetic programming-based multiple feature construction (GPMFC) is a current encouraging feature construction method which uses genetic programming to evolve new multiple features from original features for classification tasks. GPMFC can improve the accuracy, and reduce the complexity of many decision trees and rule-based classifiers; however, it cannot directly work with incomplete data. This paper proposes IGPMFC which is extended from GPMFC to tackle with incomplete data. IGPMFC uses genetic programming with interval functions to directly evolve multiple features for classification with incomplete data. Experimental results reveal that not only IGPMFC can substantially improve the accuracy, but also can reduce the complexity of learnt classifiers facing with incomplete data.

Scalable Genetic Programming by Gene-Pool Optimal Mixing and Input-Space Entropy-Based Building-Block Learning

Marco Virgolin, *Centrum Wiskunde & Informatica*, Tanja Alderliesten, *Academic Medical Center*, Cees Witteveen, *Technical University of Delft*, Peter A.N. Bosman, *Centrum Wiskunde & Informatica*

The Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) is a recently introduced model-based EA that has been shown to be capable of outperforming state-of-the-art alternative EAs in terms of scalability when solving discrete optimization problems. One of the key aspects of GOMEA's success is a variation operator that is designed to extensively exploit linkage models by effectively combining partial solutions. Here, we bring the strengths of GOMEA to Genetic Programming (GP), introducing GP-GOMEA. Under the hypothesis of having little problem-specific knowledge, and in an effort to design easy-to-use EAs, GP-GOMEA requires no parameter specification. On a set of well-known benchmark problems we find that GP-GOMEA outperforms standard GP while being on par with more recently introduced, state-of-the-art EAs. We furthermore introduce Input-space Entropy-based Building-block Learning (IEBL), a novel approach to identifying and encapsulating relevant building blocks (subroutines) into new terminals and functions. On problems with an inherent degree of modularity, IEBL can contribute to compact solution representations, providing a large potential for knock-on effects in performance. On the difficult, but highly modular Even Parity problem, GP-GOMEA+IEBL obtains excellent scalability, solving the 14-bit instance in less than 1 hour.

Session: GP4: Best Papers
Tuesday, July 18, 10:40-12:20, Saphir

Improving Generalization of Evolved Programs through Automatic Simplification

Thomas Helmuth, *Washington and Lee University*, Nicholas Freitag McPhee, *University of Minnesota, Morris*, Edward Pantridge, *MassMutual Financial Group*, Lee Spector, *Hampshire College*

Programs evolved by genetic programming unfortunately often do not generalize to unseen data. Reliable synthesis of

programs that generalize to unseen data is therefore an important open problem. We present evidence that smaller programs evolved using the PushGP system tend to generalize better over a range of program synthesis problems. Like in many genetic programming systems, programs evolved by PushGP usually have pieces that can be removed without changing the behavior of the program. We describe methods for automatically simplifying evolved programs to make them smaller and potentially improve their generalization. We present five simplification methods and analyze their strengths and weaknesses on a suite of general program synthesis benchmark problems. All of our methods use a straightforward hill-climbing procedure to remove pieces of a program while ensuring that the resulting program gives the same errors on the training data as did the original program. We show that automatic simplification, previously used both for post-run analysis and as a genetic operator, can significantly improve the generalization rates of evolved programs.

How Noisy Data Affects Geometric Semantic Genetic Programming

Luis Fernando Miranda, *Federal University of Minas Gerais*, Luiz Otavio Vilas Boas Oliveira, *Federal University of Minas Gerais*, Joao Francisco Barreto da Silva Martins, *Federal University of Minas Gerais*, Gisele Lobo Pappa, *Federal University of Minas Gerais*

Noise is a consequence of acquiring and pre-processing data from the environment, and shows fluctuations from different sources— e.g., from sensors, signal processing technology or even human error. As a machine learning technique, Genetic Programming (GP) is not immune to this problem, which the field has frequently addressed. Recently, Geometric Semantic Genetic Programming (GSGP), a semantic-aware branch of GP, has shown robustness and high generalization capability. Researchers believe these characteristics may be associated with a lower sensibility to noisy data. However, there is no systematic study on this ma er. is paper per- forms a deep analysis of the GSGP performance over the presence of noise. Using 15 synthetic datasets where noise can be controlled, we added different ratios of noise to the data and compared the results obtained with those of a canonical GP. e results show that, as we increase the percentage of noisy instances, the generalization performance degradation is more pronounced in GSGP than GP. However, in general, GSGP is more robust to noise than GP in the presence of up to 10% of noise, and presents no statistical difference for values higher than that in the test bed.

Counterexample-Driven Genetic Programming

Krzysztof Krawiec, *Poznan University of Technology*, Iwo Błądek, *Poznan University of Technology*, Jerry Swan, *University of York*

Genetic programming is an effective technique for inductive synthesis of programs from training examples of desired input-output behavior (tests). Programs synthesized in this way are not guaranteed to generalize beyond the training set, which is unacceptable in many applications. We present Counterexample-Driven Genetic Programming (CDGP) that employs evolutionary search to synthesize provably correct programs from formal specifications. CDGP employs a Satisfiability Modulo Theories (SMT) solver to formally verify programs in the evaluation phase. A failed verification produces counterexamples that are in turn used to calculate fitness and so drive the search process. When compared against a range of approaches on a suite of state-of-the-art specification-based synthesis benchmarks, CDGP systematically outperforms them, typically synthesizing correct programs faster and using fewer tests.

Session: GP5
Tuesday, July 18, 16:10-17:50, Bernstein

A Probabilistic Linear Genetic Programming with Stochastic Context-Free Grammar for solving Symbolic Regression problems

Léo Françoso Dal Piccol Sotto, *Universidade Federal de São Paulo*, Vinícius Veloso de Melo, *Universidade Federal de São Paulo*

Traditional Linear Genetic Programming algorithms are based only on the selection mechanism to guide the search. Genetic operators combine or mutate random portions of the individuals, without knowing if the result will lead to a fitter individual. Probabilistic Model Building Genetic Programming was proposed to overcome this issue through a probability model that captures the structure of the fit individuals and use it to sample new individuals. This work proposes the use of LGP with a Stochastic Context-Free Grammar, that has a probability distribution that is updated according to selected individuals. We proposed a method for adapting the grammar into the linear representation of LGP. Tests performed with the proposed probabilistic method, and with two hybrid approaches, on several symbolic regression benchmark problems show that the results are statistically better than the obtained by the traditional LGP.

Discovery of Search Objectives in Continous Domains

Paweł Liskowski, *Poznan University of Technology/Laboratory of Intelligent Decision Support Systems*, Krzysztof Krawiec, *Poznan University of Technology/Laboratory of Intelligent Decision Support Systems*

In genetic programming (GP), the outcomes of the evaluation phase can be represented as an interaction matrix, with rows corresponding to programs in a population and columns corresponding to tests that define a program synthesis task. Recent contributions on Discovery of Objectives via Clustering (DOC) and Discovery of Objectives by Factorization of interaction matrix (DOF) show that informative characterizations of programs can be automatically derived from interaction matrices in discrete domains and used as search objectives in multidimensional setting. In this paper, we propose analogous methods for contin-

uous domains and compare them with conventional GP that uses tournament selection, Age-Fitness Pareto Optimization, and GP with epsilon-lexicase selection. Experiments show that the proposed methods are effective for symbolic regression, systematically producing better-fitting models than the two former baselines, and surpassing epsilon-lexicase selection on some problems. We also investigate the hybrids of the proposed approach with the baselines, concluding that hybridization of DOC with epsilon-lexicase leads to the best overall results.

Unsure When to Stop? Ask Your Semantic Neighbors

Ivo Gonçalves, *NOVA IMS, Universidade Nova de Lisboa*, Sara Silva, *University of Lisbon*, Carlos M. Fonseca, *CISUC, Department of Informatics Engineering, University of Coimbra*, Mauro Castelli, *NOVA IMS, Universidade Nova de Lisboa*

In iterative supervised learning algorithms it is common to reach a point in the search where no further induction seems to be possible with the available data. If the search is continued beyond this point, the risk of overfitting increases significantly. Following the recent developments in inductive semantic stochastic methods, this paper studies the feasibility of using information gathered from the semantic neighborhood to decide when to stop the search. Two semantic stopping criteria are proposed and experimentally assessed in Geometric Semantic Genetic Programming (GSGP) and in the Semantic Learning Machine (SLM) algorithm (the equivalent algorithm for neural networks). The experiments are performed on real-world high-dimensional regression datasets. The results show that the proposed semantic stopping criteria are able to detect stopping points that result in a competitive generalization for both GSGP and SLM. This approach also yields computationally efficient algorithms as it allows the evolution of neural networks in less than 3 seconds on average, and of GP trees in at most 10 seconds. The usage of the proposed semantic stopping criteria in conjunction with the computation of optimal mutation/learning steps also results in small trees and neural networks.

Hot Off the Press

Session: HOP1
Tuesday, July 18, 10:40-12:20, Topas 1

Downscaling near-surface atmospheric fields with multi-objective Genetic Programming

Tanja Zerenner, *Meteorological Institute University of Bonn*, Victor Venema, *Meteorological Institute University of Bonn*, Petra Friederichs, *Meteorological Institute University of Bonn*, Clemens Simmer, *Meteorological Institute University of Bonn*

Coupled models of the soil-vegetation-atmosphere systems are increasingly used to investigate interactions between the system components. Due to the different spatial and temporal scales of relevant processes and computational restrictions, the atmospheric model generally has a lower spatial resolution than the land surface and subsurface models. We employ multi-objective Genetic Programming (MOGP) using the Strength Pareto Evolutionary Algorithm (SPEA) to bridge this scale gap. We generate high-resolution atmospheric fields using the coarse atmospheric model output and high-resolution land surface information (e.g., topography) as predictors. High-resolution atmospheric simulations serve as reference. It is impossible to perfectly reconstruct the reference fields with the available information. Thus, we simultaneously optimize the root mean square error (RMSE) and two objective functions quantifying spatial variability. Minimization solely with respect to the RMSE provides too smooth high-resolution fields. Additional objectives help to recover spatial variability. We apply MOGP to the downscaling of 10 m temperature. Our approach reproduces a larger part of the variability and is applicable for a wider range of weather conditions than a linear regression based downscaling. Original publication: T. Zerenner, V. Venema, P. Friederichs, and C. Simmer. Downscaling near-surface atmospheric fields with multi-objective Genetic Programming. Environmental Modelling and Software, 84(2016), 85-98.

