Genetic and Evolutionary Computation Conference 2015

Conference Program

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Association for Computing Machinery

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sigevo

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It is my pleasure to welcome you to Madrid for the 2015 Genetic and Evolutionary Computation Conference – GECCO 2015. This is a special year for several reasons. Firstly, sixteen years ago, in 1999, GECCO was born and held for the first time in Orlando, Florida, USA. So **happy birthday sweet sixteen, GECCO!** We are now in our teenage years, and still growing stronger. Second, thirty years ago the first ICGA, the International Conference on Genetic Algorithms, was held in 1985. Several people who attended that event are still with us today to bear witness to the strength of the (r)evolutionary ideas that were presented there. Thirdly, this year witnesses the highest ever proportion of women in the Organizing Committee, following the spirit of Women@GECCO. And last but not least, we have aimed at introducing your kids to Genetic and Evolutionary Computation by means of the nanoGECCO event.

This year's GECCO is comprised of 18 regular tracks, plus, for the second year, the Hot Off the Press (HOP) track, which offers authors of outstanding research recently published in journals and other conferences the opportunity to present their work to the GECCO community. Under the guidance of Editor-in-Chief Sara Silva, the Track Chairs and Program Committee have selected 182 out of the 505 submissions received in all tracks (excluding HOP) for oral presentation as full papers, resulting in an acceptance rate of 36%. Close to 100 short papers will be presented in the regular poster session. This year we also include an additional poster session, where late-breaking abstracts will be presented together with student papers.

A highlight of the conference is the keynote talks given by salient figures in the GECCO fields of interest. This year we wanted to enhance the experience by going back to our origins and have included a third talk from the Natural Sciences field. Our speakers and their subjects are:

- Ricard Solé, "Re-designing nature with synthetic biology: from artificial ants and tissues to a new biosphere",
- Kate Smith-Miles, "Visualising the diversity of benchmark instances and generating new test instances to elicit insights into algorithm performance",
- Manuel Martín-Loeches, "Origins and evolution of human language: saltation or gradualism?".

Altogether 32 tutorials cover topics ranging from broad and introductory to specialized and at the frontier of current research. GECCO also hosts fifteen workshops, including several new ones as well as at least one that predates GECCO itself. Further high points include the 12th Annual"Humies" Awards for Human-Competitive Results, which are again generously supported by John Koza, and a record number of nine competitions, ranging from Art to Industry. Finally, Evolutionary Computation in Practice continues to be an important and integral part of GECCO, aiming at getting us in touch with the "real world".

All this would not have been possible without the hard work and dedication of the Organizing Committee over the past year. First of all a special mention is due to Sara Silva, who did a superb job of maintaining the high quality of the conference. Anabela Simões and Gisele Pappa ensured an interesting mixture of Tutorials and Workshops respectively, while Mike Preuss was in charge of finding challenging Competitions. Katya Rodríguez-Vázquez's efforts were devoted to that key component which ensures the conference's future development: the students. Şima Etaner Uyar and Pablo García-Sánchez made us reach the public via publicity and social media, and Juan Luis Jiménez Laredo compiled all the useful information as Proceedings Chair. Thanks also go to the Track Chairs and the Program Committee for their careful reviewing of the large number of submissions received, and to the workshop chairs and tutorial presenters.

Good advice is worth more than gold and here my sincerest acknowledgement goes to the SIGEVO Business Committee, Pier Luca Lanzi and Jürgen Branke, to SIGEVO Officers Wolfgang Banzhaf, Una-May O'Reilly, Marc Schoenauer and Franz Rothlauf and to former GECCO chairs Dirk Arnold (2014) and Enrique Alba (2013). Finally, a big hand to Iñaki Hidalgo and his team at the Universidad Complutense, as well as all the volunteers, who have ensured we all get the fullest Madrid experience.

Of course, all this effort would not make any sense without you, who are reading this right now, and all GECCO's attendees. So thanks to you too and I wish you all a productive and enjoyable conference!

Anna I Esparcia Alcázar
General Chair

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Leung, Kwong Sak, *The Chinese University of Hong Kong*
Lewis, Matthew, *The Ohio State University*
Lewis, Peter R., *Aston University*
Leyva López, Juan Carlos, *Universidad de Occidente*
Li, Ke, *Department of Electrical and Computer Engineering*
Li, Xiaoou, *CINVESTAV-IPN*
Li, Xianneng, *Graduate School of Information*
Liang, Feng, *Nanyang Technological University*
Liang, Yiwen, *Wuhan University*
Liao, Tianjun, *IRIDIA*
Liapis, Antonios, *Center for Computer Games Research*
Lichodzijewski, Peter, *Dalhousie University*
Liefooghe, Arnaud, *Université Lille 1*
Limmer, Steffen, *University Erlangen*
Ling, Ping, *Jiangsu Normal University*
Lipinski, Piotr, *Computational Intelligence Research Group*
Lissovoi, Andrei, *Technical University of Denmark*
Liu, Jialin, *TAO*
Liu, Bo, *Academy of Mathematics and Systems Science*
Lobo, Daniel, *Tufts University*
Lobo, Fernando G., *University of Algarve*
Loiacono, Daniele, *Politecnico di Milano*
Lones, Michael, *Heriot-Watt University*
Lopes, Rui, *University of Coimbra*
López-Jaimes, Antonio, *CINVESTAV*
Loshchilov, Ilya, *INRIA*
Louis, Sushil, *UNR*
Lourenço, Nuno, *Universidade de Coimbra*
Lozano, Manuel, *University of Granada*
Lozano, Jose A., *University of the Basque Country*
Lu, Emiao, *Manchester Business School*
Lucas, Simon, *University of Essex*
Ludwig, Simone A., *North Dakota State University*
Luna, J. M., *University of Cordoba*
Luna, Francisco, *University of Extremadura*
Luo, Wenjian, *University of Science and Technology of China*
Lust, Thibaut, *UPMC*
Lygoe, Robert J., *Ford Motor Co Ltd*
Lyon, Robert, *University of Manchester*
Mabu, Shingo, *Yamaguchi University*
Machado, Penousal, *University of Coimbra*
Madureira, Ana Maria, *Polytechnic Institute of Porto*
Maisto, Domenico, *Institute for High Performance Computing and Networking*
Majercik, Stephen, *Bowdoin College*
Malago, Luigi, *Shinshu University*
Maldonado, Yazmin, *Instituto Tecnologico de Tijuana*
Malo, Pekka, *Aalto University School of Business*
Mambrini, Andrea, *University of Birmingham*
Manderick, Bernard, *VUB*
Mandziuk, Jacek, *Faculty of Mathematics and Information Science*
Mansor, Maszatul M., *University of Sheffield*
Manzoni, Luca, *Università degli Studi di Milano-Bicocca*
Marchiori, Elena, *Radboud University*
Maria, Ana, *University of Minho*
Marinakis, Yannis, *Technical University of Crete*
Maringer, Dietmar, *University of Basel*
Martin, Simon, *University of Stirling*
Martin, Andrew, *Dept Biochem & Mol Biol*

Martinez, Hector P., *IT-Universitetet i Kbenhavn*
Martinez, Ivette C., *Universidad Simon Bolivar*
Martí, Luis, *Pontifícia Universidade Católica do Rio de Janeiro*
Mascia, Franco, *Université Libre de Bruxelles*
Masegosa, Antonio D., *University of Deusto*
Maslov, Igor V., *EvoCo Inc*
Matsui, Shouichi, *SERL*
Mauri, Giancarlo, *University Milano-Bicocca*
Mavrovouniotis, Michalis, *De Montfort University*
Mayer, Helmut A., *University of Salzburg*
McDermott, James, *University College Dublin*
McMinn, Phil, *University of Sheffield*
McPhee, Nicholas Freitag, *University of Minnesota*
Mehnen, Jorn, *Cranfield University*
Meignan, David, *University of Osnabrück*
Meisel, Stephan, *Münster University*
Melab, Nouredine, *Université Lille 1*
Melkozerov, Alexander, *Tomsk State University of Control Systems and Radioelectronics*
Mendes, Rui, *CCTC/UM*
Mendiburu, Alexander, *University of the Basque Country*
Menzel, Stefan, *Honda Research Institute Europe*
Menzies, Tim, *ComSci / NcState University*
Merigo Lindahl, Jose M., *University of Barcelona*
Mersmann, Olaf, *TU Dortmund*
Mesejo Santiago, Pablo, *INRIA*
Meyer-Nieberg, Silja, *Universitaet der Bundeswehr Muenchen*
Meyer, Bernd, *Monash University*
Mezura-Montes, Efren, *University of Veracruz*
Miconi, Thomas, *The Neurosciences Institute*
Middendorf, Martin, *University of Leipzig*
Miikkulainen, Risto, *The University of Texas at Austin*
Miklic, Damjan, *University of Zagreb*
Mills, Rob, *University of Lisbon*
Minku, Leandro, *The Centre of Excellence for Research in Computational Intelligence and Applications*
Miramontes Hercog, Luis, *Self-Organizing Solutions*
Miranda, Eduardo Reck, *University of Plymouth*
Misir, Mustafa, *University of Freiburg*
Mitchell, George, *CCKF Ltd*
Moen, Hans Jonas Fossum, *Norwegian Defence Research Estblishment*
Mohan, Chilukuri K., *Syracuse University*
Molina, Julian, *University of Malaga*
Montanier, Jean-Marc, *BSC*
Montemanni, Roberto, *Dalle Molle Institute for Artificial Intelligence*
Montes de Oca, Marco A., *University of Delaware*
Mora, Antonio, *University of Granada*
Moses, Melanie, *University of New Mexico*
Motsinger, Alison, *North Carolina State University*
Muelas, Santiago, *Universidad Politécnica de Madrid*
Musliu, Nysret, *Vienna University of Technology*
Nakib, Amir, *Laboratoire LISSI*
Narukawa, Kaname, *Honda Research Institute Europe GmbH*
Naujoks, Boris, *Cologne University of Applied Sciences*
Nebro, Antonio, *University of Málaga*
Neruda, Roman, *Institute of Computer Science of ASCR*
Neumann, Frank, *The University of Adelaide*
Nguyen Xuan, Hoai, *Hanoi University*
Nicolau, Miguel, *University College Dublin*
Nievola, Julio Cesar, *PUCPR*
Nitschke, Geoff, *University of Cape Town*
Nobile, Marco, *Università degli Studi di Milano-Bicocca*
Nojima, Yusuke, *Osaka Prefecture University*
Noman, Nasimul, *University of Newcastle*
Ó Cinnéide, Mel, *National University of Ireland*
O'Neill, Michael, *University College Dublin*
O'Riordan, Colm, *NUI*
Ofria, Charles, *Michigan State University*
Oh, Choong Kun, *U.S. Naval Research Laboratory*
Okabe, Tatsuya, *Honda Research Institute Japan*
Olhofer, Markus, *Honda Research Institute Europe GmbH*
Oliveira, Pedro, *University of Porto*
Oliveto, Pietro S., *The University of Sheffield*
Oliwa, Tomasz, *The University of Georgia*
Olmo, Juan Luis, *University of Cordoba*
Omran, Mohammed, *Gulf University for Science & Technology*
Ono, Isao, *Tokyo Institute of Technology*
Orsenigo, Carlotta, *Politecnico di Milano*
Ortega, Julio, *Universidad de Granada*
Osaba, Eneko, *Deusto University*
Otero, Fernando, *University of Kent*
Ouni, Ali, *University of Montreal*
Paechter, Ben, *Edinburgh Napier University*
Pagnozzi, Federico, *Université Libre de Bruxelles*
Palafox, Leon, *The University of Arizona*
Palmer, Michael E., *Stanford University*
Pang, Wei, *University of Aberdeen*
Paquete, Luis, *University of Coimbra*
Parque, Victor, *Toyota Technological Institute*
Parsopoulos, Konstantinos, *University of Ioannina*
Pasquier, Philippe, *SIAT - Simon Fraser University*
Pedro, Castillo, *UGR*
Pellegrini, Paola, *IRIDIA-CoDE ULB*
Penev, Kalin, *Southampton Solent University*
Perez Caceres, Leslie, *Iridia - ULB*
Peña, Jose-Maria, *Universidad Politécnica de Madrid*
Phelps, Steve, *University of Essex*
Philippides, Andrew, *University of Sussex*
Pillay, Nelishia, *University of KwaZulu-Natal*
Pilát, Martin, *Faculty of Mathematics And Physics*
Pizzuti, Clara, *Institute for High Performance Computing and Networking*
Polani, Daniel, *University of Hertfordshire*
Poles, Silvia, *EnginSoft*
Pop, Petrica, *North University of Baia Mare*
Popovici, Elena, *Icosystem Corp*
Porumbel, Daniel, *CEDRIC*
Potter, Walter, *University of Georgia*
Poulding, Simon, *Blekinge Institute of Technology*

Pošík, Petr, *Czech Technical University in Prague*
Prandtstetter, Matthias, *AIT Austrian Institute of Technology*
Prestwich, Steve, *University College Cork*
Puchinger, Jakob, *AIT - Austrian Institute of Technology*
Puente, Cesar, *Universidad Autónoma de San Luis Potosi*
Puerta, Jose Miguel, *UCLM*
Punch, William F., *Michigan State University*
Purshouse, Robin, *University of Sheffield*
Qi, Jianlong, *Ancestry.com*
Qin, A. K., *RMIT University*
Raidl, Günther R., *Vienna University of Technology*
Randall, Marcus Christian, *School of Information Technology*
Ranjithan, Ranji S., *North Carolina State Univ*
Rasheed, Khaled, *University of Georgia*
Ray, Tom, *University of Oklahoma*
Ray, Tapabrata, *School of Aerospace*
Raymer, Michael, *Wright State University*
Read, Mark, *University of Sydney*
Reed, Patrick M., *Cornell University*
Rhyd, Lewis, *Cardiff University*
Richter, Hendrik, *HTWK Leipzig University of Applied Sciences*
Rieffel, John, *Union College*
Riff, Maria Cristina, *UTFSM*
Robert, Wille, *University of Bremen*
Robilliard, Denis, *LISIC*
Rockett, Peter, *Dept of Electronic & Electrical Engineering*
Rodriguez-Tello, Eduardo, *CINVESTAV*
Rohlfshagen, Philipp, *Schneider-Electric*
Roli, Andrea, *Alma Mater Studiorum Università di Bologna*
Rombo, Simona E., *Dep. of Mathematics and Computer Science*
Romero, Carlos, *Technical University of Madrid*
Roper, Marc, *University of Strathclyde*
Ross, Peter, *Napier University*
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*
Sagarna, Ramon, *University of the Basque Country*
Sahin, Erol, *Middle East Technical University*
Sahraoui, Houari, *DIRO*
Sakuma, Jun, *University of Tsukuba*
Salem, Ziad, *Graz University*
Sanchez, Luciano, *Universidad de Oviedo*
Santana, Roberto, *University of the Basque Country (UPV/EHU)*
Santibáñez Koref, Iván, *Technical Univ. Berlin*
Sarro, Federica, *University College London*
Sato, Hiroyuki, *The University of Electro-Communications*
Sato, Yuji, *Hosei University*
Saubion, Fredéric, *University of Angers*
Sawada, Hideyuki, *Kagawa University*
Schaefer, Robert, *AGH University of Science and Technology*
Schillaci, Massimiliano, *STMicroelectronics*
Schmitt, Manuel, *University of Erlangen-Nuremberg*
Schoenauer, Marc, *INRIA*
Scully, Peter, *Aberystwyth University*
Sebag, Michele, *Université Paris-Sud*
Segura, Carlos, *Universidad de La Laguna*
Sekanina, Lukas, *Brno University of Technology*
Semet, Yann, *Thales*
Sen, Sandip, *University of Tulsa*
Seppi, Kevin, *Brigham Young University*
Serpell, Martin, *University of the West of England*
Sevaux, Marc, *Université de Bretagne-Sud - Lab-STICC*
Sezerman, Ugur, *Sabanc University*
Shaheen, Fatima, *Loughborough University*
Shaker, Noor, *IT University of Copenhagen*
Shakya, Siddhartha, *Business Modelling & Operational Transformation Practice*
Shapiro, Jonathan Lee, *University of Manchester*
Shengxiang, Yang, *De Montfort Unviersity*
Shukla, Pradyumn Kumar, *KIT*
Siarry, Patrick, *University of Paris-Est Créteil*
Silva, Arlindo, *Polytechnic Institute of Castelo Branco*
Silva, Fernando, *Instituto de Telecomunicações; BioISI*
Sim, Kevin, *Edinburgh Napier University*
Sipper, Moshe, *Ben-Gurion University*
Skurikhin, Alexei N., *Los Alamos National Laboratory*
Smith, Jim, *University of the West of England*
Smith, Alice, *Auburn University*
Smyth, Tamara, *University of Califronia San Diego*
Solnon, Christine, *LIRIS*
Solteiro Pires, Eduardo J., *UTAD University*
Soltoggio, Andrea, *Loughborough University*
Song, Andy, *RMIT University*
Sosa Hernandez, Victor Adrian, *CINVESTAV-IPN*
Sossa, Humberto, *Instituto Politécnico Nacional*
Souza, Jerffeson, *State University of Ceara*
Spector, Lee, *Hampshire College*
Squillero, Giovanni, *Politecnico di Torino*
Standish, Russell, *High Performance Coders*
Stepney, Susan, *University of York*
Stich, Sebastian, *Université Catholique de Louvain*
Stonedahl, Forrest, *Northwestern University*
Straccia, Umberto, *ISTI-CNR*
Stracquadanio, Giovanni, *University of Oxford*
Stützle, Thomas, *Université Libre de Bruxelles*
Sudholt, Dirk, *University of Sheffield*
Suganthan, Ponnuthurai, *NTU*
Sun, Yi, *Google Inc*
Sun, Chaoli, *Taiyuan University of Science and Technology*
Sutton, Andrew Michael, *Friedrich-Schiller-Universität Jena*
Suzuki, Reiji, *Nagoya University*
Takadama, Keiki, *UEC*
Takahashi, Ricardo, *Universidade Federal de Minas Gerais*
Talbi, El-Ghazali, *INRIA*

Tan, Ying, *Peking University*
Tanaka, Kiyoshi, *Shinshu University*
Tanev, Ivan, *Faculty of Engineering*
Tarantino, Ernesto, *ICAR - CNR*
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*
Terashima Marín, Hugo, *ITESM - CSI*
Tettamanzi, Andrea G. B., *Université de Nice Sophia Antipolis*
Teuscher, Christof, *Portland State University*
Textor, Johannes, *University of Utrecht*
Teytaud, Fabien, *University of Lille Nord de France*
Thawonmas, Ruck, *Ritsumeikan University*
Thiele, Lothar, *ETH Zurich*
Thierens, Dirk, *Utrecht University*
Thompson, Tommy, *University of Derby*
Ting, Chuan-Kang, *Department of Computer Science and Information Engineering*
Tino, Peter, *University of Birmingham*
Tinos, Renato, *University of So Paulo*
Tiwari, Ashutosh, *Cranfield University*
Tiwari, Santosh, *General Motors Company*
Togelius, Julian, *IT University of Copenhagen*
Tomassini, Marco, *University of Lausanne*
Tonda, Alberto Paolo, *INRA*
Trefzer, Martin, *University of York*
Trianni, Vito, *ISTC-CNR*
Trojanowski, Krzysztof, *Institute of Computer Science*
Trunfio, Giuseppe A., *University of Sassari*
Tsoukias, Alexis, *Université Paris Dauphine*
Tuci, Elio, *Aberystwyth University*
Tuma, Matthias, *Ruhr-Universität Bochum*
Tusar, Tea, *Jozef Stefan Institute*
Tutum, Cem Celal, *Michigan State University*
Twycross, Jamie, *University of Nottingham*
U, Man Chon, *Las Vegas Sands Corporate*
Ugolotti, Roberto, *University of Parma*
Urbano, Paulo, *University of Lisbon*
Urquhart, Neil, *Edinburgh Napier University*
Vašíček, Zdeněk, *Brno University Of Technology*
Valencia-Palomo, Guillermo, *Instituto Tecnologico de Hermosillo*
Van den Herik, H. Jaap, *Tilburg University*
Vanneschi, Leonardo, *NOVA IMS*
Vatolkin, Igor, *TU Dortmund*
Veerapen, Nadarajen, *University of Stirling*
Velasco, Nubia, *Universidad de los Andes*
Ventura, Sebastian, *Universidad de Cordoba*
Verbancsics, Phillip, *Space and Naval Warfare Systems Center - Pacific*
Verel, Sebastien, *Université du Littoral Côte d'Opale*
Vergilio, Silvia, *Federal University of Paraná*
Viana, Ana, *INESC TEC*
Vidnerova, Petra, *Institute of Computer Science of ASCR*
Von Zuben, Fernando J., *Unicamp*
Vrahatis, Michael N., *University of Patras*
Wagner, Tobias, *Institute of Machining Technology*
Wanka, Rolf, *University of Erlangen-Nuremberg*
Weimer, Westley, *University of Virginia*
Wessing, Simon, *Technische Universität Dortmund*
Whigham, Peter Alexander, *University of Otago*
White, David, *University of Glasgow*
Wieloch, Bartosz, *Poznan University of Technology*
Wilkerson, Josh, *NAVAIR*
Wilson, Garnett, *Afinin Labs Inc*
Wilson, Stewart W., *Prediction Dynamics*
Wimmer, Manuel, *Vienna University of Technology*
Wineberg, Mark, *University of Guelph*
Winkler, Stephan, *University Of Applied Sciences Upper Austria*
Witt, Carsten, *Technical University Of Denmark*
Wong, M. L. Dennis, *Swinburne University of Technology*
Woodward, John R., *STIRLINGUNI*
Wright, Alden H., *University of Montana*
Wrobel, Borys, *Adam Mickiewicz University*
Wu, Annie S., *University of Central Florida*
Xie, Huayang, *Oracle New Zealand*
Yamada, Takeshi, *NTT Communication Science Labs*
Yamamoto, Lidia, *University of Strasbourg*
Yannakakis, Georgios, *IT University of Copenhagen*
Yeh, Wei-Chang, *National Tsing Hua University*
Yen, Gary G., *Oklahoma State University*
Yoo, Shin, *University College London*
Yosinski, Jason, *Cornell University*
Yu, Tian-Li, *Taiwan Evolutionary Intelligence Lab*
Yu, Tina, *Memorial University*
Yu, Yang, *Nanjing University*
Zaefferer, Martin, *Cologne University of Applied Sciences*
Zafra, Amelia, *University of Cordoba*
Zahadat, Payam, *Artificial Life Lab*
Zaharie, Daniela, *West University of Timisoara*
Zambetta, Fabio, *RMIT University*
Zapotecas Martínez, Saúl, *CINVESTAV-IPN*
Zell, Andreas, *University of Tübingen*
Zexuan, Zhu, *Shenzhen University*
Zhang, Fu, *Mathworks*
Zhang, Yuanyuan, *University College London*
Zhang, Mengjie, *Victoria University of Wellington*
Zhong, Yanfei, *Wuhan University*
Zhou, Aimin, *Department of Computer Science*

Schedule and Floor Plans

Schedule at a Glance

Saturday, July 11	Sunday, July 12	Monday, July 13	Tuesday, July 14	Wednesday, July 15
		Opening 9:00-9:30		
Tutorials and Workshops 9:00-10:50	Tutorials and Workshops 9:00-10:50	Keynote Ricard Solé 9:30-10:40	Keynote Kate Smith-Miles 9:30-10:40	SIGEVO meeting 9:00-10:40
Coffee break				
Tutorials and Workshops 11:10-13:00	Tutorials and Workshops 11:10-13:00	Paper sessions, nanoGECCO, EC in practice and Competitions 11:10-12:50	Paper sessions, Hot Off the Press and nanoGECCO 11:10-12:50	Keynote M. Martín-Loeches 11:10-12:10
Lunch on your own				Paper Sessions 12:25-14:05
Tutorials and Workshops 14:30-16:20	Tutorials and Workshops 14:30-16:20	Paper sessions, Humies, EC in practice and Competitions 14:30-16:10	Paper sessions, Hot Off the Press 14:30-16:10	
Coffee break				
Tutorials and Workshops 16:40-18:30	Tutorials and Workshops 16:40-18:30	Paper sessions, EC in practice, Hot Off the Press 16:40-18:45	Paper sessions, Hot Off the Press 16:40-18:20	
	Work/life balance panel 18:30-20:00	Posters 18:45-20:45		
	Welcome reception 20:00-22:00		Spanish Tapas reception 20:00-23:00	

Registration desk hours: Saturday and Sunday, 8:30-17:00 (closed during lunch)
Monday, 8:30-17:00 (closed during lunch)
Tuesday, 9:00-18:00 (closed during lunch)
Wednesday, 8:30-11:00

Keynotes and SIGEVO meeting: Auditorium

Welcome reception, posters and competitions: Tapices room

Spanish Tapas reception venue: Teatro Real

Our volunteers can take you there in a guided tour; please let us know if you are interested (sign on at the registration desk). Tours will leave the hotel lobby at 18:30.

Workshop and Tutorial Sessions, Saturday, July 11

	9:00-10:50	11:10–13:00	14:30–16:20	16:40–18:30
Doblón	Particle Swarm Optimization (Engelbrecht)	Runtime Analysis of Evolutionary Algorithms: Basic introduction (Lehre, Oliveto)	Parameterized Complexity Analysis of Evolutionary Algorithms (Neumann, Sutton)	Evolutionary Computation for Dynamic Optimization Problems (Yang)
Escudo	Synergies between Evolutionary Algorithms and Reinforcement Learning (Drugan)	Medical Applications of Evolutionary Computation (Smith)	Representations for Evolutionary Algorithms (Rothlauf)	Blind No More: Constant Time Non-Random Improving Moves and Exponentially Powerful Recombination (Whitley)
Comendador	Student Workshop			
Hidalgo		SecDef – Genetic and evolutionary computation in defense, security and risk management		Generative and Developmental Systems (Stanley)
Alcalá		VizGEC - Visualisation Methods in Genetic and Evolutionary Computation	Evolutionary Algorithms for Protein Structure Modeling (Shehu, De Jong)	Hyper-heuristics (Woodward, Tauritz)
Patio 1	Automatic (Offline) Configuration of Algorithms (López-Ibáñez, Stützle)	Gene Regulatory Networks (Cussat-Blanc, Banzhaf)	Continuous Optimization and CMA-ES (Hansen, Akimoto)	Evolutionary Robotics (Bredeche, Doncieux, Mouret)
Patio 2	Solving complex problems with coevolutionary algorithms (Heywood, Krawiec)	Genetic Programming (O'Reilly)	Cartesian Genetic Programming (Miller)	Theory of Evolution Strategies and Related Algorithms (Akimoto)
Patio 3	Constraint-Handling Techniques used with Evolutionary Algorithms (Coello)	Low or no cost distributed evolutionary computation (Merelo)	EvoSoft - Evolutionary Computation Software Systems	

Workshops

Introductory tutorials

Advanced tutorials

Specialized tutorials

Workshop and Tutorial Sessions, Sunday, July 12

	9:00-10:50	11:10–13:00	14:30–16:20	16:40–18:30	18:30-20:00
Doblón	Intelligent Systems for Smart Cities (Alba)	Complex Networks (Tomassini)	Multimodal Optimization (Preuss)	Theory of Swarm Intelligence (Sudholt)	
Escudo	Evolving Neural Networks (Miikkulainen)	Evolutionary Image Analysis and Signal Processing (Zhang, Cagnoni)	Evolutionary Computation: A Unified Approach (De Jong)	Women@GECCO	Work-Life balance panel
Comendador	ECADA - Evolutionary Computation for the Automated Design of Algorithms		Evolutionary Multiobjective Optimization (Brockhoff, Wagner)	Expressive Genetic Programming (Spector)	
Hidalgo	Model-Based Evolutionary Algorithms (Thierens, Bosman)	Semantic Genetic Programming (Krawiec, Moraglio)	Semantic Methods in Genetic Programming		
Alcalá	GI - Genetic Improvement		MedGEC - Medical Applications of Genetic and Evolutionary Computation		
Patio 1	Evolutionary Computation in Computational Structural Biology		Evolving Collective Behaviors in Robotics		
Patio 2	Introducing Evolutionary Rule-based Machine Learning : A Practical Guide (Urbanowicz, Browne)	Evolutionary Rule-based Machine Learning (former IWLCS)			
Patio 3	BBOB - Blackbox Optimization Benchmarking		MetaDeeP - Metaheuristic Design Patterns		
Tapices	Poster setup	Late-breaking abstracts (LBA) and student posters		Women@GECCO posters	

Workshops

Introductory tutorials

Advanced tutorials

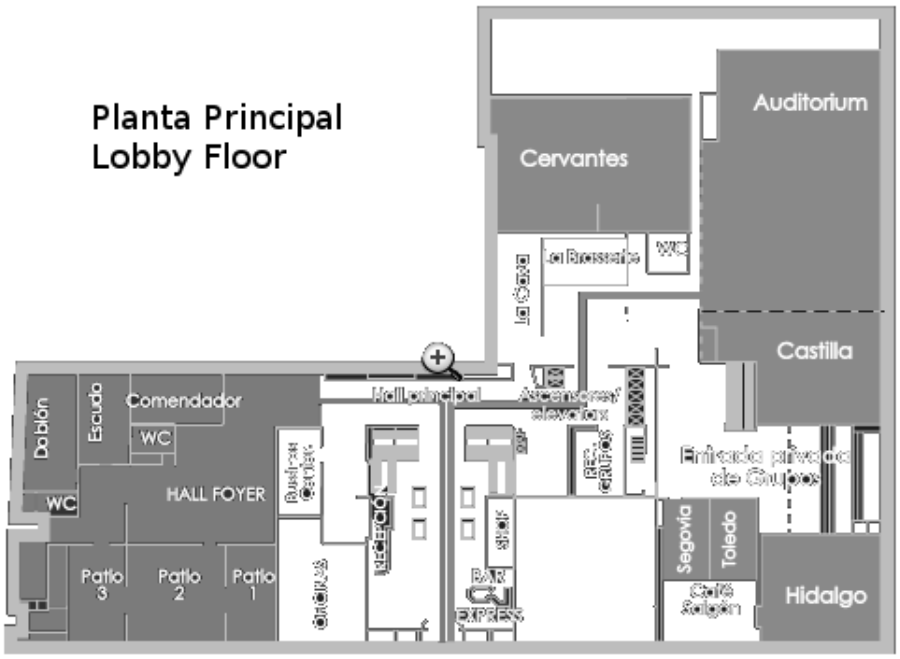
Specialized tutorials

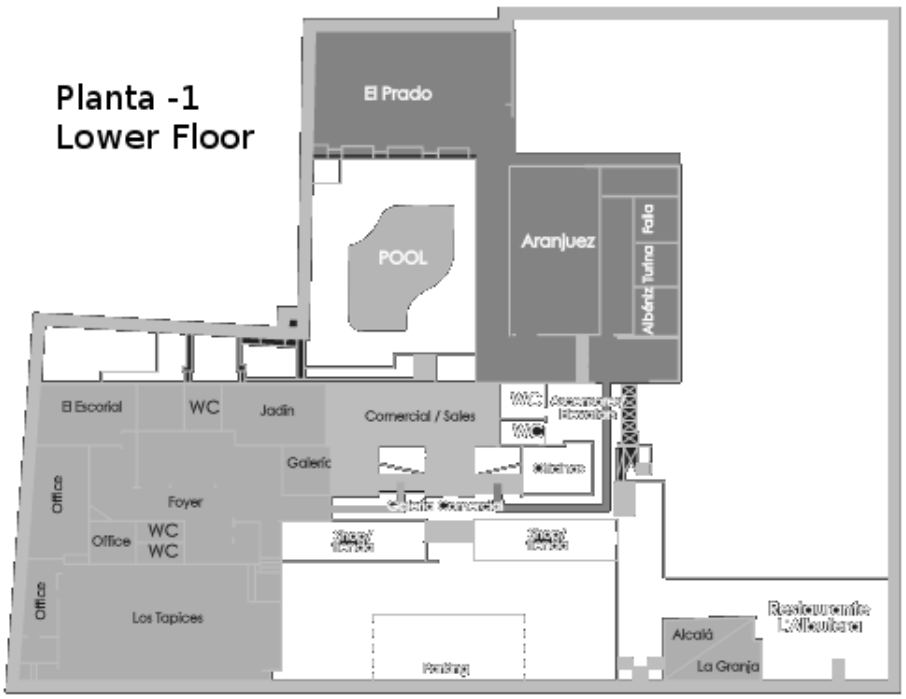
Parallel Sessions, Monday, July 13 through Wednesday, July 15

	Monday July 13 11:10-12:50	Monday July 13 14:30-16:10	Monday July 13 16:40-18:45	Tuesday July 14 11:10-12:50	Tuesday July 14 14:30-16:10	Tuesday July 14 16:40-18:20	Wednesday July 15 12:25-14:05
Doblon	RWA1	**RWA2 (BPA)**	RWA3	ECOM2	**ECOM3 (BPA)**	ECOM4	IGEC +ECOM5
Escudo	ECiP1	ECiP2	ECiP3	HOP2	HOP3	HOP4	THEORY4
Comendador	AIS-ACHEM	GDS1 + PES1	HOP1	ACO-SI3	CO2	**EML1 (BPA)**	EML2
Hidalgo	EMO1	**EMO2 (BPA)**	ALIFE1	EMO3	EMO4	EMO5	EMO6
Alcalá	**GA1 (BPA)**	GA2	GA3	nanoGECCO	THEORY2 + EDA2	GA4 + THEORY3	CO3
Patio 1	nanoGECCO	HUMIES	**BIO1+DETA1+ PES2 (BPA)**	**CO1 (BPA)**	SBSE-SS 2	**ALIFE2+GDS2 (BPA)**	EDA3
Patio 2	GP1	GP2	ECOM1	GP3	**GP4 (BPA)**	GP5	ALIFE3
Patio 3	**ACO-SI1 (BPA)**	ACO-SI2	**SBSE-SS1 + EDA1 + THEORY1 (BPA)**	DETA2	RWA4	BIO2+RWA5	SBSE-SS3
Tapices	COMPETITIONS	COMPETITIONS					

(BPA): The session includes best paper award nominees.

Floor Plans


Planta Principal
Lobby Floor
Auditorium
Cervantes
Castilla
Comendador
Escudo
Doblón
WC
WC
HALL FOYER
Patio 3
Patio 2
Patio 1
Segovia
Toledo
Hidalgo
BAR
EXPRESS


Planta -1
Lower Floor
El Prado
POOL
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Turina
El Escorial
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Jardín
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Galería
Office
Foyer
Office
WC
WC
Office
Los Tapices
Alcalá
La Granja

Track List and Abbreviations

ACO-SI: Ant Colony Optimization and Swarm Intelligence

AIS-ACHEM: Artificial Immune Systems and Artificial Chemistries

ALIFE: Artificial Life/Robotics/Evolvable Hardware

BIO: Biological and Biomedical Applications

CO: Continuous Optimization

DETA: Digital Entertainment Technologies and Arts

ECiP: Evolutionary Computation in Practice

ECOM: Evolutionary Combinatorial Optimization and Metaheuristics

EDA: Estimation of Distribution Algorithms

EML: Evolutionary Machine Learning

EMO: Evolutionary Multiobjective Optimization

GDS: Generative and Developmental Systems

GA: Genetic Algorithms

GP: Genetic Programming

HOP: Hot Off the Press

IGEC: Integrative Genetic and Evolutionary Computation

PES: Parallel Evolutionary Systems

RWA: Real World Applications

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

THEORY: Theory

nanoGECCO 2015

nanoGECCO 2015

The nanoGECCO (GECCO*10^{-9}) event is aimed at the kids aged 12-16 that come with their parents to GECCO and want to find out what this is all about. Here they can give their first steps in Genetic and Evolutionary Computation and learn by playing games!

Kids can sign up for one or two sessions:

Session 1: Monday 11:10–12:50 Room: Patio 1
Session 2: Tuesday 11:10–12:50 Room: Alcalá

Activities led by:

Una-May O'Reilly (MIT),

Terence Soule (University of Idaho),

JJ Merelo (Universidad de Granada)

Find out more at the registration desk.

