

# Inout Sculptures

Yutu Liu  
Department of Computer Science  
Texas A&M University

Hernan Molina and Ergun Akleman  
Department of Architecture  
Texas A&M University

## Abstract

In this paper, we present a set of high genus virtual sculptures which we call inout sculptures. These sculptures are obtained by showing both *inside* and *outside* of a shape with holes. Inout sculptures look interesting since they allow to simultaneously view both inside and outside of complicated shapes.

## 1 Introduction and Motivation

The people innately find a mysterious beauty in sculptures with smooth saddle regions, which we call hyperbolic sculptures. The well-known examples of such hyperbolic sculptures are Robert Longhurst's Arabesque 29th [5] and Brent Collins's hyperbolic sculptures with many smooth holes and handles [10]. In this paper, we present a method to create hyperbolic sculptures. Our idea is to simultaneously show both inside and outside of an already complicated shape that contains many holes. An example of an inout sculpture is shown in Figure 1.



**Figure 1:** Yutu Liu's 3D printed physical Inout sculpture. This sculpture is 3D printed using Dimension SST and made from ABS plastic. It is painted with gold color spray paint.

Akleman, Srinivasan, Mandal and Chen introduced a variety of methods to create high-genus surfaces such as rind modeling [3], column modeling [7], wire modeling [6, 12] and multi handles [13]. Using these methods, it is possible to easily create complicated shapes with many holes and handles, which we call high genus sculptures. Both insides and outsides of these sculptures are interesting. In this paper, we present a method to show both inside and outside of these sculptures.

This method is simultaneously discovered by the two authors of this paper, Yutu Liu and Hernan Molina, during the Computer Aided Sculpting course of Ergun Akleman (See Figures 1, 9 and 10. Both Liu and Molina wanted to show inner beauty of the sculpture that they have already created. By showing the inside, they ended up a new kind of sculptures which look more interesting than the initial sculptures. By realizing

that they have discovered a new way of creating sculptures. Akleman formalized the process and he has created a series of virtual sculptures starting from platonic solids (See Figures 6, 7 and 8). The next section presents the method to create inout sculptures.

## 2 Methodology

The method consists of only four steps and the Figures 2, 3, 4 and 5 shows the steps of the method starting from a dodecahedron. All images in these figures are screen-captures from TopMod [15, 1], an interactive topological modeling system.

1. We start with a simple mesh such as cube, dodecahedron or toroid. And we apply a high genus modeling operation to this starting mesh. There are four high genus modeling operations that can be used. The Figure 2 shows the effect of each operation on a dodecahedron. Note that all operations create the same topology for the same initial mesh. However, the structure of resulting mesh is different for each operation.
  - (a) *Wire Modeling* [7] operation replaces each edge of a 2-manifold mesh with a pipe that has a square cross-section (See Figure 2). The thickness pipes can be determined by users. For small thickness values, the resulting meshes looks like a shape that is created by a framework of matchsticks.
  - (b) *Column Modeling* [6, 12] operation converts a wire-frame structure of a mesh into a 2-manifold mesh consisting of pipes in place of the edges and joints in place of vertices in the original mesh (See Figure 2). The thickness and cross sections of joints can be determined by users.
  - (c) *Merger Sponge* [14] operation is the generalized version of Merger sponge creation [8]. Classical Merger Sponge operation can only be applied to a cube. In this case, it is possible to apply the operation to any convex manifold mesh as shown in the Figure 2.
  - (d) *Multi-Connected Handle* [13] operation allows to connect more than two faces with multi-connected handles. Choosing all the faces of a convex manifold mesh, it is possible to create the same topological structure as wire, column and merger sponge operations. However, unlike the other three operations, with this operation it is also possible to create different topological structures. For instance, Hernan Molina's sculpture in Figure 10 is created by choosing two groups of 3-connected handles starting from a cube. (See Figure 2).
2. We apply "Doo-sabin" subdivision scheme for remeshing and smoothing the mesh (See Figure 3). There exists a variety of subdivision schemes, but, among them Doo-Sabin subdivision is particularly useful [4, 9]. A subdivision scheme is a special type of remeshing operation that smoothes polygonal meshes. With successive applications of a subdivision scheme, the surface approaches a piecewise parametric surface. In this paper, we are not interested with limit behaviors of subdivision schemes, but it is important to point out that even only one application of the Doo-Sabin subdivision scheme can transform even extremely non-planar and non-convex faces to convex, almost planar faces [2]. As a result, Doo-Sabin subdivision can successively be used to smooth the mesh.
3. We apply "Rind Modeling" and punch holes to see inside of the sculpture as shown in Figure 4. Rind modeling consists of two steps: in the first (automatic) step, for any given 2-manifold mesh surface an offset surface is created based on a user defined thickness parameter. The second interactive (hole opening) step is similar to punching holes in a coconut husk or peeling an orange rind. Holes are punched by single mouse clicks on faces. If neighboring faces are punched, the result will be like peeling an orange rind. We punch holes just to see the inside and leave most parts of the shape intact. This way we can view inside while we can see the overall shape.
4. We apply "Doo-sabin" subdivision scheme again to obtain the final smoothed mesh as shown in Figure 5. Note that the shapes in Figures 2 and 5 have exactly the same topology, i.e. their genera are

