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Abstract: Recently, the first Workshop on Theoretical Aspects of Evolutionary Multiobjective Optimization (EMO) has been taking place on July 8, 2010 in Portland, OR, USA, co-located with the Genetic and Evolutionary Computation Conference (GECCO). Besides a brief presentation of the workshop talks, we mainly focus here on summarizing the results of the discussions. In particular, we present a list of open problems that has been compiled before and during the workshop by the participants. We hope that this overview of the latest forefront of theoretical research in the field of EMO will inspire future work and foster collaborations among the members of the EMO community.

Key-words: evolutionary multiobjective optimization, theory

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1 Background

The development of theoretical results in the field of Evolutionary Multiobjective Optimization (EMO) is still lagging behind the vast amount of experimental studies and the development of stochastic algorithms for multiobjective optimization problems. However, the recent years have seen an increase in theoretical studies with several diverse topics, see for example [1] for an overview. To bundle the efforts towards more theoretical studies within the EMO field, the Genetic and Evolutionary Computation Conference (GECCO) hosted the First Workshop on Theoretical Aspects of EMO during its 2010 edition. The main objectives of the workshop were: (1) communicating recent research results by talks of the participants, and (2) discussions among theoreticians and practitioners about future developments and open problems of the field. Hereby, we give a summary of the given talks and a conclusion about the discussions and the workshop outcome in terms of a list of open problems.

2 The Workshop

The workshop took place together with GECCO 2010 on July 8, 2010 and was planned as a half-day workshop with two equally long sessions. The workshop was embedded within a full day of EMO: After the tutorial on *Foundations of Evolutionary Multi-Objective Optimization* by Tobias Friedrich and Frank Neumann and the tutorial entitled *Evolutionary Multi-Criterion Optimization* by Kalyanmoy Deb, the workshop on Theoretical Aspects of EMO took place in the two afternoon slots. Both sessions contained three talks and a following discussion each. The talks had been scheduled to last only 20 minutes in order to allow for a lively discussion and enough time for questions. Interestingly, the attendance was changing drastically between the two sessions. Where the first session was well-attended (with approximately 30-40 people), the second session only saw between 5 and 10 attendees in addition to the speakers. From our perspective, these figures show that the topic was interesting but in addition, a full day with EMO topics might be too long. Maybe, the drop in attendees was amplified by another interesting workshop at the same time.

3 Overview of Workshop Papers

We received 6 submissions from 7 research groups with authors from 6 countries (Belgium, France, Germany, Mexico, the Netherlands, and Portugal). The workshop organizers reviewed all contributions and evaluated them as worth to be presented at the workshop and—after revision—to be published as workshop papers in the GECCO companion [3, 4, 5, 6, 8, 9]. All slides of the talks are available online on the workshop web page `http://taemo.gforge.inria.fr/program.php`. We give the papers' abstracts in the order of the workshop's schedule.

Adriana Lara, Oliver Schütze, Carlos A. Coello Coello
New Challenges for Memetic Algorithms on Continuous Multi-objective Problems

This work presents the main aspects to tackle when designing memetic algorithms using gradient-based local searchers. We address the main drawbacks and advantages of this coupling, when focusing on the efficiency of the local search stage. We conclude with some guidelines and draw further research paths in these topics.

Ilya Loshchilov, Marc Schoenauer, Michèle Sebag
A Pareto-Compliant Surrogate Approach for Multiobjective Optimization

This paper discusses the idea of using a single Pareto-compliant surrogate model for multiobjective optimization. While most surrogate approaches to multi-objective optimization build a surrogate model for each objective, the recently proposed mono surrogate approach by the authors aims at building a global surrogate model defined on the decision space and tightly characterizing the current Pareto set and the dominated region, in order to speed up the evolution progress toward the true Pareto set. This surrogate model is specified by combining a One-class Support Vector Machine (SVMs) to characterize the dominated points, and a Regression SVM to clamp the Pareto front on a single value. The aims of this paper are to identify issues of the proposed approach demanding further study and to raise the question of how to efficiently incorporate quality indicators, such as the hypervolume into the surrogate model.