Tutorials

Intoductory Tutorials

Particle Swarm Optimization — Saturday, July 11, 9:00-10:50, Doblón
Andries Engelbrecht, *Michigan State University, USA*

Runtime Analysis of Evolutionary Algorithms: Basic Introduction — Saturday, July 11, 11:10-13:00, Doblón
Per Kristian Lehre, *University of Nottingham, UK*
Pietro S. Oliveto, *University of Sheffield, UK*

Genetic Programming — Saturday, July 11, 11:10-13:00, Patio 2
Una-May O'Reilly, *Massachusetts Institute of Technology, USA*

Representations for Evolutionary Algorithms — Saturday, July 11, 14:30-16:20, Escudo
Franz Rothlauf, *University of Mainz, Germany*

Continuous Optimization and CMA-ES — Saturday, July 11, 14:30-16:20, Patio 1
Nikolaus Hansen, *INRIA, France*
Youhei Akimoto, *Shinshu University, Japan*

Cartesian Genetic Programming — Saturday, July 11, 14:30-16:20, Patio 2
Julian Miller, *University of York, UK*
Andrew Turner, *University of York, UK*

Hyper-heuristics — Saturday, July 11, 16:40-18:30, Alcalá
John R. Woodward, *University of Stirling, UK*
Daniel Tauritz, *Missouri University of Science and Technology, USA*

Evolutionary Robotics — Saturday, July 11, 16:40-18:30, Patio 1
Nicolas Bredeche, *Université Pierre et Marie Curie, France*
Stéphane Doncieux, *Université Pierre et Marie Curie, France*
Jean-Baptiste Mouret, *Institute for Intelligent Systems and Robotics -UPMC, France*

Evolving Neural Networks — Sunday, July 12, 9:00-10:50, Escudo
Risto Miikkulainen, *University of Texas at Austin, USA*

Model-Based Evolutionary Algorithms — Sunday, July 12, 9:00-10:50, Hidalgo
Dirk Thierens, *Utrecht University, The Netherlands*
Peter Bosman, *Centre for Mathematics and Computer Science, The Netherlands*

Introducing Rule-based machine learning - A Practical Guide — Sunday, July 12, 9:00-10:50, Patio 2
Ryan Urbanowicz, *University of Pennsylvania, USA*
Will Browne, *Victoria University of Wellington, New Zealand*

Complex Networks — Sunday, July 12, 11:10-13:00, Doblón
Marco Tomassini, *University of Lausanne, Switzerland*

Multimodal Optimization — Sunday, July 12, 14:30-16:20, Doblón
Mike Preuss, *University of Münster, Germany*

Evolutionary Computation: A Unified Approach — Sunday, July 12, 14:30-16:20, Escudo
Kenneth De Jong, *George Mason University, USA*

Evolutionary Multiobjective Optimization — Sunday, July 12, 14:30-16:20, Comendador
Dimo Brockhoff, *INRIA Lille - Nord Europe, France*
Tobias Wagner, *Technische Universität Dortmund, Germany*

Advanced Tutorials

Solving complex problems with coevolutionary algorithms — Saturday, July 11, 9:00-10:50, Patio 2
Malcolm Heywood, *Dalhousie University, Canada*
Krzysztof Krawiec, *Poznan University of Technology, Poland*

Constraint-Handling Techniques used with Evolutionary Algorithms — Saturday, July 11, 9:00-10:50, Patio 3
Carlos Coello-Coello, *CINVESTAV-IPN, Mexico*

Gene Regulatory Networks — Saturday, July 11, 11:10-13:00, Patio 1
Sylvain Cussat-Blanc, *University of Toulouse, France*
Wolfgang Banzhaf, *Memorial University of Newfoundland, Canada*

Parameterized Complexity Analysis of Evolutionary Algorithms — Saturday, July 11, 14:30-16:20, Doblón
Frank Neumann, *University of Adelaide, Australia*
Andrew Sutton, *University of Adelaide, Australia*

Evolutionary Algorithms for Protein Structure Modeling — Saturday, July 11, 14:30-16:20, Alcalá
Amarda Shehu, *George Mason University, USA*
Kenneth De Jong, *George Mason University, USA*

Evolutionary Computation for Dynamic Optimization Problems — Saturday, July 11, 16:40-18:30, Doblón
Shengxiang Yang, *De Montfort University, UK*

Blind No More: Constant Time Non-Random Improving Moves and Exponentially Powerful Recombination — Saturday, July 11, 16:40-18:30, Escudo
Darrell Whitley, *Colorado State University, USA*

Generative and Developmental Systems — Saturday, July 11, 16:40-18:30, Hidalgo
Kenneth Stanley, *University of Central Florida, USA*

Theory of Evolution Strategies and Related Algorithms — Saturday, July 11, 16:40-18:30, Patio 2
Youhei Akimoto, *Shinshu University, Japan*

Evolutionary Image Analysis and Signal Processing — Sunday, July 12, 11:10-13:00, Escudo
Mengjie Zhang, *University of Wellington, New Zealand*
Stefano Cagnoni, *University of Parma, Italy*

Semantic Genetic Programming — Sunday, July 12, 11:10-13:00, Hidalgo
Krzysztof Krawiec, *Poznan University of Technology, Poland*
Alberto Moraglio, *University of Exeter, UK*

Theory of Swarm Intelligence — Sunday, July 12, 16:40-18:30, Doblón
Dirk Sudholt, *University of Sheffield, UK*

Expressive Genetic Programming — Sunday, July 12, 16:40-18:30, Comendador
Lee Spector, *Hampshire College, USA*

Specialized Tutorials

Synergies between Evolutionary Algorithms and Reinforcement Learning — Saturday, July 11, 9:00-10:50
Madalina M. Drugan, *Vrije Universiteit Brussel, Belgium* — Escudo

Automatic (Offline) Configuration of Algorithms — Saturday, July 11, 9:00-10:50
Manuel López-Ibáñez, *IRIDIA Laboratory, ULB, Belgium* — Patio 1
Thomas Stützle, *IRIDIA laboratory, ULB, Belgium*

Medical Applications of Evolutionary Computation — Saturday, July 11, 11:10-13:00
Stephen Smith, *University of York, UK* — Escudo

Low or no cost distributed evolutionary computation — Saturday, July 11, 11:10-13:00
JJ Merelo, *CITIC - University of Granada, Spain* — Patio 3

Intelligent Systems for Smart Cities — Sunday, July 12, 9:00-10:50
Enrique Alba, *University of Málaga, Spain* — Doblón

Workshops and
Late Breaking Abstracts

Student Workshop

Organizers: Tea Tušar, *Jošef Stefan Institute*
Boris Naujoks, *Cologne University of Applied Sciences*

Session 1

Time and Location: Saturday, July 11, 9:00-10:50, Comendador

Growing and Evolving Vibrationally Actuated Soft Robots
Benjamin Berger, Alvin Andino, Andrew Danise, John Rieffel

A Method Based on Interactive Evolutionary Computation for Increasing the Effectiveness of Advertisement Texts
Quetzali Madera, Mario García-Valdez, Oscar Castillo, Alejandra Mancilla

Hard Test Generation for Maximum Flow Algorithms with the Fast Crossover-Based Evolutionary Algorithm
Vladimir Mironovich, Maxim Buzdalov

An Evolutionary Algorithm for Weighted Graph Coloring Problem
Gizem Sungu, Betul Demiroz Boz

Session 2

Time and Location: Saturday, July 11, 11:10-13:00, Comendador

Differential Evolution with a Repair Method to Solve Dynamic Constrained Optimization Problems
María-Yaneli Ameca-Alducin, Efrén Mezura-Montes, Nicandro Cruz-Ramírez

Exploiting the relationship between structural modularity and sparsity for faster network evolution
Anton Bernatskiy, Josh C. Bongard

Selection of Auxiliary Objectives with Multi-Objective Reinforcement Learning
Arina Buzdalova, Anna Matveeva, Georgiy Korneev

A computational comparison of Memetic Differential Evolution approaches
F. Cabassi, M. Locatelli

Inferring Temporal Properties of Finite-State Machine Models with Genetic Programming
Daniil Chivilikhin, Ilya Ivanov, Anatoly Shalyto

Session 3

Time and Location: Saturday, July 11, 14:30-16:20, Comendador

Towards a knowledge base for performance data: a formal model for performance comparison.
Hans Degroote, Patrick De Causmaecker

Soft computing techniques applied to corporate and personal security
P. de las Cuevas, J.J. Merelo, P. García-Sánchez

Evolutionary Design via Indirect Encoding of Non-Uniform Rational Basis Splines
Adam Gaier

Control of Crossed Genes Ratio for Directed Mating in Evolutionary Constrained Multi-Objective Optimization
Minami Miyakawa, Keiki Takadama, Hiroyuki Sato

A Hybrid MOGA-CSP for Multi-UAV Mission Planning
Cristian Ramirez-Atencia, Gema Bello-Orgaz, Maria D. R-Moreno, David Camacho

Session 4

Time and Location: Saturday, July 11, 16:40-18:30, Comendador

Evaluation-Time Bias in Asynchronous Evolutionary Algorithms
Eric O. Scott, Kenneth A. De Jong

On the Selection of Decomposition Methods for Large Scale Fully Non-separable Problems
Yuan Sun, Michael Kirley, Saman K. Halgamuge

Symbolic Regression by Grammar-based Multi-Gene Genetic Programming
Jan Žegklitz, Petr Pošík

Student posters

Time and Location: Sunday, July 12, 11:10-13:00, Tapices

SecDef: Genetic and evolutionary computation in defense, security and risk management

Organizers: Frank Moore , *University of Alaska Anchorage*
Nur Zincir-Heywood , *Dalhousie University*

Session 1

Time and Location: Saturday, July 11, 11:10-13:00, Hidalgo

Coevolutionary Agent-based Network Defense Lightweight Event System (CANDLES)
George Rush, Daniel R. Tauritz, Alexander D. Kent

Using Genetic Algorithms for Deadline-Constrained Monitor Selection in Dynamic Computer Networks
Robin Mueller-Bady, Ruediger Gad, Martin Kappes, Inmaculada Medina-Bulo

A Hybrid Matheuristic Approach for Designing Reliable Wireless Multimedia Sensor Networks
Omer Ozkan, M. Ermis, I. Bekmezci

Session 2

Time and Location: Saturday, July 11, 14:30-16:20, Hidalgo

On The Identification of Specific Peer to Peer Network Applications
Can Bozdoga, Yasemin Gokcen, Ibrahim Zincir

Evolutionary Dynamic Optimization Techniques for Marine Contamination Problem
Lokman Altin, Haluk Rahmi Topcuoglu, Murat Ermis

Botnet detection system analysis on effect of botnet evolution and feature representation
Fariba Haddadi, Nur Zincir-Heywood

VizGEC: 6th Workshop on Visualisation Methods in Genetic and Evolutionary Computation

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

Time and Location: Saturday, July 11, 11:10-13:00, Alcalá

Spatial and Temporal Visualisation of Evolutionary Algorithm Decisions in Water Distribution Network Optimisation
Ed Keedwell, Matthew Johns, Dragan Savic

ELICIT – EvoLutIonary Computation vIsualizaTionS
Antonio Cruz

Using Particle Swarm Large-scale Optimization to Improve Color Sampling based Image Matting
Lv Liang, Huang Han, Cai Zhaoquan, Hu Hui

Visualising Multi-objective Populations with Treemaps
David J. Walker

EvoSoft: Evolutionary Computation Software Systems

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

Session 1

Time and Location: Saturday, July 11, 14:30-16:20, Patio 3

An Extensible JCLEC-based Solution for the Implementation of Multi-Objective Evolutionary Algorithms
Aurora Ramírez, José Raúl Romero, Sebastián Ventura

Redesigning the jMetal Multi-Objective Optimization Framework
Antonio J. Nebro, Juan J. Durillo, Matthieu Viegne

Simplifying Problem Definitions in the HeuristicLab Optimization Environment
Andreas Scheibenpflug, Andreas Beham, Michael Kommenda, Johannes Karder, Stefan Wagner, Michael Affenzeller

Session 2

Time and Location: Saturday, July 11, 16:40-18:30, Patio 3

AntElements: An Extensible and Scalable Ant Colony Optimization Middleware
Kamil Krynicki, Javier Jaen

Designing and Modeling a Browser-based Distributed Evolutionary Computation System
J. J. Merelo Guervós, Pablo García-Sánchez

Deconstructing GAs into Visual Software Components
Leidy Garzón-Rodríguez, Henry Alberto Diosa, Sergio Rojas-Galeano

ECADA: 5th Workshop on Evolutionary Computation for the Automated Design of Algorithms

Organizers: John Woodward, *University of Stirling*
Daniel Tauritz, *Missouri University of Science and Technology*
Manuel López-Ibáñez, *Université Libre de Bruxelles*

Session 1: Foundations

Time and Location: Sunday, July 12, 9:00-10:50, Comendador

A Comparison of Genetic Programming Variants for Hyper-Heuristics
Sean Harris, Travis Bueter, Daniel R. Tauritz

Learning Genetic Representations for Classes of Real-Valued Optimization Problems
Eric O. Scott, Jeffrey K. Bassett

Hyper-Heuristics: A Study On Increasing Primitive-Space
Matthew A. Martin, Daniel R. Tauritz

Session 2: Applications

Time and Location: Sunday, July 12, 11:10-13:00, Comendador

Synthesis of Parallel Iterative Sorts with Multi-Core Grammatical Evolution
Gopinath Chennupati, R. Muhammad Atif Azad, Conor Ryan

Generating Human-readable Algorithms for the Travelling Salesman Problem using Hyper-Heuristics
Patricia Ryser-Welch, Julian F. Miller, Asta Shahriar

(Invited Talk) From Programs to Program Spaces: Leveraging Machine Learning and Optimisation for Automated Algorithm Design
Holger H. Hoos

Genetic Improvement

Organizers: W. B. Langdon, *University College, London*
David R. White, *University of Glasgow*
Justyna Petke, *University College, London*

Session 1

Time and Location: Sunday, July 12, 9:00-10:50, Alcalá

Introduction
David R. White

Rethinking Genetic Improvement Programming
David R. White, Jeremy Singer

GI4GI: Improving Genetic Improvement Fitness Functions
Mark Harman, Justyna Petke

Genetic Improvement using Higher Order Mutation

Yue Jia, Fan Wu, Mark Harman, Jens Krinke

Fitness as Task-relevant Information Accumulation
Colin G. Johnson, John R. Woodward

Genetic Improvement for Software Product Lines: An Overview and a Roadmap
Roberto E. Lopez-Herrejon, Lukas Linsbauer, Wesley K. G. Assuncao

locoGP: Improving Performance by Genetic Programming Java Source Code
Brendan Cody-Kenny, Edgar Galvan-Lopez, Stephen Barrett

Removing the Kitchen Sink from Software
Jason Landsborough, Stephen Harding, Sunny Fugate

Session 2

Time and Location: Sunday, July 12, 11:10-13:00, Alcalá

Embedded Dynamic Improvement Programming
Jerry Swan, Edward Bowles, Nathan Burles, Alexander E.I. Brownlee, Zoltan A. Kocsis, Nadarajen Veerapen

Energy Optimisation via Genetic Improvement A SBSE technique for a new era in Software Development
Bobby R. Bruce

Genetic Improvement of Energy Usage is only as Reliable as the Measurements are Accurate
Saemundur O. Haraldsson, John R. Woodward

Embedding Adaptivity in Software Systems using the ECSELR framework
Kwaku Yeboah-Antw, Benoit Baudry

Evolutionary Approximation of Software for Embedded Systems: Median Function
Vojtech Mrazek, Zdenek Vasicek, Lukas Sekanina

Repairing COTS Router Firmware without Access to Source Code or Test Suites: A Case Study in Evolutionary Software Repair
Eric Schulte, Westley Weimer, Stephanie Forrest

Grow and Graft a better CUDA pknotsRG for RNA pseudoknot free energy calculation
William B. Langdon, Mark Harman

Evolutionary Computation in Computational Structural Biology

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

Session 1

Time and Location: Sunday, July 12, 9:00-10:50, Patio 1

MeGASS: Multi-Objective Genetic Active Site Search
Sandro Izidoro, Anisio M. Lacerda, Gisele L. Pappa

Combination of Differential Evolution and fragment-based replacements for protein structure prediction
Daniel Varela, José Santos

NK Landscape Instances Mimicking the Protein Inverse Folding Problem Towards Future Benchmarks

Sune S. Nielsen, Grégoire Danoy, Pascal Bouvry, El-Ghazali Talbi

Session 2

Time and Location: Sunday, July 12, 11:10-13:00, Patio 1

Mapping Multiple Minima in Protein Energy Landscapes with Evolutionary Algorithms
Emmanuel Sapin, Kenneth A. De Jong, Amarda Shehu

An experimental analysis of the performance of side chain packing algorithms
Carlos A. Brizuela, Rosario I. Corona, Christian Lezcano, David Rodríguez, José D. Colbes

Using machine learning to explore the relevance of local and global features during conformational search in Rosetta
Mario Garza Fabre, Shaun M. Kandathil, Julia Handl, Joshua Knowles, Simon Lovell

BBOB: Blackbox Optimization Benchmarking

Organizers: Youhei Akimoto, *Shinshu University*
Anne Auger, *INRIA Saclay*
Dimo Brockhoff, *INRIA Lille*
Nikolaus Hansen, *INRIA Saclay*
Olaf Mersmann, *Technische Universitaet Dortmund*
Petr Pošik, *Czech Technical University*

Session 1

Time and Location: Sunday, July 12, 9:00-10:50, Patio 3

Introduction to the BBOB Framework

Dimension Selection in Axis-Parallel Brent-STEP Method for Black-Box Optimization of Separable Continuous Functions
Petr Pošík, Petr Baudiš

Benchmarking IPOP-CMA-ES-TPA and IPOP-CMA-ES-MSR on the BBOB Noiseless Testbed
Asma Atamna

Session 2

Time and Location: Sunday, July 12, 11:10-13:00, Patio 3

Benchmarking Gaussian Processes and Random Forests Surrogate Models on the BBOB Noiseless
Lukáš Bajer, Zbynek Pitra, Martin Holena

The Impact of Initial Designs on the Performance of MATSuMoTo on the Noiseless BBOB-2015 Testbed: A Preliminary Study
Dimo Brockhoff, Bernd Bischl, Tobias Wagner

ERML: Evolutionary Rule-based Machine Learning (former IWLCS)

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

Session 1: Optimization

Time and Location: Sunday, July 12, 11:10-13:00, Patio 2

A Lexicographic Multi-Objective Genetic Algorithm for Multi-Label Correlation-Based Feature Selection
Suwimol Jungjit, Alex A. Freitas

Metaheuristics based on Clustering in a Holonic Multiagent Model for the Flexible Job Shop Problem
Houssem Eddine Nouri, Olfa Belkahla Driss, Khaled Ghédira

Discovering Regression Rules with Ant Colony Optimization
James Brookhouse, Fernando E. B. Otero

(Invited Talk) A Potential of Evolutionary Rule-based Machine Learning for Real World Applications
Keiki Takadama

Session 2: Learning Classifier Systems

Time and Location: Sunday, July 12, 14:30-16:20, Patio 2

A novel representation of classifier conditions named sensory tag for the XCS in multistep problems
Liang-Yu Chen, Po-Ming Lee, Tzu-Chien Hsiao

Socially Guided XCS: Using Teaching Signals to Boost Learning
Anis Najar, Olivier Sigaud, Mohamed Chetouani

Continuous Endpoint Data Mining with ExSTraCS: A Supervised Learning Classifier System
Ryan J. Urbanowicz, Niranjan Ramanand, Jason H. Moore

(Invited Talk) Back to the Future: Learning Classifier Systems as Cognitive Systems
Will Browne

Session 3: Data and Spaces

Time and Location: Sunday, July 12, 16:40-18:30, Patio 2

An evolutionary missing data imputation method for pattern classification
Fabio M. F. Lobato, Vincent W. Tadaiesky, Igor M. de Araújo, Adamo L. Santana

The Relationship Between (Un)Fractured Problems and Division of Input Space
Danilo Vasconcellos Vargas, Hirotaka Takano, Junichi Murata

Semantic Methods in Genetic Programming

Organizers: Colin Johnson, *University of Kent*
Krzysztof Krawiec, *Poznan University of Technology*
Alberto Moraglio, *University of Exeter*
Michael ONeill, *University College Dublin*

Session 1: Semantic-Aware Search Algorithms

Time and Location: Sunday, July 12, 14:30-16:20, Hidalgo

Greedy Semantic Local Search for Small Solutions
Robyn Ffrancon, Marc Schoenauer

Wave: Incremental Erosion of Residual Error
David Medernach, Jeannie Fitzgerald, R. Muhammad Atif Azad, Conor Ryan

Session 2: SMGP - Semantic-Aware Selection Operators

Time and Location: Sunday, July 12, 16:40-18:30, Hidalgo

Introducing Semantic-Clustering Selection in Grammatical Evolution
Stefan Forstenlechner, Miguel Nicolau, David Fagan, Michael ONeill

Comparison of Semantic-aware Selection Methods in Genetic Programming
Paweł Liskowski, Krzysztof Krawiec, Thomas Helmuth, Lee Spector

MedGEC: Medical Applications of Genetic and Evolutionary Computation

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

Session 1: Patient Monitoring

Time and Location: Sunday, July 12, 14:30-16:20, Alcalá

Feature Set Optimization for Physical Activity Recognition using Genetic Algorithms
Alejandro Baldominos, Yago Saez, Pedro Isasi

Classification of Two-Channel Signals by Means of Genetic Programming
Daniel Rivero, Enrique Fernandez-Blanco, Julian Dorado, Alejandro Pazos

Data-Based Identification of Prediction Models for Glucosis
J. Manuel Velasco, Stephan Winkler, J. Ignacio Hidalgo, Oscar Garnica, Juan Lanchares, J. Manuel Colmenar, Esther Maqueda, Marta Botella, Jose-Antonio Rubio

Session 2: Tools for Biomedical Data Processing

Time and Location: Sunday, July 12, 16:40-18:30, Alcalá

A Symbolic Regression Based Scoring System - Improving Peptide Identifications for MS Amanda
Viktoria Dorfer, Sergey Maltsev, Stephan Dreiseitl, Karl Mechtler, Stephan M. Winkler

The Application of Bacterial Foraging to Medical IR Image Registration

Evolving Collective Behaviors in Robotics

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

Session 1

Time and Location: Sunday, July 12, 14:30-16:20, Patio 1

Evolution of Collective Behaviors by Minimizing Surprisal and by Micro-Macro Links
Heiko Hamann

The Cost of Communication: Environmental Pressure and Survivability in mEDEA
Andreas Steyven, Emma Hart, Ben Paechter

Embodied Evolution for Collective Indoor Surveillance and Location
Pedro Trueba, Abraham Prieto, Francisco Bellas, Richard J. Duro

Collective sharing of knowledge in a DREAM
Jacqueline Heinerman

Evolving Diverse Collective Behaviors Independent of Swarm Density
Payam Zahadat, Heiko Hamann, Thomas Schmickl

Session 2

Time and Location: Sunday, July 12, 16:40-18:30, Patio 1

Co-evolving Morphology and Behaviour for Robotic Swarms
Geoff Nitschke

Elements and current state-of-the-art of embodied evolutionary robotics
Nicolas Bredeche, Evert Haasdijk, Abraham Prieto

Simulating Morphological Evolution in Large Robot Populations
Florian Golemo, Marjeta Markovic, Jasper Schoormans, Peter de Jonge, Maik Couwenberg, Evert Haasdijk

Hyb-CCEA: Cooperative Coevolution of Hybrid Teams
Jorge Gomes, Pedro Mariano, Anders Lyhne Christensen

MetaDeeP: 2nd Workshop on Metaheuristic Design Patterns

Organizers: Chris Simons, *University of the West of England*
Jerry Swan, *University of Stirling*
Krzysztof Krawiec, *Poznan University of Technology*
Daniel Tauritz, *Missouri University of Science and Technology*
Jim Smith, *University of the West of England*

Time and Location: Sunday, July 12, 14:30-18:30, Patio 3

Metaheuristic Design Pattern: Preference
Hamzeh J. Aljawawdeh, Mohammed Odeh, Christopher L. Simons

Metaheuristic Design Pattern: Surrogate Fitness Functions

Alexander E.I. Brownlee, John Woodward, Jerry Swan

The Blackboard Pattern for Metaheuristics
Kevin Graham, Jerry Swan, Simon Martin

Two-B or not Two-B? Design Patterns for Hybrid Metaheuristics
Alina Patelli, Nelly Bencomo, Anikó Ekárt, Harry Goldingay, Peter R. Lewis

Women@GECCO

Organizers: Carola Doerr, *CNRS & Universite Pierre et Marie Curie*
Anna Esparcia, *Universitat Politècnica de València*
Gabriela Ochoa, *University of Stirling*
Una-May O'Reilly, *MIT*
Nur Zincir-Heywood, *Dalhousie University*
Emma Hart, *Edinburgh Napier University*
Christine Zarges, *University of Birmingham*

Time and Location: Sunday, July 12, 16:40-18:30, Escudo

Introduction of Workshop and Participants

(Invited talk) Lifelong Learning: An Academic & Personal Perspective
Emma Hart

Open Discussion

Science Slam: short performances of our 5 selected speakers.
Tea Tusar, Madalina Drugan, Julia Handl, Amarda Shehu, and Arina Buzdalova

Poster Session in location: Tapices

Late Breaking Abstracts

Organizer: Dirk Sudholt, *University of Sheffield*

Time and Location: Sunday, July 12, 11:10-13:00, Tapices

Hybridizing Genetic Algorithm with Cross Entropy for Solving Continuous Functions
Pedro Lopez-Garcia, Enrique Onieva, Eneko Osaba, Antonio D. Masegosa, Asier Perallos

An Improved Artificial Fish Swarm Algorithm in Image Segmentation application
Mingan Zhang, Yong Deng

Comparing Variable Width Backtracking and Metaheuristics, Experiments with the Maximum Diversity Problem
José-Matías Cutillas-Lozano, Miguel-Angel Franco, Domingo Giménez

Computational Matter: Evolving Computational Solutions in Materials
Julian Miller, Hajo Broersma

Developing Multi-Time Frame Trading Rules with a Trend Following Strategy, using GA
Jaime Machado, Rui Neves, Nuno Horta

Parameter-less Evolutionary Portfolio: First Experiments
José Pereira, Fernando Lobo

Various Degrees of Steadiness in NSGA-II and Their Influence on the Quality of Results
Maxim Buzdalov, Vladimir Parfenov

Examining The Stroop Effect using A Develomental Spatial Neuroevolution System
Amit Benbassat, Avishai Henik

A Parallel MOEA/D Generating Solutions in Minimum Overlapped Update Ranges of Solutions
Hiroyuki Sato, Minami Miyakawa, Elizabeth Pérez-Cortés

Generating Easy and Hard Problems using the Proximate Optimality Principle
John McCall, Lee Christie, Alexander Brownlee

Adaptive Evolution Control with P-I Similarity Index for Surrogate-assisted Evolutionary Computation
Taku Hasegawa, Kento Tsukada, Naoki Mori, Keinosuke Matsumoto

Malware Obfuscation through Evolutionary Packers
Marco Gaudesi, Andrea Marcelli, Ernesto Sanchez, Giovanni Squillero, Alberto Tonda

Evolutionary Approach For Minimizing Consumed Energy In a Personal Rapid Transit Transportation System with a Multi-Depot Network Topology
Olfa Chebbi, Jouhaina Chaouachi

Design and Development of a Genetic Algorithm for the Distance Constrained Vehicle Routing Problem with Environmental Issues
Ezzeddine Fatnassi, Jouhaina Chaouachi

Rapid Evolution of Robot Gaits
Joshua Auerbach, Grégoire Heitz, Przemyslaw Kornatowski, Dario Floreano

Probabilistic Model Enhanced Genetic Algorithm for Multi-Mode Resource Constrained Project Scheduling Problem
Mayowa Ayodele, John McCall, Olivier Regnier-Coudert

A Comparative Study of Synchronization of Parallel ACO on Multi-core Processor
Shigeyoshi Tsutsui, Noriyuki Fujimoto

Evolving Self-Adaptive Tabu Search Algorithm for Storage Location Assignment Problems
Jing Xie, Yi Mei, Andy Song

Evolved Virtual Creatures with Soft-Body Muscles
Dan Lessin, Sebastian Risi

Empirical Scaling Analyser: An Automated System for Empirical Analysis of Performance Scaling
Zongxu Mu, Holger Hoos

Keynotes

GECCO Keynote

Re-designing Nature with Synthetic Biology: from Artificial Ants and Tissues to a New Biosphere

Monday, July 13, 9:30-10:40
Auditorium + Castilla

Ricard Solé, *Universitat Pompeu Fabra*

As we enter the 21-st century, our potential to engineer biological systems is becoming a reality. The new field of synthetic biology, along with regenerative medicine and bioengineering approaches allows us to modify extant organisms while we avoid evolutionary constraints. Synthetic tissues and organs, but also new classes of tissues and even organoids have been created in the wet lab, and new forms of behaviour have been implemented using microbial life forms. Synthetic multicellular life forms, synthetic swarms and biological computers are examples of this emergent field. We will review the state of the art of the area but also explore the boundaries and potential future scenarios. These involve novel, non-standard ways of processing information and performing computations in living systems but also the possibility of using synthetic biology as an alternative path to approach climate change and its consequences. In the future, to survive might require to re-design nature from ourselves to the planet.

Biosketch: Ricard Solé is ICREA research professor (the Catalan Institute for research and Advanced Studies) currently working at the Universitat Pompeu Fabra, where he leads the Complex Systems Lab located at the PRBB. He completed two full degrees in both Physics and Biology at the University of Barcelona and received his PhD in Physics at the Polytechnic University of Catalonia with a thesis on spatiotemporal chaos and criticality in evolutionary ecology. He was founding member of the NASA-associated Astrobiology Centre on Madrid and is currently External Professor of the Santa Fe Institute (New Mexico, USA) as well as external faculty of the Center for Evolution and Cancer at UCSF. He is also on the editorial board of Biology Direct and PLoS ONE. He has been awarded with many EU grants and a James McDonnell Foundation Award and received a European Research Council Advanced Grant (ERC 2012). He has published more than 200 papers in peer reviewed journals and his results have been featured in technical and general publications and books. His main research interests involve the search for universal patterns of organization in complex systems, including prebiotic replicators, cancer, multicellularity, viruses, evodevo, protocells or language to evolved artificial objects and historical dynamics. He explores these issues using both theoretical and experimental approximations based on synthetic biology.

GECCO Keynote

Visualising the Diversity of Benchmark Instances and Generating New Test Instances to Elicit Insights into Algorithm Performance

Tuesday, July 14, 9:30-10:40
Auditorium + Castilla

Kate Smith-Miles, *Monash University*

Objective assessment of optimization algorithm performance is notoriously difficult, with conclusions often inadvertently biased towards the chosen test instances. Rather than reporting average performance of algorithms across a set of chosen instances, we discuss a new methodology to enable the strengths and weaknesses of different optimization algorithms to be compared across a broader instance space. Results will be presented on various combinatorial and continuous optimization problems to demonstrate: (i) how pockets of the instance space can be found where algorithm performance varies significantly from the average performance of an algorithm; (ii) how the properties of the instances can be used to predict algorithm performance on previously unseen instances with high accuracy; (iii) how the relative strengths and weaknesses of each algorithm can be visualized and measured objectively; and (iv) how new test instances can be generated to fill the instance space and provide desired insights into algorithmic power.

Biosketch: Kate Smith-Miles is a Professor in the School of Mathematical Sciences at Monash University in Australia, where she was Head of School from 2009-2014. She currently holds a Laureate Fellowship from the Australian Research Council (2014-2019) to conduct research into new methodologies to gain insights into algorithm strengths and weaknesses. She is also the inaugural Director of MAXIMA (the Monash Academy for Cross & Interdisciplinary Mathematical Applications). Kate obtained a B.Sc.(Hons) in Mathematics and a Ph.D. in Electrical Engineering, both from the University of Melbourne, Australia. She has published 2 books on neural networks and data mining applications, and over 230 refereed journal and international conference

papers in the areas of neural networks, combinatorial optimization, intelligent systems and data mining. She has supervised to completion 22 PhD students, and has been awarded over AUD$12 million in competitive grants, including 11 Australian Research Council grants and industry awards. From 2007-2008 she was Chair of the IEEE Technical Committee on Data Mining (IEEE Computational Intelligence Society). She was elected Fellow of the Institute of Engineers Australia (FIEAust) in 2006, and Fellow of the Australian Mathematical Society (FAustMS) in 2008. She was awarded the Australian Mathematical Society Medal in 2010 for distinguished research. In addition to her academic activities, she also regularly acts as a consultant to industry in the areas of optimisation, data mining, and intelligent systems.

GECCO Keynote

Origins and Evolution of Human Language: Saltation or Gradualism?

Wednesday, July 15, 11:10-12:10
Auditorium + Castilla

Manuel Martín-Loeches, *Complutense University of Madrid*

In the neurosciences and psycholinguistics, there are two basic views on the origin and evolution of human language. One view posits that human language in its present form emerged around 100.000 years or less in our species, as a consequence of a single gene mutation. These models view language as composed by a number of elements shared with other species and therefore not exclusively human, and one single, human-specific feature: recursion, a grammatical or syntactic property by virtue of which sentences can be nested within other sentences, in a –hypothetically– unlimited fashion. The alternative perspective considers, in turn, that more than one single feature of the human language exhibits human-specific traits. Among others, the particular typology of the human symbols, the large amount of these that a human brain is able to store, or the physiological adaptations for speech articulation. Further, recursion might not be a necessary or universal feature of human language. This gradualist perspective proposes a number of possible steps and acquisitions that would have occurred along the human lineage, by virtue of which human language, as we used it today, is the outcome of gradual, successive stages, implying therefore multiple mutations. We will review here pros- and cons- of these views, as well as how a gradualist acquisition of human language might have occurred, probably starting much earlier than the appearance of H. sapiens some 200.000 years ago.

Biosketch: Manuel Martín-Loeches is full professor at the Complutense University, Madrid, where he teaches on the neuroscientific basis of human behavior and language. He is also in charge of the Cognitive Neuroscience Section at the Center for Human Evolution and Behavior (ISCIII-UCM, Madrid, Spain) where he is leading a number of projects devoted to better understand the neural basis of human-specific behavior and cognition, such as language (syntax and semantics), religion, or art (neuroesthetics). Other areas of research in neuroscience in which he has participated, or keeps participating, include thought disorder in schizophrenia, working memory, visual attention, the relationships between brain shape and cognition, or the interactions between emotions and cognition. He has co-authored more than 100 scientific articles and 90 congress presentations, also regularly participating in courses and conferences on neuroscience and cognition, as well as in several newspapers, radio and TV programs, popularizing neuroscience knowledge and perspectives to the general public. He is also the author of the book [in Spanish] Homo sapiens' mind: the brain and the human mind (Aguilar, 2008), and co-author with Juan Luis Arsuaga of The indelible stamp: past, present and future of the human being (Debate, 2013).

Humies, Competitions, and Evolutionary Computation in Practice

Human Competitive Results: 12th Annual Humies Awards

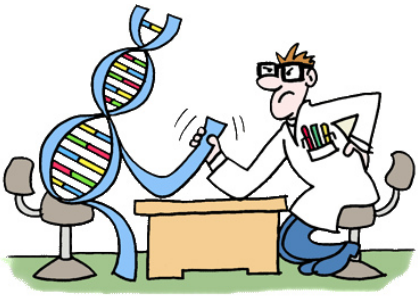
Presentations: Monday, July 13, 14:30-16:10
Patio 1

Announcement of Awards: Wednesday, July 15, 9:00-10:40
Auditorium + Castilla

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

Prizes: prizes totalling $10,000 to be awarded

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



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

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

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.

Competitions

AI Controller for the Game 2048

Organizers: Wojciech Jaskowski, Marcin Szubert

Time and Location: Monday, July 13, 11:10-12:50, Tapices

The goal of the competition is to learn an evaluation function for 2048. It is an addictive single-player, non-deterministic, puzzle game that has recently taken the Internet and mobile devices by storm. One of the reasons of the game's massive popularity is that it is very easy to learn but hard to master. The difficulty of the game together with the simplicity of its rules makes it also an interesting testbed for computational intelligence methods. We propose the competition to encourage comparison of different (evolutionary or not) learning algorithms and evaluation functions.

Black Box Optimization (BBComp)

Organizers: Ilya Loshchilov, Tobias Glasmachers

Time and Location: Monday, July 13, 11:10-12:50, Tapices

The Black Box Optimization Competition is the first competition 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 budget ranges between 10 and 100 times the problem dimension. It can be viewed as a common budget for expensive optimization. The competition aims at attacking a growing impact of over-fitting of optimization algorithms to a narrow set of benchmark problems.

Combinatorial Black-Box Optimization (CBBOC)

Organizers: Brian W. Goldman, Jerry Swan, Daniel R. Tauritz

Time and Location: Monday, July 13, 11:10-12:50, Tapices

This is CBBOC's inaugural year. It's designed to provide the GECCO community with detailed performance comparisons of a wide variety of meta-heuristics and hyper-heuristics on combinatorial problems, where the real-world problems which induce combinatorial problems have been categorized into those with no training time (good fit for out-of-the-box algorithms such as the Parameter-less Population Pyramid), those with short training time (good fit for typical evolutionary algorithms), and those with long training time (good fit for hyper-heuristics). Competitors choose which category or categories they want to submit to. The competition problems will be randomly generated by a meta-class based on NK-Landscapes.

The General Video Game AI

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

Time and Location: Monday, July 13, 11:10-12:50, Tapices

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? The Genetic and Evolutionary Computation Conference (2015) will host the second edition of this competition, where participants will count on 30 different games for training, a set of 10 games for validation, and a secret set of 10 test games for computing the final rankings.

Geometry Friends Game AI

Organizer: Rui Prada

Time and Location: Monday, July 13, 11:10-12:50, Tapices

Build AI players for Geometry Friends, a 2-player cooperative platform puzzle game. These players should be able to deal with a dynamic simulated physics environment (with gravity and friction), be capable of solving puzzles and coordinate its actions to perform the resolution of the puzzles. Each player controls one of the two characters with distinct capabilities: a yellow circle or a green rectangle. The circle can jump and the rectangle can change its shape. Both characters can move horizontally. Players will need to combine the abilities of their characters in a world with platforms to collect a set of diamonds in the least amount of time.

Industrial Challenge: Recovering missing information in heating system operating data

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

Time and Location: Monday, July 13, 14:30-16:10, Tapices

The Industrial Challenge will be held in the competition session at the Genetic and Evolutionary Computation Conference. It poses difficult real-world problems provided by industry partners from various fields. Highlights of the Industrial Challenge include interesting problem domains, real-world data and realistic quality measurement

Simulated Car Racing Championship

Organizers: Daniele Loiacono, Frank Neumann, Mohammad Reza Bonyadi, Samadhi Nallaperuma

Time and Location: Monday, July 13, 14:30-16:10, Tapices

This long standing championship awards the enthusiasts of AI games, autonomous vehicles and car racing. In a nutshell this is all about applying/comparing/creating various computational intelligence approaches to design the best autonomous car controllers and having fun through a car racing game. The competitors are asked to design a controller for a racing car that will compete on a set of unknown tracks first alone (against the clock) and then against other drivers. The controllers perceive the racing environment through a number of sensors that describe the relevant features of the car surroundings (e.g., the track limits, the position of near-by obstacles), of the car state (the fuel level, the engine RPMs, the current gear, etc.), and the current game state (lap time, number of lap, etc.). The controller can perform the typical driving actions (clutch, changing gear, accelerate, break, steering the wheel, etc.)

The Virtual Creatures Competition

Organizers: Joel Lehman, Dan Lessin

Time and Location: Monday, July 13, 14:30-16:10, Tapices

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).

Wind Farm Layout Optimization

Organizers: Sylvain Cussat-Blanc, Dennis Wilson, Silvio Rodrigues, Kalyan Veeramachaneni

Time and Location: Monday, July 13, 14:30-16:10, Tapices

Wind farm design has long been a favored application across evolutionary computation due to its complexity, the wake capture of a field being a difficult value to optimize analytically, and its pertinence to the world of alternative energy. We propose the following competition to create a basis of comparison for the existing algorithms and to encourage both new ways to solve the wind optimization problem and a new mindset for the optimization goal.

Evolutionary Computation in Practice

Organizers: Thomas Bartz-Beielstein, *Cologne University of Applied Sciences, Germany*
Anna I. Esparcia-Alcázar, *Universitat Politècnica de València, Spain*
Jörn Mehnen, *Cranfield University, UK*

Session 1: Monday, July 13, 11:10-12:50
Bridging the gap between academia and industry Escudo

Well-known speakers with outstanding reputation in academia and industry present background and insider information on how to establish reliable cooperation with industrial partners. If you are working in academia and are interested in managing industrial projects, you will receive valuable hints for your own research projects.

Session 2: Monday, July 13, 14:30-16:10
"Real" real-world optimization Escudo

In this session industry speakers will be presenting. They actually run companies in the field of optimization and applied statistics. If you attend, you will learn multiple ways to extend EC practice beyond the approaches found in textbooks.

Experts in real-world optimization with decades of experience share their approaches to creating successful projects for real-world clients. Some of what they do is based on sound project management principles, and some is specific to our type of optimization projects. In this session a panel of experts describes a range of techniques you can use to identify, design, manage, and successfully complete an EA project for a client.

Session 3: Monday, July 13, 16:40-18:45
Ask the experts / Getting a job Escudo

This lively session consists of a panel of experts with decades of real-world application experience answering questions posed by attendees of the session. In the past, we have always had two or three discussions on industrial problems that lie on the cutting edge of EA development. This session gives you the opportunity to get free consulting from the experts!

Getting a job with training in evolutionary computation can be much easier if you know the things to do and the things not to do in your last year or two of study. In this session you will hear from a panel of experts who have trained students and who have hired students to carry out real-world optimization. Highly recommended if you will be looking for a job in the next few years — or if you are thinking of changing jobs.

