How to Select the Right Optimization Method for Your Problem

Automated design optimization technology is rapidly being adopted by engineers in nearly all major industries. The potential for delivering better designs in less time compared to manual optimization approaches makes automated design optimization very attractive from both a technical and a business point of view. However, one of the main barriers to widespread usage of design optimization in industry is the difficulty of choosing an appropriate optimization search algorithm for a given problem. This white paper describes the root of this issue and proposes a solution useful for many optimization problems.

1. Limitations of Search Algorithms

It is well known that all search methods have at least some limitations. For example, some methods work effectively only when it is possible to accurately compute gradients of the solution with respect to the variables. Some methods work only for continuous or discrete variables (but not both), or for a relatively small number of variables. And some methods require a relatively large number of design evaluations to be performed in order to find an optimal solution. There is no single method or algorithm that works best on all or even a broad class of problems. In order to choose the best method for a given problem, one must first understand the type of design space that is being searched.

The design space for a given problem is defined by the types of responses and by the number, types and ranges of the design variables. For example, a two-variable design space may look like the plot shown in Figure 1, where the design landscape is plotted against the values of the two variables. Here the objective may be to find the maximum or minimum value of the response that also meets certain constraints.

A design space can be characterized primarily in terms of its smoothness (e.g., smooth, rugged, or discontinuous) and modality (e.g., uni- or multi-modal). In a smooth design space it is possible to calculate design sensitivity gradients. Solution gradients cannot be computed

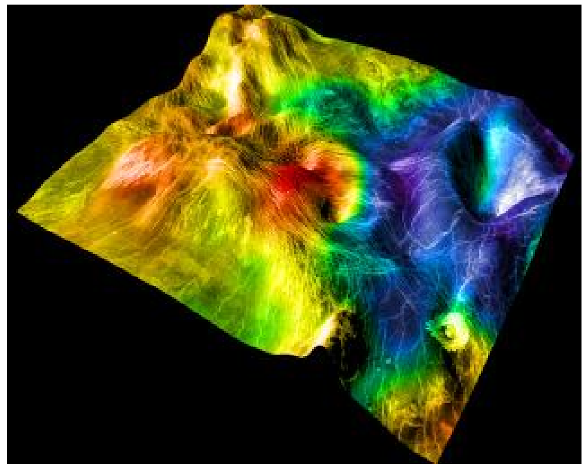

Figure 1. A typical design landscape for an engineering design problem may have several or many peaks and valleys and may be non-smooth.

directly in rugged or discontinuous design spaces. In a multi-modal design space, the design landscape may have many peaks and valleys, whereas a uni-modal design space has only one extremum. Other characteristics of a design space may also play a role in the effectiveness of a given search algorithm, such as the functional order of the solution and the interactions among the design variables.

For many engineering problems, these traits are determined primarily by the type of evaluation function (e.g., finite element solution) that is used and the type and range of design variables that have been selected. The size of the design space is determined by the number and range of the design variables. Generally, it is difficult if not impossible to know the type or character of a design space without first exploring it rather thoroughly. Herein lies the main challenge.

2. The Chicken and Egg Problem

The best search algorithm to use depends upon the type of design space that has been defined. But the characteristics of the design space are typically not known until it has been explored, which is the primary role of the search method.

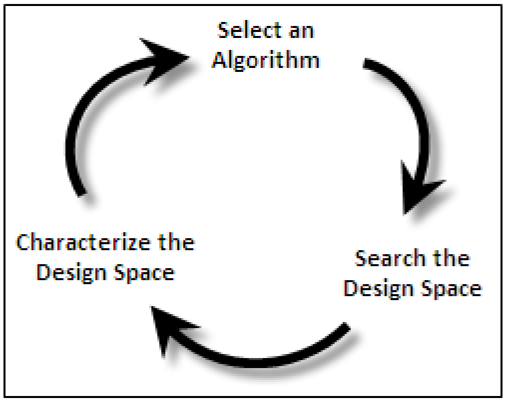

Figure 2. Often a user must solve a problem multiple times. The goal of the first set of solutions is to determine which algorithm and associated tuning parameters to use during the final solution. This is a very inefficient and ineffective way to solve optimization problems.

In order to avoid this "chicken and egg" dilemma, many engineers will simplify the definition of the design problem so as to make it solvable by a favorite search method. But this approach may drastically reduce the problem scope, perhaps sacrificing many of the benefits that might have been realized by solving the intended design problem. Moreover, defining a design problem to match the capabilities of a given search method requires significant expertise and experience with both the search method and the type of problem being solved. Often both of these requirements are lacking.

To achieve the greatest possible impact, a design problem should be defined with engineering performance and/or economic goals in mind – not based on the type of design space that might result from a certain problem statement. This means that search methods and strategies are needed that are capable of solving very general classes of problems.

3. A Generalized Robust Solution

Within HEEDS Professional, a hybrid and adaptive search strategy is employed as the default search method. This strategy, called SHERPA, uses multiple methods at once and adapts to the problem as it "learns" about the design space. So SHERPA is able to very efficiently solve many types of optimization problems, and especially those encountered most often in computer-aided engineering.

The main advantages of this approach include:

- Users need not spend time and effort trying to understand their design space before executing an optimization run. SHERPA will learn about the design space as it proceeds toward finding an optimized solution, typically yielding an efficient and effective overall approach.
- Users do not need much, if any, expertise in optimization algorithms and applications, because SHERPA makes all of the decisions about which methods to use. SHERPA contains best-in-class optimization methods in many different categories, and cleverly combines and adjusts them during a search process.
- Users can define a problem realistically, based on actual engineering and business costs and benefits, without feeling constrained by the capabilities of a particular search method. Problem definitions can be broader and include a larger number of variables.

4. Summary

The inherent limitations of individual optimization search algorithms were discussed, and the effect of these limitations on solving general optimization problems was identified. Essentially, it is not possible to select the best search method for a given problem until the nature of that problem is well understood. Thus, the effort to identify which search method to use can be more time consuming than performing the eventual search. The new algorithm SHERPA has been introduced to overcome this obstacle to applying optimization methods to realistic engineering design problems. SHERPA is a hybrid adaptive algorithm that is both robust and efficient.

For more information about SHERPA, see the white paper "SHERPA – An Efficient and Robust Optimization/Search Algorithm."

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