Thomas Voß, Tobias Friedrich, Karl Bringmann, Christian Igel
Scaling Up Indicator-based MOEAs by Approximating the Least Hypervolume Contributor: A Preliminary Study

Recently, a Monte-Carlo algorithm for approximately determining the least hypervolume contributor of a given Pareto-front approximation has been presented in (Bringmann and Friedrich 2009). We hypothesize that using this approximation instead of the exact contributing hypervolume will make the EMOAs relying on the contributing hypervolume applicable to problems with many objectives and that the resulting algorithms will push the boundaries of today's EMOAs for many-objective optimization. In this study, we employ the approximation within the steady-state MO-CMA-ES (termed $(\mu + 1)$-MO-CMA-ES and using the recent improvements presented in (Voß et al. 2010)) and the SMS-EMOA to empirically investigate whether the Monte-Carlo approximation is indeed useful in practice.

Oliver Schütze, Xavier Equivel, Adriana Lara, Carlos A. Coello Coello
Some Comments on GD and IGD and Relations to the Hausdorff Distance

When measuring distances between different objects such as different sets the use of metrics has been well established in literature. We investigate here two widely used indicators for the evaluation of Multi-objective Evolutionary Algorithms, the Generational Distance (GD) and the Inverted Generational Distance (IGD), with respect to the properties of a metric. Since the outcome is quite poor, we propose further on a new indicator which is made up of GD and IGD. The novel indicator can be viewed as an "averaged" version of the Hausdorff distance and forms a quasi-metric under certain assumptions.

Manuel López-Ibáñez, Thomas Stützle, Luís Paquete
Graphical Tools for the Analysis of Bi-objective Optimization Algorithms

An approach to the quality assessment of multi-objective SLS algorithms derives from the concept of attainment function. The attainment function extends the scalar concepts of mean and variance to random sets. The attainment function theory may completely characterize the statistical distribution of solutions in the objective space in terms of location, spread and mutual dependence. Moreover, statistical testing and inference are possible. However, the use of attainment functions is still rather limited in practice. We present here two practical applications of the first-order attainment function for analysing the output of SLS algorithms for biobjective optimization problems. Programs implementing the techniques presented here are also available. Later, we discuss what would be necessary to extend this work for more than two objectives and for other types of analysis.

Michael Emmerich, André Deutz, Johannes Kruisselbrink, Rui Li
Getting Lost or Getting Trapped: On the Effect of Moves to Incomparable Points in Multiobjective Hillclimbing

Divergent behavior may occur in elitist multiobjective EAs which allow moves to incomparable solutions. We study under which conditions this is exhibited. For simple model landscapes stochastic dynamics are studied and quantified by means of Markov chains. The studies suggest that increasing the population size tempers divergent behavior. In addition, we study whether common elitist algorithms such as NSGA-II and SMS-EMOA have divergent behavior.

4 Summary of Discussions

One result of the workshops' discussions is a list of open problems which is given in the next section. Besides that, two main topics have been discussed: organizational issues and the relation to practitioners in EMO.

Organizational Issues

- The participants agreed that this workshop shall take place regularly as a series. However, the workshop shall be co-located with a conference as the community is currently too small for a self-contained event.

- Regarding this co-location, the argument was raised that it seems to be better to continue the co-location with GECCO in comparison with, e.g., the ThRaSH workshop[1] because ThRaSH seems to be more Europe-based than GECCO; like that, also America-based and maybe even Asia-based research groups can be motivated to participate (as this was the case already this year).

- The amount of discussion and the talk lengths of the workshop were seen as appropriate. It was even the case that one participant raised the question why not the entire GECCO conference could change to this rather interactive style.

What do practitioners need?

