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Topology Optimization of Beam Structures Using Genetic Programming

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ABSTRACT

Topology optimization/design has applications in many fields and has accordingly received much attention. One important application is the design of structures having maximum strength for a given volume fraction (total amount of material), studied in detail in [1]. Unfortunately, most topology optimization algorithms optimize a set of pixels values defined on a rigid grid. There are several disadvantages to this approach such as large search spaces (especially in three dimensions), stair-cased approximation of geometry, and dubious checkerboard patterns. A new method was recently introduced for inverse scattering which attempts to alleviate many of these concerns [2].

The method described in [2] is based on genetic programming/algorithms [3, 4] and the basic principle is to use arbitrary convex polygons as building blocks to generate more complex structures. There are several advantages to this approach. First, geometries can be defined with no redundancies in their encoding. Given a large homogeneous region, a pixel method must optimize each pixel in the area; however, the proposed approach requires only as many convex polygons as necessary to define the boundary of the region. Also, because the number of points that define the convex polygons is unrestricted, this method can also represent a geometry with an arbitrary number of line segments. Finally, checkerboard patterns are not likely to appear. This approach is “top down” in that simple shapes are used as rough approximations and subsequently refined.

Geometry is encoded in this method as a binary tree data structure that defines a set of Boolean operations (such as union or set subtraction) performed on convex polygons. Each convex shape is defined as the convex hull of an arbitrary length list of points. The convex hull is defined as the smallest convex set that contains all of the points, or, equivalently, the intersection of all half planes that contain each point [5]. These point lists are then used as the leaf nodes, or operands, in the tree structure. The resulting data structure can generate complex structures such as concave and multiple shape geometries. An example of the decoding process can be found in [2].

Genetic programming is used as the optimization algorithm. Genetic programming is similar to genetic algorithms in that it also uses selection, crossover, and mutation to guide a population of potential solutions to a hopefully global optimum. Several modifications are made considering that the chromosomes

represent geometry. The most significant involves crossover. Typically, crossover is based on some fixed probability, here, however, crossover probability is based on the geometric similarity of two chromosomes. This crossover helps to control tree sizes and make the optimization more efficient. There are several possible mutation operations as the chromosome structure is flexible. Mutations can alter the structure of the trees, the structure of the point lists, or the types of operations and values of the operands. Several possibilities are discussed in [2].

The above method can be applied to beam optimization problems with few modifications. The most significant is that the method should design voids in a template structure, which is also optimized, and not the structure itself. This is easily implemented as all of the necessary operations are in place. A template structure is defined as another convex polygon, though with points inserted at the boundary and load, facilitating placing boundary conditions and applied forces. The final geometry is computed as the subtraction of the chromosome from the template. The resulting geometry can be meshed with triangular elements using automatic meshing algorithms.

As a simple example, a 1 m-by-1 m square region was optimized for minimum displacement at the load. (The optimization was "constrained" in that a penalty was added for designs with masses above a given threshold.) The x and y displacements were fixed at the left edge and a $-y$-directed point load was placed at the bottom right corner of the structure. The result, with a volume fraction (percentage of region filled with material) of 0.25, is shown in Fig. 1. A similar problem, but for a 2 m-by-1 m beam was also optimized with the result shown in Fig. 2.

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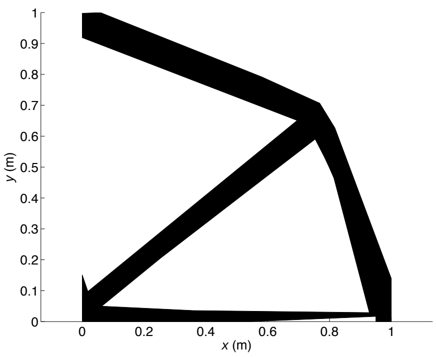

Figure 1: Square template result.

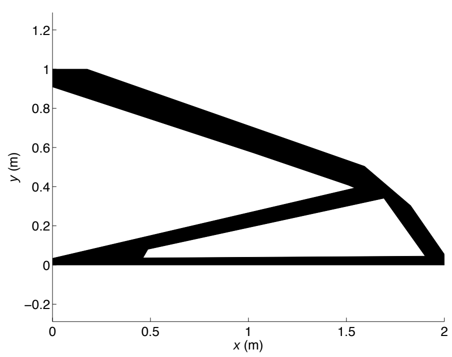

Figure 2: 2-by-1 rectangle result.