Multiple Handle Creation and Multiple Hole Opening

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Abstract

In this paper, we present the concept of multiple handle operation to create complicated high genus virtual sculptures. We have developed and implemented a simple procedure to create multiple handles that connect a set of faces in 3D. To create multiple handles, we first create a connector, which is a convex shaped mesh surface. We then simply connect each selected face to this connector surface with a simple one segment handle. If the connector is inside of the original mesh and the handles goes through the inside of the objects, the result becomes multiple hole.

1 Introduction and Motivation

The people innately find a mysterious beauty in sculptures with more than one handle and hole, which we call high genus sculptures. With development of new mathematical and computational techniques, we started to see more and more high genus sculptures. The most well-known examples of such high-genus sculptures are Bathsheba Grossman's 3D metal printed sculptures [11], Brent Collins's saddle sculptures [18], Charles Perry's aliminum and brone sculptures [13], Helaman Ferguson's brone and marble sculpture [9, 8], Carlo Séquin's 3D printed sculptures [18], Rinus Roelofs' [14] and George Hart's [12] puzzle like sculptures.

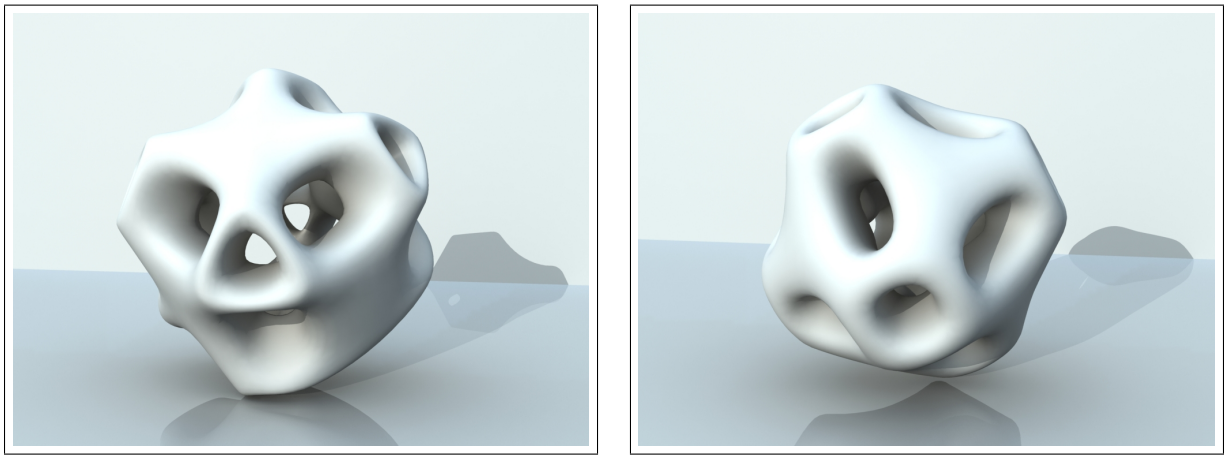

Figure 1: Hernan Molina's multiple handle sculptures.)

Akleman and Chen has recently shown that topologically there are a wide variety of high-genus surfaces and construction methodologies [**?**, **?**]. Their topological treatment does not even include geometry. By including geometry, it may be possible to have a wider variety of ways to construct high genus sculptures. Akleman, Srinivasan and Chen introduced some of geometrical approaches to create high-genus surfaces such as rind modeling [5] and multiple-segment curved handles [16]. However, such methods are based on creating handles between two faces. In this paper, we present a method to create handles between multiple

faces. Using the multiple handles, we have constructed both virtual and 3D printed physical sculptures as shown in Figures 1,6 and 7.

Note that topologically there is no difference between opening holes or creating handles [1]. In fact, handles are holes that goes through the inside of the solid shape. Contrary to conventional wisdom a handle do not have to connect only two different faces. It is possible to connect multiple faces. It is even possible to create a handle on the same face. The simplest of all handles is a single edge that connects two different faces [2]. Using multiple insert edge operations we can obtain any type of handles. For a theoretical treatment of the variety of handles, we refer the reader to [4].

Differentiating holes and handles are only useful for visualizing the geometric impact of operation in our minds. For instance, rind modeling [5] allows to punch holes in a rind type of surface, on the other hand, multiple-segment curved handles [16] allows us to connect two faces of a mesh with a smooth looking handle. Column modeling, on the other hand, converts each vertex of a manifold mesh into a convex hull and connects these convex hulls with straight handles [17].

