On Development of a New Approach for EA Acceleration in Chosen Large Optimization Problems of Mechanics

Janusz Orkisz
Cracow University of Technology
24 Warszawska St.
31-155 Cracow, Poland
+48 126282560
plorkisz@cyf-kr.edu.pl

Maciej Glowacki
Cracow University of Technology
24 Warszawska St.
31-155 Cracow, Poland
+48 126282569
mglowac@gmail.com

ABSTRACT
In this paper we briefly discuss new advances in development of an efficient approach based on Evolutionary Algorithms (EA) for solving a wide class of large, non-linear, constrained optimization problems. Two important applications to engineering mechanics are intended, namely residual stress analysis in railroad rails, and vehicle wheels, as well as a wide class of problems resulting from the Physically Based Approximation of experimental data. However, the primary objective of our long-term research is to obtain significant acceleration of the EA applied to large optimization problems, and to provide ability to solve problems when the standard EA fail. The efficiency of new speed-up techniques proposed was examined using several simple but demanding benchmark problems of computational mechanics. Results obtained so far indicate possibility of practical application of the new approach to real large engineering problems.

Keywords
Evolutionary Algorithms; speed-up techniques; Engineering Mechanics; Empirical study.

1. INTRODUCTION
New advances in development of several speed-up techniques for Evolutionary Algorithms (EA) are considered in this paper. It is a continuation of our long-term research focused on development of highly efficient approach based on Evolutionary Algorithms (EA) for solving large, non-linear constrained optimization problems [3]. Numerous important real-world problems can be formulated in such general way. In this research engineering applications of our EA approach are planned, i.e. residual stress analysis in railroad rails, and vehicle wheels [4,6], as well as a wide class of problems resulting from the Physically Based Approximation (PBA) of experimental and/or numerical data [4]. The PBA is a powerful approach for smoothing of experimental data obtained by any measurement system. It allows for simultaneous use of the whole experimental, theoretical, and heuristic knowledge of analyzed problems. This approach was successfully used, e.g., for reconstruction of residual stresses based on various measurements, such as strain gauge technique or neutronography [4]. Currently it is also applied in electrical engineering to develop the on-line monitoring system optimizing the transmission of electrical energy in overhead power lines. The PBA may be applied for smoothing of discrete data obtained from any rough numerical solution of any boundary value problem as well.

Problems mentioned above are very demanding and need application of efficient algorithms. Therefore, this research is oriented, first of all, on significant efficiency increase of the EA solution approach considered, including development of new algorithms, as well as improvements of certain existing ones. We have already proposed several general speed-up concepts [3]. Presented is here a brief overview of the proposed techniques, including both a progress in their development, and several new ideas as well.

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2. GENERAL PROBLEM FORMULATION
In the analyzed wide class of large, non-linear, constrained optimization problems, a function $u(\mathbf{x})$, $\mathbf{x} \in R^N$, given in a discrete form, e.g. expressed in terms of its nodal values u_i , $i = 1, 2, \ldots, n$, is sought. These nodal values are defined on a mesh formed by arbitrarily distributed nodes. Here N is the dimension of the physical space of the solution (e.g. 1D, 2D or 3D), and n is a number of decision variables. Each decision variable presents a nodal value of the sought solution function. The solution usually has to satisfy numerous equality, and inequality constraints. To obtain discrete formulation of optimization problem, any discretization method can be applied, including Meshless Finite Difference, and Finite Element Methods.

3. ACCELERATION TECHNIQUES
The EA are understood here as genetic algorithms with decimal-coded chromosomes. The standard algorithm considered consists of selection, crossover, and mutation operators only [2]. Our long-term research includes various ways for increasing efficiency of the EA. So far we have proposed several new acceleration techniques, including solution smoothing and balancing, a posteriori error analysis and related techniques, an adaptive step-by-step mesh refinement, as well as non-standard parallel and distributed computations. These general ideas can be applied in various ways. For instance, we have proposed two various approaches for data smoothing. One of them is based on the moving weighted least squares (MWLS) technique, and the second one uses mean solution curvature [4] introduced into the standard fitness function [3]. Our a posteriori solution error analysis is based on the stochastic nature of the EA. The improved crossover, and mutation operators take into account information about the magnitude and the distribution of estimated local

solution errors. Estimated global solution error is used in various ways as additional new criterion for selection. Appropriate constraint handling technique [1] was investigated as well.

