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学位論文題目
Improvements in understanding and performance of multi-objective differential evolution
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論文内容の要旨

Many optimization problems are formulated using more than one objective function. In the overwhelming majority of cases, the solution of a multi-objective problem is not a single element, but a set of solutions that can be no longer improved upon in all objectives simultaneously. Evolutionary algorithms are a naturally good tool to solve such problems, since they generate many solutions in one run. Differential evolution (DE) is one of the most simple and powerful evolutionary algorithms and its application to multi-objective optimization arises naturally. However, DE was originally developed for single-objective optimization and its generalization to the multi-objective model is not trivial.

The need to have a simple, powerful optimizer capable of solving continuous multi-objective problems has led many researchers to develop various versions of multi-objective DE. This rapid innovation happened without answering many outstanding questions, while introducing new ones. The first goal of this thesis is to answer some of these questions. In particular, we concentrate on the questions arising in parameter setting of multi-objective differential evolution. We investigate the relationships between the DE parameters and its performance as well as analyze the existing mechanisms to set the parameters automatically.

The next issue that arises with the transition to the multi-objective realm is the increased computational cost. Each solution now has a vector of objective function values and the mutual relationships of these vectors need to be tracked. This leads to several computational geometric problems. The reduction of computational cost of these problems is the second goal of this thesis.

In the first part, we concentrate on the first goal, that is improving our understanding of how DE works on multi-objective optimization problems. In single-objective DE it has been shown that the success of DE is highly affected by the right choice of its mutation and crossover parameters. Unfortunately, in multi-objective optimization the influence of these parameters on the performance of the algorithm is a poorly understood subject. Many authors use parameters which do not render the algorithm invariant with respect to rotation of the coordinate axes. This is a possible vulnerability, since the success of their algorithms may be caused by a hidden feature of the optimization problem and may be lost by simply rotating the coordinate axes of the problem. First, we try to see if such choice of parameters can bring consistently good performance under various rotations of the problem. We do this by extensive experimentation, using a large number of parameter combinations generated on a grid, with systematically rotated benchmark problems. We find that our results are consistent with the single-objective theory, but only for unimodal problems. On multi-modal problems, unexpectedly, parameter settings which do not render the algorithm rotationally invariant have a consistently good performance for all studied rotations.

To mitigate the problem of parameter setting, methods have been developed to automatically adjust the parameters. These methods are usually presented as a part of a unified algorithm and since these algorithms vary in other aspects than the parameter control mechanism, it is difficult to compare them and to evaluate their viability in the multi-objective environment. We go through various deterministic, adaptive, and self-adaptive approaches to parameter setting, isolate the underlying parameter control mechanisms and apply them to a single simple differential evolution algorithm. We then observe its performance and behavior on a set of benchmark problems. We find that even very simple parameter control mechanisms can compete with parameter settings

found by exhaustive grid search. We also notice that self-adaptive mechanisms seem to perform better on problems which can be optimized with a very limited set of parameters. Adaptive methods on the other hand encounter significant difficulties and seem to behave similarly on each benchmark problem. This is a significant vulnerability and it should be explored in more depth.

In the second part of the thesis, we address the second goal, that is the computational cost reduction. We are concerned with non-dominated sorting, archiving, and diversity estimation procedures. We propose a special data structure, called the M-front, to hold the best found (non-dominated) individuals. The M-front uses the geometric and algebraic properties of the Pareto dominance relation to convert orthogonal range queries into interval queries using a mechanism based on the nearest neighbor search. These interval queries are answered using dynamically sorted linked lists. The M-front can serve either to reduce the cost of non-dominated sorting, to reduce the cost of diversity estimation or as a fast archive. Experimental results show that our method can perform significantly faster than the state of the art algorithm for non-dominated sorting, with the added benefit of keeping track of all the non-dominated individuals all times. We conclude our thesis with a summary of our contributions and by outlining promising directions for future work.