2 Methodology

Our method is consists of two steps.

- Create a connector mesh.
- Connect the faces with the connector mesh.

The Figure 2 shows the effect of the displacement parameter and the Figure 3 shows the effect of the scaling parameter.

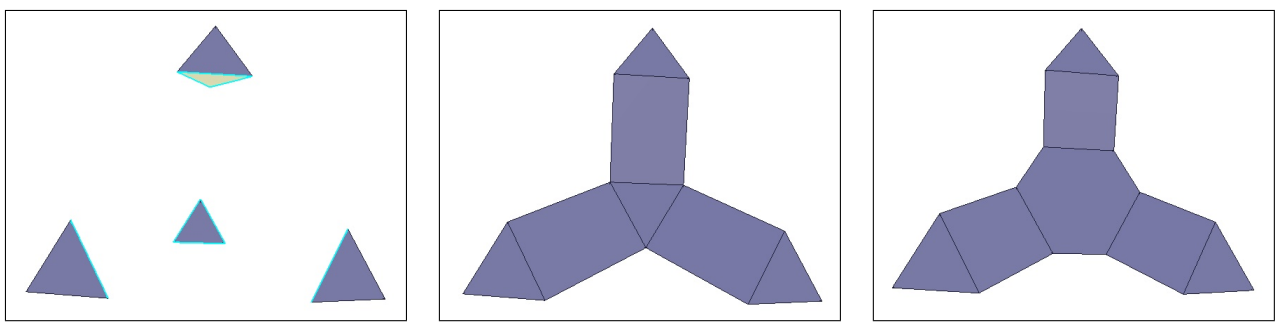

Figure 2: Connecting 4 tetrahedra with quadruple handles. The image on the right shows the initial 4 tetrahedra. The image in the middle shows a quadruple handle connection with large displacement. The image on the left shows a quadruple handle connection with small displacement.

3 Implementation and Results

We have implemented our method in an interactive modeling system developed using C++, OpenGL and FLTK[10]. The method works best when it is applied to the multiple faces of convex meshes such that the collection of the selected faces covers all the vertices or the convex mesh. For instance, by selecting only three faces of a cube, we can include all vertices as shown in Figure 4. If all the vertices are chosen, the convex hull created by these vertices will be closely related to the initial convex shape and it will provide nice handles. The Figures 4 and **??** show triple, quadruple, pentuple and hextuple hole structures that are created by applying multiple hand operation to a cube and octahedron respectively.

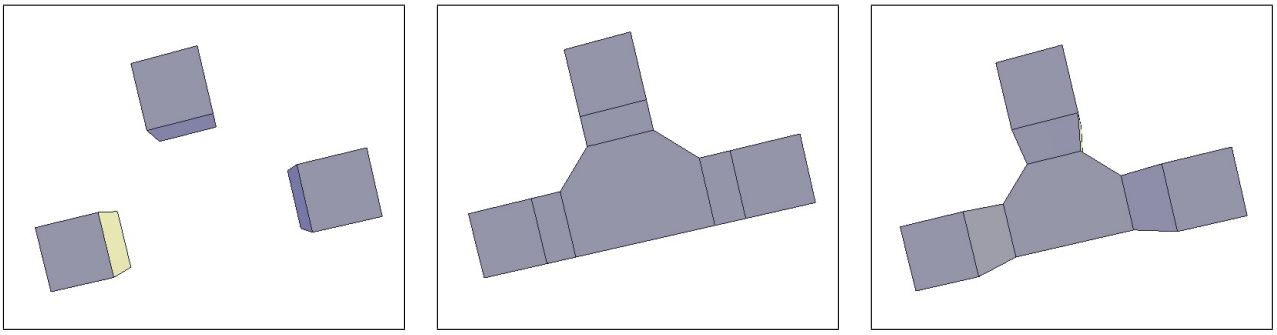

Figure 3: Connecting 3 cubes with triple handles. The image on the right shows the initial 4 tetrahedra. The image in the middle shows a triple handle connection with no scaling. The image on the left shows a triple handle connection with scaling.