Our most recent research has been focused mainly on efficient combination of the proposed speed-up techniques, and on some new concepts based on estimation of the convergence point of populations, introduced in [5]. Various approaches for estimation of the convergence point for the moving vectors of individuals between generations were discussed in [5], namely the exact, approximated (based on development into the Neumann series), and iterative ones. These general techniques can be applied to almost any population-based algorithms. We have proposed and preliminarily evaluated a specific formulation, modification, and implementation of these general approaches.

4. SAMPLES OF NUMERICAL ANALYSIS

The efficiency of speed-up techniques considered was examined using demanding benchmark problems involving large number of decision variables and constraints, including residual stress analysis in chosen elastic-perfectly plastic bodies under various cyclic loadings. Several PBA benchmark problems were analyzed as well, including smoothing of experimental data obtained by a vision measurement system, and sample inverse problems like reconstruction of residual stresses. All these benchmarks allow to choose almost any number of decision variables involved. The largest executed numerical test involved more than 3000 decision variables. The Finite Difference Method was used for discretization. We tested both 1D and 2D formulations.

In Figures 1-2 one may find typical results obtained for examination of our efficiency analysis. These figures present convergence of mean solution error of residual stress analysis applied to cyclically pressurized thick-walled cylinder used as a benchmark problem. The mathematical formulation of the optimization problem for this benchmark can be found, e.g., in [3,6]. The results shown were averaged over 10 independent solution processes. The standard algorithm used rank selection, heuristic crossover (P_C = 0.9), and non-uniform mutation (P_M = 0.1). Figure 1 shows samples of results obtained for adapting constraint handling technique combined with smoothing approach based on the MWLS technique. The following penalty function was used for constraint handling:

$$F = f + \alpha \sum_{i=1}^{n} d_i^{\beta} , \quad (1)$$

where F is the new (expanded) objective function, f is the standard fitness function, d_i is the distance of i-th decision variable to constraint boundaries, n is the number of decision variables, α and β are parameters. When comparing the best and the worst cases shown in Figure 1, the speed-up about 5 times was reached. Moreover, application of the techniques based on estimation of the convergence point of population allowed to obtain acceleration up to about 40 times. The best results were obtained for approximated approach using the truncated Neumann series (see Figure 2). It is less than in the case of our approach using step-by-step mesh refinement combined with other techniques (about 140 times) [3], but this method still may be improved and effectively combined with other ones.

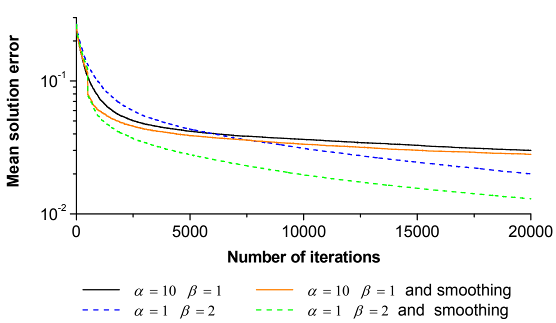

Figure 1. Smoothing approach combined with efficient constraint handling.

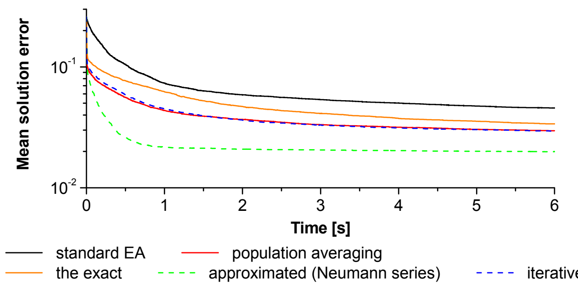

Figure 2. EA speed-up techniques based on estimation of the convergence point of population.

5. FINAL REMARKS AND PLANS

Each one of the new acceleration techniques allowed for significant acceleration of computations. Results obtained indicate a possibility of practical application of the improved EA to real complex optimization problems involving large number of decision variables and constraints.

Future research will be mostly focused on development of new auxiliary tools for our software allowing solving problems with arbitrarily irregular meshes of nodes and adaptive approach, as well as application of the improved EA to engineering problems, including residual stress analysis in railroad rails and vehicle wheels, as well as the PBA experimental and/or numerical data smoothing.

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