

EADOP Progress Report

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25.02.09

Abstract

This report is a summary of progress for the first 15 months of the EPSRC financed research project *Evolutionary Algorithms for Dynamic Optimisation Problems: Design, Analysis and Applications*, a collaboration between the University of Birmingham and the University of Leicester. The report provides details of all researchers involved, research questions investigated as well as a summary of research outputs. Current and ongoing work is reviewed and a list of topics for future work is provided.

1 Introduction

The EPSRC¹ project *Evolutionary Algorithms for Dynamic Optimisation Problems: Design, Analysis and Applications* (EADOP for short) has been running for approximately 15 months (the project has a duration of 34 months; first day: 04.12.07). It is a joint collaboration between the University of Birmingham (UoB) and the University of Leicester (UoL). The project may be summarised as follows:

Evolutionary Algorithms (EAs) have been applied successfully to a wide range of stationary optimisation problems. Many real-world problems, however, possess numerous time-variant attributes that require the continuous adaptation of the proposed solution. These dynamic attributes pose many new challenges and in this project, we will concentrate on the design and analysis of novel EAs for such dynamic optimisation problems (DOPs). In particular, we will design, evaluate and analyse theoretically new EAs for DOPs in collaboration with researchers from Honda Research Institute Europe and adapt these algorithms to deal explicitly with dynamic telecommunication optimisation problems as supplied by BT plc.

The early stage of the project (first 6 months) has been devoted almost exclusively to background reading as well as an assessment of the state of the field. This knowledge was subsequently utilised to formulate some interesting and important research questions. Subsequent effort was directed at answering (partly) some of these questions, resulting in numerous publications at leading conferences and journals. In addition to written output, several talks and presentations have been given. Finally, numerous research projects are currently underway, as detailed in the remainder of this report.

¹Grants: EP/E058884/1 (01/12/08-30/11/10; Birmingham), EP/E060722/1 (Leicester).

2 People

The project has a small number of permanent members that are either officially associated with the grant or those working in close collaboration due to similar research interests. These members are:

- Xin Yao (Principle Investigator; UoB)
- Philipp Rohlfshagen (Research Fellow; UoB)
- Trung Thanh Nguyen (PhD Student; UoB)
- Shengxiang Yang (Principle Investigator; UoL)
- Hui Cheng (Research Fellow; UoL)
- Change Li (PhD Student; UoL)
- Kyriacos Souroullas (PhD Student; UoL)

In addition to the permanent staff, other researchers have contributed actively as visitors from abroad. These members are:

- Tapabrata Ray (Lecturer from Australia; September 2009-February 2009; UoB)
- Lining Xing (PhD Student from China; November 2007-November 2008; UoB)
- Hisashi Handa (Research Fellow; September 2008 - October 2008; UoB)
- Xin Yu (External PhD Student from USTC; UoB)
- Sadaf Naseem Jat (PhD Student; UoL)
- Shakeel Arshad (PhD Student; UoL)
- Imtiaz Ali Korejo (PhD Student; UoL)

Furthermore, Fernanda Minku (PhD student at UoB) has participated in some of the weekly meetings at UoB due to her interest in concept drift (machine learning) which bears some striking similarities to the concepts encountered in dynamic optimisation. Per Kristian Lehre (research fellow at UoB) has actively worked on a paper with Philipp Rohlfshagen on the runtime analysis of the $(1 + 1)$ -EA on simple dynamic functions. Finally, Hendrik Richter from HTWK Leipzig (Germany) visited Shengxiang Yang on August 1 to 24, 2008.

3 Achievements

Meetings at UoB are held on a weekly basis (with exceptions) to discuss progress, matters of interest, joint work and in an attempt to find answers to problems encountered during individual research. Similar meetings are held at UoL. There have been few actual (i.e., multiple co-authors) collaborations to date as the majority of input to other people's work is informal. Currently, however, the group is working on two joint journal papers as discussed in section 4.

3.1 Publications

Numerous papers have been submitted to leading conferences in the field as well as selected journals.