identical. We have used the method to create a variety of in-out sculptures

- starting from toroidal mesh using column modeling (See Figure 1),
- starting from platonic solids using wire modeling (See Figures 6, 7 and 8) and
- starting from cube using multi-handles (See Figures 9 and 10).

Our results indicate that the method is useful to create complicated looking sculptures from simple shapes.

### 3 Implementation and Results

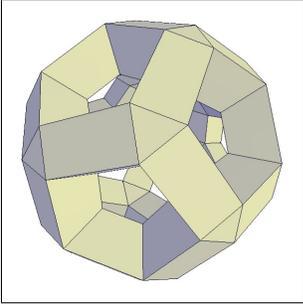
To create virtual sculptures, we used TopMod [15, 1], which is an interactive topological modeling system that provides a variety of high genus modeling operations including multi-handles, column and wire modeling and rind modeling as well as a variety of subdivision schemes including Doo-Sabin. Virtual sculptures are rendered using 3D Studio Max. Physical sculptures are 3D printed using Dimension SST, a Fused Deposition Modeling (FDM) machine developed by Stratasys. The physical sculptures are made from ABS plastic. The sculpture shown in Figure 1 is painted using a gold paint, which allows to show the structure of the sculpture better. The sculpture in Figure 10 is not painted.

### 4 Conclusion and Future Work

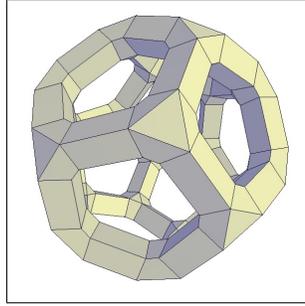
In this paper, we have presented a method to create sculptures that are obtained by showing both inside and outside of a shape with holes. These hyperbolic sculptures look interesting since they allow to simultaneously view both inside and outside of complicated shapes.

### References

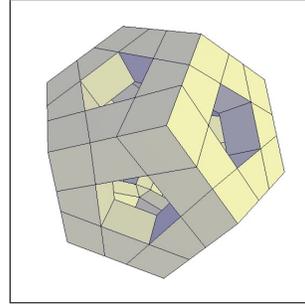
- [1] E. Akleman, J. Chen, and V. Srinivasan. A minimal and complete set of operators for the development of robust manifold mesh modelers. *Graphical Models Journal, Special issue on International Conference on Shape Modeling and Applications 2002*, 65(2):286–304, 2003.
- [2] E. Akleman, J. Chen, V. Srinivasan, and F. Eryoldas. A new corner cutting scheme with tension and handle-face reconstruction. *International Journal of Shape Modeling*, 7(2):111–121, 2001.
- [3] E. Akleman, V. Srinivasan, and J. Chen. Interactive rind modeling. In *Proceedings of Shape Modeling International 2003, Seoul, Korea, May*, pages –, 2003.
- [4] D. Doo and M. Sabin. Behavior of recursive subdivision surfaces near extraordinary points. *Computer Aided Design*, (10):356–360, 1978.
- [5] N. Friedman Robert Longhurst’s Arabesque 29. *Hyperseeing*, page 1, November 2006.
- [6] E. Mandal, E. Akleman and V. Srinivasan. Column Modeling. *Proceedings of ACM SIGGRAPH’2004 (Siggraph Sketch)*, Los Angeles, California, July 2004.
- [7] E. Mandal, E. Akleman and V. Srinivasan. Wire Modeling. *Proceedings of ACM SIGGRAPH’2003 (Siggraph Sketch)*, pp 1–1, San Diego, California, July 2003.
- [8] B. Mandelbrot. *The Fractal Geometry of Nature*. W. H. Freeman and Co., New York, 1980.
- [9] M. Sabin. Subdivision: Tutorial notes. Shape Modeling International 2001, Tutorial, May 2000.
- [10] Carlo Sequin. Sculptures. [www.cs.berkeley.edu/~sequin/](http://www.cs.berkeley.edu/~sequin/), 2006. [block-math-world.wolfram.com/Spiral.html](http://block-math-world.wolfram.com/Spiral.html), 2006.