The Unrestricted Black-Box Complexity of Jump Functions

Maxim Buzdalov, *ITMO University*, Benjamin Doerr, *Ecole Polytechnique*, Mikhail Kever, *ITMO University*

We analyze the unrestricted black-box complexity of the n-dimensional JUMP function classes. We show very precise bounds for various values of the jump size ℓ, including a novel $n + \Theta(\sqrt{n})$ bound for the extreme case that only the middle one (for n even) or the middle two (for n odd) Hamming levels are not part of the plateau surrounding the optimum. To obtain these results, we significantly extend the classic information theoretic argument. It now allows to exploit structural properties of the underlying optimization problems, whereas before it relied only on the number of different fitness values. This abstract for the GECCO'17 Hot-off-the-Press track summarizes work that appeared as M. Buzdalov, B. Doerr, and M. Kever. The unrestricted black-box complexity of jump functions. Evolutionary Computation, 24(4):719-744, 2016.

Exploring multi-objective trade-offs in the design space of a waste heat recovery system

Maizura Mokhtar, *Edinburgh Napier University*, Ian Hunt, *Edinburgh Napier University*, Stephen Burns, *Scotland's Rural*

College (SRUC), Dave Ross, *Scotland's Rural College (SRUC)*

Visualising the Pareto-optimal solutions and their objectives can be challenging, more so when the number of objectives is large. The paper proposed the combined use of clustering and parallel coordinates plots to visualise the Pareto-optimal solutions. The trade-off surface is first segmented using a clustering algorithm, and parallel coordinates plots are then used to visualise the resulting set of Pareto-optimal designs. The paper described the analysis from the waste heat recovery system optimisation commonly found in the food and drinks process industries, comprising of a desuperheater coupled to a hot water reservoir. The system was parameterised, considering typical objectives, and MOEA was used to approximate the Pareto-optimal designs. The proposed visualisation was used to better understand the sensitivity of the system's parameters and their trade-offs, providing another source of information for prospective installations. Original publication: M. Mokhtar, S. Burns, D. Ross, and I. Hunt, Exploring Multi-Objective Trade-Offs in the Design Space of a Waste Heat Recovery System, Applied Energy, Elsevier, Vol. 195, 1 June 2017, Pages 114-124

A Genetic Algorithm for Learning Parameters in Bayesian Networks using Expectation Maximization

Priya Krishnan Sundararajan, *Carnegie Mellon University*, Ole Jakob Mengshoel, *Carnegie Mellon University*

Expectation maximization (EM) is a popular algorithm for parameter estimation in situations with incomplete data. The EM algorithm has, despite its popularity, the disadvantage of often converging to local but non-global optima. Several techniques have been proposed to address this problem, for example initializing EM from multiple random starting points and then selecting the run with the highest likelihood. Unfortunately, this method is computationally expensive. In this paper, our goal is to reduce computational cost while at the same time maximizing likelihood. We propose a Genetic Algorithm for Expectation Maximization (GAEM) for learning parameters in Bayesian networks. GAEM combines the global search property of a genetic algorithm with the local search property of EM. We prove GAEM's global convergence theoretically. Experimentally, we show that GAEM provides significant speed-ups since it tends to select more fit individuals, which converge faster, as parents for the next generation. Specifically, GAEM converges 1.5 to 7 times faster while producing better log-likelihood scores than the traditional EM algorithm.

Session: HOP2
Tuesday, July 18, 14:00-15:40, Topas 1

Trading Between Quality and Non-functional Properties of Median Filter in Embedded Systems

Zdenek Vasicek, *Brno University of Technology*, Vojtech Mrazek, *Brno University of Technology*

Genetic improvement has been used to improve functional and non- functional properties of software. In this paper, we propose a new approach that applies a genetic programming (GP)-based genetic improvement to trade between functional and non-functional properties of existing software. The paper investigates possibilities and opportunities for improving non-functional parameters such as execution time, code size, or power consumption of median functions implemented using comparator networks. In general, it is impossible to improve non-functional parameters of the median function without accepting occasional errors in results because optimal implementations are available. In order to address this issue, we proposed a method providing suitable compromises between accuracy, execution time and power consumption. Traditionally, a randomly generated set of test vectors is employed so as to assess the quality of GP individuals. We demonstrated that such an approach may produce biased solutions if the test vectors are generated inappropriately. In order to measure the accuracy of determining a median value and avoid such a bias, we propose and formally analyze new quality metrics which are based on the positional error calculated using the permutation principle introduced in this paper. It is shown that the proposed method enables the discovery of solutions which show a significant improvement in execution time, power consumption, or size with respect to the accurate median function while keeping errors at a moderate level. Non-functional properties of the discovered solutions are estimated using data sets and validated by physical measurements on physical microcontrollers. The benefits of the evolved implementations are demonstrated on two real-world problems—sensor data processing and image processing. It is concluded that data processing software modules offer a great opportunity for genetic improvement. The results revealed that it is not even necessary to determine the median value exactly in many cases which helps to reduce power consumption or increase performance. The discovered implementations of accurate, as well as approximate median functions, are available as C functions for download and can be employed in a custom application (http://www.fit.vutbr.cz/research/groups/ehw/median).

Design of Power-Efficient Approximate Multipliers for Approximate Artificial Neural Networks

Vojtech Mrazek, *Brno University of Technology*, Syed Shakib Sarwar, *Purdue Univesity*, Lukas Sekanina, *Brno University of Technology*, Zdenek Vasicek, *Brno University of Technology*, Kaushik Roy, *Purdue Univesity*

Artificial neural networks (NN) have shown a significant promise in difficult tasks like image classification or speech recognition. Even well-optimized hardware implementations of digital NNs show significant power consumption. It is mainly due to non-uniform pipeline structures and inherent redundancy of numerous arithmetic operations that have to be performed to produce each single output vector. This paper provides a methodology for the design of well-optimized power-efficient NNs with a uniform structure suitable for hardware implemen-

tation. An error resilience analysis was performed in order to determine key constraints for the design of approximate multipliers that are employed in the resulting structure of NN. By means of a search based approximation method, approximate multipliers showing desired tradeoffs between the accuracy and implementation cost were created. Resulting approximate NNs, containing the approximate multipliers, were evaluated using standard benchmarks (MNIST dataset) and a real-world classification problem of Street-View House Numbers. Significant improvement in power efficiency was obtained in both cases with respect to regular NNs. In some cases, 91% power reduction of multiplication led to classification accuracy degradation of less than 2.80%. Moreover, the paper showed the capability of the back propagation learning algorithm to adapt with NNs containing the approximate multipliers.

Multilayer Optimization of Heterogeneous Networks using Grammatical Genetic Programming

Michael Fenton, *University College Dublin*, David Lynch, *University College Dublin*, Stepan Kucera, *Bell Labs Nokia*, Holger Claussen, *Bell Labs Nokia*, Michael O'Neill, *University College Dublin*

Wireless communications networks are a global trillion dollar industry, where small improvements can scale to provide significant cost savings to networks operators. In a field full of NP-hard optimisation problems, heuristic optimisation techniques such as Evolutionary Computation offer a means to provide bespoke, scalable solutions. Grammatical Genetic Programming is applied to optimise three aspects of an LTE Heterogeneous Network: setting optimal Small Cell powers and biases, Macro Cell ABS patterns, and Small Cell scheduling. The evolved heuristics yield minimum downlink rates three times greater than a baseline technique, and twice that of a state-of-the-art industry standard benchmark. This work appears in full in Fenton et al., "Multilayer Optimization of Heterogeneous Networks using Grammatical Genetic Programming", IEEE Transactions on Cybernetics, 2017. DOI: 10.1109/TCYB.2017.2688280.

Evolutionary Multi-Path Routing for Network Lifetime and Robustness in Wireless Sensor Networks

Alma A. M. Rahat, *University of Exeter*, Richard M. Everson, *University of Exeter*, Jonathan E. Fieldsend, *University of Exeter*

Wireless sensor networks frequently use multi-path routing schemes between nodes and a base station. Multi-path routing confers additional robustness against link failure, but in battery-powered networks it is desirable to choose paths which maximise the overall network lifetime — the time at which a battery is first exhausted. We introduce multi-objective evolutionary algorithms to find the routings which approximate the optimal trade-off between network lifetime and robustness. A novel measure of network robustness, the fragility, is introduced. We show that the distribution of traffic between paths in a given multi-path scheme that optimises lifetime or fragility may be found by solving the appropriate linear program. A multi-objective evolutionary algorithm is used to solve the combinatorial optimisation problem of choosing routings and traffic distributions that give the optimal trade-off between network lifetime and robustness. Efficiency is achieved by pruning the search space using k-shortest paths, braided and edge disjoint paths. The method is demonstrated on synthetic networks and a real network deployed at the Victoria & Albert Museum, London. For these networks, using only two paths per node, we locate routings with lifetimes within 3% of those obtained with unlimited paths per node. In addition, routings which halve the network fragility are located. We also show that the evolutionary multi-path routing can achieve significant improvement in performance over a braided multi-path scheme.

Session: HOP3
Tuesday, July 18, 16:10-17:50, Topas 1

Evolutionary algorithm with a directional local search for multiobjective optimization in combinatorial problems

Krzysztof Michalak, *Wroclaw University of Economics*

This abstract summarizes the results reported in the paper: Michalak, K., "Evolutionary algorithm with a directional local search for multiobjective optimization in combinatorial problems", Optimization Methods and Software, 31, 2 (2016), 392–404. In this paper a new method of performing a local search in multiobjective optimization problems is proposed. The proposed method uses a solution acceptance criterion based on aggregation of the objectives using adaptively adjusted weight vectors. A weight vector for performing the search starting from an initial solution is determined using directions in which objective improvements have been achieved in the vicinity of the initial solution. In the paper the proposed method is tested on 2-, 3- and 4-objective instances of the Travelling Salesman Problem (TSP) and the Quadratic Assignment Problem (QAP). In the experiments the proposed method outperformed two other local search methods. The proposed method focuses on solution acceptance criterion and thus can be combined with various methods of solution neighbourhood construction in the local search as well as various global search algorithms.