- P. Rohlfshagen and X. Yao (2008) Attributes of Dynamic Combinatorial Optimisation. Proceedings of the Seventh International Conference on Simulated Evolution And Learning, Lecture Notes in Computer Science, Volume 5361, Springer.
- P. Rohlfshagen and X. Yao (2009) The Dynamic Knapsack Problem Revisited: A New Benchmark Problem for Dynamic Combinatorial Optimisation. To appear in: 6th European Workshop on Evolutionary Algorithms in Stochastic and Dynamic Environments (EvoSTAR 2009).
- P. Rohlfshagen, P. K. Lehre and X. Yao (2009) Dynamic Evolutionary Optimisation: An Analysis of Frequency and Magnitude of Change. Submitted to GECCO 2009.
- P. Rohlfshagen and X. Yao (2009) Dynamic Combinatorial Optimisation Problems: An Analysis of Fitness Landscape Dynamics. Invited journal paper for Soft Computing.
- Isaacs, A., Ray, T. and Smith, W.(2009). Memetic Algorithm for Dynamic Multi-objective Optimization Problems. To appear in: IEEE Congress on Evolutionary Computation, CEC 2009.
- T. T. Nguyen and X. Yao (2009). Benchmarking and Solving Dynamic Constrained Problems. To appear in: IEEE Congress on Evolutionary Computation.
- H. K. Singh, A. Isaacs, T. T. Nguyen, T. Ray and X. Yao (2009). Performance of Infeasibility Driven Evolutionary Algorithm (IDEA) on Constrained Dynamic Single Objective Optimization Problems. To appear in: IEEE Congress on Evolutionary Computation CEC2009.
- T. T. Nguyen and X. Yao (2009). Dynamic Time-linkage Problem Revisited. To appear in: The 6th European Workshop on Evolutionary Algorithms in Stochastic and Dynamic Environments (EvoSTAR 2009).
- X. Yu, K. Tang, T. Chen, and X. Yao (2008) Empirical Analysis of Evolutionary Algorithms with Immigrants Schemes for Dynamic Optimization. Memetic Computing.
- X. Yu, K. Tang and X. Yao (2008) An Immigrants Scheme Based on Environmental Information for Genetic Algorithms in Changing Environments. Proceedings of the 2008 IEEE Congress on Evolutionary Computation, 1141-1147.
- S. Yang and X. Yao. Population-based incremental learning with associative memory for dynamic environments. IEEE Transactions on Evolutionary Computation, 12(5): 542-561, October 2008. IEEE Press.
- H. Wang, S. Yang, W. H. Ip, and D. Wang. Adaptive primal-dual genetic algorithms in dynamic environments. IEEE Transactions on Systems, Man, and Cybernetics Part B: Cybernetics, accepted in February, 2009. IEEE Press.
- H. Cheng, X. Wang, S. Yang, and M. Huang. A multipopulation parallel genetic simulated annealing based QoS routing and wavelength assignment integration algorithm for multicast in optical networks. Applied Soft Computing Journal, 9(2): 677-684, 2009.
- H. Wang, D. Wang, and S. Yang. A memetic algorithm with adaptive hill climbing strategy for dynamic optimization problems. Soft Computing, published on-

line first: 5 August 2008. Springer.

- H. Cheng, J. Cao, X. Wang, S. K. Das, and S. Yang. Stability-aware multi-metric clustering in mobile ad hoc networks with group mobility. *Wireless Communications and Mobile Computing*, published online first: 21 Apr 2008. John Wiley & Sons, Ltd.
- S. Yang and X. Yao. Population-based incremental learning with associative memory for dynamic environments. *IEEE Transactions on Evolutionary Computation*, 12(5): 542-562, October 2008. IEEE Press.
- S. Yang. Genetic algorithms with memory and elitism based immigrants in dynamic environments. *Evolutionary Computation*, 16(3): 385-416, Fall 2008. The MIT Press.
- R. Tinos and S. Yang. A self-organizing random immigrants genetic algorithm for dynamic optimization problems. *Genetic Programming and Evolvable Machines*, 8(3): 255-286, September 2007. Springer.
- S. Yang and R. Tinos. A hybrid immigrants scheme for genetic algorithms in dynamic environments. *International Journal of Automation and Computing*, 4(3): 243-254, July 2007. Springer.
- S. Yang and H. Richter. Hyper-learning for population-based incremental learning in dynamic environments. To appear in *Proceedings of the 2009 IEEE Congress on Evolutionary Computation*, 2009. IEEE Press.
- C. Li and S. Yang. A clustering particle swarm optimizer for dynamic optimization. To appear in *Proceedings of the 2009 IEEE Congress on Evolutionary Computation*, 2009. IEEE Press.
- H. Cheng and S. Yang. Genetic algorithms with elitism-based immigrants for dynamic shortest path problem in mobile ad hoc networks. To appear in *Proceedings of the 2009 IEEE Congress on Evolutionary Computation*, 2009. IEEE Press.
- L. Liu, D. Wang, and S. Yang. An immune system based genetic algorithm using permutation-based dualism for dynamic traveling salesman problems. *EvoWorkshops 2009: Applications of Evolutionary Computing*, LNCS 5484, pp. 724-733, 2009. Springer.
- C. Li and S. Yang. A generalized approach to construct benchmark problems for dynamic optimization. To appear in *Proceedings of the 7th Int. Conf. on Simulated Evolution and Learning*, 2008. Springer.
- C. Li and S. Yang. An island based hybrid evolutionary algorithm for optimization. To appear in *Proceedings of the 7th Int. Conf. on Simulated Evolution and Learning*, 2008. Springer.
- S. N. Jat and S. Yang. A memetic algorithm for the university course timetabling problem. To appear in *Proceedings of the 20th IEEE Int. Conf. on Tools with Artificial Intelligence*, 2008. IEEE Press.
- C. Li and S. Yang. Fast multi-swarm optimization for dynamic optimization problems. To appear in *Proceedings of the 4th International Conference on Natural Computation*, 2008. IEEE Press.
- H. Richter and S. Yang. Learning in abstract memory schemes for dynamic