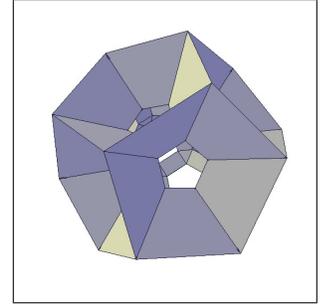
Wire Modeling



Column Modeling

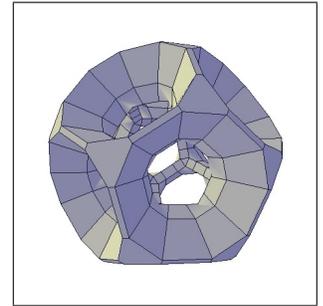
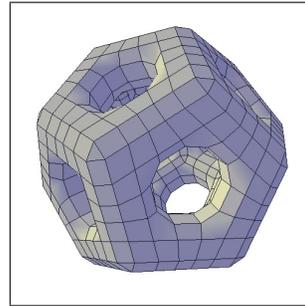
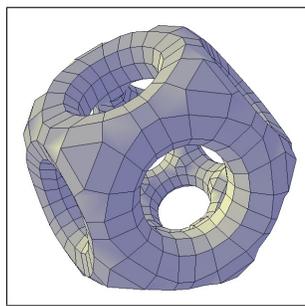
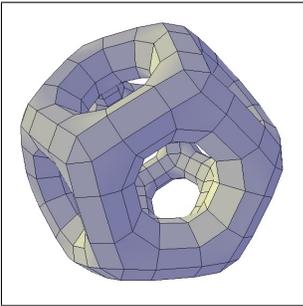


Merger Operation

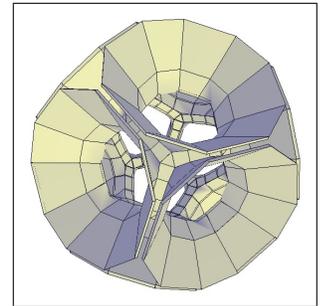
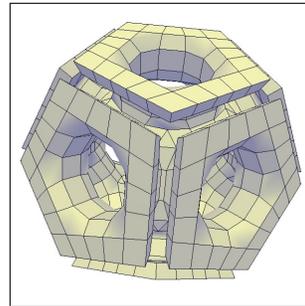
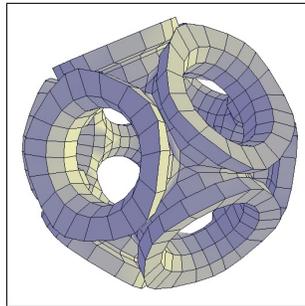
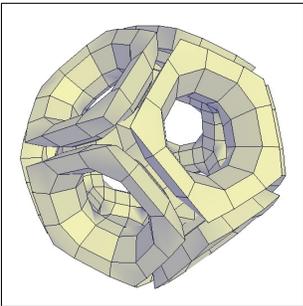


Multi-Handle

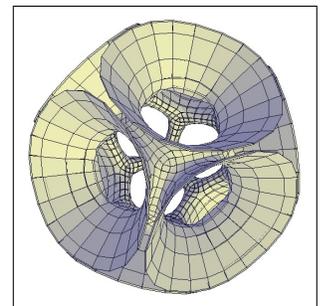
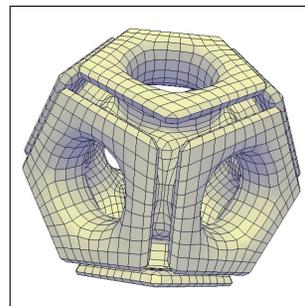
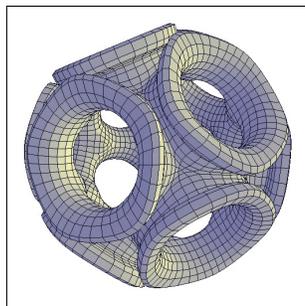
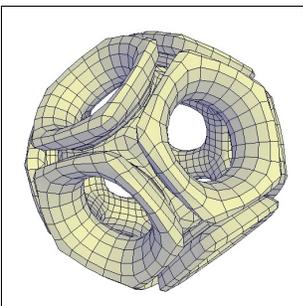
**Figure 2:** *High Genus Operations.*



