Evolutionary Generation of Neural Network Update Signals for the Topology Optimization of Structures

Nikola Aulig
Honda Research Institute Europe GmbH
Carl-Legien-Straße 30
63073 Offenbach/Main, Germany
nikola.aulig@honda-ri.de

Markus Olhofer
Honda Research Institute Europe GmbH
Carl-Legien-Straße 30
63073 Offenbach/Main, Germany
markus.olhofer@honda-ri.de

ABSTRACT

In the adaptation of natural load bearing structures like bones and trees, regions subject to high physical loads accumulate structural material based on local stimuli, while it is reduced in others. This strategy can lead to efficient structures and has been modeled in the field of topology optimization. Instead of modeling the observed strategy we target the evolutionary process, which gave rise to theses strategies. We propose to use an evolutionary process in order to find a suitable mapping from local sensory information to an update signal, based on which a structure is adapted. The target is to evolve a generalizable update signal for quality functions that can not be optimized by existing topology optimization methods. As a first study, the update signal is represented by a feed-forward neural network model and its weights are tuned by an evolutionary strategy in order to optimize a minimum compliance structure. The resulting update signal is subsequently compared to the true compliance sensitivities and indicate that evolving a neural network update signal by optimization is a demanding task, yet possible at least for the provided example problem.

Categories and Subject Descriptors

I.2.8 [**ARTIFICIAL INTELLIGENCE**]: Problem Solving, Control Methods, and Search—*Heuristic methods*;
I.2.6 [**ARTIFICIAL INTELLIGENCE**]: Learning—*Parameter learning*;
J.6 [**COMPUTER-AIDED ENGINEERING**]: Computer-aided design (CAD)

General Terms

Algorithms

Keywords

Topology optimization; evolutionary learning; evolutionary strategy; structural optimization; update signal; neural network.

1. INTRODUCTION

In nature, life forms which rely on efficient biological structures have evolved and research has identified an adaptation process behind the growth of these structures. These adaptation processes have been studied for example for bones and trees and have inspired algorithms, which can be applied for topology optimization of structures [1, 4]. The aim of the presented work is to remodel the evolution which gave rise to these processes and to use its result as a strategy for topology optimization.

Existing gradient-based topology optimization algorithms require a physics model and an analytical formulation of the problem in order to derive the sensitivities of the objective function [2]. Without the analytical sensitivities, those mathematical topology optimization methods cannot be applied. This problem is addressed by the presented research work. However, for the first experiments on our novel method the well known problem of topology optimization for minimum compliance structures was chosen as a suitable test scenario so that the standard algorithm from [3] can be used as a baseline. Figure 1 shows the topology optimization of a cantilever beam subject to a static load and optimized for minimum compliance.

2. EVOLUTIONARY NEURAL NETWORK UPDATE SIGNAL

The sensitivity of a design variable in a topology optimization can be considered as an "update signal" providing information whether material is to be added or to be removed in the respective location of the structure. We propose to generate an heuristic update signal with an evolutionary process, to be applied in problems for which the analytical sensitivities are difficult to obtain.

As a first idea the update signal can be represented by a neural network of which the weights are tuned by an evo-

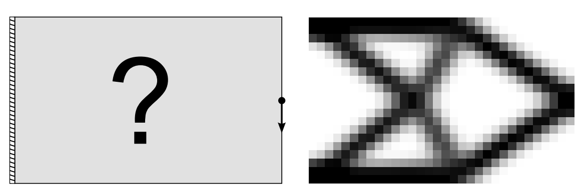

Figure 1: Example of topology optimization of a cantilever for minimum compliance. On the left side the rectangular design space, the applied force and the supports can be seen. On the right side the result of the topology optimization is given.

GECCO'13, July 6-10, 2013, Amsterdam, The Netherlands.
ACM 978-1-4503-1964-5/13/07.

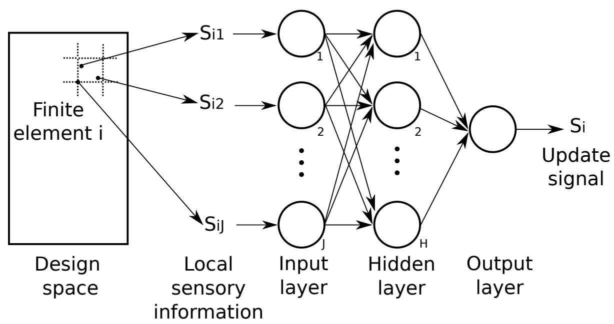

Figure 2: The mapping of local sensory information S_{ij} obtained from design variable i to the update signal S_i by using a multi-layer perceptron with one hidden layer.

lutionary optimizer. Usually, for conventional topology optimization algorithms the sensitivity of the design variables can be computed based on local properties of the structure, like local displacements or the local strain energy. Therefore, the idea is to use local sensory information which are related to the design variable as input of the neural network. The idea is illustrated in figure 2.

