Interactive structure and appearance optimization for shape design

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1 Research topic

In structural optimization, the field of *topology optimization* seeks to optimize shapes under structural objectives, such as achieving the most rigid shape using a given quantity of material and a loading scenario (see Figure 2a and 2b). An interactive algorithm for two dimensional topology optimization has already been proposed [1]. An algorithm is considered to be interactive if the response time is below 0.1 seconds [3].

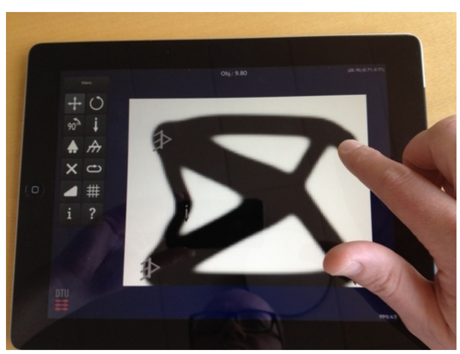
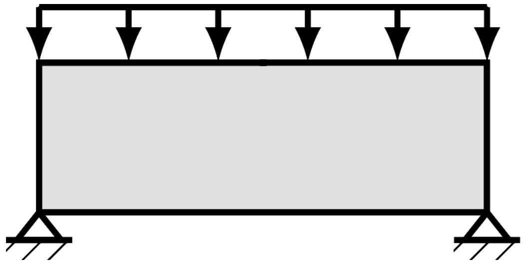


Figure 1: TopOpt App (image courtesy of [1]), available at the Android and Apple store.

Inspired by topology optimization methods, we recently introduced a technique [2] that automatically generates rigid shapes answering a specific loading scenario and resembling an input exemplar pattern (see Figure 2c), while using a user-specified quantity of material (see Figure 2d). However, the whole optimization takes up to minutes to converge. Our current goal is to devise an optimization algorithm with faster convergence (interactivity), that will allow the user to explore between changing loading scenarios and exemplar pattern parameters, as shown in Figure 3. This is specially interesting for artists and designers, being able to interactively adjust the aesthetic and functional (rigidity) specifications optimization variables. In this regard, we could collaborate together with the cole d'art de Nancy.



(a) Bridge loading scenario.

(b) Topology optimization **(rigid).**

(c) Pattern.

(d) Our approach **(rigid + pattern).**

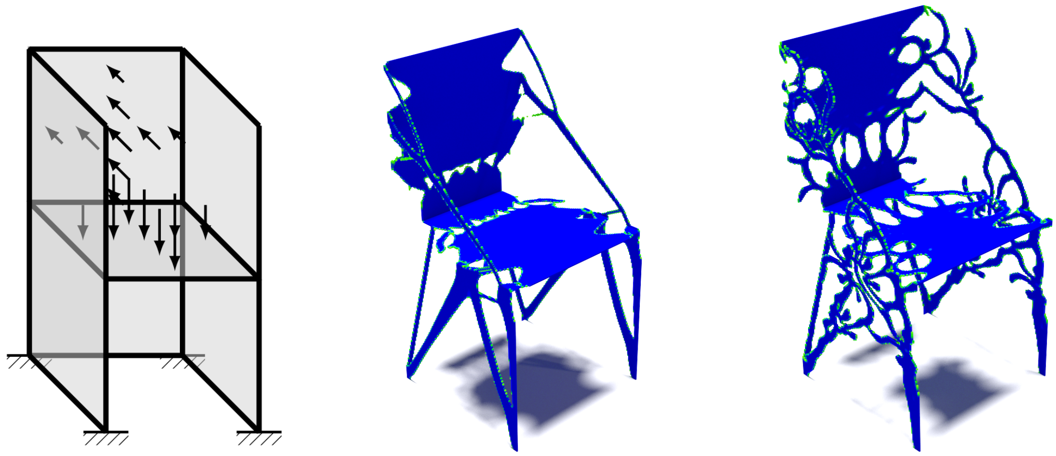
Figure 2: Bridge loading scenario: two attachments to the ground at the bottom, and forces applied on the top of the bridge. Topology optimization generates a rigid shape using a prescribed amount of material. Given a pattern (the flower), our approach finds a compromise between rigidity and resemblance to the pattern.

Figure 3: Varying the loading scenario. An interactive algorithm will allow the user to explore between these variations seamlessly.

The main challenges arising are:

- *Structural analysis performance.* The current main bottleneck of computation. Among others, reduced order methods to compute the elastic compliance could be explored.
- *Optimization formulation.* The original optimization proposed in [2] is less well-suited for interactivity. An alternative formulation could be devised.
- *Optimization convergence.* We are facing a highly non-linear optimization problem. The interactive changes of the optimization parameters (e.g. the boundary conditions) impose additional difficulties that need to be carefully studied.

In addition, the method could be extended to optimize for several interleaved 3D planes, as shown on Figure 4.



(a) Loading scenario. (b) Topology optimization. (c) Our approach [2].

Figure 4: Optimize structures along several interleaved planes in 3D, using the same pattern of Figure 2c.

The master student will tackle the aforementioned problems in a multidisciplinary team at INRIA Nancy, that is currently working in the intersection between computer graphics and structural optimization. In addition to devising efficient optimization algorithms, the student will be expected to 3D print the results of the optimization, in order to verify their expected mechanical properties.

2 Requisites

- Strong programming skills (C++, Python and OpenCL).
- Knowledge of structural optimization and finite element methods will be appreciated.
- Highly proficient in spoken and written English.

References

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[2] Martínez, J., Dumas, J., Lefebvre, S., and Wei, L.-Y. Structure and appearance optimization for controllable shape design. *ACM Trans. Graph. 34*, 6 (Oct. 2015), 229:1–229:11.

[3] Miller, R. B. Response time in man-computer conversational transactions. In *Proceedings of the December 9-11, 1968, Fall Joint Computer Conference, Part I* (1968), pp. 267–277.