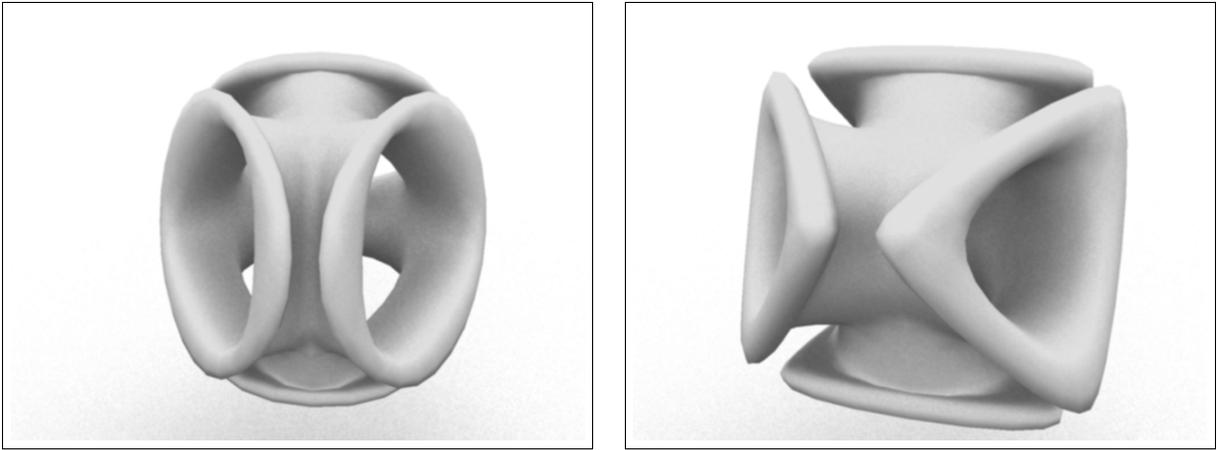
**Figure 3:** *Doo-Sabin Smoothing.*



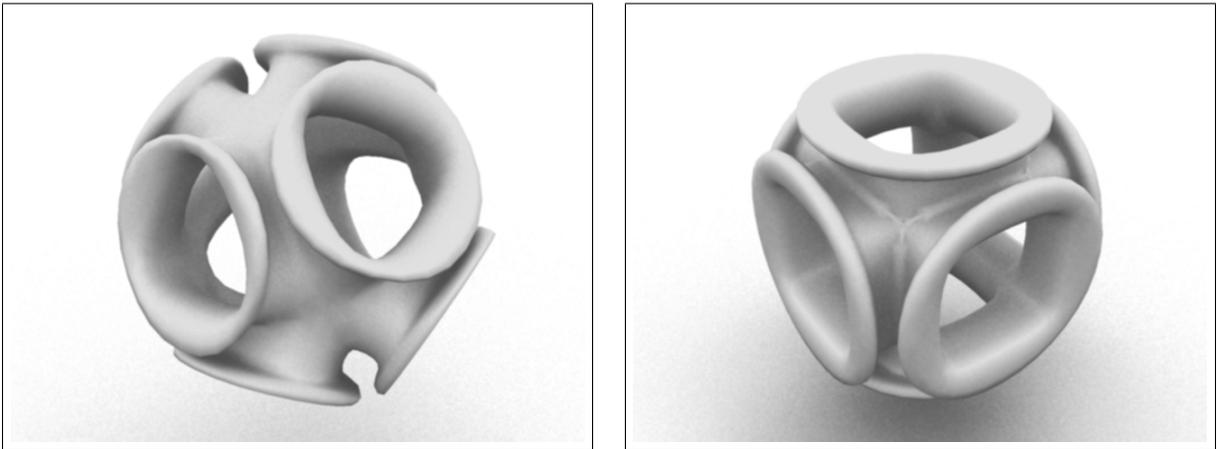
**Figure 4:** *Rind Modeling.*



**Figure 5:** *Doo-Sabin Smoothing.*

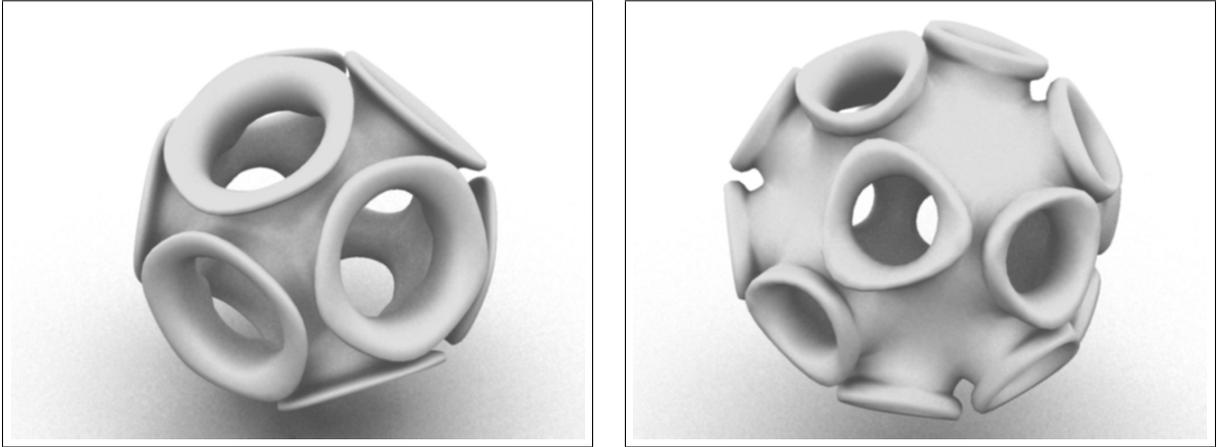


**Figure 6:** Ergun Akleman's Virtual Tetrahedral Inout Sculptures. Rendering is done by Yutu Liu using 3D Studio Max.

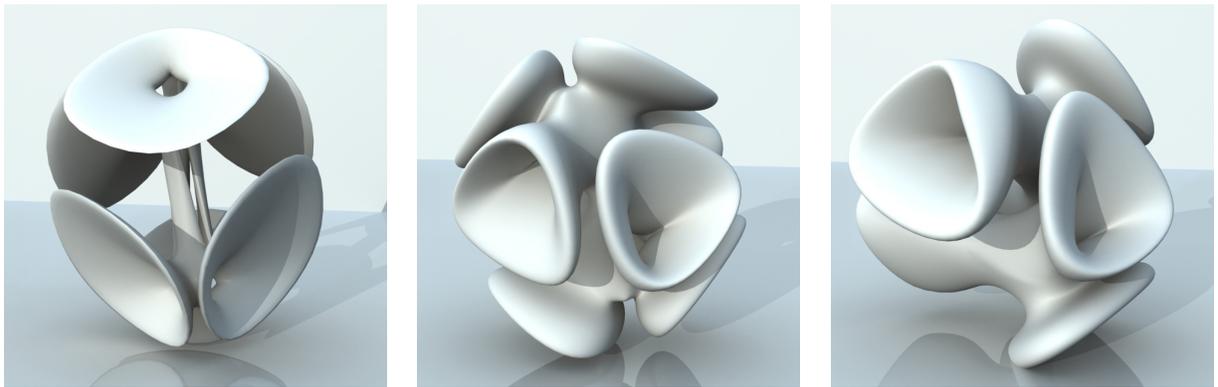


**Figure 7:** Ergun Akleman's Virtual Octahedral and Cubical Inout Sculptures. Rendering is done by Yutu Liu using 3D Studio Max.

- [11] V. Srinivasan, E. Akleman, and J. Chen. Interactive Construction of Multi-Segment Curved Handles. In *Proceedings of the Pacific Graphics 2002*, pages 429 – 435, 2002.
- [12] V. Srinivasan, E. Mandal and E. Akleman. Solidifying Frames. In *Proceedings Bridges: Mathematical Connections in Art, Music, and Science 2005*, pages 203 – 210, 2005.
- [13] V. Srinivasan, H. Molina and E. Akleman. Modeling High-Genus Sculptures Using Multi-Connected Handles and Holes. Submitted *Bridges: Mathematical Connections in Art, Music, and Science 2007*.
- [14] V. Srinivasan. *Modeling High Genus Surfaces*. Ph.D. Dissertation, Texas A&M University, 2004.
- [15] TopMod website: <http://www-viz.tamu.edu/faculty/ergun/research/topology/>



**Figure 8:** Ergun Akleman's Virtual Dodecahedral and Icosahedral Inout Sculptures. Rendering is done by Yutu Liu using 3D Studio Max.



**Figure 9:** Hernan Molina's virtual Inout sculptures. The first high genus mesh is created from a cube with two triple handles. Rendering by using 3D Studio Max.



**Figure 10:** Hernan Molina's 3D printed physical Inout sculpture. See the virtual sculpture in Figure 9. This sculpture is 3D printed using Dimension SST and made from ABS plastic.