A Gradient-based Approach to Topology Optimization with Integer Design Variable Constraints

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Abstract

The application of truss and frame topology optimization algorithms to structural engineering design problems has long been predicated on the assumption of continuous design variables. The cross-sectional areas of truss members, for example, are typically assumed as continuous. The reality, however, is that structural members must be selected from a database of available (mass-produced) section profiles. In cases where this is a severe restriction, such as sizing optimization of steel frames with discrete-linked variables, many researchers have advocated the use of stochastic search optimizers.

We propose in this work a new gradient-based approach to truss and frame topology optimization for cases where the design variables are restricted to integer magnitudes and/or a discrete set of allowable section properties. Unlike traditional truss topology optimization, each structural member is represented through the combination of multiple continuous independent design variables. These design variables are structured, combined, and penalized in a SIMP-like manner that makes intermediate (non-integer) design variable magnitudes inefficient. The approach can be further enhanced to yield solutions composed of sections from a pre-defined discrete set, which are more readily constructible. The technique therefore borrows ideas from binary continuum topology optimization, but the increased design variable dimensionality and strategic combination of these design variables allows the algorithm to search across multiple discrete values.

The new approach is evaluated on several benchmark minimum compliance design problems, as well as design problems in concrete design and materials design. Interestingly, our preliminary studies suggest the algorithm converges more quickly than equivalent formulations allowing continuous design variables, perhaps due to the increased variance in gradient magnitudes. More importantly, optimized design variable distributions are shown to satisfy predefined integer and/or discrete-set constraints in all considered cases. The proposed algorithm therefore produces solutions that are more readily transitioned to structural engineering domains.