



Title:

**Editing Operators for Cross-Sectional Data-Sets**

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Introduction:

Editing 3D objects can apply to many situations and for various purposes, such as Computer Aided Design, Reverse Engineering, medical simulations, education, gaming, or for creating works of art.

In this paper, we report on the development of a cross-sectional 3D model editor. The models we work with have properties often encountered in medical data-sets (e.g. CT scans of arteries or internal organs). However, our toolset can be applied to both engineered objects (e.g. mechanical parts) or free-form objects (e.g. human or animal figures) for various purposes.

Method:

There are many methods proposed in the literature, which offer editing of several types and for various purposes. In most cases, these methods require as input a model that has previously been structured in a specific format, either in triangle meshes with specified topology [4, 5], or in higher level representations, such as curves or surfaces [9, 15, 16, 2].

In another domain of research, several methods have been proposed for medical applications [12, 14, 3, 13, 7, 1, 8, 6], which mainly address the issue of reconstructing the surface of a 3D model, but do not provide any tools for editing the model.

This work is an effort to bridge the gap between these two domains, by providing a framework that offers editing of 3D models, which can handle unstructured input, and could potentially be used for applications such as medical simulations. The aim of this work is to provide an editing framework that uses high level parameters and allows for applying complex parametric transformations with a single deformation. We have developed a set of editing operators for cross-sectional data sets, which takes as input a 3D point cloud. Our method automates the process of selecting the points of one or more cross sections with the aim to perform modifications on these points.

The point cloud may be either structured (e.g. from a CT scan), or unstructured (e.g. from a laser scanner). In the first case, where the input is structured, a series of B-Spline contours is computed to represent the boundaries of the cross sections, and the surface of the model is subsequently easily reconstructed. In the second case, where the input is not structured, we extract the required information by (a) slicing the point cloud into cross sections, (b) projecting the points of each slice to its corresponding cross section, and (c) producing a  $G^0$  feature poly-line that represents the boundary of the cross sections, which is thereafter interpolated by a closed, smooth and continuous  $G^1$  B-Spline curve. This step uses properties of the convex hull and the Voronoi diagram and was described in detail in [10].

A suite of editing operators has been developed, using high level feature information. They can be applied either locally to a selected part of the model, or globally to the entire model. A set of free-form transformations have been presented in [11], which deform parts of the model using homogeneous transformation matrices. However, their applicability is limited as their complexity makes them unfit for end-users of CAD systems.

In our current work we have built on a new feature called the curve of centroids, and introduce a new set of editing operators that makes use of this feature. A set of user-defined parameters is used to control the editing process, making the new set of operators easy to use.

#### Editing Operators:

Our method offers a set of editing operators that perform deformations on the model using high level parameters. To facilitate editing we derive a skeleton of the model by means of a NURBS curve that interpolates all slice centroids. This enables the application for local or global transformations using this skeleton as a reference. These transformations may be applied as a whole, or change as we move along the skeleton. We call this skeleton the **curve of centroids** (Fig. 1). A series of editing operators have been implemented that make use of this feature, in order to apply modifications, such as changing the shape, the position or the thickness of a selected part:

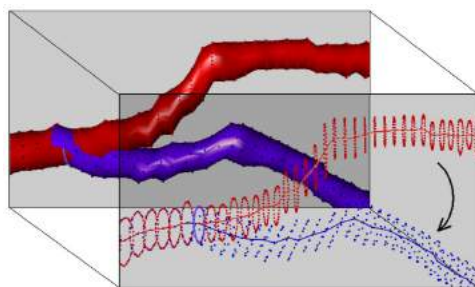


Fig. 1: Curve of Centroids: **Front:** The curve that interpolates the centroids of the slices can be edited to perform deformations on the model (Red: initial model - Blue: deformed model. **Back:** The surface of the model is adjusted according to the modification of the curve of centroids.

The **alignment operator** (Fig.2) is used to re-align the cross-sections to the curve of centroids. It may be used in combination to another operator, to improve the quality of the model, or to avoid connectivity problems. This may be required in cases where the direction of the curve is significantly different than the slicing direction.