On Constructing Ensembles for Combinatorial Optimisation

Emma Hart, *Edinburgh Napier University*, Kevin Sim, *Edinburgh Napier University*

Although the use of ensemble methods in machine-learning is ubiquitous, ensembles of optimisation algorithms have received relatively little attention. In [2] we address funda- mental questions regarding ensemble composition in optimi- sation using the domain of bin-packing as a example. We first show that ensembles constructed by random selection from a large pool of heuristics can outperform ensembles composed from individu-

ally high-performing heuristics under some conditions. We propose that this is due to the diverse nature of the randomly formed ensembles. Ensembles are then constructed using diversity as a criteria for inclusion. Experiments reveal that judicious choice of diversity metric is required to construct good ensembles. The results provide new insights into the how to undertake principled ensemble design.

Co-optimization Free Lunches: Tractability of Optimal Black-box Algorithms for Maximizing Expected Utility. Bridging Supervised Learning and Test-Based Co-optimization.

Elena Popovici, *Icosystem Corp.*

This paper takes a close look at the important commonalities and subtle differences between the well-established field of supervised learning and the much younger one of co-optimization. It explains the relationships between the problems, algorithms and views on cost and performance of the two fields, all throughout providing a two-way dictionary for the respective terminologies used to describe these concepts. The intent is to facilitate advancement of both fields through transfer and cross-pollination of ideas, techniques and results. As a proof of concept, a theoretical study is presented on the connection between existence / lack of free lunch in the two fields, showcasing a few ideas for improving computational complexity of certain supervised learning approaches.

Interval Type-2 Mutual Subsethood Fuzzy Neural Inference System (IT2MSFuNIS)

Sumati Vuppuluri, *Dayalbagh Educational Institute*, Patvardhan Chellapilla, *Dayalbagh Educational Institute*

This paper presents an interval type-2 mutual subsethood fuzzy neural inference system (IT2MSFuNIS). A mutual subsethood measure between two interval type-2 fuzzy sets (IT2 FS) has been derived and has been used in determining the similarity between the IT2 FS inputs and IT2 FS antecedents. The consequent weights are taken to be interval sets. The inputs to the system are fuzzified into IT2 FSs with Gaussian primary membership function (GPMF) having fixed center and uncertain variance. Aggregation of type-2 mutual subsethood based activation spreads is performed using product operator. The output is obtained using simplified type-reduction followed by defuzzification. The system learns using memetic procedure involving differential evolution (DE) for global search and gradient descent (GD) for local exploitation in solution space. The mathematical modeling and empirical studies of IT2MSFuNIS bring forth its efficacy in problems pertaining to function approximation, time-series prediction, control and classification. Comparisons with other type-1 and type-2 neuro-fuzzy systems verify that IT2MSFuNIS compares excellently with other models with a performance better than most of them both in terms of total number of trainable parameters and result accuracy. Empirical studies indicate the intelligent decision making capability of the proposed model. The main contribution of this paper lies in the identification of mutual subsethood to find out the correlation between IT2 FSs and to find out its applicability in diverse application domains. The improved performance of the proposed method can be attributed to the better contrast handling capacity of mutual subsethood method and uncertainty handling capacity of IT2 FSs. The integration of mutual subsethood with interval type-2 fuzzy logic puts forth a novel model with various merits as demonstrated amply with the help of well-known problems reported in the literature.

Real World Applications

Session: RWA1
Monday, July 17, 10:40-12:20, Amethyst

Automatic Generation of Optimal Quantum Key Distribution Protocols

Walter Oliver Krawec, *Iona College*, Michael G. Nelson, *Iona College*, Eric P. Geiss, *Iona College*

Quantum Key Distribution (QKD) allows two parties to establish a shared secret key secure against an all-powerful adversary. Typically, one designs new QKD protocols and then analyzes their maximal tolerated noise mathematically. If the noise in the quantum channel connecting the two parties is higher than this threshold value, they must abort. In this paper we design and evaluate a new real-coded Genetic Algorithm which takes as input statistics on a particular quantum channel (found using standard channel estimation procedures) and outputs a QKD protocol optimized for the specific given channel. We show how this method can be used to find QKD protocols for channels where standard protocols would fail.

Optimizing the Decomposition of Time Series using Evolutionary Algorithms: Soil Moisture Analytics

Aniruddha Basak, *Carnegie Mellon University*, Ole Jakob Mengshoel, *Carnegie Mellon University*, Chinmay Kulkarni, *Carnegie Mellon University*, Kevin Schmidt, *US Geological Survey*, Prathi Shastry, *Carnegie Mellon University*, Rao Rapeta, *Intel Corporation*

Soil moisture plays a crucial part in earth science, with impact on agriculture, ecology, hydrology, landslides, and water resources. Extremes in soil moisture, which we denote as peaks and valleys, caused by heavy rainfalls and subsequent dry weather, are very

important when predicting future soil moisture or even landslides. Existing methods, like moving averages, have limitations when it comes to smoothing time series data while preserving peaks and valleys. In this work, we propose a novel method, HyperSTL, for extrema-preserving smoothing of soil moisture time series. The method optimizes the an existing time series decomposition technique, Seasonal Decomposition of Time Series by Loess (STL). HyperSTL optimizes STL's control parameters, which we call hyperparameters, using an objective function over the decomposed components. We demonstrate in experiments with nine soil moisture datasets that using HyperSTL generally results in improved prediction compared to using other smoothing methods.

The Evolution of Neural Network-Based Chart Patterns: A Preliminary Study

Myoung Hoon Ha, *Seoul National University*, Byung-Ro Moon, *Seoul National University*

A neural network-based chart pattern represents adaptive parametric features, including non-linear transformations, and a template that can be applied in the feature space. The search of neural network-based chart patterns has been underexposed despite its potential expressiveness. In this paper, we formulate a general chart pattern search problem to enable cross-representational quantitative comparison of various search schemes. We suggest a HyperNEAT framework applying state-of-the-art deep neural network techniques to find attractive neural network-based chart patterns; these techniques enable a fast evaluation and search of robust patterns, as well as bringing a performance gain. The proposed framework successfully found considerable patterns on the Korean stock market. We compared newly found patterns with those found by different search schemes, showing the proposed approach has potential.

Computing New Optimized Routes for GPS Navigators Using Evolutionary Algorithms

Daniel H. Stolfi, *University of Malaga*, Enrique Alba, *University of Malaga*

GPS navigators are now present in most vehicles and smartphones. The usual goal of these navigators is to take the user in less time or distance to a destination. However, the global use of navigators in a given city could lead to traffic jams as they have a highly biased preference for some streets. From a general point of view, spreading the traffic throughout the city could be a way of preventing jams and making a better use of public resources. We propose a way of calculating alternative routes to be assigned by these devices in order to foster a better use of the streets. Our experimentation involves maps from OpenStreetMap, real road traffic, and the microsimulator SUMO. We contribute to reducing travel times, greenhouse gas emissions, and fuel consumption. To analyze the sociological aspect of any innovation, we analyze the penetration (acceptance) rate which shows that our proposal is competitive even when just 10% of the drivers are using it.

Session: RWA2
Monday, July 17, 14:00-15:40, Jade

Solving Structures of Pigment-Protein Complexes as Inverse Optimization Problems using Decomposition

Yigal Lahav, *The Galilee Research Institute - Migal*, Ofer M. Shir, *Tel-Hai College*, Dror Noy, *The Galilee Research Institute - Migal*

Simple optical spectroscopy measurements, namely circular dichroism (CD) and absorption spectra of interacting pigments can be used for deriving details of their molecular geometry. Unlike X-ray crystallography and NMR that provide highly detailed structural information but consume time and resources, optical spectroscopic measurements that provide valuable information on local interactions are fast, and easy to perform. Unfortunately, structural information may be extracted from optical spectra only upon solving an ill-defined inverse-problem (spectrum ==> structure). In this paper, we present a computational approach for addressing this problem, relying on simulation-based optimization. We introduce quantum theoretical simulations of both CD and absorption spectra of interacting chlorophylls, integrated with an effective graphical user interface to facilitate an expert's estimation of the chlorophyll geometry. The inverse-problem is then efficiently solved by decomposing it into two approximately independent subproblems and employing two different derandomized Evolution Strategies, while relying on the expert's initial search-point. Our approach is implemented for deriving the geometry of interacting chlorophylls incorporated within natural proteins. It is then demonstrated to retrieve chlorophyll geometries with low errors when compared to the respective geometries determined to near-atomic resolution by X-ray crystallography. The observations are reported and investigated in the light of non-uniqueness and uncertainty.

Monopolies Can Exist in Unmanned Airspace

Scott Stephen Forer, *University of Nevada, Reno*, Logan Yliniemi, *University of Nevada, Reno*

With the increased use of unmanned aerial vehicles (UAVs) for both commercial and private use comes the inevitability that over- saturated airspaces will exist. If an airspace becomes congested and difficult to traverse, the possibility of an entity abusing, controlling, and even monopolizing the space can be extremely dangerous. In this paper we show that this type of monopolization can exist. We use cooperative coevolutionary algorithms to examine multiple teams of UAVs coexisting in the same airspace. Considering two equally- sized teams: A and B, if Team A chooses to cooperate with Team B, and considers team B's losses as its own, the system can work fluidly. If Team A chooses to focus on its own concerns while ignoring impacts on Team B, Team B can suffer a 99% increase in midair conflicts. If Team A chooses to actively prevent Team B from fluid operation, Team B's number of midair conflicts can suffer a 394% increase.

Evolving Solution Choice and Decision Support for a Real-World Optimisation Problem.