Papers and Posters

Monday, July 13, 11:10-12:50

ACO-SI 1 (Best Paper Nominees are marked with an asterisk*)

Monday, July 13, 11:10-12:50, Patio 3
Chair: Manuel López-Ibáñez (IRIDIA, Université Libre de Bruxelles)

Evolutionary Inheritance Mechanisms for Multi-criteria Decision Making in Multi-agent Systems
Ruby Moritz, Martin Middendorf 11:10-11:35

An Ant Colony Optimization Based Memetic Algorithm for the Dynamic Travelling Salesman Problem*
Michalis Mavrovouniotis, Felipe Müller, Shengxiang Yang 11:35-12:00

The Impact of Centrality on Individual and Collective Performance in Social Problem-Solving Systems*
Diego Noble, Felipe Grando, Ricardo Araújo, Luis Lamb 12:00-12:25

Robustness of Ant Colony Optimization to Noise*
Tobias Friedrich, Timo Kötzing, Martin Krejca, Andrew Sutton 12:25-12:50

AIS-AChem

Monday, July 13, 11:10-12:50, Comendador
Chair: Jonathan Timmis (University of York); Christine Zarges (The University of Birmingham)

Securing the Internet of Things with Responsive Artificial Immune Systems
Dr. Greensmith 11:10-11:35

RAIS_TTP Revisited to Solve Relaxed Travel Tournament Problem
Elizabeth Montero, Maria-Cristina Riff 11:35-12:00

Distinguishing Adaptive Search from Random Search in Robots and T cells
George Fricke, Sarah Black, Joshua Hecker, Judy Cannon, Melanie Moses 12:00-12:25

An Immuno-inspired Approach Towards Sentence Generation
Samir Borgohain, Shivashankar Nair 12:25-12:50

EMO1

Monday, July 13, 11:10-12:50, Hidalgo
Chair: Carlos Henggeler Antunes (University of Coimbra)

A Study on Performance Evaluation Ability of a Modified Inverted Generational Distance Indicator
Hisao Ishibuchi, Hiroyuki Masuda, Yusuke Nojima 11:10-11:35

Characterizing Pareto Front Approximations in Many-objective Optimization
Md Asafuddoula, Tapabrata Ray, Hemant Singh 11:35-12:00

Improved Sampling of Decision Space for Pareto Estimation
Yiming Yan, Ioannis Giagkiozis, Peter Fleming 12:00-12:25

Finding the Trade-off between Robustness and Worst-case Quality
Juergen Branke, Ke Lu 12:25-12:50

GA1 (Best Paper Nominees are marked with an asterisk*)

Monday, July 13, 11:10-12:50, Alcalá
Chair: Ernesto Costa (University of Coimbra)

Parasite Diversity in Symbiogenetic Multiset Genetic Algorithm - Optimization of Large Binary Problems
António Manso, Luís Correia 11:10-11:35

Gray-Box Optimization using the Parameter-less Population Pyramid*
Brian Goldman, William Punch 11:35-12:00

Evolutionary Bilevel Optimization for Complex Control Tasks*
Jason Liang, Risto Miikkulainen 12:00-12:25

Mk Landscapes, NK Landscape, MAX-kSAT*
Darrell Whitley 12:25:12:50

GP1

Monday, July 13, 11:10-12:50, Patio 2
Chair: Lee Spector (Hampshire College)

Correlation Immunity of Boolean Functions: An Evolutionary Algorithms Perspective
Stjepan Picek, Claude Carlet, Domagoj Jakobovic, Julian Miller, Lejla Batina 11:10-11:35

Building Predictive Models via Feature Synthesis
Ignacio Arnaldo, Una-May O'Reilly, Kalyan Veeramachaneni 11:35-12:00

Impact of Crossover Bias in Genetic Programming
Nicholas McPhee, M. Dramdahl, David Donatucci 12:00-12:25

Strength Through Diversity: Disaggregation and Multi-Objectivisation Approaches for Genetic Programming
Jonathan Fieldsend, Alberto Moraglio 12:25-12:50

RWA1

Monday, July 13, 11:10-12:50, Doblón
Chair: Leonardo Trujillo (CICESE)

Genetic Programming for Estimation of Heat Flux between the Atmosphere and Sea Ice in Polar Regions
Karolina Stanislawska, Krzysztof Krawiec, Timo Vihma 11:10-11:35

On Evolutionary Approaches to Wind Turbine Placement with Geo-Constraints
Daniel Lückehe, Markus Wagner, Oliver Kramer 11:35-12:00

Efficient Sampling of PI Controllers in Evolutionary Multiobjective Optimization
Gilberto Reynoso-Meza, Leandro dos Santos Coelho, Roberto Z. Freite 12:00-12:25

Diversifying Multi-Objective Gradient Techniques and their Role in Hybrid Multi-Objective Evolutionary Algorithms for Deformable Medical Image Registration
Kleopatra Pirpinia, Tanja Alderliesten, Jan-Jakob Sonke, Marcel van Herk, Peter Bosman 12:25-12:50

Monday, July 13, 14:30-16:10

ACO-SI2

Monday, July 13, 14:30-16:10, Patio 3
Chair: Leslie Pérez Caceres (IRIDIA, Université Libre de Bruxelles)

An Improved Collaborative Filtering Recommendation Algorithm Based on Community Detection in Social Networks
Cen Cao, Qingjian Ni, Yuqing Zhai 14:30-14:55

Enhancing IACO$_{\mathbb{R}}$ Local Search by Mtsls1-BFGS for Continuous Global Optimization
Udit Kumar, Jayadeva Dr, Sumit Soman 14:55-15:20

Parameter Estimation in Bayesian Networks Using Overlapping Swarm Intelligence
Nathan Fortier, John Sheppard, Shane Strasser 15:20-15:45

An Ant Colony Optimizing Algorithm Based on Scheduling Preference for Maximizing Working Time of WSN
Yu Liu, Wei-Neng Chen, Xiao-min Hu, Jun Zhang 15:45-16:10

EMO2 (Best Paper Nominees are marked with an asterisk*)

Monday, July 13, 14:30-16:10, Hidalgo
Chair: Heike Trautmann (University of Munster)

An Experimental Investigation of Variation Operators in Reference-Point Based Many-Objective Optimization*
Yuan Yuan, Hua Xu, Bo Wang 14:30-14:55

Obtaining Optimal Pareto Front Approximations using Scalarized Preference Information*
Marlon Braun, Pradyumn Shukla, Hartmut Schmeck 14:55-15:20

Benchmarking Numerical Multiobjective Optimizers Revisited*
Dimo Brockhoff, Thanh-Do Tran, Nikolaus Hansen 15:20-15:45

Greedy Hypervolume Subset Selection in the Three-Objective Case*
Andreia Guerreiro, Carlos Fonseca, Luís Paquete 15:45-16:10

GA2

Monday, July 13, 14:30-16:10, Alcalá
Chair: Luís Correia (LabMAg - Univ. Lisbon)

Maintaining 2-Approximations for the Dynamic Vertex Cover Problem Using Evolutionary Algorithms
Mojgan Pourhassan, Wanru Gao, Frank Neumann 14:30-14:55

An Empirical Analysis on Dimensionality in Cellular Genetic Algorithms
Alicia Morales-Reyes, Hugo Jair Escalante, Martin Letras, Rene Cumplido 14:55-15:20

Adaptive Control of Parameter-less Population Pyramid on the Local Distribution of Inferior Individuals
Kazuyuki Inoue, Taku Hasegawa, Yuta Araki, Naoki Mori, Keinosuke Matsumoto 15:20-15:45

A Genetic Algorithm for Searching the Shortest Lattice Vector of SVP Challenge
Dan Ding, Guizhen Zhu, Xiaoyun Wang 15:45-16:10

GDS1 + PES1

Monday, July 13, 14:30-16:10, Comendador
Chair: Sebastian Risi (IT University of Copenhagen)

Confronting the Challenge of Quality Diversity
Justin Pugh, L. Soros, Paul Szerlip, Kenneth Stanley 14:30-14:55

Enhancing Divergent Search through Extinction Events
Joel Lehman, Risto Miikkulainen 14:55-15:20

Devising Effective Novelty Search Algorithms: A Comprehensive Empirical Study
Jorge Gomes, Pedro Mariano, Anders Christensen 15:20-15:45

Fast Knowledge Discovery in Time Series with GPGPU on Genetic Programming
Sungjoo Ha, Byung-Ro Moon 15:45-16:10

GP2

Monday, July 13, 14:30-16:10, Patio 2
Chair: Gisele L. Pappa (Federal University of Minas Gerais)

Using Model Checking Techniques For Evaluating the Effectiveness of Evolutionary Computing in Synthesis of Distributed Fault-Tolerant Programs
Ling Zhu, Sandeep Kulkarni 14:30-14:55

Examining the "Best of Both Worlds" of Grammatical Evolution
Peter Whigham, Grant Dick, James Maclaurin, Caitlin Owen 14:55-15:20

Performance Optimization of Multi-Core Grammatical Evolution Generated Parallel Recursive Programs
Gopinath Chennupati, R. Muhammad Azad, Conor Ryan 15:20-15:45

On the Bias of Syntactic Geometric Recombination in Genetic Programming and Grammatical Evolution
Ann Thorhauer, Franz Rothlauf 15:45-16:10

RWA2 (Best Paper Nominees are marked with an asterisk*)

Monday, July 13, 14:30-16:10, Doblón
Chair: Emma Hart (Napier University)

A Closer Look At Differential Evolution For The Optimal Well Placement Problem
Grazieli Carosio, Thomas Humphries, Ronald Haynes, Colin Farquharson 14:30-14:55

Selecting Best Investment Opportunities from Stock Portfolios Optimized by a Multiobjective Evolutionary Algorithm*
Krzysztof Michalak 14:55-15:20

Exploiting Linkage Information and Problem-Specific Knowledge in Evolutionary Distribution Network Expansion Planning*
Ngoc Hoang Luong, Han La Poutré, Peter Bosman 15:20-15:45

Evolving Solutions to TSP Variants for Active Space Debris Removal*
Dario Izzo, Ingmar Getzner, Daniel Hennes, Luís Simões 15:45-16:10

Monday, July 13, 16:40-18:45

ALIFE1

Monday, July 13, 16:40-18:45, Hidalgo
Chair: Terence Soule (University of Idaho)

Finding a Mate With No Social Skills
Chris Marriott, Jobran Chebib 16:40-17:05

The Effect of Fitness Function Design on Performance in Evolutionary Robotics
Mohammad Divband Soorati, Heiko Hamann 17:05-17:30

Improving Survivability in Environment-driven Distributed? Evolutionary Algorithms through Explicit Relative Fitness and Fitness Proportionate Communication
Emma Hart, Andreas Steyven, Ben Paechter 17:30-17:55

An Embodied Approach for Evolving Robust Visual Classifiers
Karol Zieba, Josh Bongard 17:55-18:20

BIO1+DETA1+PES2 (Best Paper Nominees are marked with an asterisk*)

Monday, July 13, 16:40-18:45, Patio 1
Chair: Stefano Cagnoni (University of Parma, Italy)

Injection, Saturation and Feedback in Meta-Heuristic Interactions*
Krzysztof Nowak, Dario Izzo, Daniel Hennes 16:40-17:05

Evolutionary Optimization of Cancer Treatments in a Cancer Stem Cell Context*
Ángel Monteagudo, José Santos 17:05-17:30

Solving Interleaved and Blended Sequential Decision-Making Problems through Modular Neuroevolution*
Jacob Schrum, Risto Miikkulainen 17:30-17:55

ECOM1

Monday, July 13, 16:40-18:45, Patio 2
Chair: Hernan Aguirre (Shinshu University)

Fighting the Symmetries: The Structure of Cryptographic Boolean Function Spaces
Stjepan Picek, Robert McKay, Roberto Santana, Tom Gedeon 16:40-17:05

Towards the User Equilibrium in Traffic Assignment Using GRASP with Path Relinking
Gabriel Ramos, Ana Bazzan 17:05-17:30

A Visual Method for Analysis and Comparison of Search Landscapes
Sebastian Volke, Dirk Zeckzer, Gerik Scheuermann, Martin Middendorf 17:30-17:55

Predicting Heuristic Search Performance with PageRank Centrality in Local Optima Networks
Sebastian Herrmann, Franz Rothlauf 17:55-18:20

Guiding Evolutionary Search with Association Rules for Solving Weighted CSPs
Madalina Raschip, Cornelius Croitoru, Kilian Stoffel 18:20-18:45

GA3

Monday, July 13, 16:40-18:45, Alcalá
Chair: Peter Bosman (Centrum Wiskunde & Informatica)

A Genetic Algorithm to Solve a Real 2-D Cutting Stock Problem with Setup Cost in the Paper Industry
Stephane Bonnevay, Philippe Aubertin, Gerald Gavin 16:40-17:05

A New Perspective on Channel Allocation in WLAN: Considering the Total Marginal Utility of the Connections for the Users
Thiago Luiz, Alan Freitas, Frederico Guimarães 17:05-17:30

Reconstructing Cross-Cut Shredded Text Documents: A Genetic Algorithm with Splicing-Driven Reproduction
Yong-Feng Ge, Yue-Jiao Gong, Wei-Jie Yu, Xiao-Min Hu, Jun Zhang 17:30-17:55

A Clustering-Based Model-Building EA for Optimization Problems with Binary and Real-Valued Variables
Krzysztof Sadowski, Peter Bosman, Dirk Thierens 17:55-18:20

A Tensor Analysis Improved Genetic Algorithm for Online Bin Packing
Shahriar Asta, Ender Ozcan 18:20-18:45

HOP1: Hot Off the Press

Monday, July 13, 16:40-18:45, Comendador
Chair: Joshua Hecker (The University of New Mexico, USA)

Beyond Pheromones: Evolving Error-Tolerant, Flexible, and Scalable Ant-Inspired Robot Swarms
Joshua P. Hecker, Melanie E. Moses 16:40-17:05

Genotype Coding, Diversity, and Dynamic Evolutionary Neural Network Environments: A Study on an Multi-agent System
Jaime Davila 17:05-17:30

Generalized Decomposition and Cross Entropy Methods for Many-Objective Optimization
Ioannis Giagkiozis, Robin C. Purshouse, Peter J. Fleming 17:30-17:55

Methods for Multi-Objective Optimization: An Analysis
Ioannis Giagkiozis, Peter J. Fleming 17:55-18:20

RWA3

Monday, July 13, 16:40-18:45, Doblón
Chair: Kevin Sim (Edinburgh Napier University)

Using Multi-Objective Artificial Immune Systems to Find Core Collections Based on Molecular Markers
Shana Schlottfeldt, Maria Emilia Walter, Jon Timmis, Andre Carvalho, Mariana Telles, Jose Alexandre Diniz-Filho 16:40-17:05

Smart Mobility Policies with Evolutionary Algorithms: The Adapting Info Panel Case
Daniel Stolfi, Enrique Alba 17:05-17:30

An Integrated Approach to Stage 1 Breast Cancer Detection
Jeannie Fitzgerald, Conor Ryan, David Medernach, Krzysztof Krawiec 17:30-17:55

Finding an Optimal LEGO(R) Brick Layout of Voxelized 3D Object Using a Genetic Algorithm
Sangyeop Lee, Jinhyun Kim, Jae Woo Kim, Byung-Ro Moon 17:55-18:20

SBSE-SS1 + EDA1 + THEORY1 **(Best Paper Nominees are marked with an asterisk*)**
Monday, July 13, 16:40-18:45, Patio 3
Chair: Gabriela Ochoa (University of Stirling)

Optimal Parameter Choices Through Self-Adjustment: Applying the 1/5-th Rule in Discrete Settings
Benjamin Doerr, Carola Doerr 16:40-17:05

Random or Genetic Algorithm Search for Object-Oriented Test Suite Generation?*
Sina Shamshiri, José Miguel Rojas, Gordon Fraser, Phil McMinn 17:05-17:30

Extracting Variability-Safe Feature Models from Source Code Dependencies in System Variants*
Wesley Assunção, Roberto Lopez-Herrejon, Lukas Linsbauer, Silvia Vergilio, Alexander Egyed 17:30-17:55

Kernels of Mallows Models for Solving Permutation-based Problems*
Josu Ceberio, Alexander Mendiburu, Jose Lozano 17:55-18:20

Improved Runtime Bounds for the (1+1) EA on Random 3-CNF Formulas Based on Fitness-Distance Correlation*
Benjamin Doerr, Frank Neumann, Andrew Sutton 18:20-18:45

Tuesday, July 14, 11:10-12:50

ACO-SI3

Tuesday, July 14, 11:10-12:50, Comendador
Chair: Andries P. Engelbrecht (University of Pretoria)

A Set-based Comprehensive Learning Particle Swarm Optimization with Decomposition for Multiobjective Traveling Salesman Problem
Xue Yu, Wei-Neng Chen, Xiao-min Hu, Jun Zhang 11:10-11:35

The Effect of Quantum and Charged Particles on the Performance of the Dynamic Vector-evaluated Particle Swarm Optimisation Algorithm
Marde Helbig, Andries Engelbrecht 11:35-12:00

Input-to-State Stability Analysis on Particle Swarm Optimization
Daqing Yi, Kevin Seppi, Michael Goodrich 12:00-12:25

Particle Swarm Optimization Based on Linear Assignment Problem Transformations
Luis Miguel Antonio, Carlos Artemio Coello Coello 12:25-12:50

CO1 (Best Paper Nominees are marked with an asterisk*)

Tuesday, July 14, 11:10-12:50, Patio 1
Chair: Ilya Loshchilov (INRIA, University Paris-Sud)

Detecting Funnel Structures by Means of Exploratory Landscape Analysis
Pascal Kerschke, Mike Preuss, Simon Wessing, Heike Trautmann 11:10-11:35

Sample Reuse in the Covariance Matrix Adaptation Evolution Strategy Based on Importance Sampling
Shinichi Shirakawa, Youhei Akimoto, Kazuki Ouchi, Kouzou Ohara 11:35-12:00

Towards an Analysis of Self-Adaptive Evolution Strategies on the Noisy Ellipsoid Model*
Alexander Melkozerov, Hans-Georg Beyer 12:00-12:25

Towards an Augmented Lagrangian Constraint Handling Approach for the (1+1)-ES*
Dirk Arnold, Jeremy Porter 12:25-12:50

DETA2

Tuesday, July 14, 11:10-12:50, Patio 3
Chair: Amy K. Hoover (University of Malta)

Controlling Crowd Simulations using Neuro-Evolution
Sunrise Wang, James Gain, Geoff Nistchke 11:10-11:35

Open Loop Search for General Video Game Playing
Diego Perez Liebana, Jens Dieskau, Martin Hunermund, Sanaz Mostaghim, Simon Lucas 11:35-12:00

Darwin's Avatars: a Novel Combination of Gameplay and Procedural Content Generation
Dan Lessin, Sebastian Risi 12:00-12:25

Interactively Evolving Compositional Sound Synthesis Networks
Björn Jónsson, Amy Hoover, Sebastian Risi 12:25-12:50

ECOM2

Tuesday, July 14, 11:10-12:50, Doblón
Chair: Francisco Baptista Pereira (Instituto Superior de Engenharia de Coimbra)

A Genetic Algorithm for Scheduling Electric Vehicle Charging
Jorge García-Álvarez, Miguel A. González, Camino R. Vela 11:10-11:35

A Dispatching rule based Genetic Algorithm for Order Acceptance and Scheduling
Su Nguyen, Mengjie Zhang, Tan Kay Chen 11:35-12:00

On the Impact of Local Search Operators and Variable Neighbourhood Search for the Generalized Travelling Salesperson Problem
Mojgan Pourhassan, Frank Neumann 12:00-12:25

A Novel Diversity-based Evolutionary Algorithm for the Traveling Salesman Problem
Carlos Segura, Salvador Botello Rionda, Arturo Hernández Aguirre, S. Ivvan Valdez Peña 12:25-12:50

EMO3

Tuesday, July 14, 11:10-12:50, Hidalgo
Chair: Christian Grimme (Münster University)

Improving Robustness of Stopping Multi-objective Evolutionary Algorithms by Simultaneously Monitoring Objective and Decision Space
Md Shahriar Mahbub, Tobias Wagner, Luigi Crema 11:10-11:35

An Approach to Mitigating Unwanted Interactions between Search Operators in Multi-Objective Optimization
Chad Byers, Betty Cheng 11:35-12:00

Fast Implementation of the Steady-State NSGA-II Algorithm for Two Dimensions Based on Incremental Non-Dominated Sorting
Maxim Buzdalov, Ilya Yakupov, Andrey Stankevich 12:00-12:25

A Performance Comparison Indicator for Pareto Front Approximations in Many-Objective Optimization
Miqing Li, Shengxiang Yang, Xiaohui Liu 12:25-12:50

GP3

Tuesday, July 14, 11:10-12:50, Patio 2
Chair: Nicholas Freitag McPhee (University of Minnesota, Morris)

General Program Synthesis Benchmark Suite
Thomas Helmuth, Lee Spector 11:10-11:35

Improving CUDA DNA Analysis Software with Genetic Programming
William Langdon, Brian Lam, Justyna Petke, Mark Harman 11:35-12:00

Efficient Evolution of High Entropy RNGs Using Single Node Genetic Programming
Philip Leonard, David Jackson 12:00-12:25

A Re-Examination of the Use of Genetic Programming on the Oral Bioavailability Problem
Grant Dick, Aysha Rimoni, Peter Whigham 12:25-12:50

HOP2: Hot Off the Press

Tuesday, July 14, 11:10-12:50, Escudo
Chair: Julian Miller (University of York)

Tuesday, July 14, 14:30-16:10

CO2

Tuesday, July 14, 14:30-16:10, Comendador
Chair: Nikolaus Hansen (INRIA-Saclay)

Dichotomy Guided Based Parameter Adaptation for Differential Evolution
Xiao-Fang Liu, Zhi-Hui Zhan, Jun Zhang 14:30-14:55

A New Repair Method For Constrained Optimization
Patrick Koch, Samineh Bagheri, Wolfgang Konen, Christophe Foussette, Peter Krause, Thomas Baeck 14:55-15:20

A Repair Method for Differential Evolution with Combined Variants to Solve Dynamic Constrained Optimization Problems
María-Yaneli Ameca-Alducin, Efrén Mezura-Montes, Nicandro Cruz-Ramírez 15:20-15:45

ECOM3 (Best Paper Nominees are marked with an asterisk*)

Tuesday, July 14, 14:30-16:10, Doblón
Chair: Carlos Cotta (University of Málaga)

Global vs Local Search on Multi-objective NK-Landscapes: Contrasting the Impact of Problem Features*
Fabio Daolio, Arnaud Liefooghe, Sébastien Verel, Hernán Aguirre, Kiyoshi Tanaka 14:30-14:55

A Sequence-based Selection Hyper-heuristic Utilising a Hidden Markov Model*
Ahmed Kheiri, Ed Keedwell 14:55-15:20

Tunnelling Crossover Networks*
Gabriela Ochoa, Francisco Chicano, Renato Tinos, Darrell Whitley 15:20-15:45

Hyperheuristics Based on Parametrized Metaheuristic Schemes
José-Matías Cutillas-Lozano, Domingo Giménez, Francisco Almeida 15:45-16:10

EMO4

Tuesday, July 14, 14:30-16:10, Hidalgo
Chair: Heike Trautmann (University of Munster)

Multi-objective Optimization with Dynamic Constraints and Objectives: New Challenges for Evolutionary Algorithms
Radhia Azzouz, Slim Bechikh, Lamjed Ben Said 14:30-14:55

A New Framework for Self-adapting Control Parameters in Multi-objective Optimization
Xin Qiu, Weinan Xu, Jian-Xin Xu, Kay Chen Tan 14:55-15:20

Incorporating User Preferences in MOEA/D through the Coevolution of Weights
Martin Pilat, Roman Neruda 15:20-15:45

Empirical Study of Multi-objective Ant Colony Optimization to Software Project Scheduling Problems
Jing Xiao, Mei-Ling Gao, Min-Mei Huang 15:45-16:10

GP4 (Best Paper Nominees are marked with an asterisk*)

Tuesday, July 14, 14:30-16:10, Patio 2
Chair: Krzysztof Krawiec (Institute of Computing Science, Poznan University of Technology) and Alberto Moraglio (University of Exeter)

Geometric Semantic Genetic Programming with Local Search
Mauro Castelli, Leonardo Trujillo, Leonardo Vanneschi, Sara Silva, Emigdio Z-Flores, Pierrick Legrand 14:30-14:55

An Efficient Structural Diversity Technique for Genetic Programming*
Armand Burks, William Punch 14:55-15:20

Genetic Programming with Epigenetic Local Search*
William La Cava, Thomas Helmuth, Lee Spector, Kourosh Danai 15:20-15:45

Memetic Semantic Genetic Programming*
Robyn Ffrancon, Marc Schoenauer 15:45-16:10

HOP3: Hot Off the Press

Tuesday, July 14, 14:30-16:10, Escudo
Chair: Jason Moore (Dartmouth College)

Artificial Immune System Driven Evolution in Swarm Chemistry
Emma Hart, Nicola Capodieci, Giacomo Cabri 14:30-14:55

Incorporating Dynamism in Emergency Route Planning Problem using Immune-Based Approach
Mohd Nor Akmal Khalid, Umi Kalsom Yusof 14:55-15:20

Gene Regulatory Network Evolution Through Augmenting Topologies
Sylvain Cussat-Blanc, Kyle Harrington, Jordan Pollack 15:20-15:45

ExSTraCS 2.0: Description and Evaluation of a Scalable Learning Classifier System
Ryan Urbanowicz, Jason Moore 15:45-16:10

RWA4

Tuesday, July 14, 14:30-16:10, Patio 3
Chair: Edgar Galvan (Trinity College Dublin)

A Model with Evolutionary Covariance-based Learning for High-Frequency Financial Forecasting
Ricardo Araujo, Adriano Oliveira, Silvio Meira 14:30-14:55

Diversity Guided Evolutionary Mining of Hierarchical Process Models
Thomas Molka, David Redlich, Marc Drobek, Xiao-Jun Zeng, Wasif Gilani 14:55-15:20

A Biased Random-key Genetic Algorithm for Placement of Virtual Machines across Geo-Separated Data Centers
Fernando Stefanello, Vaneet Aggarwal, Luciana Buriol, José Gonçalves, Mauricio Resende 15:20-15:45

A Genetic Programming Approach to Cost-Sensitive Control in Resource Constrained Sensor Systems
Afsoon Yousefi Zowj, Josh Bongard, Christian Skalka 15:45-16:10

SBSE-SS2

Tuesday, July 14, 14:30-16:10, Patio 1
Chair: Marouane Kessentini (University of Michigan)

Learning Feature-Parameter Mappings for Parameter Tuning via the Profile Expected Improvement
Jakob Bossek, Bernd Bischl, Tobias Wagner, Günter Rudolph 14:30-14:55

Operator Selection using Improved Dynamic Multi-Armed Bandit
Jany Belluz, Marco Gaudesi, Giovanni Squillero, Alberto Tonda 14:55-15:20

Reducing Energy Consumption Using Genetic Improvement
Bobby Bruce, Justyna Petke, Mark Harman 15:20-15:45

Web Service Antipatterns Detection Using Genetic Programming
Ali Ouni, Raula Gaikovina Kula, Marouane Kessentini, Katsuro Inoue 15:45-16:10

THEORY2 + EDA2

Tuesday, July 14, 14:30-16:10, Alcalá
Chair: Carola Doerr (CNRS and Univ. Sorbonne Paris 6)

First Steps Towards a Runtime Comparison of Natural and Artificial Evolution
Tiago Paixao, Jorge Perez Heredia, Dirk Sudholt, Barbora Trubenova 14:30-14:55

Population Size vs. Mutation Strength for the (1+λ) EA on OneMax
Christian Giessen, Carsten Witt 14:55-15:20

Theoretical Perspective of Convergence Complexity of Evolutionary Algorithms Adopting Optimal Mixing
Yu-Fan Tung, Tian-Li Yu 15:20-15:45

Populations can be Essential in Dynamic Optimisation
Duc-Cuong Dang, Thomas Jansen, Per Kristian Lehre 15:45-16:10

Tuesday, July 14, 16:40-18:20

ALIFE2 + GDS2 (Best Paper Nominees are marked with an asterisk*)

Tuesday, July 14, 16:40-18:20, Patio 1
Chair: Jean-Baptiste Mouret (ISIR - UPMC/CNRS)

Evolving Soft Robots in Tight Spaces
Nick Cheney, Josh Bongard, Hod Lipson 16:40-17:05

Evolving Robot Morphology Facilitates the Evolution of Neural Modularity and Evolvability
Josh Bongard, Anton Bernatskiy, Ken Livingston, Nicholas Livingston, John Long, Marc Smith 17:05-17:30

Novelty-Based Evolutionary Design of Morphing Underwater Robots*
Francesco Corucci, Marcello Calisti, Helmut Hauser, Cecilia Laschi 17:30-17:55

Innovation Engines: Automated Creativity and Improved Stochastic Optimization via Deep Learning*
Anh Nguyen, Jason Yosinski, Jeff Clune 17:55-18:20

BIO2+RWA5

Tuesday, July 14, 16:40-18:20, Patio 3
Chair: Mario Giacobini (University of Torino)

Evolution Strategies for Exploring Protein Energy Landscapes
Rudy Clausen, Emmanuel Sapin, Kenneth De Jong, Amarda Shehu 16:40-17:05

An Analysis of Integration of Hill Climbing in Crossover and Mutation operation for EEG Signal Classification
Arpit Bhardwaj, Aruna Tiwari, Vishaal Madaka, Ramesh Maddula 17:05-17:30

Metabolic Design And Engineering Through Ant Colony Optimization
Stephen Lincoln, Ian Rogers, Ranjan Srivastava 17:30-17:55

Evolutionary Learning of Syntax Patterns for Genic Interaction Extraction
Alberto Bartoli, Andrea De Lorenzo, Eric Medvet, Fabiano Tarlao, Marco Virgolin 17:55-18:20

ECOM4

Tuesday, July 14, 16:40-18:20, Doblón
Chair: Leonardo Vanneschi (ISEGI, Universidade Nova de Lisboa)

Minimizing Regular Objectives for Blocking Permutation Flow Shop Scheduling: Heuristic Approaches
Nouha Nouri, Talel Ladhari 16:40-17:05

Approximate Approaches to the Traveling Thief Problem
Hayden Faulkner, Sergey Polyakovskiy, Tom Schultz, Markus Wagner 17:05-17:30

On the Empirical Scaling Behaviour of State-of-the-art Local Search Algorithms for the Euclidean TSP
Jérémie Dubois-Lacoste, Holger Hoos, Thomas Stützle 17:30-17:55

Evaluation of a Multi-Objective EA on Benchmark Instances for Dynamic Routing of a Vehicle
Stephan Meisel, Christian Grimme, Jakob Bossek, Martin Wölck, Günter Rudolph, Heike Trautmann 17:55-18:20

EML1 (Best Paper Nominees are marked with an asterisk*)

Tuesday, July 14, 16:40-18:20, Comendador
Chair: Jan Koutnik (IDSIA)

Retooling Fitness for Noisy Problems in a Supervised Michigan-style Learning Classifier System
Ryan Urbanowicz, Jason Moore 16:40-17:05

High-Dimensional Function Approximation for Knowledge-Free Reinforcement Learning: a Case Study in SZ-Tetris
Wojciech Jaśkowski, Marcin Szubert, Paweł Liskowski, Krzysztof Krawiec 17:05-17:30

Simpler is Better: a Novel Genetic Algorithm to Induce Compact Multi-label Chain Classifiers*
Eduardo Gonçalves, Alexandre Plastino, Alex Freitas 17:30-17:55

Subspace Clustering Using Evolvable Genome Structure*
Sergio Peignier, Christophe Rigotti, Guillaume Beslon 17:55-18:20

EMO5

Tuesday, July 14, 16:40-18:20, Hidalgo
Chair: Carlos Henggeler Antunes (University of Coimbra)

A PSO Approach to Semivectorial Bilevel Programming: Pessimistic, Optimistic and Deceiving Solutions
Maria João Alves, Carlos Antunes, Pedro Carrasqueira 16:40-17:05

Multi-Objective BDD Optimization with Evolutionary Algorithms
Saeideh Shirinzadeh, Mathias Soeken, Rolf Drechsler 17:05-17:30

MOEA/VAN: Multiobjective Evolutionary Algorithm Based on Vector Angle Neighborhood
Roman Denysiuk, Lino Costa, Isabel Espírito Santo 17:30-17:55

Improved Metaheuristic Based on the R2 Indicator for Many-Objective Optimization
Raquel Hernández Gómez, Carlos Coello Coello 17:55-18:20

GA4 + THEORY3

Tuesday, July 14, 16:40-18:20, Alcalá
Chair: Per Kristian Lehre (University of Nottingham)

Elitist Black-Box Models: Analyzing the Impact of Elitist Selection on the Performance of Evolutionary Algorithms
Carola Doerr, Johannes Lengler 16:40-17:05

Money for Nothing: Speeding Up Evolutionary Algorithms Through Better Initialization
Axel de Perthuis de Laillevault, Benjamin Doerr, Carola Doerr 17:05-17:30

On the Utility of Island Models in Dynamic Optimization
Andrei Lissovoi, Carsten Witt 17:30-17:55

Solving Problems with Unknown Solution Length at (Almost) No Extra Cost
Benjamin Doerr, Carola Doerr, Timo Kützing 17:55-18:20

GP5

Tuesday, July 14, 16:40-18:20, Patio 2
Chair: William B. Langdon (University College London)

Evolutionary Image Descriptor: A Dynamic Genetic Programming Representation for Feature Extraction
Harith Al-Sahaf, Mengjie Zhang, Mark Johnston 16:40-17:05

Multiple Objective Vector-Based Genetic Programming Using Human-Derived Primitives
Jason Zutty, Daniel Long, Heyward Adams, Gisele Bennett, Christina Baxter 17:05-17:30

A GP-based Video Game Player
Baozhu Jia, Marc Ebner, Christian Schack 17:30-17:55

GEFPSO: A Framework for PSO Optimization based on Grammatical Evolution
Péricles Miranda, Ricardo Prudéncio 17:55-18:20

HOP4: Hot Off the Press

Tuesday, July 14, 16:40-18:20, Escudo
Chair: Lee Spector (Hampshire College)

The effects of asymmetric neighborhood assignment in the MOEA/D algorithm
Krzysztof Michalak 16:40-17:05

Shift-Based Density Estimation for Pareto-Based Algorithms in Many-Objective Optimization
Miqing Li, Shengxiang Yang, Xiaohui Liu 17:05-17:30

Genetic programming and serial processing for time series classification
Eva Alfaro-Cid, Ken Sharman, Anna I. Esparcia-Alcázar 17:30-17:55

Solving Uncompromising Problems with Lexicase Selection
Thomas Helmuth, Lee Spector, James Matheson 17:55-18:20

Wednesday, July 15, 12:25-14:05

ALIFE3

Wednesday, July 15, 12:25-14:05, Patio 2
Chair: Luis Correia (BioISI, Universidade de Lisboa)

Three-fold Adaptivity in Groups of Robots: The Effect of Social Learning
Jacqueline Heinerman, Dexter Drupsteen, A.E. Eiben 12:25-12:50

Novelty Search for Soft Robotic Space Exploration
Georgios Methenitis, Daniel Hennes, Dario Izzo, Arnoud Visser 12:50-13:15

Enhancing a Model-Free Adaptive Controller through Evolutionary Computation
Anthony Clark, Philip McKinley, Xiaobo Tan 13:15-13:40

Decentralized Innovation Marking for Neural Controllers in Embodied Evolution
Iñaki Fernández Pérez, Amine Boumaza, François Charpillet 13:40-14:05

CO3

Wednesday, July 15, 12:25-14:05, Alcalá
Chair: Dirk V. Arnold (Dalhousie University)

Extended Differential Grouping for Large Scale Global Optimization with Direct and Indirect Variable Interactions
Yuan Sun, Michael Kirley, Saman Halgamuge 12:25-12:50

A CMA-ES with Multiplicative Covariance Matrix Updates
Oswin Krause, Tobias Glasmachers 12:50-13:15

Global Line Search Algorithm Hybridized with Quadratic Interpolation and Its Extension to Separable Functions
Petr Baudiš, Petr Pošík 13:15-13:40

EDA3

Wednesday, July 15, 12:25-14:05, Patio 1
Chairs: Pedro Larrañaga (University of the Basque Country) and Marta Soto (ICIMAF)

Optimization by Pairwise Linkage Detection, Incremental Linkage Set, and Restricted / Back Mixing: DSMGA-II
Shih-Huan Hsu, Tian-Li Yu 12:25-12:50

An Estimation of Distribution Algorithm based on the Natural Gradient and the Boltzmann Distribution
Ignacio Segovia-Dominguez, Arturo Hernandez-Aguirre 12:50-13:15

Simplified Runtime Analysis of Estimation of Distribution Algorithms
Duc-Cuong Dang, Per Kristian Lehre 13:15-13:40

EML2

Wednesday, July 15, 12:25-14:05, Comendador
Chair: Julia Handl (University of Manchester)

Multiple Imputation for Missing Data Using Genetic Programming
Cao Truong Tran, Mengjie Zhang, Peter Andreae 12:25-12:50

Genetically-regulated Neuromodulation Facilitates Multi-Task Reinforcement Learning
Sylvain Cussat-Blanc, Kyle Harrington 12:50-13:15

Ant Colony and Surrogate Tree-Structured Models for Orderings-Based Bayesian Network Learning
Juan I. Alonso-Barba, Luis de la Ossa, Olivier Regnier-Coudert, John McCall, José A. Gómez, José M. Puerta 13:15-13:40

EMO6

Wednesday, July 15, 12:25-14:05, Hidalgo
Chair: Günter Rudolph (TU Dortmund)

Analysis of Objectives Relationships in Multiobjective Problems Using Trade-Off Region Maps
Rodrigo Pinheiro, Dario Landa-Silva, Jason Atkin 12:25-12:50

Injecting CMA-ES into MOEA/D
Saúl Zapotecas-Martínez, Bilel Derbel, Arnaud Liefooghe, Dimo Brockhoff, Hernán Aguirre, Kiyoshi Tanaka 12:50-13:15

On Maintaining Diversity in MOEA/D: Application to a Biobjective Combinatorial FJSP
Juan Jose Palacios, Bilel Derbel 13:15-13:40

Parallel Multi-Objective Evolutionary Design of Approximate Circuits
Radek Hrbacek 13:40-14:05

IGEC + ECOM5

Wednesday, July 15, 12:25-14:05, Doblón
Chair: Paweł Widera (Newcastle University)

Knowledge Transfer from Keepaway Soccer to Half-field Offense through Program Symbiosis: Building Simple Programs for a Complex Task
Stephen Kelly, Malcolm Heywood 12:25-12:50

A Local Search Approach to Genetic Programming for Binary Classification
Emigdio Z-Flores, Leonardo Trujillo, Oliver Schütze, Pierrick Legrand 12:50-13:15

Evolving Strategies for Social Innovation Games
Erkin Bahceci, Riitta Katila, Risto Miikkulainen 13:15-13:40

Generator Start-up Sequences Optimization for Network Restoration Using Genetic Algorithm and Simulated Annealing
Paul Kaufmann, Cong Shen 13:40-14:05

SBSE-SS3

Wednesday, July 15, 12:25-14:05, Patio 3
Chair: Yuanyuan Zhang (University College London)

Heuristic Model Checking using a Monte-Carlo Tree Search Algorithm
Simon Poulding, Robert Feldt 12:25-12:50

SPRINT Multi-Objective Model Racing
Tiantian Zhang, Michael Georgiopoulos, Georgios Anagnostopoulos 12:50-13:15

Deep Parameter Optimisation
Fan Wu, Westley Weimer, Mark Harman, Yue Jia, Jens Krinke 13:15-13:40

A Hyper-Heuristic for the Multi-Objective Integration and Test Order Problem
Giovani Guizzo, Gian Fritsche, Silvia Vergilio, Aurora Pozo 13:40-14:05

THEORY4

Wednesday, July 15, 12:25-14:05, Escudo
Chair: Francisco Chicano (University of Málaga)

An Evolutionary Game Theoretic Analysis of Difference Evaluation Functions
Mitchell Colby, Kagan Tumer 12:25-12:50

On Easiest Functions for Somatic Contiguous Hypermutations And Standard Bit Mutations
Dogan Corus, Jun He, Thomas Jansen, Pietro Oliveto, Dirk Sudholt, Christine Zarges 12:50-13:15

A Tight Runtime Analysis of the $(1 + (\lambda, \lambda))$ Genetic Algorithm on OneMax
Benjamin Doerr, Carola Doerr 13:15-13:40

OneMax in Black-Box Models with Several Restrictions
Carola Doerr, Johannes Lengler 13:40-14:05

Poster Session

Monday, July 13, 18:45-20:45, Tapices

ACO-SI

Solving Euclidean Steiner Tree Problems with Multi Swarm Optimization
Tom Decroos, Patrick De Causmaecker, Bart Demoen

Performance Comparison of Ant Colony Algorithms for the Scheduling of Steel Production Lines
Silvino Fernández, Segundo Álvarez, Eneko Malatsetxebarria, Pablo Valledor, Diego Díaz

Enhancing Incremental Ant Colony Algorithm for Continuous Global Optimization
Udit Kumar, Jayadeva Dr, Sumit Soman

Renumber Coevolutionary Multiswarm Particle Swarm Optimization for Multi-objective Workflow Scheduling on Cloud Computing Environment
Hai-Hao Li, Zong-Gan Chen, Zhi-Hui Zhan, Ke-Jing Du, Jun Zhang

Heuristic Search by Particle Swarm Optimization of Boolean Functions for Cryptographic Applications
Luca Mariot, Alberto Leporati

Automatic Tuning of Standard PSO Versions
Roberto Ugolotti, Stefano Cagnoni

A Dimension-Decreasing Particle Swarm Optimization Method for Portfolio Optimization
Jia-bin Wang, Wei-Neng Chen, Jun Zhang, Ying Lin

AIS-ACHEM

Grid Diversity Operator for Some Population-Based Optimization Algorithms
Ahmed Salah, Emma Hart

A Grid-facilitated AIS-based Network Scheme For Many-objective Optimization
Wilburn W. P. Tsang, Henry Y. K. Lau

ALIFE

Trading Off Resource Utilization and Task Migrations in Dynamic Load-balancing
Juan Luis Jiménez Laredo, Frédéric Guinand, Damien Olivier, Pascal Bouvry

Evolutionary Approximation of Complex Digital Circuits
Zdenek Vasicek, Lukas Sekanina

Impact of Speciation Heuristic on Crossover and Search in NEAT
Phillip Verbancsics

Crowdseeding Robot Design
Mark Wagy, Josh Bongard

CO

Investigation of Gaussian Processes and Random Forests as Surrogate Models for Evolutionary Black-Box Optimization
Lukas Bajer, Zbynek Pitra, Martin Holena

Is Global Sensitivity Analysis Useful to Evolutionary Computation?
Thomas Chabin, Alberto Tonda, Evelyne Lutton

Infeasibility Driven Evolutionary Algorithm with the Anticipation Mechanism for the Reaching Goal in Dynamic Constrained Inverse Kinematics
Patryk Filipiak, Krzysztof Michalak, Piotr Lipinski

A Reliable and Computationally Cheap Approach for Finding Robust Optimal Solutions
Seyedali Mirjalili, Andrew Lewis

A Note on Multi-Funnel Functions for Expensive Optimization Scenario
Ryoji Tanabe

An Effective Approach for Adapting the Size of Subcomponents in Large-Scale Optimization with Cooperative Coevolution
Giuseppe Trunfio

DETA

Estimating and Predicting Average Likability on Computer-Generated Artwork Variants
Jabier Martinez, Gabriele Rossi, Tewfik Ziadi, Tegawendé Bissyandé, Jacques Klein, Yves Le Traon

ECOM

Landscape Properties of the 0-1 Knapsack Problem
Khulood Alyahya, Jonathan Rowe

An Improved Co-evolutionary Decomposition-based Algorithm for Bi-level Combinatorial Optimization
Abir Chaabani, Slim Bechikh, Lamjed Ben Said, Radhia Azzouz

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An Algebraic Differential Evolution for the Linear Ordering Problem
Valentino Santucci, Marco Baioletti, Alfredo Milani

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Thiago Stehling, Sérgio de Souca, Moacir D.F. Filho

EDA

Herding Evolutionary Algorithm
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MOGCLA: A Multi-Objective Genetic Clustering Algorithm for Large Data Analysis.
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Todd Perry, Mohamed Bader-El-Den

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Evolutionary Search for An Accurate Contour Segmentation in Histopathological Images
Catalin Stoean, Ruxandra Stoean, Adrian Sandita, Cristian Mesina, Corina Gruia, Daniela Ciobanu

Enable the XCS to Dynamically Learn Multiple Problems?A Sensor Tagging Approach
Yao-Ming Wu, Liang-Yu Chen, Po-Ming Lee, Tzu-Chien Hsiao

