Make it stand - Balancing 3D shapes

Theo Braune, Jingyi Li
Institut Polytechnique de Paris - École Polytechnique
theo.braune@polytechnique.edu, jingyi.li@ip-paris.fr

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1 Problem Statement and Motivation

Given an input surface representing a solid model, our goal is to change the volume such that the center of mass will reach a feasible target and then the object can stand or hang stably in a surprising pose as shown in Figure 1.

Figure 1: Examples of some objects in surprising poses

Producing physical realizations of 3D models is very easy nowadays with 3D printing technologies. Unfortunately they often fail to stand, making it mandatory to glue the printed objects onto a heavy pedestal, which is often not convenient. Therefore, we propose to assist users in modifying existing 3D models to create novel, balanced designs so that it will hang by a rope or stand on its intended basis with the chosen orientation.

2 A State of The Art

The method introduced by Prevost et al [PWLSH13] yields a way to tackle this problem. We will follow their approach in order to generate shapes that can stand stable. Nevertheless one downside of this method is, that it requires to deform the shape. In [CSB15] Christiansen et al try to give remedy to this problem by using materials of different densities to manipulate the center of mass more efficiently. The general idea to use algorithmic methods to manipulate physical properties, but leaving the outer surface as unchanged as possible, was further developed by [WW16] who create watertight shapes that are able to float in water in desired positions. Further Bacher et al [BWBSH14] describe in their publication a method that changes the inertia tensor of a shape, in order to create a stable spinning gyroscope from a predefined shape orientation.

3 Personal Contribution

3.1 Voxelization

In order to transform our smooth mesh into a discretized and filled voxelization, we make use of the python library Open3D [ZPK18]. We followed their tutorial instructions to convert a triangulated mesh into a voxelized surface. We wrote our method to fill this voxelized surface and determine which are inner voxels and which are boundary voxels and how thick the boundary should be.

3.2 Carving

In the first stage we define our support base. To do that, we are searching in vertical direction (y-direction) for the first layer from the bottom of the shape. We specify the size of the support base. To do that, we take the convex hull of all points, that are in the first layer.
Next we define a support region, in which we are aiming to have our desired center of mass in the end. We observed, that even for a fine voxelization with 256 voxels, it is necessary to use a very small support base of the size 8x8 pixels to end up with a stable standing figure as indicated in figure 5. With the defined support base we start our carving process. We compute the center of mass and measure the deviation from our desired support zone. We determine the direction from which we need to carve, to improve the mass distribution. Next we start to carve inner layers until our center of mass is in the support base or the center of mass is in the carving layer.

3.3 Deformation

If the carving does not converge, i.e it does not end up in the support zone, we need to change the shape of the surface. For some shapes we used our own way to improve the center of mass by adding new elements to improve the center of mass. This can be convenient for some models, and it turned out to be a very effective method.

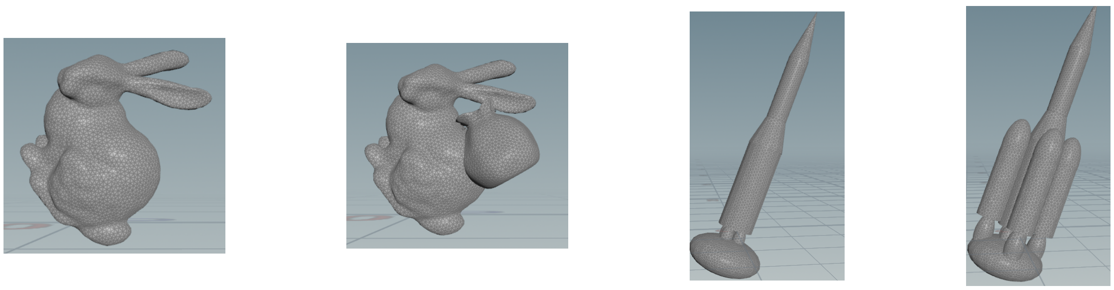

Figure 2: Illustration of how supplementary parts like a bag of Easter eggs or a set of engine boosters can improve the mass distribution.

In [PWLSH13] Prevost et al suggest to search for deformation parameters that minimize an energy that measures the deviation of the center of mass from the support base and takes the shape preservation into account. We decided to follow this idea, but to implement it in a different way.

We made use of Houdini SideFx Software to apply several cage based deformations on the mesh, where we can select different parts of the cage in different steps and manually deform parts of the shape, such that we have a mesh with a better mass distribution.

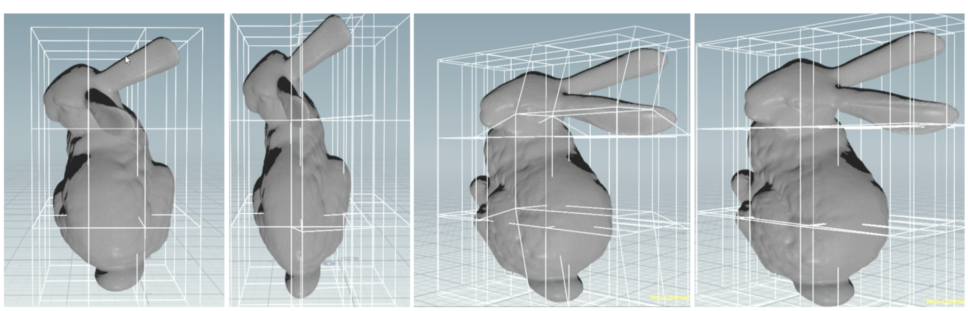

Figure 3: The deformation process done using Houdini

It should be noted, that in the current state, it is only possible to apply the deformation before the carving. Once we start carving and realize that the mesh is not working, we need to restart carving with a modified mesh.