Neil Urquhart, *Edinburgh Napier Universitry*, Achille Fonzone, *Edinburgh Napier University*

Agencies who provide social care services typically have to optimise staff allocations and the travel whilst attempting to satisfy conflicting objectives. In such cases it is desirable to have a range of solutions to choose from, allowing the agency's planning staff to explore the various options available This paper examines the use of multi-objective evolutionary algorithms to produce solutions to the Workforce Scheduling and Routing Problem (WSRP) formulated with three objectives which should be minimised: financial cost, CO2 emissions and car use. We show that financial cost and CO2 increase with the size of the problem and the imposed constraints. In order to support the planning staff in their decision making, we present an Evolutionary Algorithm based support tool that will identify a group of solutions from the Pareto front which match criterion specified by the planner. We demonstrate that our approach is able to find a wide range of solutions, which enhance the flexibility of the agency's choices, the decision support tool subsequently allows the planner to discover small groups of solutions that meet their specific requirements.

Searching for Nonlinear Relationships in fMRI Data with Symbolic Regression

James Alexander Hughes, *The University of Western Ontario*, Mark Daley, *The University of Western Ontario*

The vast majority of methods employed in the analysis of functional Magnetic Resonance Imaging (fMRI) produce exclusively linear models; however, it is clear that linear models cannot fully describe a system with the observed behavioral complexity of the human brain — an intrinsically nonlinear system. By using tools embracing the possibility of modeling the underlying nonlinear system we may uncover meaningful undiscovered relationships which further our understanding of the brain. We employ genetic programming, an artificial intelligence technique, to perform symbolic regression for the discovery of nonlinear models better suited to capturing the complexities of a high dimensional dynamic system: the human brain. fMRI data for multiple subjects performing different tasks were segmented into regions of interest and nonlinear models were generated which effectively described the system succinctly. The nonlinear models contained undiscovered relationships and selected different sets of regions of interest than traditional tools, which leads to more accurate understanding of the functional networks.

Session: RWA3
Monday, July 17, 16:10-17:50, Amethyst

A Hybrid Method for Feature Construction and Selection to Improve Wind-Damage Prediction in the Forestry Sector

Emma Hart, *Edinburgh Napier University*, Kevin Sim, *Edinburgh Napier University*, Barry Gardiner, *INRA*, Kana Kanimura, *Shinshu University*

Catastrophic damage to forests resulting from major storms has resulted in serious timber and financial losses within the sector across Europe in the recent past. Developing risk assessment methods is thus one of the keys to finding forest management strategies to reduce future damage. Previous approaches to predicting damage to individual trees have used mechanistic models of wind-flow or logistical regression with mixed results. We propose a novel filter-based Genetic Programming method for constructing a large set of new features which are ranked using the Hellinger distance metric which is insensitive to skew in the data. A wrapper-based feature-selection method that uses a random forest classifier is then applied predict damage to individual trees. Using data collected from two forests within South-West France, we demonstrate significantly improved classification results using the new features, and in comparison to previously published results. The feature-selection method retains a small set of relevant variables consisting only of newly constructed features whose components provide insights that can inform forest management policies.

University Staff Teaching Allocation: Formulating and Optimising a Many-Objective Problem

Jonathan E. Fieldsend, *University of Exeter*

The allocation of university staff to teaching exhibits a range of often competing objectives. We illustrate the use of an augmented version of NSGA-III to undertake the seven-objective optimisation of this problem, to find a trade-off front for a university department using real world data. We highlight its use in decision-making, and compare solutions identified to an actual allocation made prior to the availability of the optimisation tool. The criteria we consider include minimising the imbalance in workload distribution among staff; minimising the average load; minimising the maximum peak load; minimising the staff per module; minimising staff dissatisfaction with teaching allocations; and minimising the variation from the previous year's allocation (allocation churn). We derive mathematical forms for these various criteria, and show we can determine the maximum possible values for all criteria and the minimum values for most exactly (with lower bounds on the remaining criteria). For many of the objectives, when considered in isolation, an optimal solution may be obtained rapidly. We demonstrate the advantage of utilising such extreme solutions to drastically improve the optimisation efficiency in this many-objective optimisation problem. We also identify issues that NSGA-III can experience due to selection between generations.

Fast Pedestrian Detection Using Multimodal Estimation of Distribution Algorithms

Da-Zhao Tan, *South China University of Technology*, Wei-Neng Chen, *South China University of Technology*, Jun Zhang, *South China University of Technology*, Wei-Jie Yu, *Sun Yat-sen University*

Pedestrian detection plays a pivotal role in various domains but is still a challenging problem nowadays. In this study, we transform the multiple-pedestrian detection problem into a multimodal optimization problem and then utilize a multimodal estimation of distribution algorithm (MEDA) to optimize this problem based on Histograms of Oriented Gradients (HOG) feature and Support Vector Machines (SVM). Specifically, we adopt a three-dimensional vector to represent a rectangular region of an image and also use it to encode individuals. Then, a state-of-the-art multimodal optimization algorithm called MEDA is utilized to evolve the individuals, so that a series of optimal rectangular regions containing pedestrians can be obtained. Experiments conducted on a set of images from one pedestrian dataset called INRIA confirm that in comparison with the classical HOG-SVM method and one state-of-the-art method, the developed algorithm cannot only achieve higher detection accuracy on images containing different numbers of pedestrians, but also can remain high computational efficiency.

Towards Solving Large-Scale Precedence Constrained Production Scheduling Problems in Mining

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

Pit planning and long-term production scheduling are important tasks within the mining industry. This is a great opportunity for optimisation techniques, as the scale of a lot of mining operations means that a small percentage increase in efficiency can translate to millions of dollars in profit. The precedence constrained production scheduling problem (PCPSP) combines both of these aspects of mine optimisation and aims to find a solution which tells a mining company what part of the orebody to mine, and at what time during the life of the mine. This paper presents a GRASP-Mixed Integer Programming hybrid metaheuristic algorithm for solving the PCPSP which consists of two parts: a fast, period-by-period, random construction phase and a local improvement heuristic. It is compared to the current published state-of-the-art results on well known benchmark problems from minelib and is shown to give better quality results in four of the six instances, and within 2% of the LP upper bound in the remaining two. The PCPSP is a good candidate for hybrid metaheuristics as the size of the problems make solving them with mathematical solvers alone intractable.

Session: RWA4
Tuesday, July 18, 10:40-12:20, Bernstein

An Adaptive Prioritized ε-Preferred Evolutionary Algorithm for Approximate BDD Optimization

Saeideh Shirinzadeh, *University of Bremen*, Mathias Soeken, *EPFL*, Daniel Große, *University of Bremen, DFKI GmbH*, Rolf Drechsler, *University of Bremen, DFKI GmbH*

Approximate computing is an emerging methodology that allows to increase efficiency in a range of resilient applications for an affordable loss of precision or quality. In this paper, we exploit approximation in a multi-criteria optimization approach for the widely used data structure Binary Decision Diagrams (BDDs) to achieve higher efficiency besides lowering the inaccuracy. For this purpose, we utilize an ε-preferred evolutionary algorithm giving a higher priority to minimize BDD sizes as well as maintaining certain error constraints. In particular, we propose an adaptive ε-setting method which adds an automated factor to the algorithm based on the behavior of the function under approximation. This improves the performances of the algorithm by correcting the effect of the user set error constraints which can restrict the dimensions of the search and can lead to immature convergence. In comparison with the non-optimized BDDs, the proposed algorithm achieves a high gain of 68.02% at a low cost of 2.12% inaccuracy for the whole benchmark set. The experimental results also reveal a considerable improvement of 25.19% in the average value of error rate besides reduction in BDD sizes compared to the manual ε-setting approach.

Multi-Objective Optimization of Level of Service in Urban Transportation

Rolando Armas, *Shinshu University*, Hernán Aguirre, *Shinshu University*, Kiyoshi Tanaka, *Shinshu University*

This work investigates levels of service in urban transportation coupling a multi-objective evolutionary algorithm with the multi-agent traffic simulator MATSim. The evolutionary algorithm searches combinations of number of private/public transportation users, capacity of buses, and time interval between bus departures minimizing traffic density, travel time and fuel consumption simultaneously. MATSim simulates the movement of 27.000 agents according to the solutions of the evolutionary algorithm on a model of the traffic network of Quito city. We study the trade-off in objectives and analyze the solutions produced to gain knowledge about the conditions to achieve different levels of service. Also, we analyze particulate matter emissions for the trade-off solutions. This work is useful for decision makers to suggest policies that can improve mobility combining private and public transportation.

Evolving a Real-time Evacuation for Urban Disaster Management

Keith J. Drew, *University of Idaho*, Robert B. Heckendorn, *University of Idaho*, Ahmed Abdel-Rahim, *University of Idaho*, Homaja Pydi Kumar Marisetty, *University of Idaho*, Anton Stalick, *University of Idaho*

In an urban disaster it is important to efficiently evacuate people to safety. We use evolution strategies and a probability model to route the population by optimizing their safety. The algorithm is designed to use the strengths of evolutionary computing to repeatedly optimize an evacuation under the dynamics of a disaster such as accidents blocking critical roadways, bridge collapses, debris closures, changes in safety, and people not following evacuation directions. Our model is unconcerned with specific evacuation routes but rather evolves a robust cloud of probabilities to represent best directions of escape. We show that maintaining a population of diverse solutions may allow for rapid adaptation as a disaster unfolds. The algorithm is tested using challenging test cases as well as real-world data.

Optimization of Monitoring in Dynamic Communication Networks using a Hybrid Evolutionary Algorithm

Robin Mueller-Bady, *Frankfurt University of Applied Sciences*, Martin Kappes, *Frankfurt University of Applied Sciences*, Inmaculada Medina-Bulo, *Universidad de Cádiz*, Francisco Palomo-Lozano, *Universidad de Cádiz*

In this paper, we propose a hybrid evolutionary algorithm (EA) for the optimization of efficient monitoring in dynamic communication networks. The first step towards improving communication infrastructures is gathering information about the current situation. One part of collecting this information is to implement an adequate monitoring in the network, i.e., the optimal positions and amount of monitoring devices, in order to analyze communication flows. Solving the general monitor selection problem using evolutionary computation has already been done in the past. Our approach focuses on the efficient optimization of monitors having a dynamic search landscape, i.e., having recurring substantial changes of the underlying network model in order to simulate bulks of entering or leaving nodes and edges. Here, we compare the steady optimization versions of a common genetic algorithm (GA), the proposed hybrid EA, and a local search based EA, in conjunction with a total restart version of the hybrid EA. Empirical results are obtained using multiple well-known real-world problem instances. We show that we can achieve reliably fast high quality results using the proposed hybrid EA.