Model Selection and Overfitting in Genetic Programming: Empirical Study
Jan Žegklitz, Petr Pošík

EMO

Insertion of Artificial Individuals to Increase the Diversity of Multiobjective Evolutionary Algorithms
Jamisson Freitas, Cícero Garrozi, Mêuser Valença

A Comparative Study Use of OTL for Many-objective Optimization
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Averaged Hausdorff Approximations of Pareto Fronts based on Multiobjective Estimation of Distribution Algorithms
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Handling Crossover Bias to Improve Diversity in Multiobjective Evolutionary Optimization
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Fast Pareto Front Approximation for Cloud Instance Pool Optimization
Ana-Maria Oprescu, Alexandra (Vintila) Filip, Thilo Kielmann

Using Novelty-Biased GA to Sample Diversity in Graphs Satisfying Constraints
Peter Overbury, Luc Berthouze

Multi-objective NM-landscapes
Roberto Santana, Alexander Mendiburu, Jose Lozano

Dimensionality Reduction in Many-objective Problems Combining PCA and Spectral Clustering
Christian von Lücken, Hugo Monzón, Carlos Brizuela, Benjamín Barán

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An Empirical Comparison of Genetically Evolved Programs and Evolved Neural Networks for Multi-agent Systems Operating under Dynamic Environments
Jaime Davila

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Evolving Smart Initial Layouts for Force-Directed Graph Drawing
Farshad Ghassemi Toosi, Nikola S Nikolov, Malachy Eaton

Identification of Switched Models in Non-Stationary Time Series based on Coordinate-Descent and Genetic Algorithm
Mohammad Gorji Sefidmazgi, Mina Moradi Kordmahalleh, Abdollah Homaifar

An Adeaptive Method of Hungarian Mating Schemes in Genetic Algorithms
Chanju Jung, Yong-Hyuk Kim, Yourim Yoon, Byung-Ro Moon

When Hillclimbers Beat Genetic Algorithms in Multimodal Optimization
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On the Uselessness of Finite Benchmarks to Assess Evolutionaryand Swarm Methods
Pablo Rabanal, Ismael Rodríguez, Fernando Rubio

Pyramidal Neural Networks with Variable Receptive Fields Designed by Genetic Algorithms
Alessandra Soares, Bruno Fernandes, Carmelo Bastos-Filho

GP

Genetic C Programming with Probabilistic Evaluation
Jacqueline Christmas

Wave: A Genetic Programming Approach to Divide and Conquer
David Medernach, Jeannie Fitzgerald, R. Muhammad Atif Azad, Conor Ryan

Avoiding Overfitting in Symbolic Regression Using the First Order Derivative of GP Trees
Samaneh Sadat Mousavi Astarabadi, Mohammad Mehdi Ebadzadeh

A Single Population Genetic Programming based Ensemble Learning Approach to Job Shop Scheduling
John Park, Su Nguyen, Mengjie Zhang, Mark Johnston

Cartesian Genetic Programming Approach for Generating Substitution Boxes of Different Sizes
Stjepan Picek, Julian Miller, Domagoj Jakobovic, Lejla Batina

Evolutionary Cross-Domain Hyper-Heuristics
Patricia Ryser-Welch, Julian Miller, Shariar Asta

Recurrent Cartesian Genetic Programming Applied to Series Forecasting
Andrew Turner, Julian Miller

The Programming Game: Evaluating MCTS as an Alternative to GP for Symbolic Regression
David White, Shin Yoo, Jeremy Singer

IGEC

A Collaborative Strategy to Reduce Initial Setup Requirements of ParamILS using EvoCa
Maria-Cristina Riff, Elizabeth Montero

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A Comparison Exercise on Parallel Evaluation of Rosenbrock Function
Miguel Cárdenas-Montes, Miguel Angel Vega-Rodríguez, Juan José Rodríguez-Vázquez, Antonio Gómez-Iglesias

On the Automatic Generation of Efficient Parallel Iterative Sorting Algorithms
Gopinath Chennupati, R. Muhammad Azad, Conor Ryan

Asynchronous Parallel Evolutionary Algorithms: Leveraging Heterogeneous Fitness Evaluation Times for Scalability and Elitist Parsimony Pressure
Matthew Martin, Alex Bertels, Daniel Tauritz

RWA

Grammatical Evolution for Identifying Wikipedia Taxonomies
Lourdes Araujo, Juan Martinez-Romo, Andrés Duque

A Combinatorial Genetic Algorithm for Computational Doping based Material Design
Emrah Atilgan, Jianjun Hu

Energy Efficient Allocation and Scheduling for DVFS-enabled Multicore Environments using a Multiobjective Evolutionary Algorithm
Zorana Bankovic, Pedro López-García

Variance Reduction in Population-Based Optimization: Application to Unit Commitment
Jérémie Decock, Jialin Liu, Olivier Tetaud

Learning from Demonstration for Distributed, Encapsulated Evolution of Autonomous Outdoor Robots
Travis DeVautl, Seth Forrest, Ian Tanimoto, Terence Soule, Robert Heckendorn

Optimizing Performance of L1 Cache Memory for Embedded Systems driven by Differential Evolution
Josefa Díaz Álvarez, J. Manuel Colmenar, José L. Risco-Martín, Juan Lanchares

Learning Based Control of a Fuel Cell Turbine Hybrid Power System
Andrew Gabler, Mitchell Colby, Kagan Tumer

A Multimodal Optimization and Surprise Based Consensus Community Detection Algorithm
Guanbo Jia, Shan He, Zexuan Zhu, Jing Liu, Ke Tang

Social Specialization of Space: Clustering Households on the French Riviera
Denis Pallez, Mathieu Serrurier, Célia Pereira, Giovanni Fusco, Cristina Cao

On the Model Selection of Bernoulli Restricted Boltzmann Machines Through Harmony Search
Joao Papa, Gustavo Rosa, Kelton Costa, Nilceu Marana, Walter Scheirer, David Cox

Exploiting Evolutionary Computation in an Industrial Flow for the Development of Code-Optimized Microprocessor Test Programs
Cantoro Riccardo, Marco Gaudesi, Ernesto Sanchez, Giovanni Squillero

Using Anti-pheromone to Identify Core Objects for Multidimensional Knapsack Problems: A Two-step Ants based Approach
Nicolás Rojas, María-Cristina Riff, Elizabeth Montero

Potential-Field-Based Unit Behavior Optimization for Balancing in StarCraft II
Jonas Schmitt, Sabine Seufert, Christian Zoubek, Harald Köstler

Multi-Modal Employee Routing with Time Windows in an Urban Environment
Neil Urquhart, Emma Hart, Alistair Judson

Classifying Maritime Vessels from Satellite Imagery with HyperNEAT
Phillip Verbancsics, Josh Harguess

Software System for Container Vessel Stowage Planning using Genetic Algorithm
Miri Weiss Cohen, Adi Dahan, Izzik Kaspi

SBSE-SS

Improving Test Coverage of Formal Verification Systems via Beam Search
Mahmoud Bokhari, Markus Wagner

A Novelty Search-based Test Data Generator for Object-oriented Programs
Mohamed Boussaa, Olivier Barais, Gerson Sunye, Benoit Baudry

A Multi-objective Evolutionary Algorithm for Rule-based Performance Optimization at Software Architecture Level
Xin Du, You Ni, Peng Ye

New Adaptive Selection Strategies for Distributed Adaptive Metaheuristic Selection
Christopher Jankee, Sébastien Verel, Bilel Derbel, Cyril Flonlupt

A Search Based Approach Towards Robust Optimization in Software Product Line Scoping
Reza Karimpour, Guenther Ruhe

A Novel Heuristic Generator for JSSP Using a Tree-Based Representation of Dispatching Rules
Kevin Sim, Emma Hart

THEORY

Criteria and Convergence Rates in Noisy Optimization
Sandra Astete-Morales, Marie-Liesse Cauwet, Olivier Teytaud

Explanation of Stagnation at Points that are not Local Optima in Particle Swarm Optimization by Potential Analysis
Alexander Rass, Manuel Schmitt, Rolf Wanka

Efficient Sampling with Small Populations: a Genetic Algorithm Satisfying Detailed Balance
Chris Watkins, Yvonne Buttkewitz

Abstracts by Track

Ant Colony Optimization and Swarm Intelligence

ACO-SI1

Evolutionary Inheritance Mechanisms for Multi-criteriaDecision Making in Multi-agent Systems

Ruby Moritz, Martin Middendorf

In this paper we study the use of different evolutionary inheritance mechanisms for the adaptation of parameters in a multi-agent system where the agents have to solve tasks that are distributed within a dynamic environment. In the studied system the agents have to form teams to execute the tasks. Deciding which task to execute next is a multi-criteria decision problem for which the agents use different ranking schemes. Agents that have successfully executed several tasks can reproduce and pass the type of ranking scheme they have used and some corresponding parameter values to their successors. Three types of evolutionary mechanisms are compared: haploid, diploid, and haplo-diploid. The latter one is new for multi-agent systems. The focus of our simulation experiments is to study the influence of the different evolutionary mechanisms on the diversity of the agents and on the resulting efficiency of the multi-agent system for different dynamic environments.

An Ant Colony Optimization Based Memetic Algorithm for the Dynamic Travelling Salesman Problem

Michalis Mavrovouniotis, Felipe Müller, Shengxiang Yang

Ant colony optimization (ACO) algorithms have proved to be able to adapt for solving dynamic optimization problems (DOPs). The integration of local search algorithms has also proved to significantly improve the output of ACO algorithms. However, almost all previous works consider stationary environments. In this paper, the MAX -MIN Ant System, one of the best ACO variations, is integrated with the unstringing and stringing (US) local search operator for the dynamic travelling salesman problem (DTSP). The best solution constructed by ACO is passed to the US operator for local search improvements. The proposed memetic algorithm aims to combine the adaptation capabilities of ACO for DOPs and the superior performance of the US operator on the static travelling salesman problem in order to tackle the DTSP. The experiments show that the MAX -MIN Ant System is able to provide good initial solutions to US and the proposed algorithm outperforms other peer ACO-based memetic algorithms on different DTSPs.

The Impact of Centrality on Individual and Collective Performance in Social Problem-Solving Systems

Diego Noble, Felipe Grando, Ricardo Araújo, Luis Lamb

In this paper, we analyze the dependency between centrality and individual performance in socially-inspired problem-solving systems. By means of extensive numerical simulations, we investigate how individual performance in four different models correlate with four different classical centrality measures. Our main result shows that there is a high linear correlation between centrality and individual performance when individuals systematically exploit central positions. In this case, central individuals tend to deviate from the expected majority contribution behavior. Although there is ample evidence about the relevance of centrality in social problem-solving, our work contributes to understand that some measures correlate better with individual performance than others due to individual traits, a position that is gaining strength in recent studies.

Robustness of Ant Colony Optimization to Noise

Tobias Friedrich, Timo Kützing, Martin Krejca, Andrew Sutton

Recently Ant Colony Optimization (ACO) algorithms have been proven to be efficient in uncertain environments, such as noisy or dynamically changing fitness functions. Most of these analyses focus on combinatorial problems, such as path finding. We analyze an ACO algorithm in a setting where we try to optimize the simple OneMax test function, but with additive posterior noise sampled from a Gaussian distribution. Without noise the classical $(\mu + 1)$-EA outperforms any ACO algorithm, with smaller μ being better; however, with large noise, the $(\mu + 1)$-EA fails, even for high values of μ (which are known to help against small noise). In this paper we show that ACO is able to deal with arbitrarily large noise in a graceful manner, that is, as long as the evaporation factor ρ is small enough dependent on the parameter σ^2 of the noise and the dimension n of the search space ($\rho = \mathrm{o}(1/(n(n + \sigma \log n)^2 \log n))$), optimization will be successful.

ACO-SI2

An Improved Collaborative Filtering Recommendation Algorithm Based on Community Detection in Social Networks

Cen Cao, Qingjian Ni, Yuqing Zhai

Recommendation algorithms in social networks have attracted much attention in recent years. Collaborative filtering recommendation algorithm is one of the most commonly used recommendation algorithms. Traditional user-based collaborative filtering recommendation algorithm recommends based on the user-item rating matrix, but the large amounts of data may cause low efficiency. In this paper, we propose an improved collaborative filtering recommendation algorithm based on community detection. Firstly, the user-item rating matrix is mapped into the user similarity network. Furthermore, a novel discrete particle swarm optimization algorithm is applied to find communities in the user similarity network, and finally Top-N items are recommend to the recommended user according to the communities. The experiments on a real dataset validate the effectiveness of the proposed algorithm for improving the precision, coverage and efficiency of recommendation.

Enhancing IACO$_{\mathbb{R}}$ Local Search by Mtsls1-BFGS for Continuous Global Optimization

Udit Kumar, Jayadeva Dr, Sumit Soman

A widely known approach for continuous global optimization has been the Incremental Ant Colony Framework ($IACO_{\mathbb{R}}$). In this paper, we propose a strategy to introduce hybridization within the exploitation phase of the $IACO_{\mathbb{R}}$ framework by using the Multi-Trajectory Local Search (Mtsls1) algorithm and Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithms. Our approach entails making a probabilistic choice between these algorithms. In case of stagnation, we switch the algorithm being used based on the last iteration. We evaluate our approach on the Soft Computing (SOCO) benchmark functions and present results by computing the mean and median errors on the global optima achieved, as well as the iterations required. We compare our approach with competing methods on a number of benchmark functions, and show that the proposed approach achieves improved results. In particular, we obtain the global optima in terms of average value for **14** out of **19** benchmark functions, and in terms of the median value for all SOCO benchmarks. At the same time, the proposed approach uses fewer function evaluations on several benchmarks when compared with competing methods, which have been found to use **54%** more function evaluations.

Parameter Estimation in Bayesian Networks Using Overlapping Swarm Intelligence

Nathan Fortier, John Sheppard, Shane Strasser

Bayesian networks are probabilistic graphical models that have proven to be able to handle uncertainty in many real-world applications. One key issue in learning Bayesian networks is parameter estimation, i.e., learning the local conditional distributions of each variable in the model. While parameter estimation can be performed efficiently when complete training data is available (i.e., when all variables have been observed), learning the local distributions becomes difficult when latent (hidden) variables are introduced. While Expectation Maximization (EM) is commonly used to perform parameter estimation in the context of latent variables, EM is a local optimization method that often converges to sub-optimal estimates. Although several authors have improved upon traditional EM, few have applied population based search techniques to parameter estimation, and most existing population-based approaches fail to exploit the conditional independence properties of the networks. We introduce two new methods for parameter estimation in Bayesian networks based on particle swarm optimization (PSO). The first is a single swarm PSO, while the second is a multi-swarm PSO algorithm. In the multi-swarm version, a swarm is assigned to the Markov blanket of each variable to be estimated, and competition is held between overlapping swarms. Results of comparing these new methods to several existing approaches indicate that the multi-swarm algorithm outperforms the competing approaches when compared using data generated from a variety of Bayesian networks.

An Ant Colony Optimizing Algorithm Based on Scheduling Preference for Maximizing Working Time of WSN

Yu Liu, Wei-Neng Chen, Xiao-min Hu, Jun Zhang

With the proliferation of wireless sensor networks (WSN), the issues about how to schedule all the sensors in order to maximize the systems working time have been in the spotlight. Inspired by the promising performance of ant colony optimization (ACO) in solving combinational optimization problem, we attempt to apply it in prolonging the life time of WSN. In this paper, we propose an improved version of ACO algorithm to get solutions about selecting exact sensors to accomplish the covering task in a reasonable way to preserve more energy to maintain longer active time. The methodology is based on maximizing the disjoint subsets of sensors, in other words, in every time interval, choosing which sensor to sustain active state must be rational in certain extent. With the aid of pheromone and heuristic information, a better solution can be constructed in which pheromone denotes the previous scheduling experience, while heuristic information reflects the desirable device assignment. Orderly sensor selection is designed to construct an advisable subset for coverage task. The proposed method has been successfully applied in solving limited energy assignment problem no matter in homogenous or heterogeneous WSNs. Simulation experiments have shown it has a good performance in addressing relevant issues.

ACO-SI3

A Set-based Comprehensive Learning Particle Swarm Optimization with Decomposition for Multiobjective Traveling Salesman Problem

Xue Yu, Wei-Neng Chen, Xiao-min Hu, Jun Zhang

This paper takes the multiobjective traveling salesman problem (MOTSP) as the representative for multiobjective combinatorial problems and develop a set-based comprehensive learning particle swarm optimization (S-CLPSO) with decomposition for solving MOTSP. The main idea is to take advantages of both the multiobjective evolutionary algorithm based on decomposition (MOEA/D) framework and our previously proposed S-CLPSO method for discrete optimization. Consistent to MOEA/D, a multiobjective problem is decomposed into a set of subproblems, each of which is represented as a weight vector and solved by a particle. Thus the objective vector of a solution or the cost vector between two cities will be transformed into real fitness to be used in S-CLPSO for the exemplar construction, the heuristic information generation and the update of pBest. To validate the proposed method, experiments based on TSPLIB benchmark are conducted and the results indicate that the proposed algorithm can improve the solution quality to some degree.

The Effect of Quantum and Charged Particles on the Performance of the Dynamic Vector-evaluated Particle Swarm Optimisation Algorithm

Marde Helbig, Andries Engelbrecht

Many problems in the real-world have more than one objective, with at least two objectives in conflict with one another. In addition, at least one objective changes over time. These kinds of problems are called dynamic multi-objective optimisation prob-

lems (DMOOPs). Studies have shown that both the quantum particle swarm optimisation (QPSO) and charged particle swarm optimisation (CPSO) algorithms perform well in dynamic environments, since they maintain swarm diversity. Therefore, this paper investigates the effect of using either QPSOs or CPSOs in the sub-swarms of the dynamic vector-evaluated particle swarm optimisation (DVEPSO) algorithm. These DVEPSO variations are then compared against the default DVEPSO algorithm that uses gbest PSOs and DVEPSO using heterogeneous PSOs that contain both charged and quantum particles. Furthermore, all of the aforementioned DVEPSO configurations are compared against the dynamic multi-objective optimisation (DMOPSO) algorithm that was the winning algorithm of a comprehensive comparative study of dynamic multi-objective optimisation algorithms. The results indicate that charged and quantum particles improve the performance of DVEPSO, especially for DMOOPs with a deceptive POF and DMOOPs with a nonlinear POS.

Input-to-State Stability Analysis on Particle Swarm Optimization

Daqing Yi, Kevin Seppi, Michael Goodrich

This paper examines the dynamics of particle swarm optimization (PSO) by modeling PSO as a feedback cascade system and then applying input-to-state stability analysis. Using a feedback cascade system model we can include the effects of the global-best and personal-best values more directly in the model of the dynamics. Thus in contrast to previous study of PSO dynamics, the input-to-state stability property used here allows for the analysis of PSO both before and at stagnation. In addition, the use of input-to-state stability allows this analysis to preserve random terms which were heretofore simplified to constants. This analysis is important because it can inform the setting of PSO parameters and better characterize the nature of PSO as a dynamic system. This work also illuminates the way in which the personal-best and the global-best updates influence the bound on the particle's position and hence, how the algorithm exploits and explores the fitness landscape as a function of the personal best and global best.

Particle Swarm Optimization Based on Linear Assignment Problem Transformations

Luis Miguel Antonio, Carlos Artemio Coello Coello

Particle swarm optimization (PSO) algorithms have been widely used to solve a variety of optimization problems. Their success has motivated researchers to extend the use of these techniques to the multi-objective optimization field. However, most of these extensions have been used to solve multi-objective optimization problems (MOPs) with no more than three objective functions. Here, we propose a novel multi-objective PSO (MOPSO) algorithm characterized by the use of a recent approach that transforms a MOP into a linear assignment problem (LAP), with the aim of being able to solve many-objective optimization problems. Our proposed approach, called LAP based PSO (LAPSO), adopts the Munkres assignment algorithm to solve the generated LAPs and has no need of an external archive. LAPSO is compared with respect to three MOPSOs which are representative of the state-of-the-art in the area: the Optimized Multi-Objective Particle Swarm Optimizer (OMOPSO) the Speed-constrained Multiobjective Particle Swarm Optimizer (SMPSO) and a variant of the latter that uses the hypervolume indicator for its leader selection scheme (SMPSOhv). Our results indicate that LAPSO is able to outperform the MOPSOs with respect to which it was compared in most of the test problems adopted, specially when solving instances with more than three objectives.

Artificial Immune Systems and Artificial Chemistries

AIS-AChem

Securing the Internet of Things with Responsive Artificial Immune Systems

Dr. Greensmith

The Internet of Things is a network of 'smart' objects, transforming everyday objects into entities which can measure, sense and understand their environment. The devices are uniquely identifiable, rely on near field connectivity, often in embedded devices. The Internet of Things is designed to be deployed without human intervention or interaction. One application is the 'smart house', with components including household appliances, networked with the user able to control devices remotely. However, the security inherent in these systems is added as somewhat of an afterthought. One hypothetical scenario is where a malicious party could exploit this technology with potentially disastrous consequences, turning on a cooker remotely leading to digital arson. Reliance on standard methods is insufficient to provide the user with adequate levels of security, an area where AIS may be extremely useful. There are currently limitations with AIS applied in security, focussing on detection without providing automatic responses. This problem provides an opportunity to advance AIS in providing both an ideal scenario for testing their real-world application and to develop novel responsive AIS. A responsive version of the deterministic Dendritic Cell Algorithm will be proposed to demonstrate how responsive AIS will need to be developed to meet these future challenges through proposing the incorporation of a model of T-cell responses.

RAIS_TTP Revisited to Solve Relaxed Travel Tournament Problem

Elizabeth Montero, Maria-Cristina Riff

We are interested in methods and strategies that allow us to simplify the code of bio-inspired algorithms without altering their

performance. In this paper, we study an artificial immune algorithm specially designed to solve Relaxed Traveling Tournament Problems which has been able to obtain new bounds for some instances of this problem. We use the EvoCa tuner to analyze the components of the algorithm in order to discard some parts of the code. The results show that the filtered algorithm is able to solve the instances as well as does the original algorithm, and with this code we have obtained new bounds for some instances of the problem.

Distinguishing Adaptive Search from Random Search in Robots and T cells

George Fricke, Sarah Black, Joshua Hecker, Judy Cannon, Melanie Moses

In order to trigger an adaptive immune response, T cells move through LN searching for DC that carry antigens indicative of infection. We hypothesize that T cells adapt to cues in the LN environment to increase search efficiency. We test this hypothesis by identifying locations that are visited by T cells more frequently than a random model of search would suggest. We then test whether T cells that visit such locations have different movement patterns than other T cells. Our analysis suggests that T cells do adapt their movement in response to cues that may indicate the locations of DC targets. We test the ability of our method to identify frequently visited sites in T cells and in a swarm of simulated iAnt robots evolved to search using a suite of biologically-inspired behaviours. We compare the movement of T cells and robots that repeatedly sample the same locations in space with the movement of agents that do not resample space in order to understand whether repeated sampling alters movement. Our analysis suggests that specific environmental cues can be inferred from the movement of T cells. While the precise identity of these cues remains unknown, comparing adaptive search strategies of robots to the movement patterns of T cells lends insights into search efficiency in both systems.

An Immuno-inspired Approach Towards Sentence Generation

Samir Borgohain, Shivashankar Nair

Though human beings comprehend, imbibe and subsequently generate syntactically and semantically correct languages, the manner in which they do so has hardly been understood or unearthed. Most of the current work to achieve the same is heavily dependent on statistical and probabilistic data retrieved from a large corpus coupled with a formal grammar catering to the concerned natural language. This paper attempts to portray a technique based on an analogy described by Jerne on how his theory of the Idiotypic Network could possibly explain the human language generation capability. Starting with a repertoire of unigrams (antibodies) weaned from a corpus available a priori, we show how these can be sequenced to generate higher order n-grams that depict full or portions of correct sentences in that language. These sentences or their correct portions form a network similar to the Idiotypic Network that in turn aid in the generation of sentences or portions thereof which are new to the corpus signifying the learning of new and correct sequences. The network is built based on a modified version of the dynamics suggested by Farmer et. al. The paper describes the related dynamics of the network along with the results obtained from a corpus.

Artificial Life/Robotics/Evolvable Hardware

ALIFE1

Finding a Mate With No Social Skills

Chris Marriott, Jobran Chebib

Sexual reproductive behavior has a necessary social coordination component as willing and capable partners must both be in the right place at the right time. While there are many known social behavioral adaptations to support solutions to this problem, we explore the possibility and likelihood of solutions that rely only on non-social mechanisms. We find three kinds of social organization that help solve this social coordination problem (herding, assortative mating, and natal philopatry) emerge in populations of simulated agents with no social mechanisms available to support these organizations. We conclude that the non-social origins of these social organizations around sexual reproduction may provide the environment for the development of social solutions to the same and different problems.

The Effect of Fitness Function Design on Performance in Evolutionary Robotics

Mohammad Divband Soorati, Heiko Hamann

Fitness function design is known to be a critical feature of the evolutionary-robotics approach. Potentially, the complexity of evolving a successful controller for a given task can be reduced by integrating a priori knowledge into the fitness function which complicates the comparability of studies in evolutionary robotics. Still, there are only few publications that study the actual effects of different fitness functions on the robot's performance. In this paper, we follow the fitness function classification of Nelson et al. (2009) and investigate a selection of four classes of fitness functions that require different degrees of a priori knowledge. The robot controllers are evolved in simulation using NEAT and we investigate different tasks including obstacle avoidance and (periodic) goal homing. The best evolved controllers were then post-evaluated by examining their potential for adaptation, determining their convergence rates, and using cross-comparisons based on the different fitness function classes. The results confirm that the integration of more a

priori knowledge can simplify a task and show that more attention should be paid to fitness function classes when comparing different studies.

Improving Survivability in Environment-driven Distributed? Evolutionary Algorithms through Explicit Relative Fitness and Fitness Proportionate Communication

Emma Hart, Andreas Steyven, Ben Paechter

Ensuring the integrity of a robot swarm in terms of maintaining a? stable population of functioning robots over long periods of time is a mandatory prerequisite for building more complex systems that? achieve user-defined tasks. $mEDEA$ is an environment-driven? evolutionary algorithm that provides promising results using an? implicit fitness function combined with a random genome selection? operator. Motivated by the need to sustain a large population with sufficient spare energy to carry out user-defined tasks in the? future, we develop an explicit fitness metric providing a measure of? fitness that is relative to surrounding robots and examine two? methods by which it can influence spread of genomes. Experimental results in simulation find that use of the fitness-function provides significant improvements over the original algorithm; in particular, a method that influences the frequency and range of broadcasting? when combined with random selection has the potential to conserve? energy whilst maintaining performance, a critical factor for? physical robots.

An Embodied Approach for Evolving Robust Visual Classifiers

Karol Zieba, Josh Bongard

Despite recent demonstrations that deep learning methods can successfully recognize and categorize objects using high dimensional visual input, other recent work has shown that these methods can fail when presented with novel input. However, a robot that is free to interact with objects should be able to reduce spurious differences between objects belonging to the same class through motion and thus reduce the likelihood of overfitting. Here we demonstrate a robot that achieves more robust categorization when it evolves to use proprioceptive sensors and is then trained to rely increasingly on vision, compared to a similar robot that is trained to categorize only with visual sensors. This work thus suggests that embodied methods may help scaffold the eventual achievement of robust visual classification.

ALIFE2

Evolving Robot Morphology Facilitates the Evolution of Neural Modularity and Evolvability

Josh Bongard, Anton Bernatskiy, Ken Livingston, Nicholas Livingston, John Long, Marc Smith

Although recent work has demonstrated that modularity can increase evolvability in non-embodied systems, it remains to be seen how the morphologies of embodied agents influences the ability of an evolutionary algorithm to find useful and modular controllers for them. We hypothesize that a modular control system may enable different parts of a robot's body to sense and react to stimuli independently, enabling it to correctly recognize a seemingly novel environment as, in fact, a composition of familiar percepts and thus respond appropriately without need of further evolution. Here we provide evidence that supports this hypothesis: We found that such robots can indeed be evolved if (1) the robot's morphology is evolved along with its controller, (2) the fitness function selects for the desired behavior and (3) also selects for conservative and robust behavior. In addition, we show that if constraints (1) and (3) are relaxed, or structural modularity is selected for directly, the robots have too little or too much modularity and lower evolvability. Thus, we demonstrate a previously unknown relationship between modularity and embodied cognition: evolving morphology and control such that robots exhibit conservative behavior indirectly selects for appropriate modularity and, thus, increased evolvability.

Novelty-Based Evolutionary Design of Morphing Underwater Robots

Francesco Corucci, Marcello Calisti, Helmut Hauser, Cecilia Laschi

Recent developments in robotics demonstrated that bioinspiration and embodiement are powerful tools to achieve robust behavior in presence of little control. In this context morphological design is usually performed by humans, following a set of heuristic principles: in general this can be limiting, both from an engineering and an artificial life perspectives. In this work we thus suggest a different approach, leveraging evolutionary techniques. The case study is the one of improving the locomotion capabilities of an existing bioinspired robot. First, we explore the behavior space of the robot to discover a number of qualitatively different morphology-enabled behaviors, from whose analysis design indications are gained. The suitability of novelty search – a recent open-ended evolutionary algorithm – for this intended purpose is demonstrated. Second, we show how it is possible to condense such behaviors into a reconfigurable robot capable of online morphological adaptation (morphosis, morphing). Examples of successful morphing are demonstrated, in which changing just one morphological parameter entails a dramatic change in the behavior: this is promising for a future robot design. The approach here adopted represents a novel computed-aided, bioinspired, design paradigm, merging human and artificial creativity. This may result in interesting implications also for artificial life, having the potential to contribute in exploring underwater locomotion "as-it-could-be".

ALIFE3

Three-fold Adaptivity in Groups of Robots: The Effect of Social Learning

Jacqueline Heinerman, Dexter Drupsteen, A.E. Eiben

Adapting the control systems of robots on the fly is important in robotic systems of the future. In this paper we present and investigate a three-fold adaptive system based on evolution, individual and social learning in a group of robots and report on a

proof-of-concept study based on e-pucks. We distinguish inheritable and learnable components in the robots' makeup, specify and implement operators for evolution, learning and social learning, and test the system in an arena where the task is to learn to avoid obstacles. In particular, we make the sensory layout evolvable, the locomotion control system learnable and investigate the effects of including social learning in the 'adaptation engine'. Our simulation experiments demonstrate that the full mix of three adaptive mechanisms is practicable and that adding social learning leads to better controllers faster.

Novelty Search for Soft Robotic Space Exploration

Georgios Methenitis, Daniel Hennes, Dario Izzo, Arnoud Visser

The use of soft robots in future space exploration is still a far-fetched idea, but an attractive one. Soft robots are inherently compliant mechanisms that are well suited for locomotion on rough terrain as often faced in extra-planetary environments. Depending on the particular application and requirements, the best shape (or body morphology) and locomotion strategy for such robots will vary substantially. Recent developments in soft robotics and evolutionary optimization showed the possibility to simultaneously evolve the morphology and locomotion strategy in simulated trials. The use of techniques such as generative encoding and neural evolution were key to these findings. In this paper, we improve further on this methodology by introducing the use of a novelty measure during the evolution process. We compare fitness search and novelty search in different gravity levels and we consistently find novelty-based search to perform as good as or better than a fitness–based search, while also delivering a greater variety of designs. We propose a combination of the two techniques using fitness-elitism in novelty search to obtain a further improvement. We then use our methodology to evolve the gait and morphology of soft robots at different gravity levels, finding a taxonomy of possible locomotion strategies that are analyzed in the context of space-exploration.

Enhancing a Model-Free Adaptive Controller through Evolutionary Computation

Anthony Clark, Philip McKinley, Xiaobo Tan

Many robotic systems experience fluctuating dynamics during their lifetime. Variations can be attributed in part to material degradation and decay of mechanical hardware. One approach to mitigating these problems is to utilize an adaptive controller. For example, in model-free adaptive control (MFAC) a controller learns how to drive a system by continually updating link weights of an artificial neural network (ANN). However, determining the optimal control parameters for MFAC, including the structure of the underlying ANN, is a challenging process. In this paper we investigate how to enhance the online adaptability of MFAC-based systems through computational evolution. We apply the proposed methods to a simulated robotic fish propelled by a flexible caudal fin. Results demonstrate that the robot is able to effectively respond to changing fin characteristics and varying control signals when using an evolved MFAC controller. Notably, the system is able to adapt to characteristics not encountered during evolution. The proposed technique is general and can be applied to improve the adaptability of other cyber-physical systems.

Decentralized Innovation Marking for Neural Controllers in Embodied Evolution

Iñaki Fernández Pérez, Amine Boumaza, François Charpillet

We propose a novel innovation marking method for Neuro-Evolution of Augmenting Topologies in Embodied Evolutionary Robotics. This method does not rely on a centralized clock, which makes it well suited for the decentralized nature of EE where no central evolutionary process governs the adaptation of a team of robots exchanging messages locally. This method is inspired from event dating algorithms, based on logical clocks, that are used in distributed systems, where clock synchronization is not possible. We compare our method to odNEAT, an algorithm in which agents use local time clocks as innovation numbers, on two multi-robot learning tasks: navigation and item collection. Our experiments showed that the proposed method performs as well as odNEAT, with the added benefit that it does not rely on synchronization of clocks and is not affected by time drifts.

Biological and Biomedical Applications

BIO1

Evolutionary Optimization of Cancer Treatments in a Cancer Stem Cell Context

Ángel Monteagudo, José Santos

We used evolutionary computing for optimizing cancer treatments taking into account the presence and effects of cancer stem cells. We used a cellular automaton to model tumor growth at cellular level, based on the presence of the main cancer hallmarks in the cells. The cellular automaton allows the study of the emergent behavior of the multicellular system evolution in different scenarios defined by the predominance of the different hallmarks. When cancer stem cells (CSCs) are modeled, the multicellular system evolution is additionally dependent on the CSC tumor regrowth capability because their differentiation to non-stem cancer cells. When a standard treatment is applied against non-stem (differentiated) cancer cells, different effects are present depending on the strategy used to eliminate these non-stem cancer cells. We used Differential Evolution to optimize the treatment application strategy in terms of intensity, duration and periodicity to minimize the final outcome of tumor growth and regrowth.

BIO2

Evolution Strategies for Exploring Protein Energy Landscapes

Rudy Clausen, Emmanuel Sapin, Kenneth De Jong, Amarda Shehu

The focus on important diseases of our time has prompted many experimental labs to resolve and deposit functional structures of disease-causing or disease-participating proteins. At this point, many functional structures of wildtype and disease-involved variants of a protein exist in structural databases. The objective for computational approaches is to employ such information to discover features of the underlying energy landscape on which functional structures reside. Important questions about which subset of structures are most thermodynamically-stable remain unanswered. The challenge is how to transform an essentially discrete problem into one where continuous optimization is suitable and effective. In this paper, we present such a transformation, which allows adapting and applying evolution strategies to explore an underlying continuous variable space and locate the global optimum of a multimodal fitness landscape. The paper presents results on wildtype and mutant sequences of proteins implicated in human disorders, such as cancer and Amyotrophic lateral sclerosis. More generally, the paper offers a methodology for transforming a discrete problem into a continuous optimization one as a way to possibly address outstanding discrete problems in the evolutionary computation community.

An Analysis of Integration of Hill Climbing in Crossover and Mutation operation for EEG Signal Classification

Arpit Bhardwaj, Aruna Tiwari, Vishaal Madaka, Ramesh Maddula

A common problem in the diagnosis of epilepsy is the volatile and unpredictable nature of the epileptic seizures. Hence, it is essential to develop Automatic seizure detection methods. Genetic programming (GP) has a potential for accurately predicting a seizure in an EEG signal. However, the destructive nature of crossover operator in GP decreases the accuracy of predicting the onset of a seizure. Designing constructive crossover and mutation operators (CCM) and integrating local hill climbing search technique with the GP have been put forward as solutions. In this paper, we proposed a hybrid crossover and mutation operator, which uses both the standard GP and CCM-GP, to choose high performing individuals in the least possible time. To demonstrate our approach, we tested it on a benchmark EEG signal dataset. We also compared and analyzed the proposed hybrid crossover and mutation operation with the other state of art GP methods in terms of accuracy and training time. Our method has shown remarkable classification results. These results affirm the potential use of our method for accurately predicting epileptic seizures in an EEG signal and hint on the possibility of building a real time automatic seizure detection system.

Metabolic Design And Engineering Through Ant Colony Optimization

Stephen Lincoln, Ian Rogers, Ranjan Srivastava

Due to the vast search space of all possible combinations of reaction knockouts in Escherichia coli, determining the best combination of knockouts for over-production of a metabolite of interest is a computationally expensive task. Ant colony optimization (ACO) applied to genome-scale metabolic models via flux balance analysis (FBA) provides a means by which such a solution space may feasibly be explored. In previous work, the Minimization of Metabolic Adjustment (MoMA) objective function for FBA was used in conjunction with ACO to identify the best gene knockouts for succinic acid production. In this work, algorithmic and biological constraints are introduced to further reduce the solution space. We introduce Stochastic Exploration Edge Reduction Ant Colony Optimization, or STEER-ACO. Algorithmically, ACO is modified to refine its search space over time allowing for greater initial coverage of the solution space while ultimately honing on a high quality solution. Biologically, a heuristic is introduced allowing the maximum number of knockouts to be no greater than five. Beyond this number, cellular viability becomes suspect. Results using this approach versus previous methods are reported.

Continuous Optimization

CO1

Detecting Funnel Structures by Means of Exploratory Landscape Analysis

Pascal Kerschke, Mike Preuss, Simon Wessing, Heike Trautmann

In single-objective optimization different optimization strategies exist depending on the structure and characteristics of the underlying problem. In particular, the presence of so-called funnels in multimodal problems offers the possibility of applying techniques exploiting the global structure of the function. The recently proposed Exploratory Landscape Analysis approach automatically identifies problem characteristics based on a moderately small initial sample of the objective function and proved to be effective for algorithm selection problems in continuous black-box optimization. In this paper, specific features for detecting funnel structures are introduced and combined with the existing ones in order to classify optimization problems regarding the funnel property. The effectiveness of the approach is shown by experiments on specifically generated test instances and validation experiments on standard benchmark problems.

Sample Reuse in the Covariance Matrix Adaptation Evolution Strategy Based on Importance Sampling

Shinichi Shirakawa, Youhei Akimoto, Kazuki Ouchi, Kouzou Ohara

Recent studies reveal that the covariance matrix adaptation evolution strategy (CMA-ES) updates the parameters based on the natural gradient. The rank-based weight is considered the result of the quantile-based transformation of the objective value and the parameters are adjusted in the direction of the natural gradient estimated by Monte-Carlo with the samples drawn from the current distribution. In this paper, we propose a sample reuse mechanism for the CMA-ES. On the basis of the importance sampling, the past samples are reused to reduce the estimation variance of the quantile and the natural gradient. We derive the formula for the rank-mu update of the covariance matrix and the mean vector update using the past samples, then incorporate it into the CMA-ES without the step-size adaptation. From the numerical experiments, we observe that the proposed approach helps to reduce the number of function evaluations on many benchmark functions, especially when the number of samples at each iteration is relatively small.

Towards an Analysis of Self-Adaptive Evolution Strategies on the Noisy Ellipsoid Model:

Alexander Melkozerov, Hans-Georg Beyer

This paper analyzes the multi-recombinant self-adaptive evolution strategy (ES), denoted as $(\mu/\mu_I, \lambda)$-σSA-ES on the convex-quadratic function class under the influence of noise, which is referred to as noisy ellipsoid model. Asymptotically exact progress rate and self-adaptation response measures are derived (i.e., for $N \to \infty$, N - search space dimensionality) for the considered objective function model and verified using experimental ES runs.

Towards an Augmented Lagrangian Constraint Handling Approach for the (1+1)-ES

Dirk Arnold, Jeremy Porter

We consider the problem of devising an approach for handling inequality constraints in evolution strategies that allows converging linearly to optimal solutions on sphere functions with a single linear constraint. An analysis of the single-step behaviour of the (1+1)-ES shows that the task of balancing improvements in the objective with those in the constraint function is quite delicate, and that adaptive approaches need to be carefully designed in order to avoid failure. Based on the understanding gained, we propose a simple augmented Lagrangian approach and experimentally demonstrate good performance on a broad range of sphere functions as well as on moderately ill-conditioned ellipsoids with a single linear constraint.

CO2

Dichotomy Guided Based Parameter Adaptation for Differential Evolution

Xiao-Fang Liu, Zhi-Hui Zhan, Jun Zhang

Differential evolution (DE) is an efficient and powerful population-based stochastic evolutionary algorithm, which evolves according to the differential between individuals. The success of DE in obtaining the optima of a specific problem depends greatly on the choice of mutation strategies and control parameter values. Good parameters lead the individuals towards optima successfully. The increasing of the success rate (the ratio of entering the next generation successfully) of population can speed up the searching. Adaptive DE incorporates success-history or population-state based parameter adaptation. However, sometimes poor parameters may improve individual with small probability and are regarded as successful parameters. The poor parameters may mislead the parameter control. So, in this paper, we propose a novel approach to distinguish between good and poor parameters in successful parameters. In order to speed up the convergence of algorithm and find more good parameters, we propose a dichotomy adaptive DE (DADE), in which the successful parameters are divided into two parts and only the part with higher success rate is used for parameter adaptation control. Simulation results show that DADE is competitive to other classic or adaptive DE algorithms on a set of benchmark problem and IEEE CEC 2014 test suite.

