DeCoMo

Decision Support for Complex Multiobjective Optimization Problems

Final report

The DeCoMo project (1.1.2015-31.12.2017) was funded from the FiDiPro programme with the FiDiPro professor Yaochu Jin from the University of Surrey, UK.

The project had industrial partners Fingrid (with funding), Outotec (with funding), Valtra, Fortum Power and Heat, Simosol, DIMECC, Valmet Power and Honda Research Institute Europe.

As planned, we developed novel optimization methods for decision support in solving complex multiobjective optimization problems by combining modern evolutionary algorithms, machine learning techniques and multiple criteria decision making methods. In this, we incorporated preference information of a human decision maker. We focused on developing surrogate-assisted optimization techniques to handle computationally expensive problems having several objectives and constraints that are commonly seen in industry. The performance of the methods developed was verified with both benchmark problems and industry problems. The output of this project was a prototype of an intelligent decision support tool that can make advanced multiobjective optimization methods available for industry, thereby significantly enhancing the innovation capability and competitiveness of the Finnish industries and wider in society.

Overall, the project did meet its objectives very well.

Homepage (including additional information):
http://www.mit.jyu.fi/optgroup/decomo/decomo.html

Outcomes:

The following methods for multiobjective optimization were developed:

- K-RVEA (surrogate-assisted reference vector guided evolutionary algorithm for computationally expensive many-objective optimization)
- Constrained K-RVEA (K-RVEA which can handle constrained problems)
- K-RVEA incorporating a priori preference information (K-RVEA which does not aim at representing the whole set of Pareto optimal solutions but a part of it which represents the preference information provided by a decision maker)
- Interactive RVEA (incorporation of preference information provided by the decision maker in RVEA in an interactive fashion - RVEA does not include surrogates and, thus, is not directed at computationally expensive problems)
- Interactive K-RVEA (extension of a priori K-RVEA so that preference information is considered iteratively - this involves e.g. new challenges in surrogate management and
- flower-tree visualization tool to illustrate different high-dimensional solutions and their relationships.

According to the original plan, expertise of Prof. Jin and his group in evolutionary multiobjective optimization and machine learning was merged with the expertise of Prof. Miettinen and her group in decision support and interactive methods when developing the new methods and developing novel approaches for solving computationally expensive problems.

As a part of the project, the potential of extending the surrogate-assisted methods from simulation-based to data-driven problems was proven and this led, in part, in the profiling application of the University of Jyväskylä and, later, the establishment of the new thematic research field Decision Analytics utilizing Causal Models and Multiobjective Optimization (DEMO), http://www.jyu.fi/demo.

Publications

- Journal papers: 3 published/accepted, 2 submitted
- Conference papers: 7 published/accepted
- Conference talks: 17 (see http://www.mit.jyu.fi/optgroup/decomo/talks.html for details)
- Best student paper award in the 2017 IEEE Congress on Evolutionary Computation (CEC) conference
- In preparation: several manuscripts
- 1 PhD thesis