Session: EMO3+RWA5
Tuesday, July 18, 10:40-12:20, Amethyst

Optimizing nucleic acid sequences for a molecular data recorder

Jerzy Kozyra, *Newcastle University*, Harold Fellermann, *Newcastle University*, Ben Shirt-Ediss, *Newcastle University*, Annunziata Lopiccolo, *Newcastle University*, Natalio Krasnogor, *Newcastle University*

We recently reported the design for a DNA nanodevice that can record and store molecular signals. Here we present an evolutionary algorithm tailored to optimising nucleic acid sequences that predictively fold into our desired target structures. In our approach, a DNA device is first specified abstractly: the topology of the individual strands and their desired foldings into multi-strand complexes are described at the domain-level. Initially, this design is decomposed into a set of pairwise strand interactions. Then, we optimise candidate domains, such that the resulting sequences fold with high accuracy into desired target structures both (a) individually and (b) jointly, but also (c) to show high affinity for binding desired partners and simultaneously low affinity to bind with any undesired partner. As optimization heuristic we use a genetic algorithm that employs a linear combination of the above scores. Our algorithm was able to generate DNA sequences that satisfy all given criteria. Even though we cannot establish the theoretically achievable optima (as this would require exhaustive search), our solutions score 90% of an upper bound that ignores conflicting objectives. We envision that this approach can be generalised towards a broad class of toehold-mediated strand displacement systems.

Session: RWA6
Tuesday, July 18, 14:00-15:40, Bernstein

Solving a Supply-Chain Management Problem Using a Bilevel Approach

Zhichao Lu, *Michigan State University*, Kalyanmoy Deb, *Michigan State University*, Erik Goodman, *Michigan State University*, John Wassick, *Dow Chemical Company*

Supply-chain management problems involve a hierarchy of tasks, which must be coordinated well to find an overall optimal solution. They involve a hierarchy of decision-makers, each having its own objectives and constraints. In this paper, we consider a supply-chain management problem from an industry involving two levels of coordination: (i) yearly strategic planning in which a decision on establishing source-destination pair is required to minimize yearly transportation cost, and (ii) weekly operational planning in which a decision on the preference and schedule of available transport carriers must be made for multiple objectives: minimization of transport cost and maximization

of service quality and satisfaction of demand at each destination point. The resulting problem is bilevel and multi-objective in nature, for which the operational planning problem is nested within the strategic planning problem. Moreover, the problem involves several practical challenges, such as uncertainty in demand at each destination and non-linearity of the cost model. We propose a customized multi-objective bilevel evolutionary algorithm, which is computationally tractable. and present results on US state and ZIP-level involving about 40,000 variables of the destination points. We compare our method with current practices and report considerable cost savings.

Handling Practicalities in Agricultural Policy Optimization for Water Quality Improvements

Bradley Barnhart, *U.S. EPA ORD NHEERL WED*, Zhichao Lu, *Michigan State University*, Moriah Bostian, *Lewis and Clark University*, Ankur Sinha, *Indian Institute of Management, Ahmedabad*, Kalyanmoy Deb, *Michigan State University*, Luba Kurkalova, *North Carolina A&T*, Manoj Jha, *North Carolina A&T*, Gerald Whittaker, *Oregon State University*

Bilevel and multi-objective optimization methods are often useful to spatially target agri-environmental policy throughout a watershed. This type of problem is complex and is comprised of a number of practicalities: (i) a large number of decision variables, (ii) at least two inter-dependent levels of optimization between policy makers and policy followers, and (iii) uncertainty in decision variables and problem parameters. Given agricultural and economic data from the Raccoon watershed in central Iowa, we formulate a bilevel multi-objective optimization problem that accommodates objectives of both policy makers and farmers. The solution procedure then explicitly accounts for the nested nature of farm-level management decisions in response to agri-environmental policy incentives constructed by policy makers. We specifically examine the spatial targeting of a fertilizer-reduction incentive policy while seeking to maximize farm-level productivity while generating mandated water quality improvements using this framework. We test three different evolutionary optimization algorithms – m-BLEAQ, NSGA-II, and SPEA2 – and show that m-BLEAQ is well suited for handling the bilevel optimization problems and the considered practicalities.

Protein Design by Multiobjective Optimization: Evolutionary and Non-Evolutionary Approaches

Sandeep V. Belure, *Rutgers University*, Ofer M. Shir, *Tel-Hai College*, Vikas Nanda, *Rutgers University*

Traditional simulation-based protein design considers energy minimization of candidate conformations as a singleobjective combinatorial optimization problem. In this paper we consider a challenging protein design problem, producing twelve protein species based on collagen that uniquely assort into four groups of three: a problem defined herein as a 4-level heterotrimer. We formulate a bi-objective combinatorial minimization problem that targets both stability and specificity of the 4-level heterotrimer. In order to approximate its Pareto frontier, we utilize both evolutionary and non-evolutionary approaches, operating in either Pareto or aggregation fashions. Our practical observations suggest that the SMS-EMOA with Evolution Strategies' operators is more effective than standard heuristics deployed in computational protein design, such as Simulated Annealing, Replica Exchange or the Canonical Genetic Algorithm. We investigate the attained Pareto optimal sets using Barrier Tree analysis, aiming to provide insights into the chemical search-space, as well as to explain the observed algorithmic trends. In particular, we identify Replica Exchange as a promising non-evolutionary technique for this problem class, due to its efficient exploration capabilities. Overall, a common high-level protocol for simultaneous landscape analysis of evolutionary and non-evolutionary search methodologies is put forward for the first time.

Accurate Mixed Weibull Distribution Fitting by Differential Evolution

Pavel Krömer, *VSB-TU Ostrava*, Jana Heckenbergerova, *University of Pardubice*, Petr Musilek, *University of Alberta*

Mixed Weibull distribution is a probability distribution noted for its wide applicability in many diverse fields. The ability to accurately estimate mixed distribution parameters is essential for data-driven modeling, simulation, and analysis of the phenomena represented by mixed Weibull models. Nature-inspired metaheuristics for continuous parameter optimization have shown good potential for approximating parameters of complex statistical models. Differential evolution is a popular evolutionary real-parameter optimization method with good results in many areas. This work uses differential evolution to fit mixed Weibull distribution to data and analyzes the ability of different differential evolution variants to estimate mixture parameters.

Session: RWA7: Best Papers
Tuesday, July 18, 16:10-17:50, Saphir

Heuristic Allocation of Computational Resources

Silviu Tofan, *University of Manchester*, Richard Allmendinger, *University of Manchester*, Manuela Zanda, *ARM*, Olly Stephens, *ARM*

This study considers an actual real-world problem encountered by ARM, the world's leading semiconductor intellectual property (IP) supplier, concerning the multi-year assignment of weeks-long computationally intensive projects (executable pieces of code) across a number of capacity-limited clusters. The quality of a projects-to-cluster assignment is measured in terms of several metrics such as the even utilization of clusters, being able to realize all projects, and spreading projects of different research groups evenly across the clusters. The first (theoretical) contribution of this work is to motivate and formally define this novel application and put it in context with related literature. The second (experimental) contribution of this work

is about gaining an understanding about the problem and performing an initial investigation on how different algorithm types (random search, an EMOA, and greedy search) fare on the problem. Our study revealed that the problem has many infeasible solutions and is challenging to optimize especially for long planning horizons (more than 3 years). While the EMOA is able to outperform random and greedy search (and also the current approach used at ARM) in terms of solution quality discovered, greedy search was the computationally most efficient approach and suitable for short term planning horizons.

Evolutionary Decomposition for 3D Printing

Eric A. Yu, *University of Texas at Austin*, Jin Yeom, *University of Texas at Austin*, Cem C. Tutum, *University of Texas at Austin*, Etienne Vouga, *University of Texas at Austin*, Risto Miikkulainen, *University of Texas at Austin*

Capabilities of extrusion-based 3D-printers have progressed significantly, but complex forms are still challenging to print. One major problem is overhanging surfaces. These surfaces require extra support structure to be printed, wasting material and time. Furthermore, delicate parts of the object can be damaged when these structures are removed. One potential solution is to print the object in parts, but decomposition is difficult. This paper proposes an evolutionary approach for determining optimal object decompositions for 3D printing. Two alternative methods, with different complementary strengths, are tested: Multi-objective Genetic Algorithm (MOGA) and Covariance Matrix Adaptation Evolution Strategy (CMA-ES). MOGA is able to evolve a set of decompositions at variable complexity, i.e. number of pieces, whereas CMA-ES is able to find a limited number of comparable decompositions with significantly less computational time.

Enhanced Genetic Path Planning for Autonomous Flight

Vincent R. Ragusa, *Florida Southern College*, H. David Mathias, *Florida Southern College*, Vera A. Kazakova, *University of Central Florida*, Annie S. Wu, *University of Central Florida*

Path planning, the task of finding an obstacle-avoiding, shortest-length route from source to destination is an interesting theoretical problem with numerous applications. We present an improved genetic algorithm for path planning in a continuous, largely unconstrained real-world environment. We introduce a new domain-specific crossover operator based on path intersections. We also implement a new path correction operator that eliminates obstacle collisions from a path, leading to a dramatic search improvement despite the conceptual simplicity of the correction. Finally, in place of a standard binary measure of obstacle collisions, we present a new optimization objective measuring the degree to which a path intersects obstacles. Due to these improvements, individually and in combination, our algorithm is able to solve scenarios that are considerably more complex and exist in a more general environment than those that appear in the literature. We demonstrate the utility of our system through testing onboard an autonomous micro aerial vehicle. Further, our approach demonstrates the utility of domain-specific genetic operators for path planning. We hypothesize that such operators may be beneficial in other domains.

