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Single- and Multiple-Objective Optimization with Differential Evolution and Neural Networks

Man Mohan Rai*
NASA Ames Research Center, Moffett Field, CA-94035, USA

ABSTRACT

Genetic and evolutionary algorithms have been applied to solve numerous problems in engineering design where they have been used primarily as optimization procedures. These methods have an advantage over conventional gradient-based search procedures because they are capable of finding global optima of multi-modal functions and searching design spaces with disjoint feasible regions. They are also robust in the presence of noisy data. Another desirable feature of these methods is that they can efficiently use distributed and parallel computing resources since multiple function evaluations (flow simulations in aerodynamics design) can be performed simultaneously and independently on multiple processors. For these reasons genetic and evolutionary algorithms are being used more frequently in design optimization. Examples include airfoil and wing design and compressor and turbine airfoil design. They are also finding increasing use in multiple-objective and multidisciplinary optimization.

This lecture will focus on an evolutionary method that is a relatively new member to the general class of evolutionary methods called differential evolution (DE). This method is easy to use and program and it requires relatively few user-specified constants. These constants are easily determined for a wide class of problems. Fine-tuning the constants will off course yield the solution to the optimization problem at hand more rapidly. DE can be efficiently implemented on parallel computers and can be used for continuous, discrete and mixed discrete/continuous optimization problems. It does not require the objective function to be continuous and is noise tolerant. DE and applications to single and multiple-objective optimization will be included in the presentation and lecture notes.

A method for aerodynamic design optimization that is based on neural networks will also be included as a part of this lecture. The method offers advantages over traditional optimization methods. It is more flexible than other methods in dealing with design in the context of both steady and unsteady flows, partial and complete data sets, combined experimental and numerical data, inclusion of various constraints and rules of thumb, and other issues that characterize the aerodynamic design process. Neural networks provide a natural framework within which a succession of numerical solutions of increasing fidelity, incorporating more realistic flow physics, can be represented and utilized for optimization. Neural networks also offer an excellent framework for multiple-objective and multi-disciplinary design optimization. Simulation tools from various disciplines can be integrated within this framework and rapid trade-off studies involving one or many disciplines can be performed. The prospect of combining neural network based optimization methods and evolutionary algorithms to obtain a hybrid method with the best properties of both methods will be included in this presentation.

Achieving solution diversity and accurate convergence to the exact Pareto front in multiple-objective optimization usually requires a significant computational effort with evolutionary algorithms. In this lecture we will also explore the possibility of using neural networks to obtain estimates of the Pareto optimal front using non-dominated solutions generated by DE as training data. Neural network estimators have the potential advantage of reducing the number of function evaluations required to obtain solution accuracy and diversity, thus reducing cost to design.

All the material in the lecture notes is obtained from the following AIAA papers (which have already been presented and are available in the public domain).

1. Rai, M. M., “A Rapid Aerodynamic Design Procedure Based on Artificial Neural Networks,” AIAA Paper No. 2001-0315, AIAA 39th Aerospace Sciences Meeting, Reno, Nevada, Jan. 8-11, 2001.

2. Rai, M. M., “Three-Dimensional Aerodynamic Design Using Artificial Neural Networks,” AIAA Paper No. 2002-0987, AIAA 40th Aerospace Sciences Meeting, Reno, Nevada, Jan. 14-17, 2002.

3. Rai, M. M., “Towards a Hybrid Aerodynamic Design Procedure Based on Neural Networks and Evolutionary Methods,” AIAA Paper No. 2002-3143, AIAA 20th Applied Aerodynamics Conference, St. Louis Missouri, June 24-26, 2002.

4. Rai, M. M., “Robust Optimal Aerodynamic Design Using Evolutionary Methods and Neural Networks,” AIAA Paper No. 2004-0778, AIAA 42nd Aerospace Sciences Meeting, Reno, Nevada, Jan. 5-8, 2004.

5. Rai, M. M., “Robust Optimal Design With Differential Evolution”, AIAA Paper No. 2004-4588, Tenth AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, Albany, New York, August 30th – September 1st, 2004.

The animations that I plan to present during my presentation are from the following AIAA papers (already presented).

1. Rai, M. M., and Madavan, N. K., “Improving the Unsteady Aerodynamic Performance of Transonic Turbines Using Neural Networks,” AIAA Paper No. 2000-0169, AIAA 38th Aerospace Sciences Meeting, Reno, Nevada, January 10-13, 2000.

2. Madavan, N. K., Rai, M. M., and Huber F. W., “Redesigning Gas-Generator Turbines for Improved Unsteady Aerodynamic Performance Using Neural Networks,” *AIAA Journal of Propulsion and Power*, Vol. 17, No. 3, May-June 2001, pp. 669-677.