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Sensitivity Analysis in Systematic and Representative Benchmarking of Optimization Algorithm Performance

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Introduction

Besides the conventional and established applications of sensitivity analysis in the field of optimization [1], sensitivity analysis-based approaches can also be used in research on systematic performance analysis of meta-heuristic optimization algorithms, and the construction of synthetic industrially relevant benchmark problems.

The No Free Lunch Theorems for search and optimization [2] imply that there is no universal best algorithm for all problem types. The challenges in the field of non-convex optimization are thus moving towards the quests to identify and develop efficient algorithms for particular problem types. Industrially relevant product and process engineering problems often involve computationally expensive, highly non-linear, non-convex simulation responses. The industrial problems for which performance matters the most, are also those for which it is the most difficult to identify and develop efficient optimization approaches. Therefore often artificial test functions and benchmark problems are used in the optimization community. For most of the commonly used artificial benchmark problems for meta-heuristic optimization algorithms, it is, however, difficult to relate relative algorithm performance on one artificial problem, to any real-world problems, simulation-based problems or other artificial benchmark problems. In order to increase the value of such benchmarks from a set of many isolated statistical tests to scientific tests with some generalization value, benchmark functions with a more systematic structure are required. Various forms of variable screening and sensitivity analysis [3] can aid the construction of such improved benchmark problems [4]. Besides more systematic comparative assessments of optimization algorithms, it is also important to find ways to relate algorithm performance on artificial benchmark tests to real-world and industrial optimization problems [5]. Also, here, sensitivity analysis could aid to characterize the response behavior of real-world and simulation-based problems in order to match the problem features with particular synthetic benchmarks. By means of academic examples as well as industrial case studies, we demonstrate innovative approaches which set steps towards systematic and representative benchmarking and empirical optimization algorithm performance analysis.

Characterization of Optimization Problems (Summary)

A first step towards obtaining generalizable information from optimization benchmarks is to answer questions such as: What will happen to the optimization algorithm performance when a characteristic feature of the benchmark problem would be changed? Problem changes of practical interest could for example involve modifications of the problem dimension, the distribution of the first and higher order sensitivity indices of the model output w.r.t the model input, the smoothness of the objective function, or its multi-modality.

To investigate the answers to questions of the previously stated kind, benchmark functions parameterized w.r.t several function features were developed. By means of such parameterized test problems, the performance of meta-heuristic algorithms is systematically investigated, showing clear trends and generalizable quantitative performance characteristics of optimization algorithms w.r.t. particular problem features.

Most multidisciplinary engineering optimization problems are not only composed of an objective function but also contain one or more constraints. The objective and all the constraint functions can be dependent on the results of several computationally expensive simulations with non-linear responses. Not only the structure of the individual simulation responses is important for the performance of optimization algorithms, but also the structure and dependencies between the

simulation responses. Design variables which are important for the objective function, are not necessarily also those variables which are important for those of the non-linear constraints. In order to develop synthetic benchmark problems which are representative for particular real-world or industrial problems, it is necessary to be able to construct benchmark problems with similar response structures, and similar relations between the objective and constraints.

To address this challenge, various forms of sensitivity analysis could be used to characterize the structure of the real-world and industrially relevant optimization problems. These characteristics could then be used to construct computationally affordable benchmark functions, on which the performance of different algorithms and algorithm settings can be investigated. Such an approach could be used to select efficient algorithms for particular optimization problems, and to tune or optimize the optimization algorithm parameters to problems with particular features. An approach along the lines of these ideas has been developed and tested on a relatively complex industrial engineering problem, namely the optimization of car body structures involving crashworthiness, vibrational comfort, and weight requirements.

Discussion and Outlook

Although the results of the presented ideas and approaches are promising, the area of research of using sensitivity analysis methods for systematic insight into optimization algorithm performance is still very young, and not widespread. There is much potential for improvement, and there are still many open challenges: Which variable screening and or sensitivity analysis methods are the most suitable for such applications? How to effectively balance the trade-off between function evaluation cost and the nature and quality of the obtained sensitivity measures? Also, from the computational simulation perspective, various approaches to increase the efficiency of the response characterization need to be investigated [6]. Sensitivity analysis-based approaches can contribute towards systematic optimization algorithm assessments, with more generalizable results. They also seem an essential ingredient to extricate the problem of matching and developing efficient algorithms for complex computationally expensive industrial optimization problems.

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