Comparison of Improved Evolutionary Algorithms for Chosen Optimization Problems

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Abstract. Several acceleration techniques for Evolutionary Algorithms (EA) are considered in this paper. This long-term research is focused on development of highly efficient, improved EA for solving large, non-linear, constrained optimization problems. In particular, briefly tested on various benchmarks and discussed are here advances in development of acceleration techniques, including smoothing and balancing, adaptive step-by-step mesh refinement, as well as a'posteriori error analysis and related techniques already proposed by us. Important engineering applications in computational mechanics are planned, including 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 and/or numerical data. The improved algorithms provide significant speed-up of convergence and/or possibility of solving such large problems, when the standard EA fails.

INTRODUCTION

The general purpose of this long-term research is a significant improvement of the computational efficiency of Evolutionary Algorithms (EA) applied to a wide class of large non-linear constrained optimization problems. In this work we particularly present a brief overview of the proposed acceleration techniques, including advances in their development. We also present comparison of these techniques based on numerical analysis for various demanding benchmark problems involving large number of decision variables and constraints. The largest executed numerical tests involved over 3000 decision variables.

In the analyzed problems, a function given in the discrete form, e.g. expressed in terms of its nodal values, is sought. In order to obtain discrete formulation of the problems considered, any discretization method can be applied, including the Finite Element, as well as Meshless Finite Difference Methods used here.

The final engineering objective of this research includes residual stresses analysis [3,5,7] in railroad rails, and vehicle wheels, as well as a wide class of problems resulting from the Physically Based Approximation (PBA) of experimental and/or numerical data [5].

IMPROVED EVOLUTIONARY ALGORITHMS

The standard EA used here consists of selection, crossover, and mutation operators only [1]. Improvement of the EA can be achieved in various ways, including algorithm, software and hardware modifications. This research is mostly focused now on development and testing of new algorithms, as well as on improvements of certain existing ones. Parallel computations are considered as well, but mostly as a support for new speed-up techniques. The improved EA should provide significant acceleration of the solution process and/or a possibility of solving large problems, when the standard EA methods fail.

We have proposed and tested several new, simple but effective EA acceleration techniques, including solution smoothing and balancing, an adaptive step-by-step mesh refinement, as well as a'posteriori solution error analysis and related techniques [2,6]. Smoothing techniques are applicable to any optimization problems where a smooth (at least in subdomains) function is sought. We have proposed two different approaches for smoothing of the raw EA results. One of them is based on the moving weighted least squares (MWLS) approximation technique, and the second one uses the fitness function enriched by introducing the mean solution curvature.

A'posteriori solution error analysis is based on the assumption that we are able to generate reference solutions of sufficient quality used for the error estimation. We have proposed such technique for the reference solutions generation, based on a stochastic nature of the EA. We have also improved classic evolutionary operators (mutation, crossover and selection) in order to take into account all information about estimated local and global solution errors.

In our research we also consider other speed-up techniques, well known in the field of EA, including efficient constraint handling, hybrid algorithms, as well as standard parallel and distributed algorithms. So far we have shortly investigated efficient approaches based on penalty functions for constraint handling, population averaging, as well as techniques proposed for estimation of the convergence point of a population considered. Three approaches for estimation of the convergence point for the moving vectors of individuals between generations were discussed in [4], namely the exact, approximated (based on development into the Neumann series), and iterative ones. These general methods can be applied to almost any population-based computations. We have proposed and preliminarily evaluated a specific formulation, modification, and implementation of these general approaches used for the EA acceleration.

Our recent research has been mainly focused on comparison of various variants of proposed techniques and searching for the most efficient combinations of them.

RESULTS

The efficiency of the proposed techniques was examined by using simple but demanding benchmark problems, including residual stress analysis in chosen elastic-perfectly plastic bodies (like prismatic bar, thick-walled cylinder) under various appropriate cyclic loadings (such as bending moment, internal pressure, torsion, tension). Most of the considered benchmarks may be analyzed as either 1D or 2D problems, allowing to testing almost any number of decision variables involved. Several benchmarks using the PBA approach were analyzed as well, including smoothing of beam deflections, and reconstruction of residual stresses. Smoothing of real experimental data obtained by the vision measurement system was successfully applied as well. All proposed techniques allowed for essential speed-up of computations. The best results were obtained for our approach using step-by-step mesh refinement combined with smoothing, when acceleration up to about 140 times was reached.

CONCLUSIONS AND FUTURE WORK

Numerical tests carried out so far indicate significant speed-up of the large optimization processes involved. Results obtained show a possibility of practical application of the improved EA to analysis of real complex engineering optimization problems. Important applications in computational mechanics are planned, namely residual stress analysis in railroad rails, and vehicle wheels, as well as a wide class of problems resulting from the PBA approach.

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