1. *T. Chugh, R. Allmendinger, V. Ojalehto, K. Miettinen,* Surrogate-assisted evolutionary biobjective optimization for objectives with non-uniform latencies, Proceedings of the Genetic and Evolutionary Computation Conference, ACM, 2018, to appear.
2. *T. Chugh, Y. Jin, K. Miettinen, J. Hakanen, K. Sindhya, A surrogate-assisted reference vector guided evolutionary algorithm for computationally expensive many-objective optimization, IEEE Transactions on Evolutionary Computation, 22(1), 129-142, 2018.*
3. *T. Chugh. Handling expensive multiobjective optimization problems with evolutionary algorithms. PhD thesis, 2017. Jyväskylä Studies in Computing 263.*
4. *T. Chugh, K. Sindhya, J. Hakanen and K. Miettinen. A survey on handling computationally expensive multiobjective optimization problems with evolutionary algorithms. Soft Computing, to appear, DOI: 10.1007/s00500-017-2965-0*
5. *T. Chugh, K. Sindhya, K. Miettinen, Y. Jin, T. Kratky and P. Makkonen. Surrogate-assisted evolutionary multiobjective shape optimization of an air intake system. In Proceedings of the 2017 IEEE Congress on Evolutionary Computation (CEC), IEEE, 1541-1548, 2017 (The article won the best student paper award in IEEE CEC 2017)*
6. *K. Sindhya and J. Hakanen. Interactive inverse modeling based multiobjective evolutionary algorithm, In Proceedings of the EUROGEN 2015, International Conference on Evolutionary and Deterministic Methods for Design Optimization and Control with Applications to Industrial and Societal Problems, Springer, to appear*
7. *T. Chugh, N. Chakraborti, K. Sindhya, and Y. Jin. A data-driven surrogate-assisted evolutionary algorithm applied to a many-objective blast furnace optimization problem, Materials and Manufacturing Processes, 32, 1172-1178, 2017*
8. *J. Hakanen and J. Knowles. On using decision maker preferences with ParEGO. In Proceedings of the 9th International Conference on Evolutionary Multi-Criterion Optimization, Springer, 282-297, 2017*
9. *J. Hakanen, T. Chugh, K. Sindhya, Y. Jin and K. Miettinen. Connections of reference vectors and different types of preference information in interactive multiobjective evolutionary algorithms , in Proceedings of the IEEE Symposium Series on Computational Intelligence (IEEE SSCI 2016)", IEEE, 1-8, 2016*
10. *T. Chugh, K. Sindhya, K. Miettinen, J. Hakanen and Y. Jin. On constraint handling in surrogate-assisted evolutionary many-objective optimization , in Proceedings of the 14th International Conference on Parallel Problem Solving from Nature, Edinburg, UK, Springer, 214-224, 2016*

11. *T. Chugh, K. Sindhya, J. Hakanen, K. Miettinen. An interactive simple indicator-based evolutionary algorithm (I-SIBEA) for multiobjective optimization problems. In Proceedings of the Evolutionary Multi-Criterion Optimization (EMO), Springer, 277-291, 2015.*

Mobility

- Prof. Jin in Jyväskylä, 12 months in total
- Outgoing from Jyväskylä: Tinkle Chugh, Jussi Hakanen, Karthik Sindhya in total ~ 9 months
- Incoming to Jyväskylä: 9 people (Prof. Nirupam Chakraborti, IIT Kharagpur, Prof. Joshua Knowles, Univ. of Birmingham, Dr. Richard Allmendinger, Univ. of Manchester, Dr. Tomas Kratky, Sigma, Dr. Chaoli Sun, Univ. of Surrey, Dr. Handing Wang, Univ. of Surrey, Ran Cheng, Univ. of Surrey, Guo Yu, Univ. of Surrey, Ahsanul Habib, University of New South Wales) in total ~ 4 months

Case studies

Two companies involved provided cases to be considered.

Valtra - which led to a conference publication (received the best student paper award) and a submitted journal publication. We managed to model a complicated optimal shape design problem as a simulation-based and computationally expensive problem (and documented the challenges in modelling) with multiple objectives, showed how different pieces of simulation software can be connected to optimization and managed to find better solutions than the baseline solution with the K-RVEA method developed in the project.

One company was also willing to provide a case but the modelling (to be conducted elsewhere) was delayed and, thus, the case did not lead to optimization. In addition, another company showed special interest. Furthermore, one company has expressed interest in the software developed.

To gain more experiences with the methods, cases of visiting researchers were studied as well besides various benchmark problems. Among them, a pump design case from Dr. Kratky (paper in preparation) and steel factory data from Prof. Chakraborti (a paper has already been published on this). Furthermore, a joint research on problems involving objective functions of different latencies has been started with Dr. Allmendinger (a conference paper on this has been accepted).

