NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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PhD Thesis

HIERARCHICAL, DISTRIBUTED EVOLUTIONARY ALGORITHMS AND COMPUTATIONAL INTELLIGENCE IN AERODYNAMIC SHAPE OPTIMIZATION, ON MULTIPROCESSING SYSTEMS

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Abstract

This PhD thesis proposes, implements and assesses methods of increasing both the efficiency and effectiveness of Evolutionary Algorithms (EAs) in aerodynamic design optimization problems, with the ultimate goal of rendering them suitable for industrial use. To this end, the main role is assigned to approximate models, which substitute for the exact and time-consuming objective function to the greatest possible extent. The members of each generation are pre-evaluated with the approximate (inexact) models and the best individuals are selected, in order to be re-evaluated with the exact and computationally expensive model, e.g. a Navier-Stokes equation numerical solver. Radial basis function networks, enhanced by techniques for the self-organizing selection of centres, are used as approximate models; these are trained locally, around each newly appearing individual.

The inexact pre-evaluation is extended to distributed EAs according to the island model, with the aim of both improved design-space exploration and efficient use of parallel processing systems. The availability of more than one flow analysis models –e.g. of an integral boundary layer method and a Navier-Stokes equation solver– gives rise to hierarchical distributed EAs. In the usual two-level configuration, the low-level islands, which employ the low-cost physical model, undertake the arduous exploration of the design space and export promising individuals to the high-level islands, which use the high-cost physical model, in order to be exploited and further evolved.

In multi-objective optimization, the reasons for reduced performance of the inexact pre-evaluation compared to that of single-objective optimization are investigated and remedies are proposed. The use of approximate models with high generalization ability, the careful selection of training patterns and the detection of outlying individuals, for which a performance prediction is unsure, improves the gain from the application of inexact pre-evaluation and makes it comparable to that obtained in single-objective optimization.

The aforementioned methods are applied to typically difficult mathematical function cases for global optimization and, in particular, to internal –losses minimization of compressor cascades– and external aerodynamics –drag minimization in transonic flow conditions– shape optimization problems. In the field of turbomachinery, in particular, the hierarchical distributed EA is applied to the design of a highly loaded stator compressor cascade, in which a flow turning of 45^o is obtained with minimal losses in transonic flow conditions. The aforementioned tests have been performed in the parallel computing system of the Laboratory of Thermal Turbomachines, NTUA. The proposed methods induce a reduction in the computational cost by roughly one order of magnitude in comparison with conventional \EAs, without compromising the exploration effectiveness. The extension of the proposed algorithms in applications with computationally expensive solvers, other than aerodynamics, is straightforward.

Keywords: Single- and Multi-Objective Optimization, Aerodynamics, Turbomachines, Evolutionary Algorithms, Distributed Evolutionary Algorithms, Hierarchical Distributed Evolutionary Algorithms, Inexact Pre-Evaluation, Radial Basis Function Networks, Self-Organizing Mappings.