optimization. To appear in Proceedings of the 4th International Conference on Natural Computation, 2008. IEEE Press.

- H. Cheng and S. Yang. A Genetic-inspired joint multicast routing and channel assignment algorithm in wireless mesh networks. Proceedings of the 2008 UK Workshop on Computational Intelligence, pp. 159-164, 2008.
- C. Li and S. Yang. An adaptive mutation operator for particle swarm optimization. Proceedings of the 2008 UK Workshop on Computational Intelligence, pp. 165-170, 2008.
- R. Tinos and S. Yang. Evolutionary programming with q-Gaussian mutation for dynamic optimization problems. Proceedings of the 2008 IEEE Congress on Evolutionary Computation, pp. 1823-1830, 2008. IEEE Press.
- Y. Yan, H. Wang, D. Wang, S. Yang, and D. Z. Wang. A multi-agent based evolutionary algorithm in non-stationary environments. Proceedings of the 2008 IEEE Congress on Evolutionary Computation, pp. 2972-2979, 2008. IEEE Press.
- S. Yang and R. Tinos. Hyper-selection in dynamic environments. Proceedings of the 2008 IEEE Congress on Evolutionary Computation, pp. 3184-3191, 2008. IEEE Press.
- H. Richter and S. Yang. Memory based on abstraction for dynamic fitness functions. In Applications of Evolutionary Computing, LNCS 4974 , pp. 597-606, 2008. Berlin: Springer-Verlag.
- L. Liu, D. Wang, and S. Yang. Compound particle swarm optimization in dynamic environments. In Applications of Evolutionary Computing, LNCS 4974, pp. 617-626, 2008. Berlin: Springer-Verlag.
- R. Tinos and S. Yang. Continuous dynamic problem generators for evolutionary algorithms. Proceedings of the 2007 IEEE Congress on Evolutionary Computation, pp. 236-243, 2007. IEEE Press.

A list of additional publications not related to dynamic optimisation are as follows:

- Ray, T. and Yao, X. (2009). A Cooperative Coevolutionary Algorithm with Correlation Based Adaptive Variable Partitioning. To appear in: IEEE Congress on Evolutionary Computation, CEC 2009.
- Li-Ning Xing, Ying-Wu Chen, Ke-Wei Yang (2008). A Novel Mutation Operator Based on the Immunity Operation. European Journal of Operational Research.
- Li-Ning Xing, Ying-Wu Chen, Ke-Wei Yang (2008). Multi-Population Interactive Coevolutionary Algorithm for Flexible Job Shop Scheduling Problems. Computational Optimization and Applications.
- Xing Li-Ning, Chen Ying-Wu (2008). Multi-objective Flexible Job Shop Schedule: Design and Evaluation by Simulation Modeling. Applied Soft Computing.
- H. Cheng, X. Wang, M. Huang, and S. Yang. A review of personal communications services. To appear in Proceedings of the 9th International Conference for Young Computer Scientists, 2008. IEEE Press.
- C. Ji, Y. Zhang, M. Tong, and S. Yang. Particle filter with swarm move for optimization. Proceedings of the 10th International Conference on Parallel Problem Solving from Nature, pp. 909-918, 2008. Springer.

- S. Yang, D. Wang, T. Chai, and G. Kendall. An improved constraint satisfaction adaptive neural network for job-shop scheduling. *Journal of Scheduling*, to appear, 2009. Springer.
- C. Li and S. Yang. An adaptive learning particle swarm optimizer for function optimization. To appear in *Proceedings of the 2009 IEEE Congress on Evolutionary Computation*, 2009. IEEE Press.
- R. Tinos and S. Yang. Self-adaptation of mutation distribution in evolutionary algorithms. *Proceedings of the 2007 IEEE Congress on Evolutionary Computation*, pp. 79-86, 2007. IEEE Press (DOI: 10.1109/CEC.2007.4424457).
- H. Cheng and S. Yang. Joint multicast routing and channel assignment in multiradio multichannel wireless mesh networks using simulated annealing. To appear in *Proceedings of the 7th Int. Conf. on Simulated Evolution and Learning*, 2008. Springer.