4 Conclusion and Future Work

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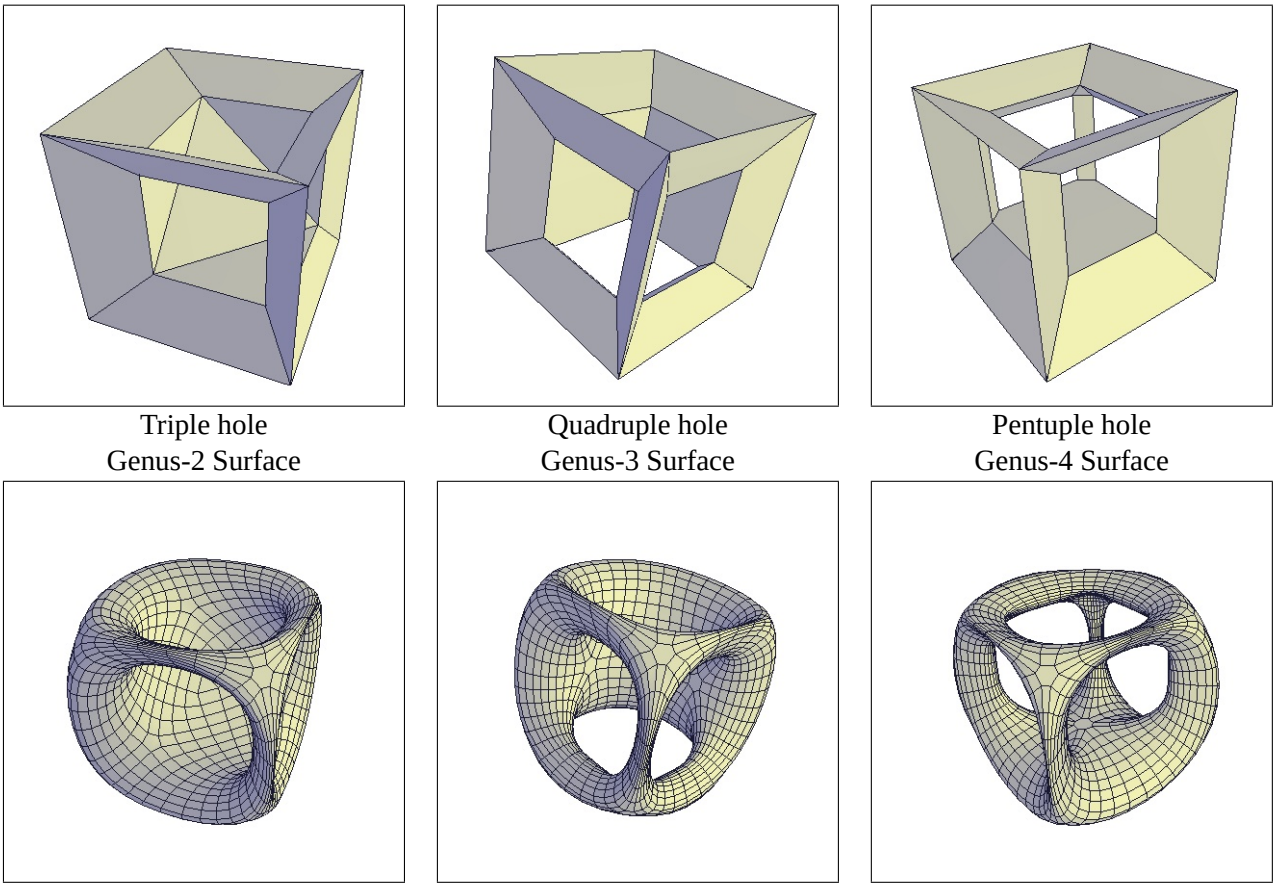

Figure 4: The top row shows opening three examples that illustrate multiple hole openings in a cube. The images in the second row are Doo-Sabin smoothed versions of the shapes in the top row.