3. EXPERIMENTAL RESULTS

An update signal as described by section 2 is represented by a neural network with a single hidden layer with eight neurons and sigmoidal activation functions and its weights are optimized with a (20,104) de-randomized evolutionary strategy for ten different random seeds. The fitness is the structural compliance with regard to the problem in figure 1, obtained by a topology optimization utilizing the update signal instead of sensitivities. The inputs of the network are the local displacements and the local material density.
Figure 3 depicts the best fitness values and the associated structures obtained by applying the best neural network individual of the evolutionary run in the topology optimization. The baseline quality achieved when using the analytical sensitivities is 0.00654 and the baseline structure can be seen in figure 1. In three cases the optimized update signals result in structures with a compliance lower than the baseline, however the other runs converge to suboptimal solutions.
In figure 4 the compliance history during the topology optimization when using the evolved update signal is compared to the compliance history when using analytical sensitivities. The topology optimization based on analytical sensitivities is approaching the optimum by a smooth descent. The evolved update signals are not providing a clear gradient direction, but an alternative way to an efficient structure.

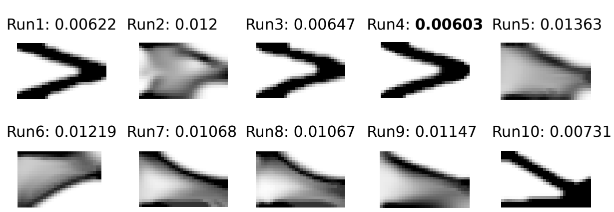

Figure 3: The resulting topologies and the associated compliance values for the best neural network update strategy evolved for each run.

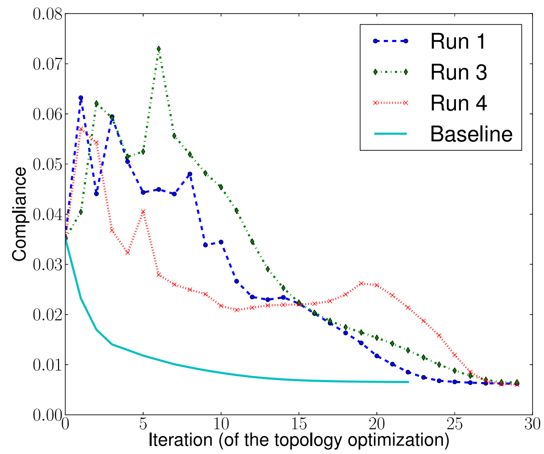

Figure 4: The figure shows the compliance during the iterations of the topology optimization, whereas the evolved neural network update signals of the three best runs are compared to the baseline.

4. DISCUSSION

The results demonstrate that a successfully evolved update signal provides a structure whose quality can exceed that of the structure found when using analytical sensitivities. The results show furthermore that, instead of approximating the analytical sensitivities, a relation evolves, which does not lead the topology optimizer in a clear gradient direction. Instead an alternative optimization path is followed, since only the final quality is of interest.
The big picture motivation behind the presented method is to evolve a generalizing update signal, which generalizes for different boundary conditions. In the scope of this work only the first step of generating the update signal for a single specific problem was addressed and demonstrated to be feasible in principle. Future work has to investigate its generalization and to improve the update signal representation towards making a convergence to the optimum more likely.

5. REFERENCES

[1] A. Baumgartner, L. Harzheim, and C. Mattheck. Sko (soft kill option): the biological way to find an optimum structure topology. *International Journal of Fatigue*, 14(6):387 – 393, 1992.

[2] M. Bendsøe and O. Sigmund. *Topology Optimization Theory, Methods and Applications*. Springer Verlag Berlin, 2nd edition edition, 2004.

[3] O. Sigmund. A 99 line topology optimization code written in matlab. *Structural and Multidisciplinary Optimization*, 21:120–127, 2001.

[4] A. Tovar. *Bone remodeling as a hybrid cellular automaton optimization process*. PhD thesis, University of Notre Dame, 2004.