3.2 Software

- Software packages of general dynamic benchmark generator, clustering PSO algorithm, adaptive learning PSO algorithm, adaptive mutation operator
- joint multicast routing and channel assignment simulation, GAs for dynamic shortest path problem simulation

3.3 Other Activities

Trung Thanh Nguyen was actively involved in the design of the CEC 2009 benchmark competition for dynamic optimisation as part of the workshop on *Evolutionary Computation in Dynamic and Uncertain Environments* organised, amongst others, by Shengxiang Yang. In particular, this resulted in a technical report:

- C. Li, S. Yang, T. T. Nguyen, E. L. Yu, X. Yao, Y. Jin, H.-G. Beyer, and P. N. Suganthan. Benchmark generator for CEC 2009 competition on dynamic optimization. Technical Report 2008, Department of Computer Science, University of Leicester, U.K., 2008.

Philipp Rohlfshagen gave an invited talk at the University of Leicester (25.11.08) entitled *Dynamic Optimisation using Evolutionary Computation: An Introduction and Beyond*. He also gave an informal departmental talk at the University of Birmingham (29.01.08) entitled *Memory in Dynamic Optimisation* as well as a talk in the Natural Computation Seminar Series (20.06.08; University of Birmingham) entitled *Molecular Algorithms for Evolutionary Computation*. Also, for the first time, the taught course *Evolutionary Computation* (02411) and *Introduction to Evolutionary Computation* (12414) has included a lecture on dynamic optimisation (in addition to multi-population approaches). In addition to departmental talks, the following conferences have been attended:

- SEAL 2008: 15 minute presentation (Philipp Rohlfshagen)

and reviews have been carried out as a member of the program committee for the following conferences:

- CEC 2009: Evolutionary Computation in Dynamic and Uncertain Environments
- EvoSTAR 2009: 6th European Workshop on Evolutionary Algorithms in Stochastic and Dynamic Environments (EvoSTOC)

The project also holds joint project meetings every 3-4 months, alternating between the two universities. The details of the meetings held at the University of Birmingham are as follows:

- March 20, 2008: University of Birmingham (7 attendees)
 - Attendance:
 - * Xin Yao, Shengxiang Yang, Hui Cheng, Philipp Rohlfshagen, Trung Thanh Nguyen, Xing Lining, Changhe Li,
 - Agenda:
 - * 1030-1100: Meet and Greet
 - * 1100-1115: Philipp Rohlfshagen
 - * 1130-1145: Xing Lining
 - * 1200-1215: Trung Thanh Nguyen
 - * 1230-1330: Lunch top floor staff house
 - * 1345-1400: Hui Cheng
 - * 1415-1430: Changhe Li
 - * 1445-1500: Coffee break
 - * 1500-1515: Tapabrata Ray
 - * 1530-1545: Hisashi Handa
 - * 1600-1700: General discussion
 - * 1700-1715: Administrative issues
- 18 July 2008, University of Leicester (7 attendees)
 - Attendance:
 - * Xin Yao, Shengxiang Yang, Yaochu Jin, Philipp Rohlfshagen, Trung Thanh Nguyen, Hui Cheng, Changhe Li
- October 17, 2008: University of Birmingham (9 attendees)
 - Attendance:
 - * Xin Yao, Shengxiang Yang, Hui Cheng, Philipp Rohlfshagen, Tapabrata Ray, Trung Thanh Nguyen, Xing Lining, Changhe Li, Kyriacos Souroullas
 - Agenda:
 - * 1030-1100: Meet and Greet
 - * 1100-1115: Philipp Rohlfshagen
 - * 1130-1145: Xing Lining
 - * 1200-1215: Trung Thanh Nguyen
 - * 1230-1330: Lunch
 - * 1330-1345: Tapabrata Ray
 - * 1400-1410: Kyriacos Souroullas

- * 1415-1430: Changhe Li
- * 1445-1500: Hui Cheng
- * 1515-1530: Coffee break
- * 1530-1645: General discussion
- * 1645-1700: Administrative issues
- * 1700: Dinner
- 25 Feb 2009, University of Leicester (9 attendees)
 - Attendance:
 - * Xin Yao, Shengxiang Yang, Yaochu Jin, Philipp Rohlfshagen, Trung Thanh Nguyen, Hui Cheng, Changhe Li, Kyriacos Souroullas