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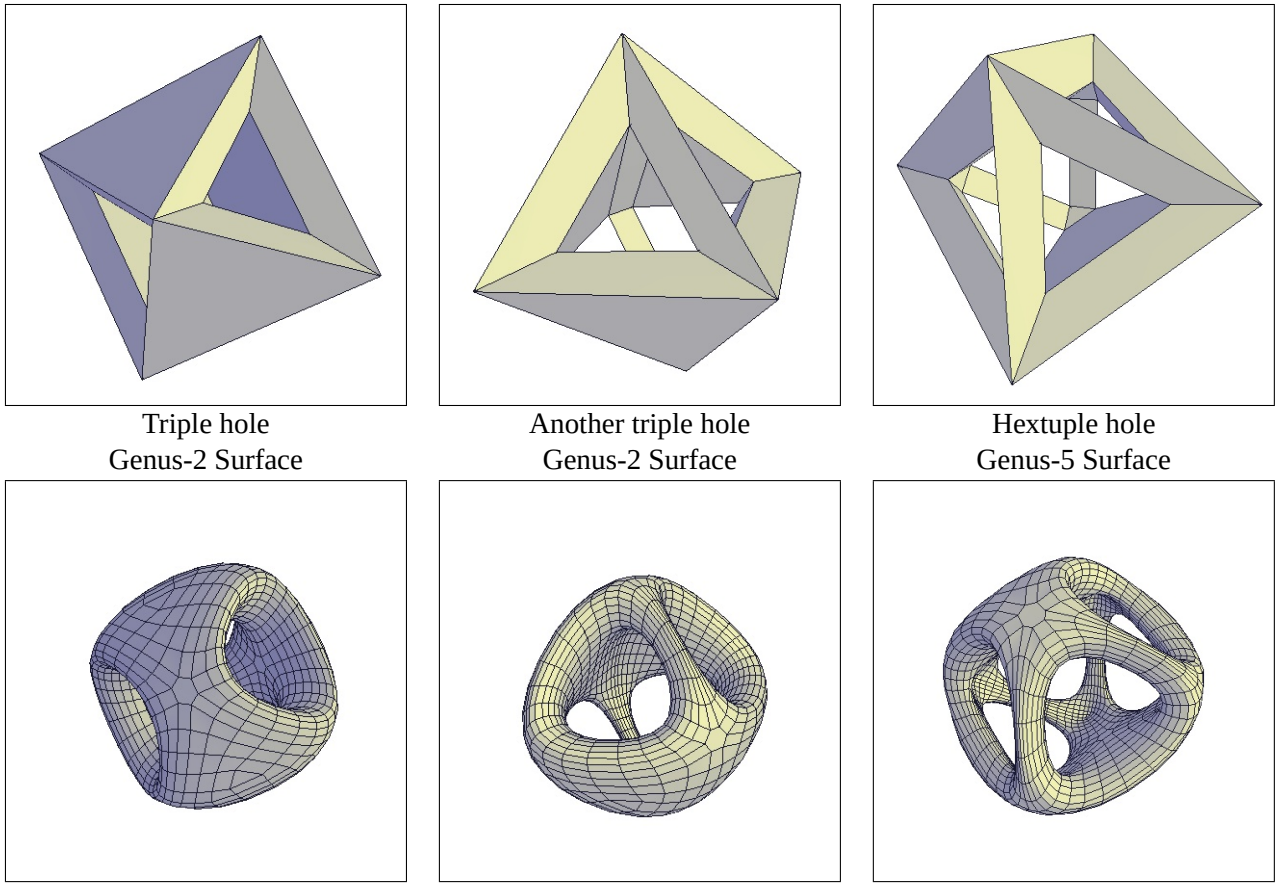

Figure 5: The top row shows opening three examples that illustrate multiple hole openings in an octahedron. The images in the second row are Doo-Sabin smoothed versions of the shapes in the top row.

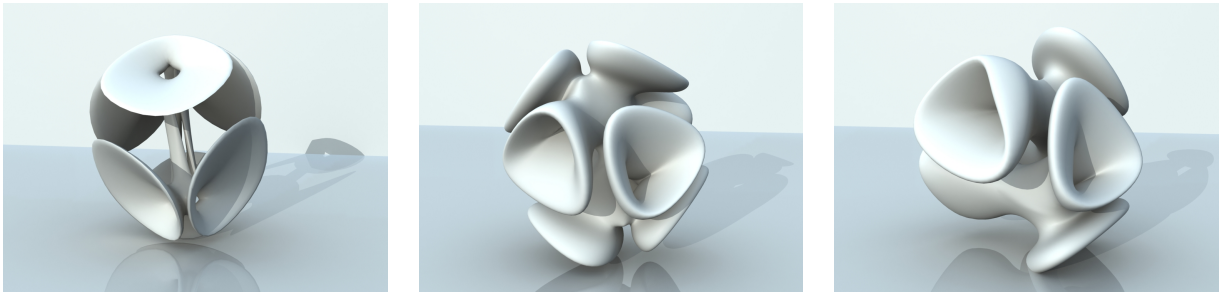

Figure 6: Hernan Molina's virtual Inout sculptures. Inital mesh is crated by using creating two triple handles.)

Figure 7: Hernan Molina's 3D printed physical Inout sculpture. See the right virtual sculpture in Figure 6.)