An Embedded System Architecture based on Genetic Algorithms for Mission and Safety Planning with UAV

Jesimar da Silva Arantes, *University of São Paulo*, Márcio da Silva Arantes, *University of São Paulo*, Claudio Fabiano Motta Toledo, *University of São Paulo*, Onofre Trindade Júnior, *University of São Paulo*, Brian Charles Williams, *Massachusetts Institute of Technology*

The present paper describes an embedded system architecture, based on genetic algorithms, aiming safety mission execution by Unmanned Aerial Vehicles (UAVs). A two-dimensional non-convex environment is considered since obstacle avoidance happens. The embedded system integrates the Mission Oriented Sensor Array (MOSA) and In-Flight Awareness (IFA) systems, where MOSA is responsible for mission accomplishment and IFA stands for flight safety. The features of MOSA and IFA are combined under a platform that applies promising genetic algorithm approaches from literature to reach their goals. First, the genetic algorithms performance running from the embedded system is compared against their performance on a personal computer architecture. Next, the proposed system is evaluated in a real-world scenario using Software-In-The-Loop (SITL) technique. The computational results showed that the embedded system provides reliable results.

Session: RWA8
Wednesday, July 19, 09:00-10:40, Jade

Exploring Trade-Offs between Target Coverage, Healthy Tissue Sparing, and the Placement of Catheters in HDR Brachytherapy for Prostate Cancer using a Novel Multi-Objective Model-Based Mixed-Integer Evolutionary Algorithm

Krzysztof Leszek Sadowski, *Utrecht University*, Marjolein C. van der Meer, *Academisch Medisch Centrum*, Ngoc Hoang Luong, *Centrum Wiskunde and Informatica*, Tanja Alderliesten, *Academisch Medisch Centrum*, Dirk Thierens, *Utrecht University*, Rob van der Laarse, *Academisch Medisch Centrum*, Yury Niatsetski, *Elekta*, Arjan Bel, *Academisch Medisch Centrum*, Peter A.N. Bosman, *Centrum Wiskunde and Informatica*

Brachytherapy is a form of radiotherapy whereby a radiation source is guided near tumors, using devices such as catheter implants. In the present clinical workflow, catheters are first placed inside or close to the tumor based on clinical expertise. Subsequently, software is used to design a plan for the delivery of radiation. Treatment planning is essentially a multi-objective optimization problem, where conflicting objectives represent radiation delivered to tumor cells and healthy cells. However, current clinical software collapses this information into a single-objective, constrained optimization problem. Moreover, catheter

positioning is typically not included. As a consequence, it is hard to obtain insight into the true nature of the trade-offs between key planning objectives and the placement of catheters. Such insights are however crucial in understanding how better treatment plans may be constructed. To obtain such insights, we interface with real-world clinical software and derive potential catheter positions for real-world patients. Selecting and configuring catheters requires mixed-integer optimization. For this reason, we extend the recently-proposed Genetic Algorithm for Model-Based mixed-Integer opTimization (GAMBIT) to tackle multi-objective optimization problems. Our results indicate that clinically acceptable plans of high quality may be achievable with less catheters than typically used in current clinical practice.

Conversion Rate Optimization through Evolutionary Computation

Risto Miikkulainen, *Sentient Technologies, Inc.*, Neil Iscoe, *Sentient Technologies, Inc.*, Aaron Shagrin, *Sentient Technologies, Inc.*, Ron Cordell, *Sentient Technologies, Inc.*, Sam Nazari, *Sentient Technologies, Inc.*, Cory Schoolland, *Sentient Technologies, Inc.*, Myles Brundage, *Sentient Technologies, Inc.*, Jonathan Epstein, *Sentient Technologies, Inc.*, Randy Dean, *Sentient Technologies, Inc.*, Gurmeet Lamba, *Sentient Technologies, Inc.*

Conversion optimization means designing a web interface so that as many users as possible take a desired action on it, such as register or purchase. Such design is usually done by hand, testing one change at a time through A/B testing, or a limited number of combinations through multivariate testing, making it possible to evaluate only a small fraction of designs in a vast design space. This paper describes Sentient Ascend, an automatic conversion optimization system that uses evolutionary optimization to create effective web interface designs. Ascend makes it possible to discover and utilize interactions between the design elements that are difficult to identify otherwise. Moreover, evaluation of design candidates is done in parallel online, i.e. with a large number of real users interacting with the system. A case study on an existing media site shows that significant improvements (i.e. over 43%) are possible beyond human design. Ascend can therefore be seen as an approach to massively multivariate conversion optimization, based on a massively parallel interactive evolution.

A Knee Point based Evolutionary Multi-objective Optimization for Mission Planning Problems

Cristian Ramirez-Atencia, *Universidad Autónoma de Madrid*, Sanaz Mostaghim, *Otto-von-Guericke Universität Magdeburg*, David Camacho, *Universidad Autónoma de Madrid*

The current boom of Unmanned Aerial Vehicles (UAVs) is increasing the number of potential industrial and research applications. One of the most demanded topics in this area is related to the automated planning of a UAVs swarm, controlled by one or several Ground Control Stations (GCSs). In this context, there are several variables that influence the selection of the most appropriate plan, such as the makespan, the cost or the risk of the mission. This problem can be seen as a Multi-Objective Optimization Problem (MOP). On previous approaches, the problem was modelled as a Constraint Satisfaction Problem (CSP) and solved using a Multi-Objective Genetic Algorithm (MOGA), so a Pareto Optimal Frontier (POF) was obtained. The main problem with this approach is based on the large number of obtained solutions, which hinders the selection of the best solution. This paper presents a new algorithm that has been designed to obtain the most significant solutions in the POF. This approach is based on Knee Points applied to MOGA. The new algorithm has been proved in a real scenario with different number of optimization variables, the experimental results show a significant improvement of the algorithm performance.

Evolutionary Approach to Optimization of Data Representation for Classification of Patterns in Financial Ultra-High Frequency Time Series

Piotr Lipinski, *Computational Intelligence Research Group, Institute of Computer Science, University of Wroclaw*

This paper proposes an evolutionary approach to optimization of data representation for classification of patterns in financial ultra-high frequency time series. Input data describe order book shapes defined by sequences of price-capital pairs coming from ask and bid orders registered on the stock market. Target data describe the change of the mid price. Classifiers based on SVM try to predict the direction of changes of the mid price on the basis of the input data. An important problem in such an approach is the representation of the input data, because the raw input data consist of long and irregular queues of orders, and need to be transformed into a feature vector. An evolutionary approach is proposed to optimize the representation of the input data by gaussian curves. Experiments performed on real-world data from the London Stock Exchange Rebuilt Order Book database confirms that the evolutionary algorithm is capable of improving significantly the results of classification.

Search-Based Software Engineering

Session: SBSE1+ACO-SI1: Best Papers
Tuesday, July 18, 10:40-12:20, Opal

Active Coevolutionary Learning of Requirements Specifications from Examples

Marcel Wever, *Heinz Nixdorf Institute, University of Paderborn*, Lorijn van Rooijen, *Heinz Nixdorf Institute, University of Paderborn*, Heiko Hamann, *Institute of Computer Engineering, University of Lübeck*

Within software engineering, requirements engineering starts from imprecise and vague user requirements descriptions and infers precise, formalized specifications. Techniques, such as interviewing by requirements engineers, are typically applied to identify the user's needs. We want to partially automate even this first step of requirements elicitation by methods of evolutionary computation. The idea is to enable users to specify their desired software by listing examples of behavioral descriptions. Users initially specify two lists of operation sequences, one with desired behaviors and one with forbidden behaviors. Then, we search for the appropriate formal software specification in the form of a deterministic finite automaton. We solve this problem known as grammatical inference with an active coevolutionary approach following Bongard and Lipson [2]. The coevolutionary process alternates between two phases: (A) additional training data is actively proposed by an evolutionary process and the user is interactively asked to label it; (B) appropriate automata are then evolved to solve this extended grammatical inference problem. Our approach leverages multi-objective evolution in both phases and outperforms the state-of-the-art technique [2] for input alphabet sizes of three and more, which are relevant to our problem domain of requirements specification.

Session: SBSE2+ECOM4
Tuesday, July 18, 14:00-15:40, Jade

Empirical Evaluation of Conditional Operators in GP Based Fault Localisation

Dahyun Kang, *Korea Advanced Institute of Science and Technology*, Jeongju Sohn, *Korea Advanced Institute of Science and Technology*, Shin Yoo, *Korea Advanced Institute of Science and Technology*

Genetic Programming has been successfully applied to learn to rank program elements according to their likelihood of containing faults. However, all GP-evolved formulæ that have been studied in the fault localization literature up to now are single expressions that only use a small set of basic functions. Based on recent theoretical analysis that different formulæ may be more effective against different classes of faults, we evaluate the impact of allowing ternary conditional operators in GP-evolved fault localization by extending our fault localization tool called FLUCCS. An empirical study based on 210 real world Java faults suggests that the simple inclusion of ternary conditional operator can help fault localization by placing up to 11% more faults at the top compared to our baseline, FLUCCS, which in itself can already rank 50% more faults at the top compared to the state-of-the-art SBFL formulæ.

A penalty-based Tabu search for constrained covering arrays.

Philippe Galinier, *Polytechnique Montreal*, Sègla Kpodjedo, *Ecole de Technologie Superieure*, Giuliano Antoniol, *Polytechnique Montreal*

Combinatorial Interaction Testing is a black-box testing technique particularly used for highly configurable software systems, which involve a number of factors (and values) that can be combined, according to some constraints. In this context, constrained covering array (CCA) is a central combinatorial problem tasked with building a test suite of minimum size and maximum coverage of the factors' interactions. In this paper, we propose CATS (Covering Array by Tabu Search), a new penalty-based tabu search algorithm to the CCA problem. Our local search approach differs from the ones previously proposed primarily by its use of a search space that allows solutions that violate inter-factor constraints. Other prominent features of CATS are the definition of so-called strategic moves used to restrict the neighborhood, and a technique to vary the tabu tenure throughout the search. We performed tests with CATS on 2-way constrained problems using 35 widely used benchmarks. Results suggest that CATS consistently outperforms previous approaches, both on the size of the test suites and the needed computation times.