Workshops

As planned, two workshops were organized. The second workshop (sharing findings of the project) entitled *Artificial Intelligence Supported Decision Making in Industry* attracted over 30 participants last autumn and very positive feedback was given. In the workshop, we disseminated information about the topic of the project and the potential of the findings and methods.

Also the companies involved in the project learned a lot and found many potential applications for the methods and approaches developed to be returned to in the future.

Summary

In the project, it was shown that there are many needs in companies related to dealing with computationally expensive or data-driven problems with conflicting objectives and the awareness of the potential of methods increased. Furthermore, the usefulness of the methods was demonstrated with various cases.

Finally, we summarize comments from the steering group members discussed in the last steering group meetings on **Exploitation, dissemination and networking**

a) *What potential customers' needs can results fulfil? What problems can be solved? What are concrete benefits for them? Are they satisfied with project outcomes?*
Needs of a company can be met through the proof-of-concept study. From the perspective of a company, the surrogate-assisted topics are very interesting and tests during a research visit appreciated. The surrogate-assisted method was regarded applicable to the cases of another company as well. For some other company, it was a bit early to comment since their case was not ready to be considered during the project and needed to be simplified. But the learning experience was regarded good and, at best, good decision support tools can help in getting better results.
A new PhD student will continue working with the themes with one of the steering group members and he was very optimistic for the future. Furthermore, the data-driven decision support approaches were regarded interesting and more such cases are likely to come up.
(That line of research will continue in the new thematic research field of the University of Jyväskylä called Decision Analytics utilizing Causal Models and Multiobjective Optimization.)

b) *How well has the project succeeded in building its national and international networks*
The steering Group agreed that networking (both national and international) during the project has succeeded very well, one example being the excellent people involved, including national and international audience and speakers in the workshop in September. Mobility has been active, papers have reached international audiences and awards have been received.

Utilization of new knowledge and expertise created in the project

a) *How to exploit the expertise and knowledge generated and documented in the project?* Person A: Expertise and knowledge can be exploited by further co-operation between parties. The methods developed in the project and earlier are suitable for many types of problems and one of the greatest difficulties in applying them is simply the lack of understanding in industry on these methods, but this has been improved by the workshop held in the project. Person B: The K-RVEA method can be utilized in industrial optimization problems. The software prototype can be improved further to create a product. Person C: If possible, we will try to apply the developed prototype in one of our case study related to the power system planning. We also invite experts (researchers who developed their knowledge during this project) to our development workshop related to the automatization of power system control room in the spring 2018. Person D: My action from this project has now arrived as I will have a new PhD student and link our tools to the tools developed in this project. So, on the one hand we will advance our tool, but on the other hand we will use multiobjective optimisation to evaluate process and system flowsheets to optimize many objectives in view of circular economy.

b) *Utilization of results e.g. in enterprise development projects*.
Person A: Two main possibilities currently seem promising to his company. The use of the optimization tools to optimize concrete structures and to optimize the parameters of simulation to match the reference plant. Person B: The results of the ventilation channel test case may be utilized in the future HVAC system design.

c) *External communications in the final phase and after the project*.
Person A: The project provided the participants with both results as well as an understandable executive summary on the possibilities. Person B: Working with the tools of Kaisa Miettinen's group as well with her input I am sure we will be able to advance multiobjectve environmental footprint optimization. This would be in my opinion an excellent avenue to show the importance of the tools of this project. I would be happy to contribute through my PhD student and Kaisa's input to this endeavour.

d) *Utilization of project results in education and expert / professional services.*
Person A: The methods developed in the project, especially the ones where decision maker's preferences are used in the optimization are usable in professional services. More details on which products and services will require further analysis internally. Person B: Software prototype can be used in educational purposes. Person C: Not directly applicable for his company. Person D: Personally, I teach simulation based footprinting of systems, plants, reactors (not just carbon footprint but a wide range of indicators, exergy, thermoeconomics, etc.). It would be great to integrate Kaisa Miettinen's tools into this in this. That would enable great playing around with different solutions, scenarios etc. all based on rigorous process and system simulation.