A New Repair Method For Constrained Optimization

Patrick Koch, Samineh Bagheri, Wolfgang Konen, Christophe Foussette, Peter Krause, Thomas Baeck

Nowadays, constraints play an important role in industry, because most industrial optimization tasks underly several restrictions. Finding good solutions for a particular problem with respect to all constraint functions can be expensive, especially when the dimensionality of the search space is large and many constraint functions are involved. Unfortunately function evaluations in industrial optimization are heavily limited, because often expensive simulations must be conducted. For such high-dimensional optimization tasks, the constraint optimization algorithm COBRA was proposed, making use of surrogate modeling for both the objective and the constraint functions. In this paper we present a new mechanism for COBRA to repair infill solutions with slightly violated constraints. The repair mechanism is based on gradient descent on surrogates of the constraint functions and aims at finding nearby feasible solutions. We test the repair mechanism on a real-world problem from the automotive industry and on other synthetic test cases. It is shown in this paper that with the integration of the repair method, the percentage of infeasible solutions is significantly reduced, leading to faster convergence and better final results.

A Repair Method for Differential Evolution with Combined Variants to Solve Dynamic Constrained Optimization Problems

María-Yaneli Ameca-Alducin, Efrén Mezura-Montes, Nicandro Cruz-Ramírez

Repair methods, which usually require feasible solutions as reference, have been employed by Evolutionary Algorithms to solve constrained optimization problems. In this work, a novel repair method, which does not require feasible solutions as reference and inspired by the differential mutation, is added to an algorithm which uses two variants of differential evolution to solve dynamic constrained optimization problems. The proposed repair method replaces a local search operator with the aim to improve the overall performance of the algorithm in different frequencies of change in the constrained space. The proposed approach is compared against other recently proposed algorithms in an also recently proposed benchmark. The results show that the proposed improved algorithm outperforms its original version and provides a very competitive overall performance with different change frequencies.

CO3

Extended Differential Grouping for Large Scale Global Optimization with Direct and Indirect Variable Interactions

Yuan Sun, Michael Kirley, Saman Halgamuge

Cooperative co-evolution is a framework that can be used to effectively solve large scale optimization problems. This approach employs a divide and conquer strategy, which decomposes the problem into sub-components that are optimized separately. However, solution quality relies heavily on the decomposition method used. Ideally, the interacting decision variables should be assigned to the same sub-component and the interdependency between sub-components should be kept to a minimum. Differential grouping, a recently proposed method, has high decomposition accuracy across a suite of benchmark functions. However, we show that differential grouping can only identify decision variables that interact directly. Subsequently, we propose an extension of differential grouping that is able to correctly identify decision variables that also interact indirectly. Empirical studies show that our extended differential grouping method achieves perfect decomposition on all of the benchmark functions investigated. Significantly, when our decomposition method is embedded in the cooperative co-evolution framework, it achieves comparable or better solution quality than the differential grouping method.

A CMA-ES with Multiplicative Covariance Matrix Updates

Oswin Krause, Tobias Glasmachers

Covariance matrix adaptation (CMA) mechanisms are core building blocks of modern evolution strategies. Despite sharing a common principle, the exact implementation of CMA varies considerably between different algorithms. In this paper, we investigate the benefits of an exponential parametrization of the covariance matrix in the CMA-ES. This technique was first proposed for the xNES algorithm. It results in a multiplicative update formula for the covariance matrix. We show that the exponential parameterization and the multiplicative update are compatible with all mechanisms of CMA-ES. The resulting algorithm, xCMA-ES, performs at least on par with plain CMA-ES. Its advantages show in particular with updates that actively decrease the sampling variance in specific directions, i.e., for active constraint handling.

Global Line Search Algorithm Hybridized with Quadratic Interpolation and Its Extension to Separable Functions

Petr Baudiš, Petr Pošík

We propose a novel hybrid algorithm "Brent-STEP" for univariate global function minimization, based on the global line search method STEP and accelerated by Brent's method, a local optimizer that combines quadratic interpolation and golden section steps. We analyze the performance of the hybrid algorithm on various one-dimensional functions and experimentally demonstrate a significant improvement relative to its constituent algorithms in most cases. We then generalize the algorithm to multivariate functions, proposing a scheme to interleave evaluations across dimensions to achieve smoother and more efficient convergence. We experimentally demonstrate the highly competitive performance of the proposed multivariate algorithm on separable functions of the BBOB benchmark. The combination of good performance and smooth convergence on separable functions makes the algorithm an interesting candidate for inclusion in algorithmic portfolios or hybrid algorithms that aim to provide good performance on a wide range of problems.

Digital Entertainment Technologies and Arts

DETA1

Solving Interleaved and Blended Sequential Decision-Making Problems through Modular Neuroevolution

Jacob Schrum, Risto Miikkulainen

Many challenging sequential decision-making problems require agents to master multiple tasks, such as defense and offense in many games. Learning algorithms thus benefit from having separate policies for these tasks, and from knowing when each one is appropriate. How well the methods work depends on the nature of the tasks: Interleaved tasks are disjoint and have different semantics, whereas blended tasks have regions where semantics from different tasks overlap. While many methods work well in interleaved tasks, blended tasks are difficult for methods with strict, human-specified task divisions, such as Multitask Learning. In such problems, task divisions should be discovered auto-

matically. To demonstrate the power of this approach, the MM-NEAT neuroevolution framework is applied in this paper to two variants of the challenging video game of Ms. Pac-Man. In the simplified interleaved version of the game, the results demonstrate when and why such machine-discovered task divisions are useful. In the standard blended version of the game, a surprising, highly effective machine-discovered task division surpasses human-specified divisions, achieving the best scores to date in this game. Modular neuroevolution is thus a promising technique for discovering multimodal behavior for challenging real-world tasks.

DETA2

Controlling Crowd Simulations using Neuro-Evolution

Sunrise Wang, James Gain, Geoff Nistchke

Crowd simulations have become increasingly popular in films over the last decade, appearing in large crowd shots of many big name block-buster films. An important requirement for crowd simulations in films is that they should be directable both at a high and low level. As agent-based techniques allow for low-level directability and more believable crowds, they are typically used in this field. However, due to the bottom-up nature of these techniques, to achieve high level directability, agent-level parameters must be adjusted until the desired crowd behavior emerges. As manually adjusting parameters is a time consuming and tedious process, this paper investigates a method for automating this, using Neuro-Evolution. To this end, the Conventional Neuro-Evolution (CNE), Covariance Matrix Adaptation Evolutionary Strategy (CMA-ES), Neuro-Evolution of Augmenting Topologies (NEAT), and Enforced Sub Populations (ESP) algorithms are compared across a variety of representative crowd simulation scenarios. Overall, it was found that CMA-ES generally performs the best across the selected simulations.

Open Loop Search for General Video Game Playing

Diego Perez Liebana, Jens Dieskau, Martin Hunermund, Sanaz Mostaghim, Simon Lucas

General Video Game Playing is a sub-field of Game Artificial Intelligence, where the goal is to find algorithms capable of playing many different real-time games, some of them unknown a priori. In this scenario, the presence of domain knowledge must be severely limited, or the algorithm will overfit to the training games and perform poorly on the unknown games of the test set. Research in this area has been of special interest in the last years, with emerging contests like the General Video Game AI (GVG-AI) Competition. This paper introduces three different open loop techniques for dealing with this problem. First, a simple directed depth first search algorithm is employed as a baseline. Then, a tree search algorithm with a multi-armed bandit based tree policy is presented, followed by a Rolling Horizon Evolutionary Algorithm (RHEA) approach. In order to test these techniques, the games from the GVG-AI Competition framework are used as a benchmark, evaluation on a training set of 29 games, and submitting to the 10 unknown games at the competition website. Results show how the general game-independent heuristic proposed works well across all algorithms and games, and how the RHEA becomes the best evolutionary technique in the rankings of the test set.

Darwin's Avatars: a Novel Combination of Gameplay and Procedural Content Generation

Dan Lessin, Sebastian Risi

The co-evolution of morphology and control for virtual creatures enables the creation of a novel form of gameplay and procedural content generation. Starting with a creature evolved to perform a simple task such as locomotion and removing its brain, the remaining body can be employed in a compelling interactive control problem. Just as we enjoy the challenge and reward of mastering helicopter flight or learning to play a musical instrument, learning to control such a creature through manual activation of its actuators presents an engaging and rewarding puzzle. Importantly, the novelty of this challenge is inexhaustible, since the evolution of virtual creatures provides a way to procedurally generate content for such a game. An endless series of creatures can be evolved for a task, then have their brains removed to become the game's next human-control challenge. To demonstrate this new form of gameplay and content generation, a proof-of-concept game–tentatively titled Darwin's Avatars–was implemented using evolved creature content, and user tested. This implementation also provided a unique opportunity to compare human and evolved control of evolved virtual creatures, both qualitatively and quantitatively, with interesting implications for improvements and future work.

Interactively Evolving Compositional Sound Synthesis Networks

Björn Jónsson, Amy Hoover, Sebastian Risi

While the success of electronic music often relies on the uniqueness and quality of selected timbres, many musicians struggle with complicated and expensive equipment and techniques to create their desired sounds. Instead, this paper presents a technique for producing novel timbres that are evolved by the musician through interactive evolutionary computation. Each timbre is produced by an oscillator, which is represented by a special type of artificial neural network (ANN) called a compositional pattern producing network (CPPN). While traditional ANNs compute only sigmoid functions at their hidden nodes, CPPNs can theoretically compute any function and can build on those present in traditional synthesizers (e.g. square, sawtooth, triangle, and sine waves functions) to produce completely novel timbres. Evolved with NeuroEvolution of Augmenting Topologies (NEAT), the aim of this paper is to explore the space of potential sounds that can be generated through such compositional sound synthesis networks (CSSNs). To study the effect of evolution on subjective appreciation, participants in a listener study ranked evolved timbres by personal preference, resulting in preferences skewed toward the first and last generations. In the long run, the CSSN's ability to generate a variety of different and rich timbre opens up the intriguing possibility of evolving a complete CSSN-encoded synthesizer.

Estimation of Distribution Algorithms

EDA1

Kernels of Mallows Models for Solving Permutation-based Problems

Josu Ceberio, Alexander Mendiburu, Jose Lozano

Recently, distance-based exponential probability models, such as Mallows and Generalized Mallows, have demonstrated their validity in the context of estimation of distribution algorithms (EDAs) for solving permutation problems. However, despite their successful performance, these models are unimodal, and therefore, they are not flexible enough to accurately model populations with solutions that are very sparse with regard to the distance metric considered under the model. In this paper, we propose using kernels of Mallows models under the Kendall's-tau and Cayley distances within EDAs. In order to demonstrate the validity of this new algorithm, Mallows Kernel EDA, we compare its performance with the classical Mallows and Generalized Mallows EDAs, on a benchmark of 90 instances of two different types of permutation problems: the quadratic assignment problem and the permutation flowshop scheduling problem. Experimental results reveal that, in most cases, Mallows Kernel EDA outperforms the Mallows and Generalized Mallows EDAs under the same distance. Moreover, the new algorithm under the Cayley distance obtains the best results for the two problems in terms of average fitness and computational time.

EDA2

Theoretical Perspective of Convergence Complexity of Evolutionary Algorithms Adopting Optimal Mixing

Yu-Fan Tung, Tian-Li Yu

The optimal mixing evolutionary algorithms (OMEAs) have recently drawn much attention for their robustness, small size of required population, and efficiency in terms of number of function evaluations (NFE). In this paper, the performances and behaviors of convergence in OMEAs are studied by investigating the mechanism of optimal mixing (OM), the variation operator in OMEAs, under two scenarios—one-layer and two-layer masks. For the case of one-layer masks, the required population size is derived from the viewpoint of initial supply, while the convergence time is derived by analyzing the progress of sub-solution growth. NFE is then asymptotically bounded with rational probability by estimating the probability of performing evaluations. For the case of two-layer masks, empirical results indicate that the required population size is proportional to both the degree of cross competition and the results from the one-layer-mask case. The derived models also indicate that population sizing is decided by initial supply when disjoint masks are adopted, that the high selection pressure imposed by OM makes the composition of sub-problems impact little on NFE, and that the population size requirement for two-layer masks increases with the reverse-growth probability.

EDA3

Optimization by Pairwise Linkage Detection, Incremental Linkage Set, and Restricted / Back Mixing: DSMGA-II

Shih-Huan Hsu, Tian-Li Yu

This paper proposes a new evolutionary algorithm, called DSMGA-II, to efficiently solve optimization problems via exploiting problem substructures. The proposed algorithm adopts pairwise linkage detection and stores the information in the form of dependency structure matrix (DSM). A new linkage model, called the incremental linkage set, is then constructed by using the DSM. Inspired by the idea of optimal mixing, the restricted mixing and the back mixing are proposed. The former aims at efficient exploration under certain constrains. The latter aims at exploitation by refining the DSM so as to reduce unnecessary evaluations. Experimental results show that DSMGA-II outperforms LT-GOMEA and hBOA in terms of number of function evaluations on the concatenated/folded/cyclic trap problems, NK-landscape problems with various degrees of overlapping, 2D Ising spin-glass problems, and MAX-SAT. The investigation of performance comparison with P3 is also included.

An Estimation of Distribution Algorithm based on the Natural Gradient and the Boltzmann Distribution

Ignacio Segovia-Dominguez, Arturo Hernandez-Aguirre

This paper introduces an Estimation of Distribution Algorithm (EDA), in which the parameters of the search distribution are updated by the natural gradient technique. The parameter updating is guided via the Kullback-Leibler divergence between the multivariate Normal and the Boltzmann densities. This approach makes sense because it is well-known that the Boltzmann function yields a reliable model to simulate particles near to optimum locations. Three main contributions are presented here in order to build an effective EDA. The first one is a natural gradient formula which allows for an update of the parameters of a density function. These equations are related to an exponential parametrization of the search distribution. The second contribution involves the approximation of the developed gradient formula and its connection to the importance sampling method. The third contribution is a parameter update rule which is designed to control the exploration and exploitation phases of the algorithm. The proposed EDA is tested on a benchmark of 16 problems and compared versus the XNES and iAMaLGaM algorithms. The statistical results show that the performance of the proposed method is competitive and it is the winner in several problems.

Simplified Runtime Analysis of Estimation of Distribution Algorithms

Duc-Cuong Dang, Per Kristian Lehre

Estimation of distribution algorithms (EDA) are stochastic search methods that look for optimal solutions by learning and sampling from probabilistic models. Despite their popularity,

there are only few rigorous theoretical analyses of their performance. Even for the simplest EDAs, such as the Univariate Marginal Distribution Algorithm (UMDA) which assumes independence between decision variables, there are only a handful of results about its runtime, and results for simple functions such as Onemax are still missing. In this paper, we show that the recently developed level-based theorem for non-elitist populations is directly applicable to runtime analysis of EDAs. To demonstrate this approach, we derive easily upper bounds on the expected runtime of the UMDA.

Evolutionary Combinatorial Optimization and Metaheuristics

ECOM1

Fighting the Symmetries: The Structure of Cryptographic Boolean Function Spaces

Stjepan Picek, Robert McKay, Roberto Santana, Tom Gedeon

We explore the problem space of maximum nonlinearity problems for balanced Boolean functions, examining the symmetry structure and fitness landscapes in the most common (bit string) representation. We present theoretical analyses of well understood aspects, together with detailed enumeration of the 4-bit problem, sampling of the 6-bit problem based on known optima, and sampling of the 8-bit problem based on its fittest known solutions. We show that these problems have many more symmetries than is generally noted, with implications for crossover and for distributional methods. We explore the large-scale plateau structure of the problem, with similar implications for local search. We show that symmetries yield additional information that may yield more effective search methods.

Towards the User Equilibrium in Traffic Assignment Using GRASP with Path Relinking

Gabriel Ramos, Ana Lucia Bazzan

Solving the traffic assignment problem (TAP) is an important step towards an efficient usage of the traffic infrastructure. A fundamental assignment model is the so-called User Equilibrium (UE), which may turn into a complex optimisation problem. In this paper, we present the use of the GRASP metaheuristic to approximate the UE of the TAP. A path relinking mechanism is also employed to promote a higher coverage of the search space. Moreover, we propose a novel performance evaluation function, which measures the number of vehicles that have an incentive to deviate from the routes to which they were assigned. Through experiments, we show that our approach outperforms classical algorithms, providing solutions that are, on average, significantly closer to the UE. Furthermore, when compared to classical methods, the fairness achieved by our assignments is considerably better. These results indicate that our approach is efficient and robust, producing reasonably stable assignments.

A Visual Method for Analysis and Comparison of Search Landscapes

Sebastian Volke, Dirk Zeckzer, Gerik Scheuermann, Martin Middendorf

Combinatorial optimization problems and corresponding (meta-)heuristics have received much attention in the literature. Especially, the structural or topological analysis of search landscapes is important for evaluating the applicability and the performance of search operators for a given problem. However, this analysis is often tedious and usually the focus is on one specific problem and only a few operators. We present a visual analysis method that can be applied to a wide variety of problems and search operators. The method is based on steepest descent walks and shortest distances in the search landscape. The visualization shows the search landscape as seen by the search algorithm. It supports the topological analysis as well as the comparison of search landscapes. We showcase the method by applying it to two different search operators on the TSP, the QAP, and the SMTTP. Our results show how differences between search operators manifest in the search landscapes and how conclusions about the suitability of the search operator for different optimizations can be drawn.

Predicting Heuristic Search Performance with PageRank Centrality in Local Optima Networks

Sebastian Herrmann, Franz Rothlauf

Previous studies have used statistical analysis of fitness landscapes such as ruggedness and deceptiveness in order to predict the expected quality of heuristic search methods. Novel approaches for predicting the performance of heuristic search are based on the analysis of local optima networks (LONs). A LON is a compressed stochastic model of a fitness landscape's basin transitions. Recent literature has suggested using various LON network measurements as predictors for local search performance. In this study, we suggest PageRank centrality as a new measure for predicting the performance of heuristic search methods using local search. PageRank centrality is a variant of Eigenvector centrality and reflects the probability that a node in a network is visited by a random walk. Since the centrality of high-quality solutions in LONs determines the search difficulty of the underlying fitness landscape and since the big valley property suggests that local optima are not randomly distributed in the search space but rather clustered and close to one another, PageRank centrality can serve as a good predictor for local search performance. In our experiments for NK-models and the traveling salesman problem, we found that the PageRank centrality is a very good predictor for the performance of first-improvement local search as well as simulated annealing, since it explains more than 90% of the variance of search performance. Furthermore, we found that PageRank centrality is a better predictor of search performance than traditional approaches

such as ruggedness, deceptiveness, and the length of the shortest path to the optimum.

Guiding Evolutionary Search with Association Rules for Solving Weighted CSPs

Madalina Raschip, Cornelius Croitoru, Kilian Stoffel

Weighted constraint satisfaction problems are difficult optimization problems that could model applications from various domains. Evolutionary algorithms are not the first option for solving such type of problems. In this work, the evolutionary algorithm uses the information extracted from the previous best solutions to guide the search in the next iterations. After the archive of previous best solutions has been sufficiently (re)filled, a data mining module is called to find association rules between variables and values. The generated rules are used to improve further the search process. Different methods of applying the association rules are investigated. Computational experiments are done on academic and real-world problem instances. The obtained results validate the approach and show that it is competitive with existing approaches in literature.

ECOM2

A Genetic Algorithm for Scheduling Electric Vehicle Charging

Jorge García-Álvarez, Miguel A. González, Camino R. Vela

This paper addresses a problem motivated by a real life environment, in which we have to schedule the charge of electric vehicles in a parking, subject to a set of constraints, with the objective of minimizing the total tardiness. We consider both the static version of the problem, where we know in advance the arrival time, charging time and due date of every vehicle, and also the dynamic version of it. We design a genetic algorithm with some components specifically tailored to deal with the problem. In the experimental study we evaluate the proposed algorithm in a benchmark set taken from the literature, and we also compare it against the state-of-the-art showing that our proposal is significantly better.

A Dispatching rule based Genetic Algorithm for Order Acceptance and Scheduling

Su Nguyen, Mengjie Zhang, Tan Kay Chen

Order acceptance and scheduling is an interesting and chal- lenging scheduling problem in which two decisions need to be handled simultaneously. While the exact methods are not efficient and sometimes impractical, existing meta-heuristics proposed in the literature still have troubles dealing with large problem instances. In this paper, a dispatching rule based genetic algorithm is proposed to combine the advan- tages of existing dispatching rules/heuristics, genetic algo- rithm and local search. The results indicates that the pro- posed methods are effective and efficient when compared to a number of existing heuristics with a wide range of problem instances.

On the Impact of Local Search Operators and Variable Neighbourhood Search for the Generalized Travelling Salesperson Problem

Mojgan Pourhassan, Frank Neumann

The generalized travelling salesperson problem is an important NP-hard combinatorial optimization problem where local search approaches have been very successful. We investigate the two hierarchical approaches of Hu and Raidl (2008) for solving this problem from a theoretical perspective. We examine the complementary abilities of the two approaches caused by their neighbourhood structures and the advantage of combining them into variable neighbourhood search. We first point out complementary abilities of the two approaches by presenting instances where they mutually outperform each other. Afterwards, we introduce an instance which is hard for both approaches, but where a variable neighbourhood search combining them finds the optimal solution in polynomial time.

A Novel Diversity-based Evolutionary Algorithm for the Traveling Salesman Problem

Carlos Segura, Salvador Botello Rionda, Arturo Hernández Aguirre, S. Ivvan Valdez Peña

The Traveling Salesman Problem (TSP) is one of the most well-known NP-hard combinatorial optimization problems. In order to deal with large TSP instances, several heuristics and metaheuristics have been devised. In this paper, a novel memetic scheme that incorporates a new diversity-based replacement strategy is proposed and applied to the largest instances of the TSPLIB benchmark. The novelty of our method is that it combines the idea of transforming a single-objective problem into a multi-objective one, by considering diversity as an explicit objective, with the idea of adapting the balance induced between exploration and exploitation to the various optimization stages. In addition, the intensification capabilities of the individual learning method incorporated in the memetic scheme are also adapted by taking into account the stopping criterion. Computational results show the clear superiority of our scheme when compared against state-of-the-art schemes. To our knowledge, our proposal is the first evolutionary scheme that readily solves an instance with more than 30,000 cities to optimality.

ECOM3

Global vs Local Search on Multi-objective NK-Landscapes: Contrasting the Impact of Problem Features

Fabio Daolio, Arnaud Liefooghe, Sébastien Verel, Hernán Aguirre, Kiyoshi Tanaka

Computationally hard multi-objective combinatorial optimization problems are common in practice, and numerous evolutionary multi-objective optimization (EMO) algorithms have been proposed to tackle them. Our aim is to understand which (and how) problem features impact the search performance of such approaches. In this paper, we consider two prototypical dominance-based algorithms: a global EMO strategy using an ergodic variation operator (GSEMO) and a neighborhood-based

local search heuristic (PLS). Their respective runtime is estimated on a benchmark of combinatorial problems with tunable ruggedness, objective space dimension, and objective correlation (ρMNK-landscapes). In other words, benchmark parameters define classes of instances with increasing empirical problem hardness; we enumerate and characterize the search space of small instances. Our study departs from simple performance comparison to systematically analyze the correlations between runtime and problem features, contrasting their association with search performance within and across instance classes, for both chosen algorithms. A mixed-model approach then allows us to further generalize from the experimental design, supporting a sound assessment of the joint impact of instance features on EMO search performance.

A Sequence-based Selection Hyper-heuristic Utilising a Hidden Markov Model

Ahmed Kheiri, Ed Keedwell

Selection hyper-heuristics are optimisation methods that operate at the level above traditional (meta-)heuristics. Their task is to evaluate low level heuristics and determine which of these to apply at a given point in the optimisation process. Traditionally this has been accomplished through the evaluation of individual or paired heuristics. In this work, we propose a hidden Markov model based method to analyse the performance of, and construct, longer sequences of low level heuristics to solve difficult problems. The proposed method is tested on the well known hyper-heuristic benchmark problems within the CHeSC 2011 competition and compared with a large number of algorithms in this domain. The empirical results show that the proposed hyper-heuristic is able to outperform the current best-in-class hyper-heuristic on these problems with minimal parameter tuning and so points the way to a new field of sequence-based selection hyper-heuristics.

Tunnelling Crossover Networks

Gabriela Ochoa, Francisco Chicano, Renato Tinos, Darrell Whitley

Local optima networks are a recent model of fitness landscapes. They compress the landscape by representing local optima as nodes, and search transitions among them as edges. Previous local optima networks considered transitions based on mutation; this study looks instead at transitions based on deterministic recombination. We define and analyse networks based on the recently proposed partition crossover for k-bounded pseudo-Boolean functions, using NKq landscapes as a case study. Partition crossover was initially proposed for the travelling salesman problem, where it was found to "tunnel" between local optima, i.e., jump from local optimum to local optimum. Our network analysis shows that this also happens for NK landscapes: local optima are densely connected via partition crossover. We found marked differences between the adjacent and random interaction NK models. Surprisingly, with the random model, instances have a lower number of local optima on average, but their networks are more sparse and decompose into several clusters. There is also large variability in the size and pattern of connectivity of instances coming from the same landscape parameter values. These network features offer new insight informing why some instances are harder to solve than others.

Hyperheuristics Based on Parametrized Metaheuristic Schemes

José-Matías Cutillas-Lozano, Domingo Giménez, Francisco Almeida

The use of a unified parametrized scheme for metaheuristics facilitates the development of metaheuristics and their application. The unified scheme can also be used to implement hyperheuristics on top of parametrized metaheuristics, selecting appropriate values for the metaheuristic parameters, and consequently the metaheuristic itself. The applicability of hyperheuristics to efficiently solve computational search problems is tested with the application of local and global search methods (GRASP, Tabu Search, Genetic algorithms and Scatter Search) and their combinations to three problems: a problem of optimization of power consumption in operation of wells,the determination of the kinetic constants of a chemical reaction and the maximum diversity problem. The hyperheuristic approach provides satisfactory values for the metaheuristic parameters and consequently satisfactory metaheuristics.

ECOM4

Minimizing Regular Objectives for Blocking Permutation Flow Shop Scheduling: Heuristic Approaches

Nouha Nouri, Talel Ladhari

The objective of this work is to present and evaluate metaheuristics for the blocking permutation flow shop scheduling problem subject to regular objectives. The blocking problem is known to be NP-hard with more than two machines. We assess the difficulty level of this problem by developing two population-based meta-heuristics: Genetic Algorithm and Artificial Bee Colony algorithm. The final goal is to measure the performance of these proposed techniques and potentially contribute in possible improvements in the blocking benchmark instances. Furthermore, computational tests carried out on randomly generated test problems show that the approaches consistently yields good solutions in a moderate amount of time. Finally, an updated list of best-known solutions for the Taillard's and Ronconi and Henriques's benchmark is exposed: new best-known solutions for the blocking flow shop scheduling problem with makespan, total flow time, and total tardiness criteria are found.

Approximate Approaches to the Traveling Thief Problem

Hayden Faulkner, Sergey Polyakovskiy, Tom Schultz, Markus Wagner

This study addresses the recently introduced Traveling Thief Problem (TTP) which combines the classical Traveling Salesman Problem (TSP) with the 0-1 Knapsack Problem (KP). The problem consists of a set of cities, each containing a set of avail-

able items with weights and profits. It involves searching for a permutation of the cities to visit and a decision on items to pick. A selected item contributes its profit to the overall profit at the price of higher transportation cost incurred by its weight. The objective is to maximize the resulting profit. We propose a number of problem-specific packing strategies run on top of TSP solutions derived by the Chained Lin-Kernighan heuristic. The investigations provided on the set of benchmark instances prove their rapidity and efficiency when compared with an approximate mixed integer programming based approach and state-of-the-art heuristic solutions from the literature.

On the Empirical Scaling Behaviour of State-of-the-art Local Search Algorithms for the Euclidean TSP

Jérémie Dubois-Lacoste, Holger Hoos, Thomas Stützle

We present a thorough empirical investigation of the scaling behaviour of state-of-the-art local search algorithms for the TSP; in particular, we study the scaling of running time required for finding optimal solutions to Euclidean TSP instances. We use a recently introduced bootstrapping approach to assess the statistical significance of the scaling models thus obtained and contrast these models with those recently reported for the Concorde algorithm. In particular, we answer the question whether the scaling behaviour of state-of-the-art local search algorithms for the TSP differs by more than a constant from that required by Concorde to find the first optimal solution to a given TSP instance.

Evaluation of a Multi-Objective EA on Benchmark Instances for Dynamic Routing of a Vehicle

Stephan Meisel, Christian Grimme, Jakob Bossek, Martin Wölck, Günter Rudolph, Heike Trautmann

We evaluate the performance of a multi-objective evolutionary algorithm on a class of dynamic routing problems with a single vehicle. In particular we focus on relating algorithmic performance to the most prominent characteristics of problem instances. The routing problem considers two types of customers: mandatory customers must be visited whereas optional customers do not necessarily have to be visited. Moreover, mandatory customers are known prior to the start of the tour whereas optional customers request for service at later points in time with the vehicle already being on its way. The multi-objective optimization problem then results as maximizing the number of visited customers while simultaneously minimizing total travel time. As an a-posteriori evaluation tool, the evolutionary algorithm aims at approximating the related Pareto set for specifically designed benchmarking instances differing in terms of number of customers, geographical layout, fraction of mandatory customers, and request times of optional customers. Conceptional and experimental comparisons to online heuristic procedures are provided.

ECOM5

Generator Start-up Sequences Optimization for Network Restoration Using Genetic Algorithm and Simulated Annealing

Paul Kaufmann, Cong Shen

In the domain of power grid systems, scheduling tasks are widespread. Typically, linear programming (LP) techniques are used to solve these tasks. For cases with high complexity, linear system modeling is often cumbersome. There, other modeling approaches allow for a more compact representation being typically also more accurate as non-linear dependencies can be captured natively. In this work, we focus on the optimization of a power plant start-up sequence, which is part of the network restoration process of a power system after a blackout. Most large power plants cannot start on their own without cranking energy from the outside grid. These are the non-black start (NBS) units. As after a blackout we assume all power plants being shut down, self-contained power plants (black start (BS) units), such as the hydroelectric power plants, start first and boot the NBS units one after each other. Once a NBS unit is restored, it supports the restoration process and because an average NBS unit is much larger than a BS unit, NBS unit's impact on the restoration process is typically dominant. The overall restoration process can take, depending on the size of the blackout region and the damaged components, some hours to weeks. And as the blackout time corresponds directly to economic and life losses, its reduction, even by some minutes, is worthwhile. In this work we compare two popular metaheuristics, the genetic (GA) and simulated annealing (SA) algorithms on start-up sequence optimization and conclude that an efficient restoration plan can be evolved reliably and, depending on the implementation, in a very short period of time allowing for an integration into a real-time transmission system operation tool.

Evolutionary Machine Learning

EML1

Retooling Fitness for Noisy Problems in a Supervised Michigan-style Learning Classifier System

Ryan Urbanowicz, Jason Moore

An accuracy-based rule fitness is a hallmark of most modern Michigan-style learning classifier systems (LCS), a powerful, flexible, and largely interpretable class of machine learners. However, rule-fitness based solely on accuracy is not ideal for identifying 'optimal' rules in supervised learning. This is particularly true for noisy problem domains where perfect rule accuracy essentially guarantees over-fitting. Rule fitness based on accuracy alone is unreliable for reflecting the global 'value' of a given rule since rule accuracy is based on a subset of the training instances. While moderate over-fitting may not dramatically hinder LCS classification or prediction performance,

the interpretability of the solution is likely to suffer. Additionally, over-fitting can impede algorithm learning efficiency and leads to a larger number of rules being required to capture relationships. The present study seeks to develop an intuitive multi-objective fitness function that will encourage the discovery, preservation, and identification of 'optimal' rules through accuracy, correct coverage of training data, and the prior probability of the specified attribute states and class expressed by a given rule. We demonstrate the advantages of our proposed fitness by implementing it into the ExSTraCS algorithm and performing evaluations over a large spectrum of complex, noisy, simulated datasets.

High-Dimensional Function Approximation for Knowledge-Free Reinforcement Learning: a Case Study in SZ-Tetris

Wojciech Jaśkowski, Marcin Szubert, Paweł Liskowski, Krzysztof Krawiec

SZ-Tetris, a restricted version of Tetris, is a difficult reinforcement learning task. Previous research showed that, similarly to the original Tetris, value function-based methods such as temporal difference learning, do not work well for SZ-Tetris. The best performance in this game was achieved by employing direct policy search techniques, in particular the cross-entropy method in combination with handcrafted features. Nonetheless, a simple heuristic hand-coded player scores even higher. Here we show that it is possible to equal its performance with CMA-ES (Covariance Matrix Adaptation Evolution Strategy). We demonstrate that further improvement is possible by employing systematic n-tuple network, a knowledge-free function approximator, and VD-CMA-ES, a linear variant of CMA-ES for high dimension optimization. Last but not least, we show that a large systematic n-tuple network (involving more than 4 million parameters) allows the classical temporal difference learning algorithm to obtain similar average performance to VD-CMA-ES, but at 20 times lower computational expense, leading to the best policy for SZ-Tetris known to date. These results enrich the current understanding of difficulty of SZ-Tetris, and shed new light on the capabilities of particular search paradigms when applied to representations of various characteristics and dimensionality.

Simpler is Better: a Novel Genetic Algorithm to Induce Compact Multi-label Chain Classifiers

Eduardo Gonçalves, Alexandre Plastino, Alex Freitas

Multi-label classification (MLC) is the task of assigning multiple class labels to an object based on the features that describe the object. One of the most effective MLC methods is known as Classifier Chains (CC). This approach consists in training q binary classifiers linked in a chain, y1 -¿ y2 -¿ ... -¿ yq, with each responsible for classifying a specific label in l1, l2, ..., lq. The chaining mechanism allows each individual classifier to incorporate the predictions of the previous ones as additional information at classification time. Thus, possible correlations among labels can be automatically exploited. Nevertheless, CC suffers from two important drawbacks: (i) the label ordering is decided at random, although it usually has a strong effect on predictive accuracy; (ii) all labels are inserted into the chain, although some of them might carry irrelevant information to discriminate the others. In this paper we tackle both problems at once, by proposing a novel genetic algorithm capable of searching for a single optimized label ordering, while at the same time taking into consideration the utilization of partial chains. Experiments on benchmark datasets demonstrate that our approach is able to produce models that are both simpler and more accurate.

Subspace Clustering Using Evolvable Genome Structure

Sergio Peignier, Christophe Rigotti, Guillaume Beslon

In this paper we present an evolutionary algorithm to tackle the subspace clustering problem. Subspace clustering is recognized as more difficult than standard clustering since it requires to identify not only the clusters but also the various subspaces where the clusters hold. We propose to tackle this problem with a bio-inspired algorithm that includes many bio-like features like variable genome length and organization, functional and non-functional elements, and variation operators including chromosomal rearrangements. These features give the algorithm a large degree of freedom to achieve subspace clustering with satisfying results on a reference benchmark with respect to state of the art methods. One of the main advantages of the approach is that it needs only one subspace clustering ad-hoc parameter: the maximal number of clusters. This is a single and intuitive parameter that sets the maximal level of details of the clustering, while other algorithms require more complicated parameter space exploration. The other parameters of the algorithm are related to the evolution strategy (population size, mutation rate, ...) and for them we use a single setting that turns out to be effective on all the datasets of the benchmark.

EML2

Multiple Imputation for Missing Data Using Genetic Programming

Cao Truong Tran, Mengjie Zhang, Peter Andreae

Missing values are a common problem in many real world databases. Inadequate handing of missing data can lead to serious problems in data analysis. A common way to cope with this problem is to use imputation methods to fill missing values with plausible values. This paper proposes GPMI, a multiple imputation method that uses genetic programming as a regression method to estimate missing values. Experiments on eight datasets with six levels of missing values compare GPMI with seven other popular and advanced imputation methods on two measures: the prediction accuracy and the classification accuracy. The results show that, in most cases, GPMI not only achieves better prediction accuracy, but also better classification accuracy than the other imputation methods.

Genetically-regulated Neuromodulation Facilitates Multi-Task Reinforcement Learning

Sylvain Cussat-Blanc, Kyle Harrington

In this paper, we use a gene regulatory network (GRN) to

regulate a reinforcement learning controller, the State- Action-Reward-State-Action (SARSA) algorithm. The GRN serves as a neuromodulator of SARSAs learning parame- ters: learning rate, discount factor, and memory depth. We have optimized GRNs with an evolutionary algorithm to regulate these parameters on specific problems but with no knowledge of problem structure. We show that genetically- regulated neuromodulation (GRNM) performs comparably or better than SARSA with fixed parameters. We then ex- tend the GRNM SARSA algorithm to multi-task problem generalization, and show that GRNs optimized on multi- ple problem domains can generalize to previously unknown problems with no further optimization.

Ant Colony and Surrogate Tree-Structured Models for Orderings-Based Bayesian Network Learning

Juan I. Alonso-Barba, Luis de la Ossa, Olivier Regnier-Coudert, John McCall, José A. Gómez, José M. Puerta

Structural learning of Bayesian networks is a very expensive task even when sacrifying the optimality of the result. Because of that, there are some proposals aimed at obtaining relative-quality solutions in short times. One of them, namely Chain-ACO, searches an ordering among all variables with Ant Colony Optimization and a chain-structured surrogate model, and then uses this ordering to build a Bayesian network by means of the well-known K2 algorithm. This work is based on Chain-ACO. We evaluate the impact of using a tree-structured surrogate model instead of a chain to evaluate orderings during the search. Moreover, we propose a variation of the way K2 builds the network, which consists of allowing some changes in the positions of the variables whenever they such changes not produce a cycle. This modification of the process may improve the score of the final network, without (almost) any additional cost.

EMO1

Characterizing Pareto Front Approximations in Many-objective Optimization

Md Asafuddoula, Tapabrata Ray, Hemant Singh

A Pareto Optimal Front (POF) provides the set of optimal trade-off solutions formulti-objective optimization problems. The characteristics of the POF, e.g. continuity, convexity, spread and uniformity are important in the context of decision making and performance assessment. Most of the existing metrics (hypervolume, inverted generational distance, coverage etc.) were originally designed for two or three objective optimization problems with an aim of assessing the quality of non-dominated solutions delivered by various algorithms. The metrics provide little information about the nature of the front and some of them (e.g. hypervolume) are computationally expensive for problems involving large number of objectives. For problems with more than three objectives, existing tools for visualization such as parallel plots, spider/radar plots and scatter plots also offer limited useful information in terms of the nature of the front. In this paper, we introduce an alternative scalar measure of diversity that is suitable for characterizing POF approximations of optimization problems with high number of objectives. The diversity is measured against a Reference Pareto Front, a set of points uniformly spread on the hyperplane with unit intercepts. We also illustrate that the computation of such a metric is a natural extension of decomposition based evolutionary algorithms which attempt to align solutions with the reference directions constructed using the Ideal point and uniformly distributed points on the hyperplane. In particular, the perpendicular distances between the uniformly distributed reference directions and their closest solutions in the nondominated front provides information about the diversity, while the shortest distance of every solution from the hyperplane provides information about the convexity of the POF. The proposed metrics are illustrated using a number of test problems involving up to fifteen objectives.

Finding the Trade-off between Robustness and Worst-case Quality

Juergen Branke, Ke Lu

Many real-world problems are subject to uncertainty, and often solutions should not only be good, but also robust against environmental disturbances or deviations from the decision variables. While most papers dealing with robustness aim at finding solutions with a high expected performance given a distribution of the uncertainty, we examine the trade-off between the allowed deviations from the decision variables (tolerance level), and the worst case performance given the allowed deviations. A possible application are manufacturing tolerances, where an engineer can specify an allowed tolerance for manufacturing, but a low tolerance requirement incurs substantially higher manufacturing cost, whereas a high tolerance requirement usually means having to accept a lower worst-case quality of the solution.¡/par¿¡par¿More specifically, in this paper, we suggest two multi- objective evolutionary algorithms to compute the available trade offs between allowed tolerance level and worst-case quality of the solutions. Both algorithms are 2-level nested algorithms. While the first algorithm is point-based in the sense that the lower level computes a point of worst case for each upper level solution, the second algorithm is envelope-based, in the sense that the lower level computes a whole trade-off curve between worst-case oftness and tolerance level for each upper level solution.