A Context-Based Refactoring Recommendation Approach Using Simulated Annealing: Two Industrial Case Studies

Marouane Kessentini, *University of Michigan*, Troh-Josselin Dea, *University of Michigan*, Ali Ouni, *UAE University*

Refactoring is an extremely important solution to reduce and manage the growing complexity of software systems. However, maintaining a high-level code quality can be expensive since time and monetary pressures force developers to neglect to improve the quality of their source code. Thus, programmers are "opportunistic" when they apply refactorings since most of them are interested in improving the quality of the code fragments that they frequently update or those related to the planned activities for the next release (fixing bugs, adding new functionalities, etc.). In this work, we describe a search based approach to recommend refactorings based on the analysis of the history

of changes to maximize the recommended refactorings for 1) recently modified classes, 2) classes containing incomplete refactorings detected in previous releases, and 3) buggy classes identified based on bug reports. The obtained results on several software systems shows significant improvements of the relevance of recommended refactorings and much lower execution time comparing to existing search-based refactoring techniques.

Session: SBSE3
Tuesday, July 18, 16:10-17:50, Diamant

An Adaptive Fitness Function Based on Branch Hardness for Search Based Testing

Xiong Xu, *Institute of Software, Chinese Academy of Sciences*, Ziming Zhu, *Institute of Software, Chinese Academy of Sciences*, Li Jiao, *Institute of Software, Chinese Academy of Sciences*

Search based software testing has received great attention as a means of automating the test data generation, and the goal is to improve various criteria. There are different types of coverage criteria. In this paper, we deal with the path coverage. Concretely, we focus on the path that is the most difficult to cover. One major limitation of search based testing is the inefficient and insufficiently informed fitness function. To address this problem, we propose an adaptive fitness function based on branch hardness. The branch hardness is measured by the expected number of visits of each branch in the program, which is modeled by an absorbing discrete time Markov chain. By tuning the parameters of branch hardness heuristically, the search hardness, evaluated by the variation coefficient of the fitness function, of generating test data can be minimized. Therefore, this new fitness function is more flexible than the traditional counterparts. In addition, we point out that the present definition of branch distance and the use of normalizing functions are problematic, and propose some improvements. Finally, the empirical study reveals the promising result of our proposal in this paper.

Multi-Objective Black-Box Test Case Selection for System Testing

Remo Lachmann, *TU Braunschweig*, Michael Felderer, *University of Innsbruck*, Manuel Nieke, *TU Braunschweig*, Sandro Schulze, *Otto-von-Guericke-Universität Magdeburg*, Christoph Seidl, *TU Braunschweig*, Ina Schaefer, *TU Braunschweig*

Testing is a fundamental task to ensure software quality. Regression testing aims to ensure that changes to software do not introduce new failures. As resources are often limited and testing comprises a vast amount of test cases, different regression strategies have been proposed to reduce testing effort by selecting or prioritizing important test cases, e.g., code coverage (to ensure a sufficient testing depth). However, in system testing, source code is often not available creating a black-box system. In this paper, we introduce an automated, multi-objective test case selection technique in black-box systems using genetic algorithms. We define seven different objectives, based on metadata, allowing a flexible test case selection for a variety of systems. For evaluation, we apply our technique on two different subject systems assessing the feasibility and suitability of our test case selection approach. Results indicate that our approach is applicable based on different data available and is able to outperform random test case selection and retest-all.

A Search for Improved Performance in Regular Expressions

Brendan Cody-Kenny, *University College Dublin*, Michael Fenton, *University College Dublin*, Adrian Ronayne, *Fidelity Investments*, Eoghan Considine, *Fidelity Investments*, Thomas McGuire, *Fidelity Investments*, Michael O'Neill, *University College Dublin*

The primary aim of automated performance improvement is to reduce the running time of programs while maintaining (or improving on) functionality. In this paper, Genetic Programming is used to find performance improvements in regular expressions for an array of target programs, representing the first application of automated software improvement for run-time performance in the Regular Expression language. This particular problem is interesting as there may be many possible alternative regular expressions which perform the same task while exhibiting subtle differences in performance. A benchmark suite of candidate regular expressions is proposed for improvement. We show that the application of Genetic Programming techniques can result in performance improvements in all cases. As we start evolution from a known good regular expression, diversity is critical in escaping the local optima of the seed expression. In order to understand diversity during evolution we compare an initial population consisting of only seed programs with a population initialised using a combination of a single seed individual with individuals generated using PI Grow and Ramped-half-and-half initialisation mechanisms.

Mining Cross Product Line Rules with Multi-Objective Search and Machine Learning

Safdar Aqeel Safdar, *Simula Research Laboratory*, Hong Lu, *Simula Research Laboratory*, Tao Yue, *Simula Research Laboratory and University of Oslo*, Shaukat Ali, *Simula Research Laboratory*

Nowadays, an increasing number of systems are being developed by integrating products (belonging to different product lines) that communicate with each other through information networks. Cost-effectively supporting Product Line Engineering (PLE) and in particular enabling automation of configuration in PLE is a challenge. Capturing rules is the key for enabling automation of configuration. Product configuration has a direct impact on runtime interactions of communicating products. Such products might be within or across product lines and there usually don't exist explicitly specified rules constraining configurable parameter values of such products. Manually specifying such rules is tedious, time-consuming, and requires ex-

pert's knowledge of the domain and the product lines. To address this challenge, we propose an approach named as SBRM that combines multi-objective search with machine learning to mine rules. To evaluate the proposed approach, we performed a real case study of two communicating Video Conferencing Systems belonging to two different product lines. Results show that SBRM performed significantly better than Random Search in terms of fitness values, Hyper-Volume, and machine learning quality measurements. When comparing with rules mined with real data, SBRM performed significantly better in terms of Failed Precision (18%), Failed Recall (72%), and Failed F-measure (59%).

Theory

Session: THEORY1
Monday, July 17, 14:00-15:40, Smaragd

Upper Bounds on the Runtime of the Univariate Marginal Distribution Algorithm on OneMax

Carsten Witt, *Technical University of Denmark*

A runtime analysis of the Univariate Marginal Distribution Algorithm (UMDA) is presented on the OneMax function for wide ranges of the parameters μ and λ. If $\mu \geq c \log n$ for some constant $c > 0$ and $\lambda = (1 + \Theta(1))\mu$, a general bound $O(\mu n)$ on the expected runtime is obtained. This bound crucially assumes that all marginal probabilities of the algorithm are confined to the interval $[1/n, 1 - 1/n]$. If $\mu \geq c' \sqrt{n} \log n$ for a constant $c' > 0$ and $\lambda = (1 + \Theta(1))\mu$, the behavior of the algorithm changes and the bound on the expected runtime becomes $O(\mu\sqrt{n})$, which typically even holds if the borders on the marginal probabilities are omitted. The results supplement the recently derived lower bound $\Omega(\mu\sqrt{n} + n \log n)$ by Krejca and Witt (FOGA 2017) and turn out as tight for the two very different values $\mu = c \log n$ and $\mu = c' \sqrt{n} \log n$. They also improve the previously best known upper bound $O(n \log n \log \log n)$ by Dang and Lehre (GECCO 2015).

When is it Beneficial to Reject Improvements?

Samadhi Nallaperuma, *University of Sheffield*, Pietro Simone Oliveto, *University of Sheffield*, Jorge Perez Heredia, *University of Sheffield*, Dirk Sudholt, *University of Sheffield*

We investigate two popular trajectory-based algorithms from biology and physics to answer a question of general significance: when is it beneficial to reject improvements? A distinguishing factor of SSWM (Strong Selection Weak Mutation), a popular model from population genetics, compared to the Metropolis algorithm, is that the former can reject improvements, while the latter always accepts them. We investigate when one strategy outperforms the other. Since we prove that both algorithms converge to the same stationary distribution, we concentrate on identifying a class of functions inducing large mixing times, where the algorithms will outperform each other over a long period of time. The outcome of the analysis is the definition of a function where SSWM is efficient, while Metropolis requires at least exponential time.

Running Time Analysis of the (1+1)-EA for OneMax and LeadingOnes under Bit-wise Noise

Chao Qian, *University of Science and Technology of China*, Chao Bian, *University of Science and Technology of China*, Wu Jiang, *University of Science and Technology of China*, Ke Tang, *University of Science and Technology of China*

Previous running time analyses of evolutionary algorithms (EAs) in noisy environments often studied the one-bit noise model, which flips a randomly chosen bit of a solution before evaluation. In this paper, we study a natural extension of one-bit noise, the bit-wise noise model, which independently flips each bit of a solution with some probability. We analyze the running time of the (1+1)-EA solving OneMax and LeadingOnes under bit-wise noise for the first time, and derive the ranges of the noise level for polynomial and super-polynomial running time bounds. The analysis on LeadingOnes under bit-wise noise can be easily transferred to one-bit noise, and improves the previously known results.

The (1+λ) Evolutionary Algorithm with Self-Adjusting Mutation Rate

Benjamin Doerr, *Laboratoire d'Informatique (LIX), École Polytechnique*, Christian Gießen, *Technical University of Denmark*, Carsten Witt, *Technical University of Denmark*, Jing Yang, *Laboratoire d'Informatique (LIX), École Polytechnique*

We propose a new way to self-adjust the mutation rate in population-based evolutionary algorithms. Roughly speaking, it consists of creating half the offspring with a mutation rate that is twice the current mutation rate and the other half with half the current rate. The mutation rate is then updated to the rate used in that subpopulation which contains the best offspring. We analyze how the $(1 + \lambda)$ evolutionary algorithm with this self-adjusting mutation rate optimizes the OneMax test function. We prove that this dynamic version of the $(1 + \lambda)$ EA finds the optimum in an expected optimization time (number of fitness evaluations) of $O(n\lambda/ \log \lambda + n \log n)$. This time is asymptotically smaller than the optimization time of the classic $(1 + \lambda)$ EA. Previous work shows that this performance is best-possible among all λ-parallel mutation-based unbiased black-box algorithms. This result shows that the new way of adjusting the mutation rate can find optimal dynamic parameter values on the fly. Since our adjustment mechanism is simpler than the ones pre-

viously used for adjusting the mutation rate and does not have parameters itself, we are optimistic that it will find other applications.

