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Chapter III

Generalized Extremal Optimization: A New Meta-Heuristic Inspired by a Model of Natural Evolution

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ABSTRACT

In this chapter a recently proposed meta-heuristic devised to be used in complex optimization problems is presented. Called Generalized Extremal Optimization (GEO), it was inspired by a simple co-evolutionary model, developed to show the emergence of self-organized criticality in ecosystems. The algorithm is of easy implementation, does not make use of derivatives and can be applied to unconstrained or constrained problems, non-convex or even disjoint design spaces, with any combination of continuous, discrete or integer variables. It is a global search meta-heuristic, like the Genetic Algorithm (GA) and the Simulated Annealing (SA), but with the advantage of having only one free parameter to adjust. The GEO has been shown to be competitive to the GA and the SA in tackling complex design spaces and a useful tool in real design problems. Here the algorithm is described, including a step-by-step implementation to a simple numerical example, its main characteristics highlighted, and its efficacy as a design tool illustrated with an application to satellite thermal design.

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INTRODUCTION

Many numeric techniques have been developed to address optimization problems in science and engineering (Glover & Kochenberg, 2003; Pardalos & Romeijn, 2002; Vanderplaats, 1998). The existence of many types of optimization methods is the consequence of a practical and theoretic observation: The efficiency of a given optimization algorithm is dependent on the kind of problem that is being tackled. In fact, it can be said that there is not a technique that is better than all others for all problems, but that there exists those that are more appropriate for a given class of problems (Vanderplaats, 1998; Wolpert & Macready, 1995). Traditionally, the most used methods are based on local search algorithms, frequently using the gradient of the objective function as a "guide" to the search of the optimum in the design space.

Gradient-based methods are very efficient when applied to problems where the design space is convex, with continuous design variables and when there are no severe non-linearities in the objective function or its constraints. However, many engineering problems have complex design spaces, which may be non-convex, disjoint, have severe non-linearities in the objective function and its constraints or contain a mix of continuous, discrete and integer design variables (Eldred, 1998). These characteristics may decrease considerably the efficiency of the gradient-based methods, making them converge to sub-optimal designs.

A common feature of a complex design space is the existence of multiple local optima (Eldred, 1998). In such case, a gradient-based method would converge to the nearest local minimum from where the search was started. Hence, in a practical case where the design space is not known *a priori*, if a gradient-based or any other local search algorithm is used, global search strategies must be implemented so that the probability of being trapped in a local minimum is diminished. A more general approach is to use a global search algorithm. Global optimization algorithms try to identify the global optima in the design space, using either a deterministic or a heuristic approach. Theoretically, the deterministic approach would guarantee that at least one global optimum can be found, but it has usually prohibitive computational costs for large problems or complex design spaces. On the other hand, heuristic strategies that use a stochastic component to perform the global search can yield a high probability of reaching the global solution, or solutions, with acceptable computational costs for problems considered too hard to address with global deterministic strategies (Pintér, 2002).

One class of global optimization algorithms that has been receiving great attention lately is the algorithms based on natural phenomena. The motivation behind this approach may be the observation that natural processes are frequently self-optimized. Whether to save energy, reduce waste or produce fitter organisms, nature developed robust, self-regulating mechanisms that tend to produce simple and efficient solutions. Algorithms based on the evolution of species (Davis et al., 1999), on the annealing of metals (Kirkpatrick et al., 1983), on the functioning of the brain (Freeman & Skapura, 1991), on the immune system (Castro & Timmis, 2002) and even on the social behavior of ants (Bonabeau et al., 2000) have been proposed and used in science and engineering to address many kinds of problems. Of these, maybe the most commonly used are Simulated Annealing (SA) (Kirkpatrick et al., 1983), Genetic Algorithms (GAs) (Goldberg, 1989) or variations of them.

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