3.4 Printing

To convert our boolean grid into a printable .stl file, we used the python library voxelfuse[Bra20]. Thanks to the Télécom Paris Fablab we are able to print our shapes in their 3D-Printer. We used a Creality3D CR-10S Pro Imprimante 3D to start printing our models. We discovered, that for our special purposes, it is necessary to use as much infill in the print as possible, which increases drastically the material consumption and printing time.

4 Results and Limitations

4.1 Voxelization

The voxelization results are shown below and we can see that it perfectly preserves the original shape of the object.

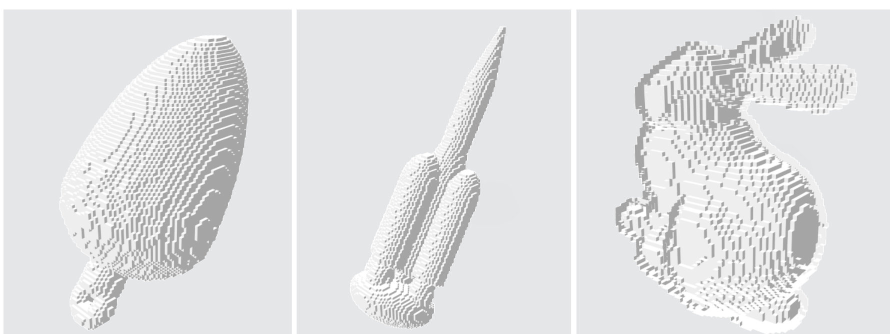

Figure 4: The voxelization results

4.2 Carving

The carving results are shown below. We have observed that a trade-off must be made because, on the one hand, the surface must be as thin as possible so that carving converges and the weight of the surface does not interfere with the center of gravity. On the other hand, from a material point of view, it is a challenge to print thin surfaces because it reduces the solidity.

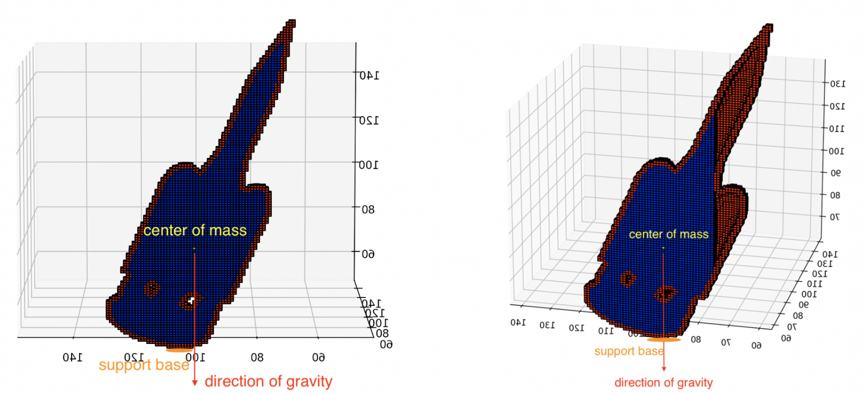

Figure 5: The vertical section before and after carving

But in some cases, carving is not enough for objects to stand stably like in Figure 6

Figure 6: The failure case for carving. The left pose is what we desire but it falls down to the right pose.

4.3 Our Printed Models

We printed 4 models with 3D printer including two pine-cones, one bunny and one rocket. The carved bunny failed as shown before but the carved rocket model stands perfectly on the desired pose. One of the pine-cones we carved fails but after we deformed its surface, it can hang with the chosen orientation. Although it succeeds, there is a hole on its surface, because the surface of the void is too thin and it is stuck to the supporters. This model has size of around 10cm x 5cm x 4cm. It weighs around 120g. In our setup it took around 16 hours to print this model and around 80 meters of filament.

Figure 7: Our successful cases of the standing rocket and the hanging pine-cone. We also show the hole on the pine-cone.

The code for this project can be found at `https://github.com/JeansLli/X-INF574_3D-printing`.

References

[Bra20] Aukes D. Brauer J. Jeffries C Brauer, C. Voxelfuse, 2020.

[BWBSH14] Moritz Bächer, Emily Whiting, Bernd Bickel, and Olga Sorkine-Hornung. Spin-it: Optimizing moment of inertia for spinnable objects. *ACM Transactions on Graphics (TOG)*, 33(4):1–10, 2014.

[CSB15] Asger Nyman Christiansen, Ryan Schmidt, and J Andreas Bærentzen. Automatic balancing of 3d models. *Computer-Aided Design*, 58:236–241, 2015.

[PWLSH13] Romain Prévost, Emily Whiting, Sylvain Lefebvre, and Olga Sorkine-Hornung. Make it stand: balancing shapes for 3d fabrication. *ACM Transactions on Graphics (TOG)*, 32(4):1–10, 2013.

[WW16] Lingfeng Wang and Emily Whiting. Buoyancy optimization for computational fabrication. In *Computer Graphics Forum*, volume 35, pages 49–58. Wiley Online Library, 2016.

[ZPK18] Qian-Yi Zhou, Jaesik Park, and Vladlen Koltun. Open3d: A modern library for 3d data processing. *CoRR*, abs/1801.09847, 2018.