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Bayes approach to solving T.E.A.M. benchmark problems 22 and 25 and its comparison with other optimization techniques

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A B S T R A C T

The Bayes approach is used for solution of benchmark problems 22 and 25. The main purpose of the paper is to evaluate its applicability for solving complex technical problems (up to now, this technique was only very rarely used in the domain of such tasks). The parameters of this approach are compared with characteristics of several other heuristic and deterministic optimization techniques implemented in commercial code COMSOL Multiphysics and own open-source application Agros Suite. The results confirm that the Bayes approach is superior in a number of aspects and for the solution of real-life tasks it represents a powerful and prospective alternative to existing optimization methods

1. Introduction

Nowadays, optimization techniques represent a very important and desired tool in the domain of designing particular elements or even complex systems in many (and not only) technical branches [1,2]. Optimization is expected to improve their parameters, characteristics and other properties, bring savings in production costs, increase of their efficiency, safety, and so forth. In the last five decades, a great number of both deterministic and heuristic algorithms have been suggested and successfully applied in solution of various problems, as far as these problems were not too much complicated [3]. Anyway, it is known that the time necessary for finding the optimum strongly increases with the number of parameters to be optimized, which is even more expressed in nonlinear or multiphysics problems. Other complications may occur in defining the objective functions and their eventual weighting.

Despite of availability of up to now developed advanced optimization techniques, the solution of complex optimization problems is still rather slow. This is related with searching the sample space in case of the heuristic algorithms or slow convergence of the deterministic algorithms. Another danger consists in the possibility that the algorithm stops at some local extreme instead of the global one. That is why all over the world further efficient techniques are permanently proposed and explored.

Many of the above techniques are also used for solving complex technical problems. But their reliability and speed may strongly differ from one another, which depends on the type of the task solved. The most prospective and versatile algorithms with a wide spectrum of applicability were also implemented into existing professional codes. Nevertheless, the development in the area is not yet finished from far, which is confirmed by a great number of relevant recent papers and books.

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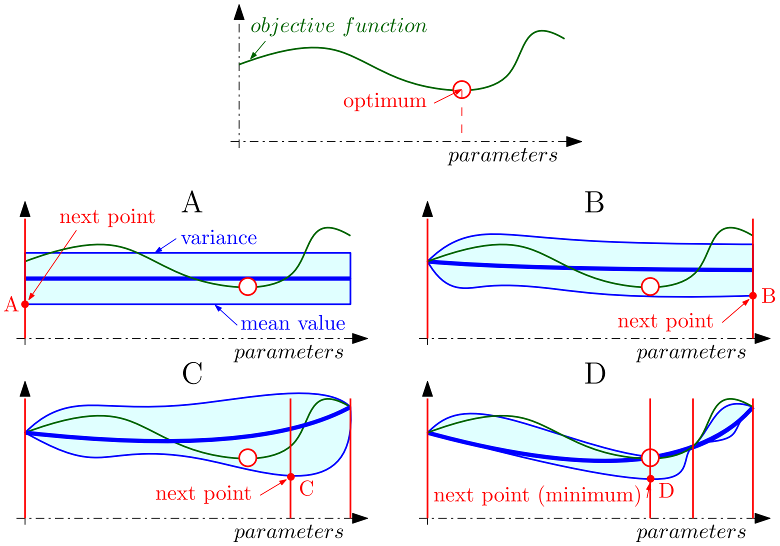

Fig. 1. Bayesian optimization.

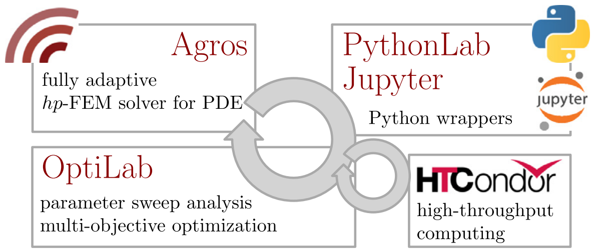

Fig. 2. Agros Suite.

The Bayes optimization technique is not new [4], but due to its implementation complexity it was used rather for solving some artificial mathematical problems defined on simple domains (such as unit squares, circles, etc.) [5,6]. As it has not been implemented in any professional FEM-based code so far, the authors built its algorithms to their own application Agros Suite with the aim to carry out a number of tests and then to optimize several tasks whose results are known. The choice fell on two T.E.A.M. benchmarks 22 and 25. The details of the work are described in the following sections.

2. Benchmark problems 22 and 25

The first solved example, *T.E.A.M. benchmark problem 22* [7–9] is an interesting optimization problem of electromagnetic design, which deals with the optimization of a superconducting magnetic energy storage (SMES) configuration, see Fig. 3. It can be formulated as a multiobjective problem [10] with two objectives:

- to minimize the stray field evaluated along lines (Fig. 3), while not violating the quench condition assuring the superconductivity state,
- to minimize the deviation from the prescribed value for the stored energy [11].

The multiobjective problems can be treated (mapped) as a constrained mono-objective tasks [12] using, for example, the weighted sum of the particular objectives. Of course, this method can limit the search number of the promising alternatives. Nevertheless, in this work, the problem 22 has been analyzed as a mono-objective problem.

The second selected problem *T.E.A.M. Workshop Problem 25 – The Optimization of Die Press Model* [13] has been considered as a 2-D non-linear benchmark for testing various types of numerical algorithms [14–16]. It is the numerical optimization of the shape of a die press, which is used to produce anisotropic permanent magnets (Fig. 9). It can be, as the previous example, analysed as a multiobjective problem [17] or as a mono-objective problem [18]. The interesting peculiarity of this problem is that the objective function is very flat around the global minimum, so that it can be a very sensitive to the selected kind of the optimization method (approximation etc.)

To prepare a control set of results of the both selected benchmark problems 22 and 25, the commercial software package *COMSOL Multiphysics* with the *COMSOL Optimization Module* has been used.

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