EMO2

Obtaining Optimal Pareto Front Approximations using Scalarized Preference Information

Marlon Braun, Pradyumn Shukla, Hartmut Schmeck

Scalarization techniques are a popular method for articulating preferences in solving multi-objective optimization problems. These techniques, however, have so far proven to be ill-suited in finding a preference-driven approximation that still captures the Pareto front in its entirety. Therefore, we propose a new concept that defines an optimal distribution of points on the front given a specific scalarization function. It is proven that such an approximation exists for every real-valued problem irrespective of

the shape of the corresponding front under some very mild conditions. We also show that our approach works well in obtaining an equidistant approximation of the Pareto front if no specific preference is articulated. Our analysis is complemented by the presentation of a new algorithm that implements the aforementioned concept. We provide in-depth simulation results to demonstrate the performance of our algorithm. The analysis also reveals that our algorithm is able to outperform current state-of-the-art algorithms on many popular benchmark problems.

Evolutionary Multiobjective Optimization

EMO1

A Study on Performance Evaluation Ability of a Modified Inverted Generational Distance Indicator

Hisao Ishibuchi, Hiroyuki Masuda, Yusuke Nojima

The inverted generational distance (IGD) has been frequently used as a performance indicator for many-objective problems where the use of the hypervolume is difficult. However, since IGD is not Pareto compliant, it is possible that misleading Pareto incompliant results are obtained. Recently, a simple modification of IGD was proposed by taking into account the Pareto dominance relation between a solution and a reference point when their distance is calculated. It was also shown that the modified indicator called IGD+ is weakly Pareto compliant. However, actual effects of the modification on performance comparison have not been examined. Moreover, IGD+ has not been compared with other distance-based weakly Pareto compliant indicators such as the additive epsilon indicator and the D1 indicator (i.e., IGD with the weighted achievement scalarizing function). In this paper, we examine the effect of the modification by comparing IGD+ with IGD for multiobjective and many-objective problems. In computational experiments, we generate a large number of ordered pairs of non-dominated solution sets where one is better than the other. Two solution sets in each pair are compared by the above-mentioned performance indicators. We examine whether each indicator can correctly say which solution set is better between them.

Improved Sampling of Decision Space for Pareto Estimation

Yiming Yan, Ioannis Giagkiozis, Peter Fleming

Pareto Estimation (PE) is a novel method for increasing the density of Pareto optimal solutions across the entire Pareto Front or in a specific region of interest. PE identifies the inverse mapping of Pareto optimal solutions, namely, from objective space to decision space. This identification can be performed using a number of modeling techniques, how- ever, for the sake of simplicity in this work we use a radial basis neural network. In any modeling method, the quality of the resulting model depends heavily on the training samples used. The original version of PE uses the result- ing set of Pareto optimal solutions from any multi-objective optimization algorithm and then utilizes this set to identify the aforementioned mapping. However, we argue that this selection may not always be the best possible and propose an alternative scheme to improve the resulting set of Pareto optimal solutions in order to produce higher quality samples for the identification scheme in PE. The proposed approach is integrated with MAEA-gD, and the resulting solutions are used with PE. The results show that the proposed method shows promise, in that there is measurable improvement in the quality of the estimated PE in terms of the coverage and density.

EMO2

An Experimental Investigation of Variation Operators in Reference-Point Based Many-Objective Optimization

Yuan Yuan, Hua Xu, Bo Wang

Reference-point based multi-objective evolutionary algorithms (MOEAs) have shown promising performance in many-objective optimization. However, most of existing research within this area focused on improving the environmental selection procedure, and little work has been done on the effect of variation operators. In this paper, we conduct an experimental investigation of variation operators in a typical reference-point based MOEA, i.e., NSGA-III. First, we provide a new NSGA-III variant, i.e., NSGA-III-DE, which introduces differential evolution (DE) operator into NSGA-III, and we further examine the effect of two main control parameters in NSGA-III-DE. Second, we have an experimental analysis of the search behavior of NSGA-III-DE and NSGA-III. We observe that NSGA-III-DE is generally better at exploration whereas NSGA-III normally has advantages in exploitation. Third, based on this observation, we present two other NSGA-III variants, where DE operator and genetic operators are simply combined to reproduce solutions. Experimental results on several benchmark problems show that very encouraging performance can be achieved by three suggested new NSGA-III variants. Our work also indicates that the performance of NSGA-III is significantly bottlenecked by its variation operators, providing opportunities for the study of the other alternative ones.

Benchmarking Numerical Multiobjective Optimizers Revisited

Dimo Brockhoff, Thanh-Do Tran, Nikolaus Hansen

Algorithm benchmarking plays a vital role in designing new optimization algorithms and in recommending efficient and robust algorithms for practical purposes. So far, two main approaches have been used to compare algorithms in the evolutionary multiobjective optimization (EMO) field: (i) displaying empirical attainment functions and (ii) reporting statistics on quality indicator values. Most of the time, EMO benchmarking studies compare algorithms for fixed and often arbitrary budgets of func-

tion evaluations although the algorithms are any-time optimizers. Instead, we propose to transfer and adapt standard benchmarking techniques from the single-objective optimization and classical derivative-free optimization community to the field of EMO. Reporting *target-based runlengths* allows to compare algorithms with varying numbers of function evaluations quantitatively. Displaying *data profiles* can aggregate performance information over different test functions, problem difficulties, and quality indicators. We apply this approach to compare three common algorithms on a new test function suite derived from the well-known single-objective BBOB functions. The focus thereby lies less on gaining insights into the algorithms but more on showcasing the concepts and on what can be gained over current benchmarking approaches.

Greedy Hypervolume Subset Selection in the Three-Objective Case

Andreia Guerreiro, Carlos Fonseca, Luís Paquete

Given a non-dominated point set $Xr \subset Rd$ of size n and a suitable reference point $r \in Rd$, the Hypervolume Subset Selection Problem (HSSP) consists of finding a subset of size $k \leq n$ that maximizes the hypervolume indicator. It arises in connection with multiobjective selection and archiving strategies, as well as Pareto-front approximation post-processing for visualization and/or interaction with a decision maker. Efficient algorithms to solve the HSSP are available only for the 2-dimensional case, achieving a time complexity of $O(n(k+logn))$. In contrast, the best upper bound available for $d > 2$ is $O(n^{\frac{d}{2}}logn + n^{n-k})$. Since the hypervolume indicator is a monotone submodular function, the HSSP can be approximated to a factor of $(1-1/e)$ using a greedy strategy. Such a greedy algorithm for the 3-dimensional HSSP is proposed in this paper. The time complexity of the algorithm is shown to be $O(n^2)$, which considerably improves upon recent complexity results for this approximation problem.

EMO3

Improving Robustness of Stopping Multi-objective Evolutionary Algorithms by Simultaneously Monitoring Objective and Decision Space

Md Shahriar Mahbub, Tobias Wagner, Luigi Crema

Appropriate stopping criteria for multi-objective evolutionary algorithms (MOEA) are an important research topic due to the computational cost of function evaluations, particularly on real-world problems. Most common stopping criteria are based on a fixed budget of function evaluations or the monitoring of the objective space. In this work, we propose a stopping criterion based on monitoring both the objective and decision space of a problem. Average Hausdorff distance (AHD) and genetic diversity are used, respectively. Two-sided t-tests on the slope coefficients after regression analyses are used to detect the stagnation of the AHD and the genetic diversity. The approach is implemented for two widely used MOEAs: NSGA-II and SPEA2. It is compared to a fixed budget, the online convergence detection approach, and the individual monitoring of each space on four bi-objective and two three-objective benchmark problems. Our experimental results reveal that the combined approach achieved significantly better results than the approaches considering only one of the spaces. In particular, we find that the combined consideration runs longer and hence more robustly ensures a well-approximated Pareto front. Nevertheless, on average 29% and 17% function evaluations are saved for NSGA-II and SPEA2, respectively, compared to standard budget recommendations.

An Approach to Mitigating Unwanted Interactions between Search Operators in Multi-Objective Optimization

Chad Byers, Betty Cheng

At run time, software systems often face a myriad of adverse environmental conditions and system failures that cannot be anticipated during the system's initial design phase. These uncertainties drive the need for dynamically adaptive systems that are capable of providing self-* properties (e.g., self-monitoring, self-adaptive, self-healing, etc.). Prescriptive techniques to manually preload these systems with a limited set of configurations often result in brittle, rigid designs that are unable to cope with environmental uncertainty. An alternative approach is to embed a search technique capable of exploring and generating optimal reconfigurations at run time. Increasingly, DAS applications are defined by multiple competing objectives (e.g., cost vs. performance) in which a set of valid solutions with a range of trade-offs are to be considered rather than a single optimal solution. While leveraging a multi-objective optimization technique, NSGA-II, to manage these competing objectives, hidden interactions were observed between search operators that prevented fair competition among solutions and restricted search from regions where valid optimal configurations existed. In this follow-on work, we demonstrate the role that niching can play in mitigating these unwanted interactions by explicitly creating favorable regions within the objective space where optimal solutions can equally compete and co-exist.

Fast Implementation of the Steady-State NSGA-II Algorithm for Two Dimensions Based on Incremental Non-Dominated Sorting

Maxim Buzdalov, Ilya Yakupov, Andrey Stankevich

Genetic algorithms (GAs) are widely used in multi-objective optimization for solving complex problems. There are two distinct approaches for GA design: generational and steady-state algorithms. Most of the current state-of-the-art GAs are generational, although there is an increasing interest to steady-state algorithms as well. However, for algorithms based on non-dominated sorting, most of steady-state implementations have higher computation complexity than their generational counterparts, which limits their applicability. We present a fast implementation of a steady-state version of the NSGA-II algorithm for two dimensions. This implementation is based on a data structure which has O(N) complexity for single solution insertion and deletion in the worst case. The experimental results show that our implementation works noticeably faster than steady-

state NSGA-II implementations which use fast non-dominated sorting.

A Performance Comparison Indicator for Pareto Front Approximations in Many-Objective Optimization

Miqing Li, Shengxiang Yang, Xiaohui Liu

Increasing interest in simultaneously optimizing many objectives (typically more than three objectives) of problems leads to the emergence of various many-objective algorithms in the evolutionary multi-objective optimization field. However, in contrast to the development of algorithm design, how to assess many-objective algorithms has received scant concern. Many performance indicators are designed in principle for any number of objectives, but in practice are invalid or infeasible to be used in many-objective optimization. In this paper, we explain the difficulties that popular performance indicators face and propose a performance comparison indicator (PCI) to assess Pareto front approximations obtained by many-objective algorithms. PCI evaluates the quality of approximation sets with the aid of a reference set constructed by themselves. The points in the reference set are divided into many clusters, and the proposed indicator estimates the minimum moves of solutions in the approximation sets to weakly dominate these clusters. PCI has been verified both by an analytic comparison with several well-known indicators and by an empirical test on four groups of Pareto front approximations with different numbers of objectives and problem characteristics.

EMO4

Multi-objective Optimization with Dynamic Constraints and Objectives: New Challenges for Evolutionary Algorithms

Radhia Azzouz, Slim Bechikh, Lamjed Ben Said

Dynamic Multi-objective Optimization (DMO) is a challenging research topic since the objective functions, constraints, and problem parameters may change over time. Several evolutionary algorithms have been proposed to deal with DMO problems. Nevertheless, they were restricted to unconstrained or domain constrained problems. In this work, we focus on the dynamicty of problem constraints along with time-varying objective functions. As this is a very recent research area, we have observed a lack of benchmarks that simultaneously take into account these characteristics. To fill this gap, we propose a set of test problems that extend a suite of static constrained multi-objective problems. Moreover, we propose a new version of the Dynamic Non dominated Sorting Genetic Algorithm II to deal with dynamic constraints by replacing the used constraint-handling mechanism by a more elaborated and self-adaptive penalty function. Empirical results show that our proposal is able to: (1) handle dynamic environments and track the changing Pareto front and (2) handle infeasible solutions in an effective and efficient manner which allows avoiding premature convergence. Moreover, the statistical analysis of the obtained results emphasize the advantages of our proposal over the original algorithm on both aspects of convergence and diversity on most test problems.

A New Framework for Self-adapting Control Parameters in Multi-objective Optimization

Xin Qiu, Weinan Xu, Jian-Xin Xu, Kay Chen Tan

Proper tuning of control parameters is critical to the performance of a multi-objective evolutionary algorithm (MOEA). However, the developments of tuning methods for multi-objective optimization are insufficient compared to single-objective optimization. To circumvent this issue, this paper proposes a novel framework that can self-adapt the parameter values from an objective-based perspective. Optimal parametric setups for each objective will be efficiently estimated by combining single-objective tuning methods with a grouping mechanism. Subsequently, the position information of individuals in objective space is utilized to achieve a more efficient adaptation among multiple objectives. The new framework is implemented into two classical Differential-Evolution-based MOEAs to help to adapt the scaling factor F in an objective-wise manner. Three state-of-the-art single-objective tuning methods are applied respectively to validate the robustness of the proposed mechanisms. Experimental results demonstrate that the new framework is effective and robust in solving multi-objective optimization problems.

Incorporating User Preferences in MOEA/D through the Coevolution of Weights

Martin Pilat, Roman Neruda

The resulting set of solutions obtained by MOEA/D depends on the weights used in the decomposition. In this work, we use this feature to incorporate user preferences into the search. We use co-evolutionary approach to change the weights adaptively during the run of the algorithm. After the user specifies their preferences by assigning binary preference values to the individuals, the co-evolutionary step improves the distribution of weights by creating new (offspring) weights and selecting those that better match the user preferences. The algorithm is tested on a set of benchmark functions with a set of different user preferences.

Empirical Study of Multi-objective Ant Colony Optimization to Software Project Scheduling Problems

Jing Xiao, Mei-Ling Gao, Min-Mei Huang

The Software Project Scheduling Problem (SPSP) focuses on the management of software engineers and tasks in a software project so as to complete the tasks with a minimal cost and duration. Its becoming more and more important and challenging with the rapid development of software industry. In this paper, we employ a Multi-objective Evolutionary Algorithm using Decomposition and Ant Colony (MOEA/D-ACO) to solve the SPSP. To the best of our knowledge, it is the first application of Multi-objective Ant Colony Optimization (MOACO) to SPSP. Two heuristics capable of guiding the algorithm to search better in the SPSP model are examined. Experiments are conducted on a set of 36 publicly available instances. The results are compared with the implementation of another multi-objective evolutionary algorithm called NSGA-II for SPSP. MOEA/D-ACO does

not outperform NSGA-II for most of complex instances in terms of Pareto Front. But MOEA/D-ACO can obtain solutions with much less time for all instances in our experiments and it outperforms NSGA-II with less duration for most of test instances. The performance may be improved with tuning of the algorithm such as incorporating more heuristic information or using other MOACO algorithms, which deserve further investigation.

EMO5

A PSO Approach to Semivectorial Bilevel Programming: Pessimistic, Optimistic and Deceiving Solutions

Maria João Alves, Carlos Antunes, Pedro Carrasqueira

In a bilevel programming problem, the upper level decision maker (leader) decides first, but he must incorporate the reaction of the lower level decision maker (follower) in his decision. The existence of multiple objectives at the lower level gives rise to a set of lower level efficient solutions for each leader's decision, which poses additional difficulties for the leader to anticipate the follower's reaction. The optimistic approach assumes that the follower accepts any efficient solution, while the pessimistic approach considers that the leader prepares for the worst case. In this work, we first discuss the assumptions and implications of optimistic vs. pessimistic approaches in bilevel problems with multiple objective functions at the lower level (semivectorial bilevel problems) or at both levels. Three types of solutions are analyzed: the optimistic, pessimistic and deceiving solutions, the latter being a new solution concept introduced herein, which represents the worst outcome of a failed optimistic approach (i.e., when the leader believes that the follower will pursue his own interests but the follower does not react accordingly). Then we propose a particle swarm optimization algorithm to semivectorial bilevel problems, which aims to approximate these three types of solutions in a single run. Some experimental results of the algorithm are presented.

Multi-Objective BDD Optimization with Evolutionary Algorithms

Saeideh Shirinzadeh, Mathias Soeken, Rolf Drechsler

Binary Decision Diagrams (BDDs) are widely used in electronic design automation and formal verification. BDDs are a canonical representation of Boolean functions with respect to a variable ordering. Finding a variable ordering resulting in a small number of nodes and paths is a primary goal in BDD optimization. There are several approaches minimizing the number of nodes or paths in BDDs, but yet no method has been proposed to minimize both objectives at the same time. In this paper, BDD optimization is carried out as a bi-objective problem using two aforementioned criteria. For this purpose, we have exploited NSGA-II which has been proven to fit problems with a small number of objectives. Furthermore, the algorithm is facilitated with an objective priority scheme that allows to incorporate preference to one of the objectives. Experimental results show that our multi-objective BDD optimization algorithm has achieved a good trade-off between the number of nodes and the number of paths. Comparison of the results obtained by applying priority to the number of nodes or paths with node and path minimization techniques demonstrates that the proposed algorithm can find the minimum of the preferred objective in most cases as well as lowering the other objective simultaneously.

MOEA/VAN: Multiobjective Evolutionary Algorithm Based on Vector Angle Neighborhood

Roman Denysiuk, Lino Costa, Isabel Espírito Santo

Natural selection favors the survival and reproduction of organisms that are best adapted to their environment. Selection mechanism in evolutionary algorithms mimics this process, aiming to create environmental conditions in which artificial organisms could evolve solving the problem at hand. This paper proposes a new selection scheme for evolutionary multiobjective optimization. The similarity measure that defines the concept of the neighborhood is a key feature of the proposed selection. Contrary to commonly used approaches, usually defined on the basis of distances between either individuals or weight vectors, it is suggested to consider the similarity and neighborhood based on the angle between individuals in the objective space. The smaller the angle, the more similar individuals. This notion is exploited during the mating and environmental selections. The convergence is ensured by minimizing distances from individuals to a reference point, whereas the diversity is preserved by maximizing angles between neighboring individuals. Experimental results reveal a highly competitive performance and useful characteristics of the proposed selection. Its strong diversity preserving ability allows to produce a significantly better performance on some problems when compared with stat-of-the-art algorithms.

Improved Metaheuristic Based on the R2 Indicator for Many-Objective Optimization

Raquel Hernández Gómez, Carlos Coello Coello

In recent years, performance indicators were introduced as a selection mechanism in multi-objective evolutionary algorithms (MOEAs). A very attractive option is the $R2$ indicator due to its low computational cost and weak-Pareto compatibility. This indicator requires a set of utility functions, which map each objective to a single value. However, not all the utility functions available in the literature scale properly for more than four objectives and the diversity of the approximation sets is sensitive to the choice of the reference points during normalization. In this paper, we present an improved version of a MOEA based on the $R2$ indicator, which takes into account these two key aspects, using the achievement scalarizing function and statistical information about the population's proximity to the true Pareto optimal front. Moreover, we present a comparative study with respect to some other emerging approaches, such as NSGA-III (based on Pareto dominance), Δ_p-DDE (based on the Δ_p indicator) and some other MOEAs based on the $R2$ indicator, using the DTLZ and WFG test problems. Experimental results indicate that our approach outperforms the original algorithm as well as the other MOEAs in the majority of the test instances, making it a suitable

alternative for solving many-objective optimization problems.

EMO6

Analysis of Objectives Relationships in Multiobjective Problems Using Trade-Off Region Maps

Rodrigo Pinheiro, Dario Landa-Silva, Jason Atkin

Understanding the relationships between objectives in many-objective optimisation problems is desirable in order to develop more effective algorithms. We propose a technique for the analysis and visualisation of complex relationships between many (three or more) objectives. This technique looks at conflicting, harmonious and independent objectives relationships from different perspectives. To do that, it uses correlation, trade-off regions maps and scatter-plots in a four step approach. We apply the proposed technique to a set of instances of the well-known multiobjective multidimensional knapsack problem. The experimental results show that with the proposed technique we can identify local and complex relationships between objectives, trade-offs not derived from pairwise relationships, gaps in the fitness landscape, and regions of interest. Such information can be used to tailor the development of algorithms.

Injecting CMA-ES into MOEA/D

Saúl Zapotecas-Martínez, Bilel Derbel, Arnaud Liefooghe, Dimo Brockhoff, Hernán Aguirre, Kiyoshi Tanaka

MOEA/D is an aggregation-based evolutionary algorithm which has been proved extremely efficient and effective for solving multi-objective optimization problems. It is based on the idea of decomposing the original multi-objective problem into several single-objective subproblems by means of well-defined scalarizing functions. Those single-objective subproblems are solved in a cooperative manner by defining a neighborhood relation between them. This makes MOEA/D particularly interesting when attempting to plug and to leverage single-objective optimizers in a multi-objective setting. In this context, we investigate the benefits that MOEA/D can achieve when coupled with CMA-ES, which is believed to be a powerful single-objective optimizer. We rely on the ability of CMA-ES to deal with injected solutions in order to update different covariance matrices with respect to each subproblem defined in MOEA/D. We show that by cooperatively evolving neighboring CMA-ES components, we are able to obtain competitive results for different multi-objective benchmark functions.

On Maintaining Diversity in MOEA/D: Application to a Biobjective Combinatorial FJSP

Juan Jose Palacios, Bilel Derbel

MOEA/D is a generic decomposition-based multiobjective optimization framework which has been proved to be extremely effective in solving a broad range of optimization problems especially for continuous domains. In this paper, we consider applying MOEA/D to solve a bi-objective scheduling combinatorial problem in which task durations and due-dates are uncertain. Surprisingly, we find that the conventional MOEA/D implementation provides poor performance in our application setting. We show that this is because the replacement strategy underlying MOEA/D is suffering some shortcomes that lead to low population diversity, and thus to premature convergence. Consequently, we investigate existing variants of MOEA/D and we propose a novel and simple alternative replacement component at the aim of maintaining population diversity. Through extensive experiments, we then provide a comprehensive analysis on the relative performance and the behavior of the considered algorithms. Besides being able to outperform existing MOEA/D variants, as well as the standard NSGA-II algorithm, our investigations provide new insights into the search ability of MOEA/D and highlight new research opportunities for improving its design components.

Parallel Multi-Objective Evolutionary Design of Approximate Circuits

Radek Hrbacek

Evolutionary design of digital circuits has been well established in recent years. Besides correct functionality, the demands placed on current circuits include the area of the circuit and its power consumption. By relaxing the functionality requirement, one can obtain more efficient circuits in terms of the area or power consumption at the cost of an error introduced to the output of the circuit. As a result, a variety of trade-offs between error and efficiency can be found. In this paper, a multi-objective evolutionary algorithm for the design of approximate digital circuits is proposed. The scalability of the evolutionary design has been recently improved using parallel implementation of the fitness function and by employing spatially structured evolutionary algorithms. The proposed multi-objective approach uses Cartesian Genetic Programming for the circuit representation and a modified NSGA-II algorithm. Multiple isolated islands are evolving in parallel and the populations are periodically merged and new populations are distributed across the islands. The method is evaluated in the task of approximate arithmetical circuits design.

Generative and Developmental Systems

GDS1

Confronting the Challenge of Quality Diversity

Justin Pugh, L. Soros, Paul Szerlip, Kenneth Stanley

In contrast to the conventional role of evolution in evolutionary computation (EC) as an optimization algorithm, a new class of evolutionary algorithms has emerged in recent years that instead aim to accumulate as diverse a collection of discoveries as possible, yet where each variant in the collection is as fit as it can be. Often applied in both neuroevolution and morphological evolution, these new quality diversity (QD) algorithms are particularly well-suited to evolution's inherent strengths, thereby offering a promising niche for EC within the broader field of machine learning. However, because QD algorithms are so new, until now no comprehensive study has yet attempted to systematically elucidate their relative strengths and weaknesses under different conditions. Taking a first step in this direction, this paper introduces a new benchmark domain designed specifically to compare and contrast QD algorithms. It then shows how the degree of alignment between the measure of quality and the behavior characterization (which is an essential component of all QD algorithms to date) impacts the ultimate performance of different such algorithms. The hope is that this initial study will help to stimulate interest in QD and begin to unify the disparate ideas in the area.

Enhancing Divergent Search through Extinction Events

Joel Lehman, Risto Miikkulainen

A challenge in evolutionary computation is to create representations as evolvable as those in natural evolution. This paper hypothesizes that extinction events, i.e. mass extinctions, can significantly increase evolvability, but only when combined with a divergent search algorithm, i.e. a search driven towards diversity (instead of optimality). Extinctions amplify diversity-generation by creating unpredictable evolutionary bottlenecks. Persisting through multiple such bottlenecks is more likely for lineages that diversify across many niches, resulting in indirect selection pressure for the capacity to evolve. This hypothesis is tested through experiments in two evolutionary robotics domains. The results show that combining extinction events with divergent search increases evolvability, while combining them with convergent search offers no similar benefit. The conclusion is that extinction events may provide a simple and effective mechanism to enhance performance of divergent search algorithms.

Devising Effective Novelty Search Algorithms: A Comprehensive Empirical Study

Jorge Gomes, Pedro Mariano, Anders Christensen

Novelty search is a state-of-the-art evolutionary approach that promotes behavioural novelty instead of pursuing a static objective. Along with a large number of successful applications, many different variants of novelty search have been proposed. It is still unclear, however, how some key parameters and algorithmic components influence the evolutionary dynamics and performance of novelty search. In this paper, we conduct a comprehensive empirical study focused on novelty search's algorithmic components. We study the "k" parameter – the number of nearest neighbours used in the computation of novelty scores; the use and function of an archive; how to combine novelty search with fitness-based evolution; and how to configure the mutation rate of the underlying evolutionary algorithm. Our study is conducted in a simulated maze navigation task. Our results show that the configuration of novelty search can have a significant impact on performance and behaviour space exploration. We conclude with a number of guidelines for the implementation and configuration of novelty search, which should help future practitioners to apply novelty search more effectively.

GDS2

Evolving Soft Robots in Tight Spaces

Nick Cheney, Josh Bongard, Hod Lipson

Soft robots have become increasingly popular in recent years and justifiably so. Their compliant structures and (theoretically) infinite degrees of freedom allow them to undertake tasks which would be impossible for their rigid body counterparts, such as conforming to uneven surfaces, efficiently distributing stress, and passing through small apertures. Previous work in the automated deign of soft robots has shown examples of these squishy creatures performing traditional robotic task like locomoting over flat ground. However, designing soft robots for traditional robotic tasks fails to fully utilize their unique advantages. In this work, we present the first example of a soft robot evolutionarily designed for reaching or squeezing through a small aperture a task naturally suited to its type of morphology. We optimize these creatures with the CPPN-NEAT evolutionary algorithm, introducing a novel implementation of the algorithm which includes multi-objective optimization while retaining its speciation feature for diversity maintenance. We show that more compliant and deformable soft robots perform more effectively at this task than their less flexible counterparts. This work serves mainly as a proof of concept, but we hope that it helps to open the door for the better matching of tasks with appropriate morphologies in robotic design in the future.

Innovation Engines: Automated Creativity and Improved Stochastic Optimization via Deep Learning

Anh Nguyen, Jason Yosinski, Jeff Clune

The Achilles Heel of stochastic optimization algorithms is getting trapped on local optima. Novelty Search avoids this problem by encouraging a search in all interesting directions. That occurs by replacing a performance objective with a reward for novel behaviors, as defined by a human-crafted, and often simple, behavioral distance function. While Novelty Search is a major conceptual breakthrough and outperforms traditional

stochastic optimization on certain problems, it is not clear how to apply it to challenging, high-dimensional problems where specifying a useful behavioral distance function is difficult. For example, in the space of images, how do you encourage novelty to produce hawks and heroes instead of endless pixel static? Here we propose a new algorithm, the Innovation Engine, that builds on Novelty Search by replacing the human-crafted behavioral distance with a Deep Neural Network (DNN) that can recognize interesting differences between phenotypes. The key insight is that DNNs can recognize similarities and differences between phenotypes at an abstract level, wherein novelty means interesting novelty. For example, a novelty pressure in image space does not explore in the low-level pixel space, but instead creates a pressure to create new types of images (e.g. churches, mosques, obelisks, etc.). Here we describe the long-term vision for the Innovation Engine algorithm, which involves many technical challenges that remain to be solved. We then implement a simplified version of the algorithm that enables us to explore some of the algorithm's key motivations. Our initial results, in the domain of images, suggest that Innovation Engines could ultimately automate the production of endless streams of interesting solutions in any domain: e.g. producing intelligent software, robot controllers, optimized physical components, and art.

Genetic Algorithms

GA1

Parasite Diversity in Symbiogenetic Multiset Genetic Algorithm - Optimization of Large Binary Problems

António Manso, Luís Correia

Symbiogenetic MuGA (SMuGA) is a co-evolutionary model exploiting the concept of symbiosis over the Multiset Genetic Algorithm (MuGA). It evolves two species: hosts that represent a solution to the problem, and parasites that represent part-solutions. SMuGA has been proved valuable in the optimization of a variety of deceptive functions. However its performance decreased in large scale difficult problems. This paper presents a new version of SMuGA with improvements centered on the evolution process of the parasites. The most significant advance is provided by using a diversity measure to modulate the evolution of parasites. The algorithm is tested with very good results in deceptive functions with up to 1024 bits. The paper is concluded with an analysis of the advantages and limitations of the approach, and with perspectives for future developments.

Gray-Box Optimization using the Parameter-less Population Pyramid

Brian Goldman, William Punch

Unlike black-box optimization problems, gray-box optimization problems have known, limited, non-linear relationships between variables. Though more restrictive, gray-box problems include many real-world applications in network security, computational biology, VLSI design, and statistical physics. Leveraging these restrictions, the Hamming-Ball Hill Climber (HBHC) can efficiently find high quality local optima. We show how 1) a simple memetic algorithm in conjunction with HBHC can find global optima for some gray-box problems and 2) a gray-box version of the Parameter-less Population Pyramid (P3), utilizing both the HBHC and the known information about variable relationships, outperforms all of the examined algorithms. While HBHC's inclusion into P3 adds a parameter, we show experimentally it can be fixed to 1 without adversely effecting search. We provide experimental evidence on NKq-Landscapes and Ising Spin Glasses that Gray-Box P3 is effective at finding the global optima even for problems with thousands of variables. This capability is complemented by its efficiency, with running time and memory usage decreased by up to a linear factor from Black-Box P3. On NKq this results in a 375x speedup for problems with at least 1,000 variables.

Evolutionary Bilevel Optimization for Complex Control Tasks

Jason Liang, Risto Miikkulainen

Most optimization algorithms must undergo time consuming parameter adaptation in order to optimally solve complex, real-world control tasks. Parameter adaptation is inherently a bilevel optimization problem where the lower level objective function is the performance of the control parameters discovered by an optimization algorithm and the upper level objective function is the performance of the algorithm given its parametrization. In this paper, a novel method called MetaEvolutionary Algorithm (MEA) is presented and shown to be capable of efficiently discovering optimal parameters for neuroevolution to solve control problems. In two challenging examples, double pole balancing and helicopter hovering, MEA discovers optimized parameters that result in better performance than hand tuning and other automatic methods. Bilevel optimization in general and MEA in particular, is thus a promising approach for solving difficult control tasks.

Mk Landscapes, NK Landscape, MAX-kSAT

Darrell Whitley

This paper investigates Gray Box Optimization for pseudo-Boolean optimization problems composed of M subfunctions, where each subfunction accepts at most k variables. We will refer to these as Mk Landscapes. In Gray Box optimization, the optimizer is given access to the set of M subfunctions. If the set of subfunctions is k-bounded and separable, the Gray Box optimizer is guaranteed to return the global optimum with 1 evaluation. A problem is said to be *order k deceptive* if the average values of hyperplanes over combinations of k variables cannot be used to infer a globally optimal solution. Hyperplane aver-

ages are always efficiently computable for Mk Landscapes. If a problem is not deceptive, the Gray Box optimizer also returns the global optimum after 1 evaluation. Finally, these concepts are used to understand the nonlinearity of problems in the complexity class P, such as Adjacent NK Landscapes. These ideas are also used to understand the problem structure of NP Hard problems such as MAX-kSAT and general Mk Landscapes. In general, NP Hard problems are profoundly deceptive.

GA2

Maintaining 2-Approximations for the Dynamic Vertex Cover Problem Using Evolutionary Algorithms

Mojgan Pourhassan, Wanru Gao, Frank Neumann

Evolutionary algorithms have been frequently used to deal with dynamic optimization problems, but their success is hard to understand from a theoretical perspective. With this paper, we contribute to the theoretical understanding of evolutionary algorithms for dynamic combinatorial optimization problems. We examine a dynamic version of the classical vertex cover problem and analyse evolutionary algorithms with respect to their ability to maintain a 2-approximation. Analysing the different evolutionary algorithms studied by Jansen et al. (2013), we point out where two previously studied approaches are not able to maintain a 2-approximation even if they start with a solution of that quality. Furthermore, we point out that the third approach is very effective in maintaining 2-approximations for the dynamic vertex cover problem.

A Tensor Analysis Improved Genetic Algorithm for Online Bin Packing

Shahriar Asta, Ender Ozcan

Mutation in a Genetic Algorithm is the key variation operator adjusting the genetic diversity in a population throughout the evolutionary process. Often, a fixed mutation probability is used to perturb the value of a gene. In this study, we describe a novel data science approach to adaptively generate the mutation probability for each locus. The trail of high quality candidate solutions obtained during the search process is represented as a 3rd order tensor. Factorizing that tensor captures the common pattern between those solutions, identifying the degree of mutation which is likely to yield improvement at each locus. An online bin packing problem is used as an initial case study to investigate the proposed approach for generating locus dependent mutation probabilities. The empirical results show that the tensor approach improves the performance of a standard Genetic Algorithm on almost all classes of instances, significantly.

Adaptive Control of Parameter-less Population Pyramid on the Local Distribution of Inferior Individuals

Kazuyuki Inoue, Taku Hasegawa, Yuta Araki, Naoki Mori, Keinosuke Matsumoto

Many evolutionary techniques such as genetic algorithms (GAs) employ parameters that facilitate user control of search dynamics. However, these parameters require time-consuming tuning processes to avoid problems such as premature convergence. Unlike many GAs, the Parameter-less Population Pyramid (P3) is an optimization model that avoids premature convergence due to the pyramid-like structure of populations, and thus P3 can be applied to a wide range of problems without parameter tuning. P3 approaches to search would be useful for constructing a novel theory for optimal search using GAs. In this study, we propose a novel technique "analysis based on the Distribution of Inferior Individuals in the local neighborhood" (DII analysis). DII analysis can be applied to local search techniques, including P3. The computational complexity of applied problems can be estimated based on a number of local optima according to the results obtained using DII. We also propose combining P3 with DII analysis (P3-DII), which controls the maximum number of fitness evaluations performed by genetic operators. The computational experiments were carried out taking several combinational problems as examples. According to our experimental results, we demonstrated that P3-DII found several optimal solutions that P3 failed to find.

A Genetic Algorithm for Searching the Shortest Lattice Vector of SVP Challenge

Dan Ding, Guizhen Zhu, Xiaoyun Wang

In this paper, we propose a genetic algorithm for solving the shortest vector problem (SVP) based on sparse representation of short lattice vectors, which, we prove, can guarantee finding the shortest lattice vector under a Markov analysis. With some heuristic improvements (local search and heuristic pruning), the SVP genetic algorithm, by experimental results, outperforms other SVP algorithms, like the famous Kannan-Helfrich algorithm under SVP challenge benchmarks. In summary, we, for the first time, adopt the genetic algorithm in solving the shortest vector problem, based on which lattice-based cryptosystem is as a promising candidate for post-quantum cryptography.

An Empirical Analysis on Dimensionality in Cellular Genetic Algorithms

Alicia Morales-Reyes, Hugo Jair Escalante, Martin Letras, Rene Cumplido

Cellular or fine grained Genetic Algorithms (GAs) are a massively parallel algorithmic approach to GAs. Decentralizing their population allows alternative ways to explore and to exploit the solutions landscape. Individuals interact locally through nearby neighbors while the entire population is globally exploring the search space throughout a predefined population's topology. Having a decentralized population requires the definition of other algorithmic configuration parameters; such as shape and number of individuals within the local neighborhood, population's topology shape and dimension, local instead of global selection criteria, among others. In this article, attention is paid to the population's topology dimension in cGAs. Several benchmark problems are assessed for 1, 2, and 3 dimensions while combining a local selection criterion that significantly affect overall selective pressure. On the other hand, currently available high performance processing platforms such as Field

Programmable Gate Arrays (FPGAs) and Graphics Processing Units (GPUs) offer massively parallel fabrics. Therefore, having a strong empirical base to understand structural properties in cellular GAs would allow to combine physical properties of these platforms when designing hardware architectures to tackle difficult optimization problems where timing constraints are mandatory.

GA3

A Genetic Algorithm to Solve a Real 2-D Cutting Stock Problem with Setup Cost in the Paper Industry

Stephane Bonnevay, Philippe Aubertin, Gerald Gavin

This paper deals with the Two-Dimensional Cutting Stock Problem with Setup Cost (2CSP-S). This problem is composed of three optimization sub-problems: a 2-D Bin Packing (2BP) problem (to place images on patterns), a Linear Programming (LP) problem (to find for each pattern the number of stock sheets to be printed) and a combinatorial problem (to find the number of each image on each pattern). In this article, we solve the 2CSP-S focusing on this third sub-problem. A genetic algorithm was developed to automatically find the proper number of each image on patterns. It is important to notice that our approach is not a new packing technique. This work was conducted for a paper industry company and experiments were realized on real and artificial datasets.

A New Perspective on Channel Allocation in WLAN: Considering the Total Marginal Utility of the Connections for the Users

Thiago Luiz, Alan Freitas, Frederico Guimarães

The channel allocation problem consists in defining the frequency used by Access Points (APs) in Wireless Local Area Networks (WLAN). An overlap of channels in a WLAN is the major factor of performance reduction for the users in a network. For this reason, we propose a new model for channel allocation that aims to maximize the total quality of the connection of the user by considering their marginal utility. The results show that an allocation model that does not take into account the total utility of each connection tends to prioritize the quality of connection of a few users and lead to a large unbalance in the distribution of connection speed between users. Thus, the new model can handle the importance of degradation caused by the levels of interference in the user connection separately.

Reconstructing Cross-Cut Shredded Text Documents: A Genetic Algorithm with Splicing-Driven Reproduction

Yong-Feng Ge, Yue-Jiao Gong, Wei-Jie Yu, Xiao-Min Hu, Jun Zhang

In this work we focus on reconstruction of cross-cut shredded text documents (RCCSTD), which is of high interest in the fields of forensics and archeology. A novel genetic algorithm, with splicing-driven crossover, four mutation operators, and a row-oriented elitism strategy, is proposed to improve the capability of solving RCCSTD in complex space. We also design a novel and comprehensive objective function based on both edge and empty vector-based splicing error to guarantee that the correct reconstruction always has the lowest cost value. Experiments are conducted on six RCCSTD scenarios, with experimental results showing that the proposed algorithm significantly outperforms the previous best-known algorithms for this problem.

A Clustering-Based Model-Building EA for Optimization Problems with Binary and Real-Valued Variables

Krzysztof Sadowski, Peter Bosman, Dirk Thierens

We propose a novel clustering-based model-building evolutionary algorithm to tackle optimization problems that have both binary and real-valued variables. The search space is clustered every generation using a distance metric that considers binary and real-valued variables jointly in order to capture and exploit dependencies between variables of different types. After clustering, linkage learning takes place within each cluster to capture and exploit dependencies between variables of the same type. We compare this with a model-building approach that only considers dependencies between variables of the same type. Additionally, since many real-world problems have constraints, we examine the use of different well-known approaches to handling constraints: constraint domination, dynamic penalty and global competitive ranking. We experimentally analyze the performance of the proposed algorithms on various unconstrained problems as well as a selection of well-known MINLP benchmark problems that all have constraints, and compare our results with the Mixed-Integer Evolution Strategy (MIES). We find that our approach to clustering that is aimed at the processing of dependencies between binary and real-valued variables can significantly improve performance in terms of required population size and function evaluations when solving problems that exhibit properties such as multiple optima, strong mixed dependencies and constraints.

GA4

Elitist Black-Box Models: Analyzing the Impact of Elitist Selection on the Performance of Evolutionary Algorithms

Carola Doerr, Johannes Lengler

Black-box complexity theory provides lower bounds for the runtime %classes of black-box optimizers like evolutionary algorithms and serves as an inspiration for the design of new genetic algorithms. Several black-box models covering different classes of algorithms exist, each highlighting a different aspect of the algorithms under considerations. In this work we add to the existing black-box notions a new *elitist black-box model*, in which algorithms are required to base all decisions solely on (a fixed number of) the best search points sampled so far. Our model combines features of the ranking-based and the memory-restricted black-box models with elitist selection. We provide several examples for which the elitist black-box complexity is exponentially larger than that the respective complexities in all previous black-box models, thus showing that the elitist black-box complexity can be much closer to the runtime of typical

evolutionary algorithms. We also introduce the concept of p-Monte Carlo black-box complexity, which measures the time it takes to optimize a problem with failure probability at most p. Even for small p, the p-Monte Carlo black-box complexity of a function class F can be smaller by an exponential factor than its typically regarded Las Vegas complexity (which measures the *expected* time it takes to optimize F).

