Managing Variable-Dimension Structural Optimization Problems using Generative Algorithms

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Design dimension can vary during the development of many engineering systems. For example, in truss design or automotive powertrain design, as system elements are added or removed, the continuous design variables associated with these system elements are added or removed from the set of design variables. One significant challenge is that the number of system elements in the optimal design is not known a priori, so a design vector that permits description of the optimal system topology cannot always be defined. One well-known solution is to use a ground-structure approach, where a large number of available system elements are pre-defined, and the optimization vector specifies the existence (and in some cases size and shape) of these elements. This approach is fundamentally limited, as the number and relationship of elements cannot deviate from what is allowed by the ground structure. Established approaches that discretize a given design domain, such as SIMP, are similar in that the number of potential system elements and the available relationships between them are predefined. Here we present a new approach, based on generative algorithms, that overcomes these limitations by accommodating variable design dimension problems and allowing the exploration of design alternatives not prescribed a priori.

Generative algorithms produce output based on a set of rules that is applied iteratively. This class of algorithms has been used widely in the fields of generative art and architecture. Recently one type of generative algorithm, cellular division, has been applied to structural topology optimization, but these early implementations have been limited to predefined design domains. Here we use a generative algorithm that outputs truss topology based on a set of rules, and an inner loop solves the shape and size optimization problem for each candidate topology using sequential linear programming. Adjusting the generative algorithm rules results in different topologies (often with different numbers of system elements). The generative algorithm is used as an abstraction of the topology optimization problem, i.e., the rule specification serves as an indirect representation of the system topology. Instead of optimizing in the topology design space directly, we optimize in the rule space. Design space dimension varies, whereas the rule space dimension is constant. The generative algorithm maps a design in the rule space to the design space. Since the rule space dimension does not grow with system dimension, this approach provides the potential for scaling up to much larger system design problems than what can be solved using existing methods.

The generative algorithm based method is demonstrated using a truss design problem. In addition, the same problem is solved using two alternative approaches for comparison: 1) a genetic algorithm optimizing directly in the design space via a ground structure approach, and 2) a cellular automata method also implemented using a ground structure. These investigations allow explication of the relationship between the proposed method and established techniques for topology optimization. These initial investigations indicate that generative algorithms are a promising approach for structural optimization.