- A very general question that was raised was *What are the constants in results with $\mathcal{O}$-notation?* A question, theoreticians should be aware of in any kind of study.

- More specific to EMO, the question was asked how (limit) results regarding the number of objectives relate to practical optimization scenarios. In other words, can we give some (hard) results for a fixed number of objectives, e.g., in terms of the runtime of the hypervolume approximation algorithm used by Voß et al. [9]?

- Another question highly related to EMO but to the best of our knowledge not much tackled from a theoretical point-of-view was how theoretical results can relate to decision making. Although very general, this fundamental question might rise more interesting concrete research questions in the future and should be mentioned here. For more details on that topic from a practical viewpoint, we refer to the recent overview by Miettinen et al. [7].

What do theoreticians need to serve practitioners?

- Last, Thomas Voß asked the (rhetorical) question, what we theoreticians want from practitioners—a question that unfortunately remains unanswered after the workshop. Nevertheless, we should think about it in the future when writing our papers in order to attract practitioners to read theoretical papers and employ the proven results in practice.

5 List of Open Problems

We asked certain colleagues[2] beforehand and especially the workshop participants themselves to mention interesting open research questions that, according

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[1]http://trsh2010.gforge.inria.fr/
[2]Many thanks to Joshua Knowles, Jörn Mehnen, and Carlo Poloni for their contributions.

to their opinion, shall be addressed in the future. We report and emphasize these ideas here briefly. For the following problems, we see a need for more effective methods from a practical point of view, as well as the need for fundamental theory as a guideline and support for the design and a better understanding of sophisticated methods.

- Efficient multi-objective meta-modeling

- EMO algorithms for dynamic real world applications

- Alternatives to the Pareto-dominance criterion (maybe by different cone types, order relations): less precise but faster, supporting many-objectives, robust against noise, easy to interpret for users.

- Which algorithm properties should/could be tested quickly, e.g., with an open-source software framework, in order to identify the quality of algorithms? Such a widely accepted standard for performance assessment is likely to be useful in particular when a paper with yet another algorithm that is supposedly better than all other algorithms known to the world has to be reviewed.

- How does complexity grow with an increasing number of objectives and how do we face these difficulties (with respect to both search and decision making)? Can we figure out a strategy to *navigate* through the many-objectives space while having an *estimate* of what we neglect?

- Explore and exploit connections to theory on decision making for interactive algorithms.

- Most EMO theory takes a microscopic approach. There may be potential in macroscopic views as considered for theory on single-objective evolutionary algorithms, like, e.g., statistical physics.

- Can we apply *adversaries* to the study of archivers/elitism to obtain useful worst-case results? Can we show a link to or extend the Free Lunch results of Corne and Knowles [2]?

- Worst-case results are quite easy for theoreticians to obtain but might not be relevant for practicioners as the worst-case is often described by unrealistic problem instances. Hence, it is desirable to have a clearer picture which algorithms are suitable for which problem instances. A first step could be a theoretical worst-case analyses combined with experimental studies which demonstrate (positive or negative) performance regarding "typical" instances.

- Transferring results from single-objective theory to the multiobjective case may reach advances.

6 Perspectives

To conclude, the workshop on Theoretical Aspects of Evolutionary Multiobjective Optimization has seen six presentations of state-of-the-art theoretical

studies in the EMO field. Although the attendance between the two sessions was mixed and we do not know the reason for that, the first workshop of its kind can be seen as a (small) success. The format with enough time for questions and discussions has been appreciated and the overall response was positive. Unfortunately, the discusssion rounds have not been as lively as expected but we have to keep in mind the competition among researchers and the fact that not everybody wants to talk about unpublished results and ongoing work. In the light of these statements, it has to be discussed whether this workshop will/should take place again at next year's GECCO and whether the format should be kept.

Last, let us note that your comments and remarks are highly welcome. You can contact us at any time via the e-mail addresses mentioned on the first page.

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