Money for Nothing: Speeding Up Evolutionary Algorithms Through Better Initialization

Axel de Perthuis de Laillevault, Benjamin Doerr, Carola Doerr

That the initialization can have a significant impact on the performance of evolutionary algorithms (EAs) is a well known fact in the empirical evolutionary computation literature. Surprisingly, it has nevertheless received only little attention from the theoretical community. We bridge this gap by providing a thorough runtime analysis for a simple *iterated random sampling* initialization. In the latter, instead of starting an EA with a random sample, it is started in the best of k search points that are taken from the search space uniformly at random. Implementing this strategy comes at almost no cost, neither in the actual coding work nor in terms of wall-clock time. Taking the best of two random samples already decreases the $\Theta(n \log n)$ expected runtime of the (1+1) EA and Randomized Local Search on onemax by an additive term of order $\sqrt{n}$. The optimal gain that one can achieve with iterated random sampling is an additive term of order $\sqrt{n \log n}$. This also determines the best possible mutation-based EA for onemax, a question left open in [Sudholt, IEEE TEC 2013]. At the heart of our analysis is a very precise bound for the maximum of k independent Binomially distributed variables with success probability $1/2$.

Solving Problems with Unknown Solution Length at (Almost) No Extra Cost

Benjamin Doerr, Carola Doerr, Timo Kützing

Most research in the theory of evolutionary computation assumes that the problem at hand has a fixed problem size. This assumption does not always apply to real-world optimization challenges, where the length of an optimal solution may be unknown a priori. Following up on previous work of Cathabard, Lehre, and Yao [FOGA 2011] we analyze variants of the (1+1) evolutionary algorithm for problems with unknown solution length. For their setting, in which the solution length is sampled from a geometric distribution, we provide mutation rates that yield an expected optimization time that is of the same order as that of the (1+1) EA knowing the solution length. We then show that almost the same run times can be achieved even if *no* a priori information on the solution length is available. Finally, we provide mutation rates suitable for settings in which neither the solution length nor the positions of the relevant bits are known. Again we obtain almost optimal run times for the ONEMAX and LEADINGONES test functions, thus solving an open problem from Cathabard et al.

Genetic Programming

GP1

Correlation Immunity of Boolean Functions: An Evolutionary Algorithms Perspective

Stjepan Picek, Claude Carlet, Domagoj Jakobovic, Julian Miller, Lejla Batina

Boolean functions are essential in many stream ciphers. When used in combiner generators, they need to have sufficiently high values of correlation immunity, alongside other properties. In addition, correlation immune functions with small Hamming weight reduce the cost of masking countermeasures against side-channel attacks. Various papers have examined the applicability of evolutionary algorithms for evolving cryptographic Boolean functions. However, even when authors considered correlation immunity, it was not given the highest priority. Here, we examine the effectiveness of three different EAs, namely, Genetic Algorithms, Genetic Programming (GP) and Cartesian GP for evolving correlation immune Boolean functions. Besides the properties of balancedness and correlation immunity, we consider several other relevant cryptographic properties while maintaining the optimal trade-offs among them. We show that evolving correlation immune Boolean functions is an even harder objective than maximizing nonlinearity.

Building Predictive Models via Feature Synthesis

Ignacio Arnaldo, Una-May O'Reilly, Kalyan Veeramachaneni

We introduce Evolutionary Feature Synthesis (EFS), a regression method that generates readable, nonlinear models of small to medium size datasets in seconds. EFS is, to the best of our knowledge, the fastest regression tool based on evolutionary computation reported to date. The feature search involved in the proposed method is composed of two main steps: feature composition and feature subset selection. EFS adopts a bottom-up feature composition strategy that eliminates the need for a symbolic representation of the features and exploits the variable selection process involved in pathwise regularized linear regression to perform the feature subset selection step. The result is a regression method that is competitive against neural networks, and outperforms both linear methods and Multiple Regression Genetic Programming, up to now the best regression tool based on evolutionary computation.

Impact of Crossover Bias in Genetic Programming

Nicholas McPhee, M. Dramdahl, David Donatucci

In tree-based genetic programming (GP) with sub-tree crossover, the parent contributing the root portion of the tree (the root parent) often contributes more to the semantics of the re-

sulting child than the non-root parent. Previous research demonstrated that when the root parent had greater fitness than the non-root parent, the fitness of the child tended to be better than if the reverse were true. Here we explore the significance of that asymmetry by introducing the notion of crossover bias, where we bias the system in favor of having the more fit parent as the root parent. In this paper we apply crossover bias to several problems. In most cases we found that crossover bias either improved performance or had no impact. We also found that the effectiveness of crossover bias is dependent on the problem, and significantly dependent on other parameter choices. While this work focuses specifically on sub-tree crossover in tree-based GP, artificial and biological evolutionary systems often have substantial asymmetries, many of which remain understudied. This work suggests that there is value in further exploration of the impacts of these asymmetries.

Strength Through Diversity: Disaggregation and Multi-Objectivisation Approaches for Genetic Programming

Jonathan Fieldsend, Alberto Moraglio

An underlying problem in genetic programming (GP) is how to ensure sufficient useful diversity in the population during search. Having a wide range of diverse (sub)component structures available for recombination and/or mutation is important in preventing premature converge. We propose two new fitness disaggregation approaches that make explicit use of the information in the test cases (i.e., program semantics) to preserve diversity in the population. The first method preserves the best programs which pass each individual test case, the second preserves those which are non-dominated across test cases (multi-objectivisation). We use these in standard GP, and compare them to using standard fitness sharing, and using standard (aggregate) fitness in tournament selection. We also examine the effect of including a simple anti-bloat criterion in the selection mechanism. We find that the non-domination approach, employing anti-bloat, significantly speeds up convergence to the optimum on a range of standard Boolean test problems. Furthermore, its best performance occurs with a considerably smaller population size than typically employed in GP.

GP2

Using Model Checking Techniques For Evaluating the Effectiveness of Evolutionary Computing in Synthesis of Distributed Fault-Tolerant Programs

Ling Zhu, Sandeep Kulkarni

In most applications using genetic programming (GP), objective functions are obtained by a terminating calculation. However, the terminating calculation cannot evaluate distributed fault-tolerant programs accurately. A key distinction in synthesizing distributed fault-tolerant programs is that they are inherently non-deterministic, potentially having infinite computations and executing in an unpredictable environment. In this study, we apply a model checking technique - Binary Decision Diagrams (BDDs) - to GP, evaluating distributed programs by computing reachable states of the given program and identifying whether it satisfies its specification. We present scenario-based multi-objective approach that each program is evaluated under different scenarios which represent various environments. The computation of the programs are considered in two different semantics respectively: interleaving and maximum-parallelism. In the end, we illustrate our approach with a Byzantine agreement problem, a token ring problem and a consensus protocol using failure detector S. For the first time, this work automatically synthesizes the consensus protocol with S. The results show the proposed method enhances the effectiveness of GP in all studied cases when using maximum-parallelism semantic.

Examining the "Best of Both Worlds" of Grammatical Evolution

Peter Whigham, Grant Dick, James Maclaurin, Caitlin Owen

Grammatical Evolution (GE) has a long history in evolutionary computation. Central to the behaviour of GE is the use of a linear representation and grammar to map individuals from search spaces into problem spaces. This genotype to phenotype mapping is often argued as a distinguishing property of GE relative to other techniques, such as context-free grammar genetic programming (CFG-GP). Since its initial description, GE research has attempted to incorporate information from the grammar into crossover, mutation, and individual initialisation, blurring the distinction between genotype and phenotype and creating GE variants closer to CFG-GP. This is argued to provide GE with the "best of both worlds", allowing degrees of grammatical bias to be introduced into operators to best suit the given problem. This paper examines the behaviour of three grammar-based search methods on several problems from previous GE research. It is shown that, unlike CFG-GP, the performance of "pure" GE on the examined problems closely resembles that of random search. The results suggest that further work is required to determine the cases where the "best of both worlds" of GE are required over a straight CFG-GP approach.

Performance Optimization of Multi-Core Grammatical Evolution Generated Parallel Recursive Programs

Gopinath Chennupati, R. Muhammad Azad, Conor Ryan

Although Evolutionary Computation (EC) has been used with considerable success to evolve computer programs, the majority of this work has targeted the production of serial code. Recent work with Grammatical Evolution (GE) produced Multi-core Grammatical Evolution (MCGE-II), a system that natively produces parallel code, including the ability to execute recursive calls in parallel. This paper extends this work by including practical constraints into the grammars and fitness functions, such as increased control over the level of parallelism for each individual. These changes execute the best-of-generation programs faster than the original MCGE-II with an average factor of 8.13 across a selection of hard problems from the literature. We analyze the time complexity of these programs and identify avoiding excessive parallelism as a key for further performance scaling. We amend the grammars to evolve a mix of serial and parallel

code, which spawns only as many threads as is efficient given the underlying OS and hardware; this speeds up execution by a factor of 9.97.

On the Bias of Syntactic Geometric Recombination in Genetic Programming and Grammatical Evolution

Ann Thorhauer, Franz Rothlauf

For fixed-length binary representations as used in genetic algorithms, standard recombination operators (e.g., one-point crossover) are unbiased. Thus, the application of recombination only reshuffles the alleles and does not change the statistical properties in the population. Using a geometric view on recombination operators, most search operators for fixed-length strings are geometric, which means that the distances between offspring and their parents are less than, or equal to, the distance between their parents. In genetic programming (GP) and grammatical evolution (GE), the situation is different since the recombination operators are applied to variable-length structures. Thus, most recombination operators for GE and GP are not geometric. This paper focuses on the bias of recombination in GE and GP and studies whether the application of recombination alone produces specific types of solutions with a higher probability. We consider two different types of recombination operators: standard recombination and syntactic geometric recombination. In our experiments, we performed random walks through the binary tree search space and found that syntactic geometric recombination operators are biased and strongly reduce population diversity. In a performance comparison, we found that syntactic geometric recombination leads to large fitness improvements in the first generations, but that fitness converges after several generations and no further search is possible.

GP3

General Program Synthesis Benchmark Suite

Thomas Helmuth, Lee Spector

Recent interest in the development and use of non-trivial benchmark problems for genetic programming research has highlighted the scarcity of general program synthesis (also called "traditional programming") benchmark problems. We present a suite of 29 general program synthesis benchmark problems systematically selected from sources of introductory computer science programming problems. This suite is suitable for experiments with any program synthesis system driven by input/output examples. We present results from illustrative experiments using our reference implementation of the problems in the PushGP genetic programming system. The results show that the problems in the suite vary in difficulty and can be useful for assessing the capabilities of a program synthesis system.

Improving CUDA DNA Analysis Software with Genetic Programming

William Langdon, Brian Lam, Justyna Petke, Mark Harman

We genetically improve BarraCUDA using a BNF grammar incorporating C scoping rules with GP. Barracuda maps next generation DNA sequences to the human genome using the Burrows-Wheeler algorithm (BWA) on nVidia Tesla parallel graphics hardware (GPUs). GI using phenotypic tabu search with manually grown code can graft new features giving more than 100 fold speed up on a performance critical kernel without loss of accuracy.

Efficient Evolution of High Entropy RNGs Using Single Node Genetic Programming

Philip Leonard, David Jackson

Random Number Generators are an important aspect of many modern day software systems, cryptographic protocols and modelling techniques. To be more accurate, it is Pseudo Random Number Generators (PRNGs) that are more commonly used over their expensive, and less practical hardware based counterparts. Given that PRNGs rely on some deterministic algorithm (typically a Linear Congruential Generator) we can leverage Shannons theory of information as our fitness function in order to generate these algorithms by evolutionary means. In this paper we compare traditional Genetic Programming (GP) against its graph based implementation, Single Node Genetic Programming (SNGP), for this task. We show that with SNGPs unique program structure and use of dynamic programming, it is possible to obtain smaller, higher entropy PRNGs, over six times faster and produced at a solution rate twice that achieved using Kozas standard GP model. We also show that the PRNGs obtained from evolutionary methods produce higher entropy outputs than other widely used PRNGs and Hardware RNGs (specifically recordings of atmospheric noise), as well as surpassing them in a variety of other statistical tests presented in the NIST RNG test suite.

A Re-Examination of the Use of Genetic Programming on the Oral Bioavailability Problem

Grant Dick, Aysha Rimoni, Peter Whigham

Difficult benchmark problems are in increasing demand in Genetic Programming (GP). One problem seeing increased usage is the oral bioavailability problem, which is often presented as a challenging problem to both GP and other machine learning methods. However, few properties of the bioavailability data set have been demonstrated, so attributes that make it a challenging problem are largely unknown. This work uncovers important properties of the bioavailability data set, and suggests that the perceived difficulty in this problem can be partially attributed to a lack of pre-processing, including features within the data set that contain no information, and contradictory relationships between the dependent and independent features of the data set. The paper then re-examines the performance of GP on this data set, and contextualises this performance relative to other regression methods. Results suggest that a large component of the observed performance differences on the bioavailability data set can be attributed to variance in the selection of training and testing data. Differences in performance between GP and other methods disappear when multiple training/testing splits are used within experimental work, with performance typ-

ically no better than a null modelling approach of reporting the mean of the training data.

GP4

An Efficient Structural Diversity Technique for Genetic Programming

Armand Burks, William Punch

Genetic diversity plays an important role in avoiding premature convergence, which is a phenomenon that stifles the search effectiveness of evolutionary algorithms. However, approaches that avoid premature convergence by maintaining genetic diversity can do so at the cost of efficiency, requiring more fitness evaluations to find high quality solutions. We introduce a simple and efficient genetic diversity technique that is capable of avoiding premature convergence while maintaining a high level of search quality in tree-based genetic programming. Our method finds solutions to a set of benchmark problems in significantly fewer fitness evaluations than the algorithms that we compared against.

Genetic Programming with Epigenetic Local Search

William La Cava, Thomas Helmuth, Lee Spector, Kourosh Danai

We focus on improving genetic programming through local search of the space of program structures using an inheritable epigenetic layer that specifies active and inactive genes. We explore several genetic programming implementations that represent the different properties that epigenetics can provide, such as passive structure, phenotypic plasticity, and inheritable gene regulation. We apply these implementations to several symbolic regression and program synthesis problems. For the symbolic regression problems, the results indicate that epigenetic local search consistently improves genetic programming by producing smaller solution programs with better fitness. Furthermore, we find that incorporating epigenetic modification as a mutation step in program synthesis problems can improve the ability of genetic programming to find exact solutions. By analyzing population homology we show that the epigenetic implementations maintain diversity in silenced portions of programs which may provide protection from premature convergence.

Memetic Semantic Genetic Programming

Robyn Ffrancon, Marc Schoenauer

Semantic Backpropagation (SB) was introduced in GP so as to take into account the semantics of a GP tree at all intermediate states of the program execution, i.e., at each node of the tree. The idea is to compute the optimal "should-be" values each subtree should return, whilst assuming that the rest of the tree is unchanged, so as to minimize the fitness of the tree. To this end, the Random Desired Output (RDO) mutation operator, uses SB in choosing, from a given library, a tree whose semantics are preferred to the semantics of a randomly selected subtree from the parent tree. Pushing this idea one step further, this paper introduces the Brando (BRANDO) operator, which selects from the parent tree the overall best subtree for applying RDO, using a small randomly drawn static library. Used within a simple Iterated Local Search framework, BRANDO can find the exact solution of many popular Boolean benchmarks in reasonable time whilst keeping solution trees small, thus paving the road for truly memetic GP algorithms.

Geometric Semantic Genetic Programming with Local Search

Mauro Castelli, Leonardo Trujillo, Leonardo Vanneschi, Sara Silva, Emigdio Z-Flores, Pierrick Legrand

Since its introduction, Geometric Semantic Genetic Programming (GSGP) has aroused the interest of numerous researchers and several studies have demonstrated that GSGP is able to effectively optimize training data by means of small variation steps, that also have the effect of limiting overfitting. In order to speed up the search process, in this paper we propose a system that integrates a local search strategy into GSGP (called GSGP-LS). Furthermore, we present a hybrid approach, that combines GSGP and GSGP-LS, aimed at exploiting both the optimization speed of GSGP-LS and the ability to limit overfitting of GSGP. The experimental results we present, performed on a set of complex real-life applications, show that GSGP-LS achieves the best training fitness while converging very quickly, but severely overfits. On the other hand, GSGP converges slowly relative to the other methods, but is basically not affected by overfitting. The best overall results were achieved with the hybrid approach, allowing the search to converge quickly, while also exhibiting a noteworthy ability to limit overfitting. These results are encouraging, and suggest that future GSGP algorithms should focus on finding the correct balance between the greedy optimization of a local search strategy and the more robust geometric semantic operators.

GP5

Evolutionary Image Descriptor: A Dynamic Genetic Programming Representation for Feature Extraction

Harith Al-Sahaf, Mengjie Zhang, Mark Johnston

Texture classification aims at categorising instances that have a similar repetitive pattern. In computer vision, texture classification represents a fundamental element in a wide variety of applications, which can be performed by detecting texture primitives of the different classes. Using image descriptors to detect prominent features has been widely adopted in computer vision. Building an effective descriptor becomes more challenging when there are only a few labelled instances. This paper proposes a new Genetic Programming (GP) representation for evolving an image descriptor that operates directly on the raw pixel values and uses only two instances per class. The new method synthesises a set of mathematical formulas that are used to generate the feature vector, and the classification is then performed using a simple instance-based classifier. Determining the length of the feature vector is automatically handled by the new method. Two GP and nine well-known non-GP methods

are compared on two texture image data sets for texture classification in order to test the effectiveness of the proposed method. The proposed method is also compared to three hand-crafted descriptors namely domain-independent features, local binary patterns, and Haralick texture features. The results show that the proposed method has superior performance over the competitive methods.

Multiple Objective Vector-Based Genetic Programming Using Human-Derived Primitives

Jason Zutty, Daniel Long, Heyward Adams, Gisele Bennett, Christina Baxter

Traditional genetic programming only supports the use of arithmetic and logical operators on scalar features. The GTMOEP (Georgia Tech Multiple Objective Evolutionary Programming) framework builds upon this by also handling feature vectors, allowing the use of signal processing and machine learning functions as primitives, in addition to the more conventional operators. GTMOEP is a novel method for automated, data-driven algorithm creation, capable of outperforming human derived solutions. As an example, GTMOEP was applied to the problem of predicting how long an emergency responder can remain in a hazmat suit before the effects of heat stress cause the user to become unsafe. An existing third-party physics model was leveraged for predicting core temperature from various situational parameters. However, a sustained high heart rate also means that a user is unsafe. To improve performance, GTMOEP was evaluated to predict an expected pull time, computed from both thresholds during human trials. GTMOEP produced dominant solutions in multiple objective space to the performance of predictions made by the physics model alone, resulting in a safer algorithm for emergency responders to determine operating times in harsh environments. The program generated by GTMOEP will be deployed to a mobile application for their use.

A GP-based Video Game Player

Baozhu Jia, Marc Ebner, Christian Schack

A general video game player is an an agent that can learn to play different video games with no specific domain knowledge. We are working towards developing a GP-based general video game player. Our system currently extracts game state features from screen grabs. This information is then passed on to the game player. Fitness is computed from data obtained directly from the internals of the game simulator. For this paper, we compare three different types of game state features. These features differ in how they describe the position to the nearest object surrounding the player. We have tested our genetic programming game player system on three games: Space Invaders, Frogger and Missile Command. Our results show that a playing strategy for each game can be found efficiently for all three representations.

GEFPSO: A Framework for PSO Optimization based on Grammatical Evolution

Péricles Miranda, Ricardo Prudéncio

In this work, we propose a framework to automatically generate effective PSO designs by adopting Grammatical Evolution (GE). In the proposed framework, GE searches for adequate structures and parameter values (e.g., acceleration constants, velocity equations and different particles' topology) in order to evolve the PSO design. For this, a high-level Backus-Naur Form (BNF) grammar was developed, representing the search space of possible PSO designs. In order to verify the performance of the proposed method, we performed experiments using 16 diverse continuous optimization problems, with different levels of difficulty. In the performed experiments, we identified the parameters and components that most affected the PSO performance, as well as identified designs that could be reused across different problems. We also demonstrated that the proposed method generates useful designs which achieved competitive solutions when compared to well succeeded algorithms from the literature.

Hot Off the Press

HOP1

Beyond Pheromones: Evolving Error-Tolerant, Flexible, and Scalable Ant-Inspired Robot Swarms

Joshua P. Hecker, Melanie E. Moses

For robot swarms to operate outside of the laboratory in complex real-world environments, they require the kind of error tolerance, flexibility, and scalability seen in living systems. While robot swarms are often designed to mimic some aspect of the behavior of social insects or other organisms, no systems have yet addressed all of these capabilities in a single framework. We describe a swarm robotics system that emulates ant behaviors which govern memory, communication, and movement, as well as an evolutionary process that tailors those behaviors into foraging strategies that maximize performance under varied and complex conditions. The system evolves appropriate solutions to different environmental challenges. Solutions include: i) increased communication when sensed information is reliable and resources to be collected are highly clustered, ii) less communication and more individual memory when cluster sizes are variable, and iii) greater dispersal with increasing swarm size. Analysis of the evolved behaviors reveals the importance of interactions among behaviors, and of the interdependencies between behaviors and environments. The effectiveness of interacting behaviors depends on the uncertainty of sensed information, the resource distribution, and the swarm size. Such interactions could not be manually specified, but are effectively evolved in simulation and transferred to physical robots. This work is the first to demonstrate high-level robot swarm behaviors that can be automatically tuned to produce efficient collective foraging strategies in varied and complex environments.

Genotype Coding, Diversity, and Dynamic Evolutionary Neural Network Environments: A Study on an Multi-agent System

Jaime Davila

This paper reports the effects that different coding schemes at the genetic level have on the evolution of neural network multi-agent systems that operate under dynamic (changing) environments. Types of NN encoding include direct encoding of weights and three different L-Systems. Empirical results show that even variations within the same type of coding scheme can have considerable effects on evolution. Several different analysis of both genotypes and phenotypes are used in order to explain the differences caused by the coding schemes.

Generalized Decomposition and Cross Entropy Methods for Many-Objective Optimization

Ioannis Giagkiozis, Robin C. Purshouse, Peter J. Fleming

Decomposition-based algorithms for multi-objective optimization problems have increased in popularity in the past decade. Although convergence to the Pareto optimal front (PF) for such algorithms can often be superior to that of Pareto-based alternatives, the problem of effectively distributing Pareto optimal solutions in a high-dimensional space has not been solved. In this work, we introduce a novel concept which we call generalized decomposition. Generalized decomposition provides a framework with which the decision maker (DM) can guide the underlying search algorithm toward specific regions of interest, or the entire Pareto front, with the desired distribution of Pareto optimal solutions. The method simplifies many-objective problems by unifying the three performance objectives of an a posteriori multi-objective optimizer – convergence to the PF, evenly distributed Pareto optimal solutions and coverage of the entire front – to only one, that of convergence. A framework, established on generalized decomposition, and an estimation of distribution algorithm (EDA) based on low-order statistics, namely the cross-entropy method, is created to illustrate the benefits of the proposed concept for many-objective problems. The algorithm – MACE-gD – is shown to be highly competitive with the existing best-in-class decomposition-based algorithm (MOEA/D) and a more elaborate EDA method (RM-MEDA).

Methods for Multi-Objective Optimization: An Analysis

Ioannis Giagkiozis, Peter J. Fleming

Decomposition-based methods are often cited as the solution to multi-objective nonconvex optimization problems with an increased number of objectives. These methods employ a scalarizing function to reduce the multi-objective problem into a set of single objective problems, which upon solution yield a good approximation of the set of optimal solutions. This set is commonly referred to as Pareto front. In this work we explore the implications of using decomposition-based methods over Pareto-based methods on algorithm convergence from a probabilistic point of view. Namely, we investigate whether there is an advantage of using a decomposition-based method, for example using the Chebyshev scalarizing function, over Pareto-based methods. We find that, under mild conditions on the objective function, the Chebyshev scalarizing function has an almost identical effect to Pareto-dominance relations when we consider the probability of finding superior solutions for algorithms that follow a balanced trajectory. We propose the hypothesis that this seemingly contradicting result compared with currently available empirical evidence, signals that the disparity in performance between Pareto-based and decomposition-based methods is due to the inability of the former class of algorithms to follow a balanced trajectory. We also link generalized decomposition to the results in this work and show how to obtain optimal scalarizing functions for a given problem, subject to prior assumptions on the Pareto front geometry.

HOP2

Evolutionary Approach to Approximate Digital Circuits Design

Zdenek Vasicek and Lukas Sekanina

In approximate computing, the requirement of perfect functional behavior can be relaxed because some applications are inherently error resilient. Approximate circuits, which fall into the approximate computing paradigm, are designed in such a way that they do not fully implement the logic behavior given by the specification and hence their accuracy can be exchanged for lower area, delay or power consumption. In order to automate the design process, we propose to evolve approximate digital circuits which show a minimal error for a supplied amount of resources. The design process which is based on Cartesian Genetic Programming (CGP) can be repeated many times in order to obtain various tradeoffs between the accuracy and area. A heuristic seeding mechanism is introduced to CGP which allows for improving not only the quality of evolved circuits, but also reducing the time of evolution. The efficiency of the proposed method is evaluated for the gate as well as the functional level evolution. In particular, approximate multipliers and median circuits which show very good parameters in comparison with other available implementations were constructed by means of the proposed method.

Hybrid Evolutionary Approaches to Maximum Lifetime Routing and Energy Efficiency in Sensor Mesh Networks

Alma A. M. Rahat, Richard M. Everson, Jonathan E. Fieldsend

Mesh network topologies are becoming increasingly popular in battery powered wireless sensor networks, primarily due to the extension of network range. However, multi-hop mesh networks suffer from higher energy costs, and the routing strategy employed directly affects the lifetime of nodes with limited energy resources. Hence when planning routes there are trade-offs to be considered between individual and system-wide battery lifetimes. We present a multi-objective routing optimisation approach using hybrid evolutionary algorithms to approximate the optimal trade-off between minimum lifetime and the average lifetime of nodes in the network. In order to accomplish this combinatorial optimisation rapidly, our approach prunes the

search space using k-shortest path pruning and a graph reduction method which finds candidate routes promoting long minimum lifetimes. When arbitrarily many routes from a node to the base station are permitted, optimal routes may be found as the solution to a well-known linear program. We present an evolutionary algorithm that finds good routes when each node is allowed only a small number of paths to the base station. This algorithm uses an evolutionary algorithm to propose new paths and a linear program to discover the optimum proportion of time that each path should be active. We show how employing separate optimisations in the two pruned search spaces before combining them in a final optimisation in the combination of the spaces is more effective than a single optimisation in the combined space. On a real network deployed in the Victoria & Albert Museum, London, these solutions, using only three paths per node, are able to achieve minimum lifetimes of over 99% of the optimum linear program solution's time to first sensor battery failure.

Learning to Anticipate Flexible Choices in Multiple Criteria Decision-Making Under Uncertainty

Carlos R. B. Azevedo, Fernando J. Von Zuben

In several applications, a solution must be selected from a set of tradeoff alternatives for operating in dynamic and noisy environments. In this paper, such multicriteria decision process is handled by anticipating flexible options predicted to improve the decision maker future freedom of action. A methodology is then proposed for predicting tradeoff sets of maximal hypervolume, where a multiobjective metaheuristic was augmented with a Kalman filter and a dynamical Dirichlet model for tracking and predicting flexible solutions. The method identified decisions that were shown to improve the future hypervolume of tradeoff investment portfolio sets for outofsample stock data, when compared to a myopic strategy. Anticipating flexible portfolios was a superior strategy for smoother changing artificial and realworld scenarios, when compared to always implementing the decision of median risk and to randomly selecting a portfolio from the evolved anticipatory stochastic Pareto frontier, whereas the median choice strategy performed better for abruptly changing markets. Correlations between the portfolio compositions and future hypervolume were also observed.

Evolving computational solutions with carbon nanotube device

Julian F. Miller, Kester D. Clegg, Maktuba Mohid

We report for the first time on discovering solutions to two well-known classes of computational problems using hybrid "in materio" computation. Evolution-in-materio is a technique that uses evolutionary algorithms to search for configurations of physical materials that can carry out computation. The work was published in two papers in Parallel Problem Solving from Nature (PPSN) in September 2014. The papers described how the EIM technique was applied to two well-known classes of problem: the travelling salesman problem (TSP) and data classification. The latter paper was nominated for the best paper award. The computational device used in these works consists of a single-walled carbon nanotube / polymer composite material deposited on a micro-electrode array. This is the first time that evolutionary algorithms have been used to configure a carbon nanotube device to solve computational problems. The work is exciting because it shows that evolution can be used to search materials to perform computation without a detailed understanding of the internal physics of the devices. This may lead to entirely new ways of solving computational problems. Following Arthur Samuel we try to *make materials do what is needed to be done, without being told exactly how to do it*.

HOP3

Artificial Immune System driven evolution in Swarm Chemistry

Emma Hart, Nicola Capodieci, Giacomo Cabri

Morphogenetic engineering represents an interesting field in which models, frameworks and algorithms can be tested in order to study how self-* properties and emergent behaviours can arise in potentially complex and distributed systems. In this field, the morphogenetic model we will refer to is swarm chemistry, since a well known challenge in this dynamical process concerns discovering mechanisms for providing evolution within coalescing systems of particles. These systems consist in sets of moving particles able to self-organise in order to create shapes or geometrical formations that provide robustness towards external perturbations. We present a novel mechanism for providing evolutionary features in swarm chemistry that takes inspiration from artificial immune system literature, more specifically regarding idiotypic networks. Starting from a restricted set of chemical recipes, we show that the system evolves to new states, using an autonomous method of detecting new shapes and behaviours free from any human interaction.

Incorporating Dynamism in Emergency Route Planning Problem using Immune-Based Approach

Mohd Nor Akmal Khalid, Umi Kalsom Yusof

The occurrence of emergency events tends to spark a very chaotic reaction, inducing a large surge of demand (number of evacuees) which exceeds the available resources (pathway/network). Planning a suitable evacuation route and identifying the shortest evacuation route before the occurrence of extreme events are crucial for an effective evacuation process. Although evacuation plans can be orchestrated in advance, probable crowd dynamics, especially group-based characteristics (e.g. group formation, group relation, group competition, etc.), may occur, often rendering unfeasible evacuation plan. Therefore, creating a dynamic and effective emergency route planning (ERP) approach is of utmost importance. Various ERP approaches have been proposed, which includes mathematical-based approach, heuristic-driven approach, and meta-heuristic approach. The lack of meta-heuristic approaches in the domain of ERP problem, although its capability of handling dynamic constraints and produces optimum result, serve as an encouragement of applying this approach. Therefore, an integrated evacu-

ation planning with dynamism (iEvaP+) approach is proposed to cater the dynamic of groups in crowd and optimizing the route selection mechanism, where the use of immune-based meta-heuristic approach had effectively produces reliable results (average percentage difference of the best solution is about 54.14%)

Gene Regulatory Network Evolution Through Augmenting Topologies

Sylvain Cussat-Blanc, Kyle Harrington, Jordan Pollack

Artificial gene regulatory networks are biologically-inspired dynamical systems used to control various kinds of agents, from the cells in developmental models to embodied robot swarms. Most recent work uses a genetic algorithm or an evolution strategy in order to optimize the network for a specific task. However, the empirical performances of these algorithms are unsatisfactory. This paper presents an algorithm that primarily exploits a network distance metric which allows genetic similarity to be used for speciation and variation of gene regulatory networks. This algorithm, inspired by the successful neuroevolution of augmenting topologies (NEAT) algorithm's use in evolving neural networks and compositional pattern-producing networks, is based on a specific initialization method, a crossover operator based on gene alignment, and speciation based upon gene regulatory network structures. We demonstrate the effectiveness of this new algorithm by comparing our approach both to a standard genetic algorithm and to evolutionary programming on four different experiments from three distinct problem domains, where the proposed algorithm excels on all experiments.

ExSTraCS 2.0: Description and Evaluation of a Scalable Learning Classifier System

Ryan Urbanowicz, Jason Moore

Algorithmic scalability is a major concern for any machine learning strategy in this age of 'big data'. A large number of potentially predictive attributes is emblematic of problems in bioinformatics, genetic epidemiology, and many other fields. Previously, ExSTraCS was introduced as an extended Michigan-style supervised learning classifier system that combined a set of powerful heuristics to successfully tackle the challenges of classification, prediction, and knowledge discovery in complex, noisy, and heterogeneous problem domains. While Michigan-style learning classifier systems are powerful and flexible learners, they are not considered to be particularly scalable. For the first time, this paper presents a complete description of the ExSTraCS algorithm and introduces an effective strategy to dramatically improve learning classifier system scalability. ExSTraCS 2.0 addresses scalability with (1) a rule specificity limit, (2) new approaches to expert knowledge guided covering and mutation mechanisms, and (3) the implementation and utilization of the TuRF algorithm for improving the quality of expert knowledge discovery in larger datasets. Performance over a complex spectrum of simulated genetic datasets demonstrated that these new mechanisms dramatically improve nearly every performance metric on datasets with 20 attributes and made it possible for ExSTraCS to reliably scale up to perform on related 200 and 2000-attribute datasets. ExSTraCS 2.0 was also able to reliably solve the 6, 11, 20, 37, 70, and 135 multiplexer problems, and did so in similar or fewer learning iterations than previously reported, with smaller finite training sets, and without using building blocks discovered from simpler multiplexer problems. Furthermore, ExSTraCS usability was made simpler through the elimination of previously critical run parameters.

HOP4

The effects of asymmetric neighborhood assignment in the MOEA/D algorithm

Krzysztof Michalak

The Multiobjective Evolutionary Algorithm Based on Decomposition (MOEA/D) is a very efficient multiobjective evolutionary algorithm introduced in recent years. This algorithm works by decomposing a multiobjective optimization problem to many scalar optimization problems and by assigning each specimen in the population to a specific subproblem. The MOEA/D algorithm transfers information between specimens assigned to the subproblems using a neighborhood relation. In this paper it is shown that parameter settings commonly used in the literature cause an asymmetric neighbor assignment which in turn affects the selective pressure and consequently causes the population to converge asymmetrically. The paper contains theoretical explanation of how this bias is caused as well as an experimental verification. The described effect is undesirable, because a multiobjective optimizer should not introduce asymmetries not present in the optimization problem. The paper gives some guidelines on how to avoid such artificial asymmetries.

Shift-Based Density Estimation for Pareto-Based Algorithms in Many-Objective Optimization

Miqing Li, Shengxiang Yang, Xiaohui Liu

It is commonly accepted that Pareto-based evolutionary multi-objective optimization (EMO) algorithms encounter difficulties in dealing with many-objective problems. In these algorithms, the ineffectiveness of the Pareto dominance relation for a high-dimensional space leads diversity maintenance mechanisms to play the leading role during the evolutionary process, while the preference of diversity maintenance mechanisms for individuals in sparse regions results in the final solutions distributed widely over the objective space but distant from the desired Pareto front. Intuitively, there are two ways to address this problem: 1) modifying the Pareto dominance relation and 2) modifying the diversity maintenance mechanism in the algorithm. In this paper, we focus on the latter and propose a shift-based density estimation (SDE) strategy. The aim of our study is to develop a general modification of density estimation in order to make Pareto-based algorithms suitable for many-objective optimization. In contrast to traditional density estimation that only involves the distribution of individuals in the population, SDE covers both the distribution and convergence information of individuals. The application of SDE in three popular Pareto-based algorithms demonstrates its usefulness in handling many-objective prob-

lems. Moreover, an extensive comparison with five state-of-the-art EMO algorithms reveals its competitiveness in balancing convergence and diversity of solutions. These findings not only show that SDE is a good alternative to tackle many-objective problems, but also present a general extension of Pareto-based algorithms in many-objective optimization.

Genetic programming and serial processing for time series classification

Eva Alfaro-Cid, Ken Sharman, Anna I. Esparcia-Alcázar

This work describes an approach devised by the authors for time series classification. In our approach genetic programming is used in combination with a serial processing of data, where the last output is the result of the classification. The use of genetic programming for classification, although still a field where more research in needed, is not new. However, the application of genetic programming to classification tasks is normally done by considering the input data as a feature vector. That is, to the best of our knowledge, there are not examples in the genetic programming literature of approaches where the time series data are processed serially and the last output is considered as the classification result. The serial processing approach presented here fills a gap in the existing literature. This approach was tested in three different problems. Two of them are real world problems whose data were gathered for on-line or conference competitions. As there are published results of these two problems this gives us the chance of comparing the performance of our approach against top performing methods. The serial processing of data in combination with genetic programming obtained competitive results in both competitions, showing its potential for solving time series classification problems. The main advantage of our serial processing approach is that it can easily handle very large data sets.

Solving Uncompromising Problems with Lexicase Selection

Thomas Helmuth, Lee Spector, James Matheson

We describe a broad class of problems, called uncompromising problems, characterized by the requirement that solutions must perform optimally on each of many test cases. Many of the problems that have long motivated genetic programming research, including the automation of many traditional programming tasks, are uncompromising. We describe and analyze the recently proposed lexicase parent selection algorithm and show that it can facilitate the solution of uncompromising problems by genetic programming. Unlike most traditional parent selection techniques, lexicase selection does not base selection on a fitness value that is aggregated over all test cases; rather, it considers test cases one at a time in random order. We present results comparing lexicase selection to more traditional parent selection methods, including standard tournament selection and implicit fitness sharing, on four uncompromising problems: finding terms in finite algebras, designing digital multipliers, counting words in files, and performing symbolic regression of the factorial function. We provide evidence that lexicase selection maintains higher levels of population diversity than other selection methods, which may partially explain its utility as a parent selection algorithm in the context of uncompromising problems.

Integrative Genetic and Evolutionary Computation

IGEC

Knowledge Transfer from Keepaway Soccer to Half-field Offense through Program Symbiosis: Building Simple Programs for a Complex Task

Stephen Kelly, Malcolm Heywood

Half-field Offense (HFO) is a sub-task of Robocup 2D Simulated Soccer. HFO is a challenging, multi-agent machine learning problem in which a team of offense players attempt to manoeuvre the ball past a defending team and around the goalie in order to score. The agent's sensors and actuators are noisy, making the problem highly stochastic and partially observable. These same real-world characteristics have made Keepaway soccer, which represents one sub-task of HFO, a popular testbed in the reinforcement learning and task-transfer literature in particular. We demonstrate how policies initially evolved for Keepaway can be reused within a symbiotic framework for coevolving policies in genetic programming (GP), with no additional training or transfer function, in order to improve learning in the HFO task. Moreover, the highly modular policies discovered by GP are shown to be significantly less complex than solutions based on traditional value-function optimization while achieving the same level of play in HFO.

A Local Search Approach to Genetic Programming for Binary Classification

Emigdio Z-Flores, Leonardo Trujillo, Oliver Schütze, Pierrick Legrand

In standard genetic programming (GP), a search is performed over a syntax space defined by the set of primitives, looking for the best expressions that minimize a cost function based on a training set. However, most GP systems lack a numerical optimization method to fine tune the implicit parameters of each candidate solution. Instead, GP relies on more exploratory search operators at the syntax level. This work proposes a memetic GP, tailored for binary classification problems. In the proposed method, each node in a GP tree is weighted by a real-valued parameter, which is then numerically optimized using a continuous transfer function and the Trust Region algorithm is used as a local search method. Experimental results show that potential classifiers produced by GP are improved by the local searcher, and hence the overall search is improved achieving significant performance gains, that are competitive with state-of-the-art methods on well-known benchmarks.

Evolving Strategies for Social Innovation Games

Erkin Bahceci, Riitta Katila, Risto Miikkulainen

While evolutionary computation is well suited for automatic discovery in engineering, it can also be used to gain insight into how humans and organizations could perform more effectively in competitive problem-solving domains. This paper formalizes human creative problem solving as competitive multi-agent search, and advances the hypothesis that evolutionary computation can be used to discover effective strategies for it. In experiments in a social innovation game (similar to a fantasy sports league), neural networks were first trained to model individual human players. These networks were then used as opponents to evolve better game-play strategies with the NEAT neuroevolution method. Evolved strategies scored significantly higher than the human models by innovating, retaining, and retrieving less and by imitating more, thus providing insight into how performance could be improved in such domains. Evolutionary computation in competitive multi-agent search thus provides a possible framework for understanding and supporting various human creative activities in the future.

Parallel Evolutionary Systems

PES1

Fast Knowledge Discovery in Time Series with GPGPU on Genetic Programming

Sungjoo Ha, Byung-Ro Moon

We tackle the problem of knowledge discovery in time series data using genetic programming and GPGPUs. Using genetic programming, various precursor patterns that have certain attractive qualities are evolved to predict the events of interest. Unfortunately, evolving a set of diverse patterns typically takes huge execution time, sometimes longer than one month for this case. In this paper, we address this problem by proposing a parallel GP framework using GPGPUs, particularly in the context of big financial data. By maximally exploiting the structure of the nVidia GPGPU platform on stock market time series data, we were able see more than 250-fold reduction in the running time.