Further activities (carried out from the UoL side) are as follows:

- Conference special sessions
 - Special Session on Evolutionary Computation in Dynamic and Uncertain Environments (ECiDUE09) for CEC-2009, Trondheim, Norway, 18-21 May, 2009.
- Competitions
 - Competition on Evolutionary Computation in Dynamic and Uncertain Environments for CEC-2009, Trondheim, Norway, 18-21 May, 2009.
- Journal special issues
 - Neri, F. and Yang, S. (guest-editors), Thematic Issue on Memetic Computing in the Presence of Uncertainties for the Journal of Memetic Computing, Springer, ongoing, to be published in 2010.

Finally, the following talks have also been given:

- Keynote speech, Evolutionary Computation for Dynamic Optimization Problems, at the 2008 International Symposium on Applied Computing and Computational Sciences (ACCS 2008), Hong Kong, China, August 1-3, 2008.
- Keynote speech, Evolutionary Computation in Dynamic Environments: Taking the Challenges, at the 2nd Int. Symp. on Intelligence Computation and Applications (ISICA 2007), Wuhan, China, September 21-23, 2007.
- Seminar talk, College of Information Science and Engineering, Northeastern University, China, 30 December, 2008.
- Seminar talk, Immigrants Schemes for Evolutionary Algorithms in Dynamic Environments, Centre for Computational Intelligence, School of Computing, De Montfort University, UK, 22nd November, 2007.
- Seminar talk, Evolutionary Computation in Dynamic Environments, Department of Industrial and Systems Engineering, Hong Kong Polytechnic University, Hong Kong, 5th October, 2007.

4 Past, Current and Future Work

The list of publications is a good reflection of past work. Numerous additional projects are currently underway (and not yet published) as detailed below. This section also outlines some topics we intend to consider in the near future.

4.1 Past and Current Work

At UoB, we are currently working on two joint publications that include all members of the Birmingham EADOP group. The first paper is a critical assessment of the field of dynamic evolutionary computation. In this paper, we attempt to identify shortcomings in current computational models (e.g., algorithms, benchmark problems) that we believe need to be addressed for the field to progress further. We review a representative range of real-world applications, existing benchmark problems, existing frameworks and definitions to identify overlap and gaps. We also intend to propose a much more extensive framework that may be used to unambiguously characterise work (e.g., dynamics, algorithms) in the dynamic domain.

The second paper we are working on regards a dynamic version of the capacitated arc routing problem (CARP) with special emphasis on winter gritting. Here the goal is to introduce a dynamic framework for the problem and an algorithm that guarantees good approximate solutions in very short periods of time. We consider a wide range of different dynamics that occur during the implementation of the solution to which the algorithm needs to react as quickly as possible. We also consider the two-objective problem where solution quality should be maximised without altering the existing solution too much.

A list of additional topics (in addition to those listed previously) we are currently working on is as follows:

- Runtime analysis of the $(1 + 1)^*$ -EA on composite functions (Philipp)
- Constrained combinatorial optimisation problems (Philipp)
- Dynamic constrained real-valued optimisation problems (Thanh)
- Time-linkage (Thanh)

4.2 Future Work

In the near future, we are planning to hold a one-day workshop on the (dynamic) CARP. The workshop is to be held under the *Bridging the Gap* scheme that attempts to bring together researchers from different disciplines as well as representatives from industry. Further details may be found in a separate document.

The following is a list of topics that we have identified as potentially interesting and which we intend to address in the near future:

- Statistical measures for dynamic problems (Thanh)
- Dynamic unconstrained optimisation (Thanh)
- Analytical work on memory in random dynamics (Philipp)
- Analytical work on simple population based GA in the dynamic domain (Philipp)

- Analytical/empirical work on crossover and mutation (Philipp)

5 Conclusions

The research group has addressed a wide range of topics in the field of dynamic optimisation with numerous publications at a wide range of conferences. The topics investigated may be summarised as follows:

- Critical assessment of the field of evolutionary dynamic optimisation (in progress)
- Review of real-world problems (in progress)
- Extensive frameworks/set of definitions for dynamic optimisation problems
- Time-linkage
- Benchmark generation (continuous and combinatorial domain)
- Constrained continuous optimisation
- Analysis of dynamics in the combinatorial domain
- Fitness landscape analysis in the combinatorial domain (subset sum problem)
- Dynamic capacitated arc routing problem (framework and algorithm)
- Runtime analysis of $(1 + 1)$ -EA of specially designed functions
- Analytical comparison of $(1 + 1)$ -EA and $(1 + 1)^*$ -EA