Session: GA2+THEORY2
Tuesday, July 18, 14:00-15:40, Diamant

Sorting by Swaps with Noisy Comparisons

Tomas Gavenciak, *ETH Zurich*, Barbara Geissmann, *ETH Zurich*, Johannes Lengler, *ETH Zurich*

We study sorting of permutations by random swaps if the comparison operator is noisy. The noise is not associated with the underlying fitness, but is inherent to the comparison operator. This type of fitness-independent noise has not been studied before in the community, but is prototypical for comparison-based evolutionary algorithms, which often do not need to compute or approximate explicit fitness values. As quality measure, we compute the average fitness of the stationary distribution. To measure runtime, we compute the minimal number of steps after which the expected fitness approximates the average fitness of the stationary distribution. As mutations we allow swaps of any two elements which have distance at most r. We give theoretical results for the extreme cases r=1 and r=n, and experimental results for intermediate cases. We find a tradeoff between faster convergence (for large r) and better average quality of the solution after convergence (for small r).

Improved Runtime Bounds for the Univariate Marginal Distribution Algorithm via Anti-Concentration

Per Kristian Lehre, *The University of Birmingham*, Phan Trung Hai Nguyen, *The University of Birmingham*

Unlike traditional evolutionary algorithms which produce offspring via genetic operators, Estimation of Distribution Algorithms (EDAs) sample solutions from probabilistic models which are learned from selected individuals. It is hoped that EDAs may improve optimisation performance on epistatic fitness landscapes by learning variable interactions. However, hardly any rigorous results are available to support claims about the performance of EDAs, even for fitness functions without epistasis. The expected runtime of the Univariate Marginal Distribution Algorithm (UMDA) on ONEMAX was recently shown to be in $\mathcal{O}(n\lambda \log \lambda)$. Later, Krejca and Witt proved the lower bound $\Omega(\lambda\sqrt{n} + n \log n)$ via an involved drift analysis. We prove a $O(n\lambda)$ bound, given some restrictions on the population size. This implies the tight bound $\Theta(n \log n)$ when $\lambda = O(\log n)$, matching the runtime of classical EAs. Our analysis uses the level-based theorem and anti-concentration properties of the Poisson-binomial distribution. We expect that these generic methods will facilitate further analysis of EDAs.

Session: THEORY3+ENUM3: Best Papers
Tuesday, July 18, 16:10-17:50, Opal

Runtime Analysis of the $(1 + (\lambda, \lambda))$ Genetic Algorithm on Random Satisfiable 3-CNF Formulas

Maxim Buzdalov, *ITMO University*, Benjamin Doerr, *Ecole Polytechnique*

The $(1 + (\lambda, \lambda))$ genetic algorithm showed a surprisingly good performance on some optimization problems. Its theoretical analysis so far was restricted to the OneMax test function, where this GA profited from the perfect fitness-distance correlation. We conduct a rigorous runtime analysis of this GA on random satisfiable 3-SAT instances having at least logarithmic density, which are known to have a weaker fitness-distance correlation. We prove that this GA with fixed not too large population size performs better than $\Theta(nlogn)$, which is a lower bound for most evolutionary algorithms on pseudo-Boolean problems with unique optimum. However, the self-adjusting version of the GA risks reaching population sizes at which the intermediate selection of the GA, due to the weaker fitness-distance correlation, can not distinguish a profitable offspring from others. We show that it can be overcome by equipping the self-adjusting GA with an upper limit for the population size. Apart from sparse instances, this limit can be chosen such that the asymptotic performance does not degrade compared to the OneMax case. Overall, this work shows that the $(1 + (\lambda, \lambda))$ GA can provably have a good performance on combinatorial search and optimization problems also in the presence of a weaker fitness-distance correlation.

Session: THEORY4
Wednesday, July 19, 09:00-10:40, Diamant

Unknown Solution Length Problems With No Asymptotically Optimal Run Time

Benjamin Doerr, *Ecole Polytechnique*, Carola Doerr, *CNRS and LIP6, Sorbonne Universites, UPMC Univ Paris 06*, Timo Kötzing, *Hasso Plattner Institute*

We revisit the problem of optimizing a fitness function of unknown dimension; that is, we face a function defined over bitstrings of large length N, but only $n \ll N$ of them have an influence on the fitness. Neither the position of these relevant bits nor their number is known. In previous work, variants of the $(1 + 1)$ evolutionary algorithm (EA) have been developed that solve, for arbitrary $s \in \mathbb{N}$, such OneMax and LeadingOnes instances, simultaneously for all $n \in \mathbb{N}$, in expected time $O(n(\log(n))^2 \log\log(n) \dots \log^{(s-1)}(n)(\log^{(s)}(n))^{1+\varepsilon})$ and $O(n^2 \log(n) \log\log(n) \dots \log^{(s-1)}(n)(\log^{(s)}(n))^{1+\varepsilon})$, respectively; that is, in almost the same time as if n and the relevant bit positions were known. In this work, we prove the first,

almost matching, lower bounds for this setting. For LeadingOnes, we show that, for every $s \in \mathbb{N}$, the $(1+1)$ EA with any mutation operator treating zeros and ones equally has an expected run time of $\omega(n^2 \log(n) \log\log(n) \dots \log^{(s)}(n))$ when facing problem size n. Aiming at closing the small remaining gap, we realize that, quite surprisingly, there is no asymptotically best performance. For any algorithm solving, for all n, all instances of size n in expected time at most $T(n)$, there is an algorithm doing the same in time $T'(n)$ with $T' = o(T)$. For OneMax we show results of similar flavor.

Reoptimization Times of Evolutionary Algorithms on Linear Functions Under Dynamic Uniform Constraints

Feng Shi, *Central South University*, Martin Schirneck, *Hasso Plattner Institute*, Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Frank Neumann, *The University of Adelaide*

The investigations of linear pseudo-Boolean functions play a central role in the area of runtime analysis of evolutionary computing techniques. Having an additional linear constraint on a linear function is equivalent to the NP-hard knapsack problem and special problem classes have been investigated recently by means of rigorous runtime analysis. In this paper, we extend these studies to problems with dynamic constraints and investigate the runtime of different evolutionary algorithms to recompute an optimal solution when the constraint bound changes by a certain amount. We study the classical (1+1) EA and population based algorithms and show that they recompute an optimal solution very efficiently. Furthermore, we show that a variant of the $(1+(\lambda,\lambda))$ GA helps to recompute the optimal solution more efficiently in some cases.

Island Models Meet Rumor Spreading

Benjamin Doerr, *École Polytechnique*, Philipp Fischbeck, *Hasso Plattner Institute*, Clemens Frahnow, *Hasso Plattner Institute*, Tobias Friedrich, *Hasso Plattner Institute*, Timo Kötzing, *Hasso Plattner Institute*, Martin Schirneck, *Hasso Plattner Institute*

Island models in evolutionary computation solve problems by a careful interplay of independently running evolutionary algorithms on the island and an exchange of good solutions between the islands. In this work, we conduct rigorous run time analyses for such island models trying to simultaneously obtain good run times and low communication effort. We improve the existing upper bounds for the communication effort (i) by improving the run time bounds via a careful analysis, (ii) by setting the balance between individual computation and com- munication in a more appropriate manner, and (iii) by replacing the usual communicate-with-all-neighbors approach with randomized rumor spreading, where each island contacts a randomly chosen neighbor. This epidemic communication paradigm is known to lead to very fast and robust information dissemination in many applications. Our results concern islands running simple (1+1) evolutionary algorithms, we regard d-dimensional tori and complete graphs as communication topologies, and optimize the classic test functions OneMax and LeadingOnes.

Instructions for Session Chairs and Presenters

BEC 2017

Instructions for Session Chairs and Presenters

Instructions for Session Chairs

Thank you for agreeing to chair a session. Session chairs are essential to keep sessions on schedule and moderate the question period.

- Arrive at your session early to check the room and the equipment set-up.
- Let the conference organizers at the registration desk know of any problems or if adjustments are needed.
- If you chair a best paper session, please remind the audience that this is a best paper session, distribute the ballots that you will find in the room at the beginning of the session, and collect the votes at the end of the session. After the session, bring the ballots to the registration desk.
- Follow the scheduled order of talks, as well as presentation times.
- In the unlikely event that a speaker is absent, announce a break until the next presentation is due to start. Breathe normally.
- Do not start early, as participants may be moving between sessions/presentations.
- Introduce each speaker.
- Speakers are allocated 25 minutes for a presentation: 20 minutes for set up and presentation, and 5 minutes for questions.
- Make sure the speaker adheres to the maximum time allotted.
- Moderate questions. If there are no questions, ask one yourself (time permitting). Do not start the next presentation early (or late).
- If a session is without a chair, we ask the last scheduled speaker to perform these duties.

Instructions for Paper Presenters

- Projectors/beamers and screens will be available for all presentations.
- Presenters are required to bring (or arrange) their own presentation device (such as a laptop).
- The only guaranteed connection to the projector/beamer is VGA. If your device doesn't support this, make sure that you have a converter for your device, or ask to use somebody else's presentation device.
- Quickly check that the device you are using for the presentation works with the projector before the start of the session.
- Talks are allocated 25 minutes: 20 minutes for set up and presentation, and 5 minutes for questions.

The above holds for the papers in the main conference sessions and HOP sessions, contact workshop chairs for workshop-specific details.

Instructions for Poster Presenters

- The poster session will be held on Monday, July 17, 17:50-20:00 in the Saphir room.
- Hang up your poster during the session the precedes the poster session.
- Poster boards and thumb tacks or tape will be available.
- The definitive maximum poster dimensions are 90 cm (width) x 120 cm (height). Note: the ISO paper size A0 (closely) fits this maximum size.

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