PES2

Injection, Saturation and Feedback in Meta-Heuristic Interactions

Krzysztof Nowak, Dario Izzo, Daniel Hennes

Meta-heuristics have proven to be an efficient method of handling difficult global optimization tasks. A recent trend in evolutionary computation is the use of several meta-heuristics at the same time, allowing for occasional information exchange among them in hope to take advantage from the best algorithmic properties of all. Such an approach is inherently parallel and, with some restrictions, has a straight forward implementation in a heterogeneous island model. We propose a methodology for characterizing the interplay between different algorithms, and we use it to discuss their performance on real-parameter single objective optimization benchmarks. We introduce the new concepts of feedback, saturation and injection, and show how they are powerful tools to describe the interplay between different algorithms and thus to improve our understanding of the internal mechanism at work in large parallel evolutionary set-ups.

Real World Applications

RWA1

Genetic Programming for Estimation of Heat Flux between the Atmosphere and Sea Ice in Polar Regions

Karolina Stanislawska, Krzysztof Krawiec, Timo Vihma

The Earth surface and atmosphere exchange heat via turbulent fluxes. An accurate description of the heat exchange is essential in modelling the weather and climate. In these models the heat fluxes are described applying the Monin-Obukhov similarity theory, where the flux depends on the air-surface temperature difference and wind speed. The theory makes idealized assumptions and the resulting estimates often have large errors. This is the case particularly in conditions when the air is warmer than the Earth surface, i.e., the atmospheric boundary layer is stably stratified, and turbulence is therefore weak. This is a common situation over snow and ice in the Arctic and Antarctic. In this paper, we present alternative models for heat flux estimation evolved by means of genetic programming (GP). To this aim, we utilize the best heat flux data collected in the Arctic and Antarctic sea ice zones. We obtain GP models that are more accurate, robust, and conceptually novel from the viewpoint of meteorology. Contrary to the Monin-Obukhov theory, the GP equations are not solely based on the air-surface temperature difference and wind speed, but include also radiative fluxes that improve the performance of the method. These results open the door to a new class of approaches to heat flux prediction with potential applications in weather and climate models.

On Evolutionary Approaches to Wind Turbine Placement with Geo-Constraints

Daniel Lückehe, Markus Wagner, Oliver Kramer

Wind turbine placement, i.e., the geographical planning of wind turbine locations, is an important first step to an efficient integration of wind energy. The turbine placement problem becomes a difficult optimization problem due to varying wind distributions at different locations and due to the mutual interference in the wind field known as wake effect. Artificial and environmental geological constraints make the optimization problem even more difficult to solve. In our paper, we focus on the evolutionary turbine placement based on an enhanced wake effect model fed with real-world wind distributions. We model geo-constraints with real-world data from OpenStreetMap. Besides the realistic modeling of wakes and geo-constraints, the focus of the paper is on the comparison of various evolutionary optimization approaches. We propose four variants of evolution strategies with turbine-oriented mutation operators and compare to state-of-the-art optimizers like the CMA-ES in a detailed experimental analysis on three benchmark scenarios.

Efficient Sampling of PI Controllers in Evolutionary Multi-objective Optimization

Gilberto Reynoso-Meza, Leandro dos Santos Coelho, Roberto Z. Freite

Proportional-Integral (PI) controllers remain as a practical and reliable solution for multivariable control for several industrial applications. Efforts to develop new tuning techniques fulfilling several performance indicators and guaranteeing robustness are worthwhile. Evolutionary multiobjective optimization (EMO) has been used for multivariable PI controller tuning, due to their flexibility and its advantages to depict the trade off among conflicting objectives. It is a regular practice bounding the search space as a hyperbox; nevertheless, the shape of the feasible space of PI parameters which are internally stable for a given control loop is irregular. Therefore, such hyperbox could enclose feasible and unfeasible solutions or contain a subset of the feasible set. In the former case, convergence capabilities of an algorithm could be compromised; in the latter case, search space is not fully explored. In this work, a coding mechanism is proposed in order to explore more efficiently the PI parameters feasible set (that is, all feasible solutions and only feasible solutions) in EMO. With the example provided, the advantages to approximate a Pareto front for 2, 3 and 5 objectives are shown, validating the mechanism as useful for EMO in multivariable PI controller tuning.

Diversifying Multi-Objective Gradient Techniques and their Role in Hybrid Multi-Objective Evolutionary Algorithms for Deformable Medical Image Registration

Kleopatra Pirpinia, Tanja Alderliesten, Jan-Jakob Sonke, Marcel van Herk, Peter Bosman

Gradient methods and their value in single-objective, real-valued optimization are well-established. As such, they play a key role in tackling real-world, hard optimization problems such as deformable image registration (DIR). A key question is to which extent gradient techniques can also play a role in a multi-objective approach to DIR. We therefore aim to exploit gradient information within an evolutionary-algorithm-based multi-objective optimization framework for DIR. Although an analytical description of the multi-objective gradient (the set of all Pareto-optimal improving directions) is available, it is nontrivial how to best choose the most appropriate direction per solution because these directions are not necessarily uniformly distributed in objective space. To address this, we employ a Monte-Carlo method to obtain a discrete, spatially-uniformly distributed approximation of the set of Pareto-optimal improving directions. We then apply a diversification technique in which each solution is associated with a unique direction from this set based on its multi- as well as single-objective rank. To assess its utility, we compare a state-of-the-art multi-objective evolutionary algorithm with three different hybrid versions thereof on several benchmark problems and two medical DIR problems. Results show that the diversification strategy successfully leads to unbiased improvement, helping an adaptive hybrid scheme solve all problems, but the evolutionary algorithm remains the most powerful optimization method, providing the best balance between proximity and diversity.

RWA2

A Closer Look At Differential Evolution For The Optimal Well Placement Problem

Grazieli Carosio, Thomas Humphries, Ronald Haynes, Colin Farquharson

Energy demand has increased considerably with the growth of world population, increasing the interest in the hydrocarbon reservoir management problem. Companies are concerned with maximizing oil recovery while minimizing capital investment and operational costs. A first step in solving this problem is to consider optimal well placement. In this work, we investigate the Differential Evolution (DE) optimization method, using distinct configurations with respect to population size, mutation factor, crossover probability, and mutation strategy, to solve the well placement problem. By assuming a bare control procedure, one optimizes the parameters representing positions of injection and production wells. The Tenth SPE Comparative Solution Project and MATLAB Reservoir Simulation Toolbox (MRST) are the benchmark dataset and simulator used, respectively. The goal is to evaluate the performance of DE in solving this important real-world problem. We show that DE can find high-quality solutions, when compared with a reference from the literature, and a preliminary analysis on the results of multiple experiments gives useful information on how DE configuration impacts its performance.

Selecting Best Investment Opportunities from Stock Portfolios Optimized by a Multiobjective Evolutionary Algorithm

Krzysztof Michalak

Multiobjective optimization of portfolios aims at finding sets of stocks which are expected to provide a possibly high return while retaining a moderate level of risk. The Pareto front of portfolios generated by the optimization algorithm represents attainable trade-offs between returns obtained by the portfolios and the level of risk involved in the investment. This paper studies the relationship between location of portfolios in the Pareto front and future returns of these portfolios. It is observed that the highest future returns can be obtained for the portfolios with the highest return and risk measures observed in the past but also for those with the lowest return and risk in the Pareto front. Neither constantly selecting portfolios with high return on historical data nor, conversely, those with low historical risk (but also low return) yields high future returns. Based on these observations a method is proposed for adaptively selecting the best portfolios for investment from solutions contained in the Pareto front. The proposed method selects high-return (but also high-risk) portfolios or low-risk (but also low-return) portfolios based on the behaviour of the stock marked index in the time period preceding the moment of investment. The proposed method outperforms both the strategy of always selecting the portfolios with the highest return from the past and the risk-averse strategy of selecting portfolios with low risk measure.

Exploiting Linkage Information and Problem-Specific Knowledge in Evolutionary Distribution Network Expansion Planning

Ngoc Hoang Luong, Han La Poutré, Peter Bosman

This paper tackles the Distribution Network Expansion Planning (DNEP) problem that has to be solved by distribution network operators to decide which, where, and/or when enhancements to electricity networks should be introduced to satisfy the future power demands. We compare two evolutionary algorithms (EAs) for optimizing expansion plans: the classic genetic algorithm (GA) with uniform crossover and the Gene-pool Optimal Mixing Evolutionary Algorithm (GOMEA) that learns and exploits linkage information between problem variables. We study the impact of incorporating different levels of problem-specific knowledge in the variation operators as well as two constraint-handling techniques: constraint domination and repair mechanisms. Experiments show that the use of problem-specific variation operators is far more important for the classic GA to find high-quality solutions to the DNEP problem. GOMEA is found to have far more robust performance even when an out-of-box variant is used that doesn't exploit problem-specific knowledge. Based on experiments, we suggest that when selecting optimization algorithms for real-world applications like DNEP, EAs that have the ability to model and exploit problem structures, such as GOMEAs and estimation-of-distribution algorithms, should be given priority, especially when problem-specific knowledge is not straightforward to exploit, e.g. in the case of black-box optimization.

Evolving Solutions to TSP Variants for Active Space Debris Removal

Dario Izzo, Ingmar Getzner, Daniel Hennes, Luís Simões

The space close to our planet is getting more and more polluted. Orbiting debris are posing an increasing threat to operational orbits and the cascading effect, known as Kessler syndrome, may result in a future where the risk of orbiting our planet at some altitudes will be unacceptable. Many argue that the debris density at the Low Earth Orbit (LEO) has already reached a level sufficient to trigger such a cascading effect. An obvious consequence is that we may soon have to actively clean space from debris. Such a space mission will involve a complex combinatorial decision as to choose which debris to remove and in what order. In this paper, we find that this part of the design of an active debris removal mission (ADR) can be mapped into increasingly complex variants to the classic Travelling Salesman Problem (TSP) and that they can be solved by the Inver-over algorithm improving the current state-of-the-art in ADR mission design. We define static and dynamic cases, according to whether we consider the debris orbits as fixed in time or subject to orbital perturbations. We are able, for the first time, to select optimally objects from debris clouds of considerable size: hundreds debris pieces considered while previous works stopped at tens.

RWA3

Using Multi-Objective Artificial Immune Systems to Find Core Collections Based on Molecular Markers

Shana Schlottfeldt, Maria Emilia Walter, Jon Timmis, Andre Carvalho, Mariana Telles, Jose Alexandre Diniz-Filho

Germplasm collections are an important strategy for conservation of diversity, a challenge in ecoinformatics. It is common to select a core to represent the genetic diversity of a germplasm collection, aiming to minimize the costs of conservation, while ensuring the maximization of genetic variation. For the problem of finding a core for a germplasm collection, we proposed the use of a constrained multi-objective artificial immune algorithm (MAIS), based on principles of systematic conservation planning (SCP), and incorporating heterozygosity information. Therefore, optimization takes genotypic diversity and variability patterns into account. As a case study, we used Dipteryx alata molecular marker information. We were able to identify within several accessions, the exact entries that should be chosen to preserve species diversity. MAIS presented better performance measure results when compared to NSGA-II. The proposed approach can be used to help construct cores with maximal genetic richness, and also be extended to in situ conservation. As far as we know, this is the first time that an AIS algorithm is applied to the problem of finding a core for a germplasm collection using heterozygosity information as well.

Smart Mobility Policies with Evolutionary Algorithms: The Adapting Info Panel Case

Daniel Stolfi, Enrique Alba

In this article we propose the Yellow Swarm architecture for reducing travel times, greenhouse gas emissions and fuel consumption of road traffic by using several LED panels to suggest changes in the direction of vehicles (detours) for different time slots. These time intervals are calculated using an evolutionary algorithm, specifically designed for our proposal, which evaluates many working scenarios based on real cities, imported from OpenStreetMap into the SUMO traffic simulator. Our results show an improvement in average travel times, emissions, and fuel consumption even when only a small percentage of drivers follow the indications provided by our panels.

An Integrated Approach to Stage 1 Breast Cancer Detection

Jeannie Fitzgerald, Conor Ryan, David Medernach, Krzysztof Krawiec

We present an automated, end-to-end approach for Stage 1 breast cancer detection. The first phase of our proposed workflow takes individual digital mammograms as input and outputs several smaller sub-images from which the background has been removed. Next, we extract a set of features which capture textural information from the segmented images. In the final phase, the most salient of these features are fed into a Multi-Objective Genetic Programming system which then evolves classifiers capable of identifying those segments which may have suspicious areas that require further investigation. A key aspect of this work is the examination of several new experimental configurations which focus on textural asymmetry between breasts. The best evolved classifier using such a configuration can deliver results of 100% accuracy on true positives and a false positive per image rating of just 0.33, which is better than the current state of the art.

Finding an Optimal LEGO(R) Brick Layout of Voxelized 3D Object Using a Genetic Algorithm

Sangyeop Lee, Jinhyun Kim, Jae Woo Kim, Byung-Ro Moon

In this paper, we propose a genetic algorithm for a LEGO(R) brick layout problem. The task is to build a given 3D object with LEGO(R) bricks. A brick layout is modeled as a solution to a combinatorial optimization problem, through intermediate voxelization, which tries to maximize the connectivity and then minimize the number of used bricks. We attack the problem in the context of genetic search. The proposed randomized greedy algorithm produces initial solutions, and the solutions are effectively improved by an evolutionary process. New domain-specific methods are proposed as well, which include a random boundary mutation and a thickening approach. We tested our algorithm on various objects collected from the web. Experimental results showed that the algorithm produces efficient, and mostly optimal solutions for benchmark models. Unlike some previous works, our algorithm is not limited to assemble few specific objects, but it can deal with diverse kind of objects. To the best of our knowledge, this is the most extensive empirical study on the problem.

RWA4

A Model with Evolutionary Covariance-based Learning for High-Frequency Financial Forecasting

Ricardo Araujo, Adriano Oliveira, Silvio Meira

Several approaches have been investigated to develop models able to solve forecasting problems. However, a limitation arises in the particular case of daily-frequency financial forecasting and is called the random walk dilemma (RWD). In this context, the concept of time phase adjustment can be included in forecasting models to overcome such a drawback. But the evolution of trading systems has increased the frequency for performing operations in the stock market for fractions of seconds, which requires the analysis of high-frequency financial time series. Thus, this work proposes a model, called the increasing decreasing linear neuron (IDLN), to forecast high-frequency financial time series from the Brazilian stock market. Furthermore, an evolutionary covariance-based method with automatic time phase adjustment is presented for the design of the proposed model, and the obtained results overcame those obtained by classical forecasting models in the literature.

Diversity Guided Evolutionary Mining of Hierarchical Process Models

Thomas Molka, David Redlich, Marc Drobek, Xiao-Jun Zeng, Wasif Gilani

Easy-to-understand and up-to-date models of business processes are important for enterprises, as they aim to describe how work is executed in reality and provide a starting point for process analysis and optimization. With an increasing amount of event data logged by information systems today, the automatic discovery of process models from process logs has become possible. Whereas most existing techniques focus on the discovery of well-formalized models (e.g. Petri nets) which are popular among researchers, business analysts prefer business domain-specific models (such as Business Process Model Notation, BPMN) which are not well formally specified. We present and evaluate an approach for discovering the latter type of process models by formally specifying a hierarchical view on business process models and applying an evolution strategy on it. The evolution strategy efficiently finds process models which best represent a given event log by using fast methods for process model conformance checking, and is partly guided by the diversity of the process model population. The approach contributes to the field of evolutionary algorithms by showing that they can be successfully applied in the real-world use case of process discovery, and contributes to the process discovery domain by providing a promising alternative to existing methods.

A Biased Random-key Genetic Algorithm for Placement of Virtual Machines across Geo-Separated Data Centers

Fernando Stefanello, Vaneet Aggarwal, Luciana Buriol, José Gonçalves, Mauricio Resende

Cloud computing has recently emerged as a new technology for hosting and supplying services over the Internet. This technology has brought many benefits, such as eliminating the need for maintaining expensive computing hardware and allowing business owners to start from small and increase resources only when there is a rise in service demand. With an increasing demand for cloud computing, providing performance guarantees for applications that run over cloud become important. Applications can be abstracted into a set of virtual machines with certain guarantees depicting the quality of service of the application. In this paper, we consider the placement of these virtual machines across multiple data centers, meeting the quality of service requirements while minimizing the bandwidth cost of the data centers. This problem is a generalization of the NP-hard Generalized Quadratic Assignment Problem (GQAP). We formalize the problem and propose a novel algorithm based on a biased random-key genetic algorithm (BRKGA) to find near-optimal solutions for the problem. The experimental results show that the proposed algorithm is effective in quickly finding feasible solutions and it produces better results than a baseline aproach provided by a commercial solver and a multi-start algorithm.

A Genetic Programming Approach to Cost-Sensitive Control in Resource Constrained Sensor Systems

Afsoon Yousefi Zowj, Josh Bongard, Christian Skalka

Resource constrained sensor systems are an increasingly attractive option in a variety of environmental monitoring domains, due to continued improvements in sensor technology. However, sensors for the same measurement application can differ in terms of cost and accuracy, while fluctuations in environmental conditions can impact both application requirements and available energy. This raises the problem of automatically controlling heterogeneous sensor suites in resource constrained sensor system applications, in a manner that balances cost and accuracy of available sensors. We present a method that employs a hierarchy of model ensembles trained by genetic programming (GP): if model ensembles that poll low-cost sensors exhibit too much prediction uncertainty, they automatically transfer the burden of prediction to other GP-trained model ensembles that poll more expensive and accurate sensors. We show that, for increasingly challenging datasets, this hierarchical approach makes predictions with equivalent accuracy yet lower cost than a similar yet non-hierarchical method in which a single GP-generated model determines which sensors to poll at any given time. Our results thus show that a hierarchy of GP-trained ensembles can serve as a control algorithm for heterogeneous sensor suites in resource constrained sensor system applications that balances cost and accuracy.

___RWA5___

Evolutionary Learning of Syntax Patterns for Genic Interaction Extraction

Alberto Bartoli, Andrea De Lorenzo, Eric Medvet, Fabiano Tarlao, Marco Virgolin

There is an increasing interest in the development of techniques for automatic relation extraction from unstructured text. The biomedical domain, in particular, is a sector that may greatly benefit from those techniques due to the huge and ever increasing amount of scientific publications describing observed phenomena of potential clinical interest. In this paper, we consider the problem of automatically identifying sentences that contain interactions between genes and proteins, based solely on a dictionary of genes and proteins and a small set of sample sentences in natural language. We propose an evolutionary technique for learning a classifier that is capable of detecting the desired sentences within scientific publications with high accuracy. The key feature of our proposal, that is internally based on Genetic Programming, is the construction of a model of the relevant syntax patterns in terms of standard part-of-speech annotations. The model consists of a set of regular expressions that are learned automatically despite the large alphabet size involved. We assess our approach on two realistic datasets and obtain 74% accuracy, a value sufficiently high to be of practical interest and that is in line with significant baseline methods.

Search-Based Software Engineering and Self-* Search

___SBSE-SS1___

Optimal Parameter Choices Through Self-Adjustment: Applying the 1/5-th Rule in Discrete Settings

Benjamin Doerr, Carola Doerr

While evolutionary algorithms are known to be very successful for a broad range of applications, the algorithm designer is often left with many algorithmic choices, for example, the size of the population, the mutation rates, and the crossover rates of the algorithm. These parameters are known to have a crucial influence on the optimization time, and thus need to be chosen carefully, a task that often requires substantial efforts. Moreover, the optimal parameters can change during the optimization process. It is therefore of great interest to design mechanisms that dynamically choose best-possible parameters. An example for such an update mechanism is the one-fifth success rule for step-size adaption in evolutionary strategies. While in continuous domains this principle is well understood also from a mathematical point of view, no comparable theory is available for problems in discrete domains. In this work we show that the one-fifth success rule can be effective also in discrete settings. We regard the $(1 + (\lambda, \lambda))$ GA proposed in [Doerr/Doerr/Ebel: From

black-box complexity to designing new genetic algorithms, TCS 2015]. We prove that if its population size is chosen according to the one-fifth success rule then the expected optimization time on ONEMAX is linear. This is better than what *any* static population size λ can achieve and is asymptotically optimal also among all adaptive parameter choices.

Random or Genetic Algorithm Search for Object-Oriented Test Suite Generation?

Sina Shamshiri, José Miguel Rojas, Gordon Fraser, Phil McMinn

Achieving high structural coverage is an important aim in software testing. Several search-based techniques have proved successful at automatically generating tests that achieve high coverage. However, despite the well- established arguments behind using evolutionary search algorithms (e.g., genetic algorithms) in preference to random search, it remains an open question whether the benefits can actually be observed in practice when generating unit test suites for object-oriented classes. In this paper, we report an empirical study on the effects of using a genetic algorithm (GA) to generate test suites over generating test suites incrementally with random search, by applying the EvoSuite unit test suite generator to 1,000 classes randomly selected from the SF110 corpus of open source projects. Surprisingly, the results show little difference between the coverage achieved by test suites generated with evolutionary search compared to those generated using random search. A detailed analysis reveals that the genetic algorithm covers more branches of the type where standard fitness functions provide guidance. In practice, however, we observed that the vast majority of branches in the analyzed projects provide no such guidance.

Extracting Variability-Safe Feature Models from Source Code Dependencies in System Variants

Wesley Assunção, Roberto Lopez-Herrejon, Lukas Linsbauer, Silvia Vergilio, Alexander Egyed

To effectively cope with increasing customization demands, companies that have developed variants of software systems are faced with the challenge of consolidating all the variants into a Software Product Line, a proven development paradigm capable of handling such demands. A crucial step in this challenge is to reverse engineer feature models that capture all the required feature combinations of each system variant. Current research has explored this task using propositional logic, natural language, and search-based techniques. However, using knowledge from the implementation artifacts for the reverse engineering task has not been studied. We propose a multi-objective approach that not only uses standard precision and recall metrics for the combinations of features but that also considers variability-safety, i.e. the property that, based on structural dependencies among elements of implementation artifacts, asserts whether all feature combinations of a feature model are in fact well-formed software systems. We evaluate our approach with five case studies and highlight its benefits for the software engineer.

SBSE-SS2

Learning Feature-Parameter Mappings for Parameter Tuning via the Profile Expected Improvement

Jakob Bossek, Bernd Bischl, Tobias Wagner, Günter Rudolph

The majority of algorithms can be controlled or adjusted by parameters. Their values can substantially affect the algorithms' performance. Since the manual exploration of the parameter space is tedious – even for few parameters – several automatic procedures for *parameter tuning* have been proposed. Recent approaches also take into account some characteristic properties of the problem instances, frequently termed *instance features*. These approaches, however, rely on a subdivision of the instances into discrete clusters. Our contribution is the proposal of a novel concept for feature-based algorithm parameter tuning, which applies an approximating surrogate model for learning the continuous feature-parameter mapping. To accomplish this, we learn a joint model of the algorithm performance based on both the algorithm parameters and the instance features. The required data is gathered using a recently proposed acquisition function for model refinement in surrogate-based optimization: the *profile expected improvement*. This function provides an avenue for maximizing the information required for the *feature-parameter mapping*, i.e., the mapping from instance features to the corresponding optimal algorithm parameters. The approach is validated by applying the tuner to exemplary evolutionary algorithms and problems, for which theoretically grounded or heuristically determined feature-parameter mappings are available.

Operator Selection using Improved Dynamic Multi-Armed Bandit

Jany Belluz, Marco Gaudesi, Giovanni Squillero, Alberto Tonda

Evolutionary algorithms greatly benefit from an optimal application of the different genetic operators during the optimization process: thus, it is not surprising that several research lines in literature deal with the self-adapting of activation probabilities for operators. The current state of the art revolves around the use of the Multi-Armed Bandit (MAB) and Dynamic Multi-Armed bandit (D-MAB) paradigms, that modify the selection mechanism based on the rewards of the different operators. Such methodologies, however, update the probabilities after each operator's application, creating possible issues with positive feedbacks and impairing parallel evaluations, one of the strongest advantages of evolutionary computation in an industrial perspective. Moreover, D-MAB techniques often rely upon measurements of population diversity, that might not be applicable to all real-world scenarios. In this paper, we propose a generalization of the D-MAB approach, paired with a simple mechanism for operator management, that aims at removing several limitations of other D-MAB strategies, allowing for parallel evaluations and self-adaptive parameter tuning. Experimental results show that the approach is particularly effective with frameworks containing many different operators, even when some of them are ill-suited for the problem at hand, or are sporadically failing, as it commonly happens in the real world.

Reducing Energy Consumption Using Genetic Improvement

Bobby Bruce, Justyna Petke, Mark Harman

Genetic Improvement (GI) is an area of Search Based Software Engineering which seeks to improve software's non-functional properties by treating program code as if it were genetic material which is then evolved to produce more optimal solutions. Hitherto, the majority of focus has been on optimising program's execution time which, though important, is only one of many non-functional targets. The growth in mobile computing, cloud computing infrastructure, and ecological concerns are forcing developers to focus on the energy their software consumes. We report on investigations into using GI to automatically find more energy efficient versions of the MiniSAT Boolean satisfiability solver when specialising for three downstream applications. Our results find that GI can successfully be used to reduce energy consumption by up to 25%

Web Service Antipatterns Detection Using Genetic Programming

Ali Ouni, Raula Gaikovina Kula, Marouane Kessentini, Katsuro Inoue

Service-Oriented Architecture (SOA) is an emerging paradigm that has radically changed the way software applications are architected, designed and implemented. SOA allows developers to structure their systems as a set of ready-made, reusable and compostable services. The leading technology used today for implementing SOA is Web Services. Indeed, like all software, Web services are prone to change constantly to add new user requirements or to adapt to environment changes. Poorly planned changes may risk introducing antipatterns into the system. Consequently, this may ultimately leads to a degradation of software quality, evident by poor quality of service (QoS). In this paper, we introduce an automated approach to detect Web service antipatterns using genetic programming. Our approach consists of using knowledge from real-world examples of Web service antipatterns to generate detection rules based on combinations of metrics and threshold values. We evaluate our approach on a benchmark of 310 Web services and a variety of five types of Web service antipatterns. The statistical analysis of the obtained results provides evidence that our approach is efficient to detect most of the existing antipatterns with a score of 85% of precision and 87% of recall.

SBSE-SS3

Heuristic Model Checking using a Monte-Carlo Tree Search Algorithm

Simon Poulding, Robert Feldt

Monte-Carlo Tree Search algorithms have proven extremely effective at playing games that were once thought to be difficult for AI techniques owing to the very large number of possible game states. The key feature of these algorithms is that rather than exhaustively searching game states, the algorithm navigates the tree using information returned from a relatively small number of random game simulations. A practical limitation of software model checking is the very large number of states that a model can take. Motivated by an analogy between exploring game states and checking model states, we propose that Monte-Carlo Tree Search algorithms might also be applied in this domain to efficiently navigate the model state space with the objective of finding counterexamples which correspond to potential software faults. We describe such an approach based on Nested Monte-Carlo Search—a tree search algorithm applicable to single player games—and compare its efficiency to traditional heuristic search algorithms when using Java PathFinder to locate deadlocks in 12 Java programs.

SPRINT Multi-Objective Model Racing

Tiantian Zhang, Michael Georgiopoulos, Georgios Anagnostopoulos

Multi-objective model selection, which is an important aspect of Machine Learning, refers to the problem of identifying a set of Pareto optimal models from a given ensemble of models. This paper proposes SPRINT-Race, a multi-objective racing algorithm based on the Sequential Probability Ratio Test with an Indifference Zone. In SPRINT-Race, a non-parametric ternary-decision sequential analogue of the sign test is adopted to identify pair-wise dominance and non-dominance relationship. In addition, a Bonferroni approach is employed to control the overall probability of any erroneous decisions. In the fixed confidence setting, SPRINT-Race tries to minimize the computational effort needed to achieve a predefined confidence about the quality of the returned models. The efficiency of SPRINT-Race is analyzed on artificially-constructed multi-objective model selection problems with known ground-truth. Moreover, SPRINT-Race is applied to identifying the Pareto optimal parameter settings of Ant Colony Optimization algorithms in the context of solving Traveling Salesman Problems. The experimental results confirm the advantages of SPRINT-Race for multi-objective model selection.

Deep Parameter Optimisation

Fan Wu, Westley Weimer, Mark Harman, Yue Jia, Jens Krinke

We introduce a mutation-based approach to automatically discover and expose 'deep' (previously unavailable) parameters that affect a program's runtime costs. These discovered parameters, together with existing ('shallow') parameters, form a search space that we tune using search-based optimisation in a bi-objective formulation that optimises both time and memory consumption. We implemented our approach and evaluated it on four real-world programs. The results show that we can improve execution time by 12% or achieve a 21% memory consumption reduction in the best cases. In three subjects, our deep parameter tuning results in a significant improvement over the baseline of shallow parameter tuning, demonstrating the potential value of our deep parameter extraction approach.

A Hyper-Heuristic for the Multi-Objective Integration and Test Order Problem

Giovani Guizzo, Gian Fritsche, Silvia Vergilio, Aurora Pozo

Multi-objective evolutionary algorithms (MOEAs) have been efficiently applied to Search-Based Software Engineering (SBSE) problems. However, skilled software engineers waste significant effort designing such algorithms for a particular problem, adapting them, selecting operators and configuring parameters. Hyper-heuristics can help in these tasks by dynamically selecting or creating heuristics. Despite of such advantages, we observe a lack of works regarding this subject in the SBSE field. Considering this fact, this work introduces HITO, a Hyper-heuristic for the Integration and Test Order Problem. It includes a set of well-defined steps and is based on two selection functions (Choice Function and Multi-armed Bandit) to select the best low-level heuristic (combination of mutation and crossover operators) in each mating. To perform the selection, a quality measure is proposed to assess the performance of low-level heuristics throughout the evolutionary process. HITO was implemented using NSGA-II and evaluated to solve the integration and test order problem in seven systems. The introduced hyper-heuristic obtained the best results for all systems, when compared to a traditional algorithm.

Theory

THEORY1

Improved Runtime Bounds for the (1+1) EA on Random 3-CNF Formulas Based on Fitness-Distance Correlation

Benjamin Doerr, Frank Neumann, Andrew Sutton

With this paper, we contribute to the theoretical understanding of randomized search heuristics by investigating their behavior on random 3-SAT instances. We improve the results for the (1+1) EA obtained by Sutton and Neumann [PPSN 2014, 942–951] in three ways. First, we reduce the upper bound by a linear factor and prove that the (1+1) EA obtains optimal solutions in time $O(n \log n)$ with high probability on asymptotically almost all high-density satisfiable 3-CNF formulas. Second, we extend the range of densities for which this bound holds to satisfiable formulas of at least logarithmic density. Finally, we complement these mathematical results with numerical experiments that summarize the behavior of the (1+1) EA on formulas along the density spectrum, and suggest that the implicit constants hidden in our bounds are low. Our proofs are based on analyzing the run of the algorithm by establishing a fitness-distance correlation. This approach might be of independent interest and we are optimistic that it is useful for the analysis of randomized search heuristics in various other settings. To our knowledge, this is the first time that fitness-distance correlation is explicitly used to rigorously prove a performance statement for an evolutionary algorithm.

THEORY2

First Steps Towards a Runtime Comparison of Natural and Artificial Evolution

Tiago Paixao, Jorge Perez Heredia, Dirk Sudholt, Barbora Trubenova

Evolutionary algorithms (EAs) form a popular optimisation paradigm inspired by natural evolution. In recent years the field of evolutionary computation has developed a rigorous analytical theory to analyse their runtime on many illustrative problems. Here we apply this theory to a simple model of natural evolution. In the Strong Selection Weak Mutation (SSWM) evolutionary regime the time between occurrence of new mutations is much longer than the time it takes for a new beneficial mutation to take over the population. In this situation, the population only contains copies of one genotype and evolution can be modelled as a (1+1)-type process where the probability of accepting a new genotype (improvements or worsenings) depends on the change in fitness. We present an initial runtime analysis of SSWM, quantifying its performance for various parameters and investigating differences to the (1+1)EA. We show that SSWM can have a moderate advantage over the (1+1)EA at crossing fitness valleys and study an example where SSWM outperforms the (1+1)EA by taking advantage of information on the fitness gradient.

Population Size vs. Mutation Strength for the (1+λ) EA on OneMax

Christian Giessen, Carsten Witt

The (1+1) EA with mutation probability c/n, where $c > 0$ is an arbitrary constant, is studied for the classical ONEMAX function. Its expected optimization time is analyzed exactly (up to lower order terms) as a function of c and λ. It turns out that $1/n$ is the only optimal mutation probability if $\lambda = o(\ln n \ln\ln n / \ln\ln\ln n)$, which is the cut-off point for linear speed-up. However, if λ is above this cut-off point then the standard mutation probability $1/n$ is no longer the only optimal choice. Instead, the expected number of generations is (up to lower order terms) independent of c, irrespectively of it being less than 1 or greater. The results are obtained by a careful study of order statistics of the binomial distribution and variable drift theorems for upper and lower bounds.

Populations can be Essential in Dynamic Optimisation

Duc-Cuong Dang, Thomas Jansen, Per Kristian Lehre

Real-world optimisation problems are often dynamic. Previously good solutions must be updated or replaced due to changes in objectives and constraints. It is often claimed that evolutionary algorithms are particularly suitable for dynamic optimisation because a large population can contain different solutions that may be useful in the future. However, rigorous, theoreti-

cal demonstrations for how populations in dynamic optimisation can be essential are sparse and restricted to special cases. This paper provides theoretical explanations of how populations can be essential in evolutionary dynamic optimisation. The ability of evolutionary algorithms to track optimal solutions is investigated by considering a Hamming ball of optimal points that moves randomly through the search space. It is shown that algorithms based on a single individual are likely to be unable to track the optimum while non-elitist population-based evolutionary algorithms can be able to do so with overwhelmingly high probability. It is shown that this holds for a range of the most commonly used selection mechanisms even without diversity enhancing mechanisms. Appropriate parameter settings to achieve this behaviour are derived for these selection mechanisms.

THEORY3

On the Utility of Island Models in Dynamic Optimization

Andrei Lissovoi, Carsten Witt

A simple island model with λ islands and migration occurring after every τ iterations is studied on the dynamic fitness function Maze. This model is equivalent to a (1+λ) EA if $\tau = 1$, i.e., migration occurs during every iteration. It is proved that even for an increased offspring population size up to $\lambda = O(n^{1-\epsilon})$, the (1+$\lambda$) EA is still not able to track the optimum of Maze. If the migration interval is increased, the algorithm is able to track the optimum even for logarithmic λ. Finally, the relationship of τ, λ, and the ability of the island model to track the optimum is investigated more closely.

THEORY4

An Evolutionary Game Theoretic Analysis of Difference Evaluation Functions

Mitchell Colby, Kagan Tumer

One of the key difficulties in cooperative coevolutionary algorithms is solving the credit assignment problem. Given the performance of a team of agents, it is difficult to determine the effectiveness of each agent in the system. One solution to solving the credit assignment problem is the difference evaluation function, which has produced excellent results in many multi-agent coordination domains, and exhibits the desirable theoretical properties of alignment and sensitivity. However, to date, there has been no prescriptive theoretical analysis deriving conditions under which difference evaluations improve the probability of selecting optimal actions. In this paper, we derive such conditions. Further, we prove that difference evaluations do not alter the Nash equilibria locations or the relative ordering of fitness values for each action, meaning that difference evaluations do not typically harm converged system performance in cases where the conditions are not met. We then demonstrate the theoretical findings using an empirical basins of attraction analysis.

On Easiest Functions for Somatic Contiguous Hypermutations And Standard Bit Mutations

Dogan Corus, Jun He, Thomas Jansen, Pietro Oliveto, Dirk Sudholt, Christine Zarges

Understanding which function classes are easy and which are hard for a given algorithm is a fundamental question for the analysis and design of bio-inspired search heuristics. A natural starting point is to consider the easiest and hardest functions for an algorithm. For the (1+1)EA using standard bit mutation it is well known that OneMax is an easiest function with unique optimum while Trap is a hardest. In this paper we extend the analysis of easiest function classes to the contiguous somatic hypermutation (CHM) operator used in artificial immune systems. We define a function MinBlocks and prove that it is an easiest function for the (1+1)EA using CHM, presenting both a runtime and a fixed budget analysis. Since MinBlocks is, up to a factor of 2, a hardest function for standard bit mutations, we consider the effects of combining both operators into a hybrid algorithm. We show that an easiest function for the hybrid algorithm is not just a trivial weighted combination of the respective easiest functions for each operator. Nevertheless, by combining the advantages of both operators, the hybrid algorithm has optimal asymptotic performance on both OneMax and MinBlocks.

A Tight Runtime Analysis of the $(1 + (\lambda, \lambda))$ Genetic Algorithm on OneMax

Benjamin Doerr, Carola Doerr

Understanding how crossover works is still one of the big challenges in evolutionary computation research, and making our understanding precise and proven by mathematical means might be an even bigger one. As one of few examples where crossover provably is useful, the $(1 + (\lambda, \lambda))$ Genetic Algorithm (GA) was proposed recently in [Doerr, Doerr, Ebel. Lessons From the Black-Box: Fast Crossover-Based Genetic Algorithms. TCS 2015]. Using the fitness level method, the expected optimization time on general ONEMAX functions was analyzed and a $O(\max\{n \log(n)/\lambda, \lambda n\})$ bound was proven for any offspring population size $\lambda \in [1..n]$. We improve this work in several ways, leading to sharper bounds and a better understanding of how the use of crossover speeds up the runtime in this algorithm. We first improve the upper bound on the runtime to $O(\max\{n \log(n)/\lambda, n\lambda \log\log(\lambda)/\log(\lambda)\})$. This improvement is made possible from observing that in the parallel generation of λ offspring via crossover (but not mutation), the best of these often is better than the expected value, and hence several fitness levels can be gained in one iteration. We then present the first lower bound for this problem. It matches our upper bound for all values of λ. This allows to determine the asymptotically optimal value for the population size. It is $\lambda = \Theta(\sqrt{\log(n) \log\log(n)/\log\log\log(n)})$, which gives an optimization time of $\Theta(n\sqrt{\log(n) \log\log\log(n)/\log\log(n)})$. Hence the improved runtime analysis both gives a runtime guar-

antee improved by a super-constant factor and yields a better actual runtime (faster by more than a constant factor) by suggesting a better value for the parameter λ. We finally give a tail bound for the upper tail of the runtime distribution, which shows that the actual runtime exceeds our runtime guarantee by a factor of $(1+\delta)$ with probability $O((n/\lambda^2)^{-\delta})$ only.

OneMax in Black-Box Models with Several Restrictions

Carola Doerr, Johannes Lengler

As in classical runtime analysis the ONEMAX problem is the most prominent test problem also in black-box complexity theory. It is known that the unrestricted, the memory-restricted, and the ranking-based black-box complexities of this problem are all of order $n/\log n$, where n denotes the length of the bit strings. The combined memory-restricted ranking-based black-box complexity of ONEMAX, however, was not known. We show in this work that it is $\Theta(n)$ for the smallest possible size bound, that is, for (1+1) black-box algorithms. We extend this result by showing that even if elitist selection is enforced, there exists a linear time algorithm optimizing ONEMAX with failure probability $o(1)$. This is quite surprising given that all previously regarded algorithms with $o(n \log n)$ runtime on ONEMAX, in particular the quite natural $(1+(\lambda,\lambda))$ GA, heavily exploit information encoded in search points of fitness much smaller than the current best-so-far solution. Also for other settings of μ and λ we show that the $(\mu+\lambda)$ *elitist memory-restricted ranking-based black-box complexity* of ONEMAX is as small as (an advanced version of) the information-theoretic lower bound. Our result enlivens the quest for natural evolutionary algorithms optimizing ONEMAX in $o(n \log n)$ iterations.

Instructions

Instructions for Session Chairs and Presenters

Instructions for Session Chairs

Thank you for agreeing to chair a session. Session chairs are essential to keep sessions on schedule and moderate the question period.

- Arrive a few minutes early to check on room and equipment set-up. Let the conference organizers at the registration desk know if problems arise or adjustments are needed.
- Please follow the scheduled order of talks, as well as presentation times.
- In the unlikely event that a speaker is absent, we ask you to announce a short break until the next presentation is due to start. Breathe normally.
- Do not start early, as participants may be moving between sessions/presentations.
- Introduce each speaker.
- Speakers presenting accepted full papers during the technical sessions are allocated 25 minutes for each presentation; 20 minutes for set up and presentation and 5 minutes for questions.
- Moderate questions.
- If you chair a best paper session, please remind the audience that this is a best paper session, distribute the ballots that you will find in the room at the beginning of the session, and collect the votes at the end of the session. After the session, please bring the ballots to the registration desk.

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

Instructions for Paper Presenters

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

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

Instructions for Poster Presenters

- The regular poster session will be held on Monday, July 13, 18:45-20:45, Tapices room.
- The Late Breaking Abstract and Student poster sessions will be held on Sunday, July 12th, 11:10-13:00, Tapices room.
- The Women@GECCO poster session will be held on Sunday, July 12th, between 16:40 and 18:30, Tapices room.
- Poster set-up is 30 minutes prior to the start of each session.
- For the Sunday sessions, posters may be left on for the Welcome reception which will take place on the same evening.
- Poster boards and thumbtacks or tape will be available.
- Posters should be no more than 90cm (36”) wide and 188cm (74”) high.