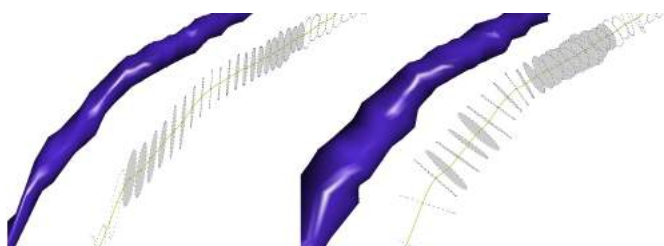


Fig. 2: Alignment Operator: It is used to re-align the selected cross sections to the curve of centroids.

The **displacement operator** (Fig. 3) performs a translation, rotation and/or scaling of the selected cross-sections according to a point of reference. The adjacent cross-sections ( $C_0..C_1$  and  $C_2..C_3$ ) are also partially deformed to preserve their connectivity with the displaced region ( $C_1..C_2$ ).

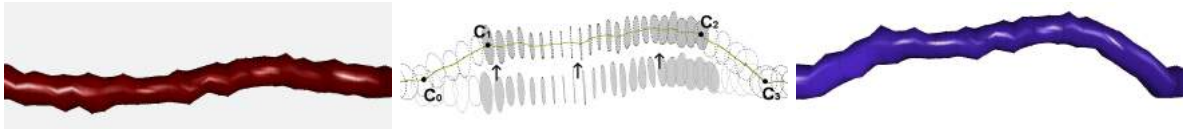


Fig. 3: Displacement Operator: It can be used for translation, rotation and/or scaling. **Left:** The initial model in red. **Center** Details of the operator. **Right** The edited model in blue.

The selected cross-sections may also be stretched according to the parameters of the **elastic operator** (Fig. 4). The surface of the model always follows the transformation of the curve of centroids.

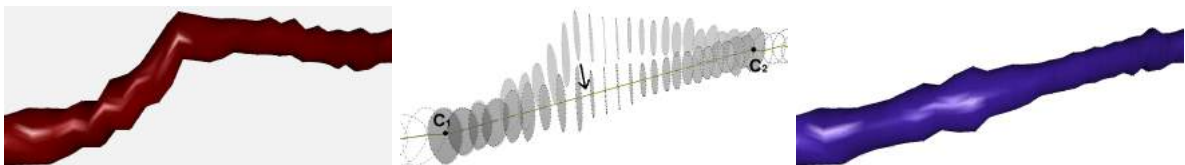


Fig. 4: Deformations with the elastic operator. **Left:** The initial model. **Center:** The transformation. **Right:** The edited model.

The thickness of a part may be modified with the use of the **inflation operator** (Fig. 5). The selected cross-sections are scaled around their centroids, while the curve of centroids remains unaffected. The neighboring cross-sections are also updated, to preserve their connectivity. The parameters are different from the displacement operator, as in this case the centroids are unaffected by the transformation, whereas in the displacement operator a different point of reference may be used.

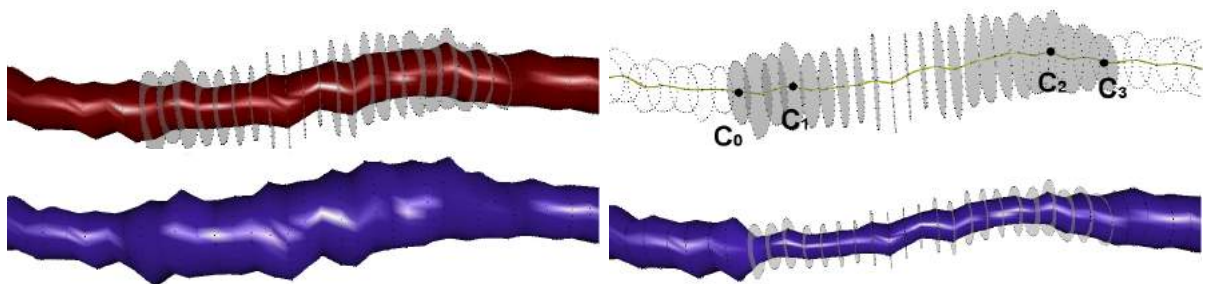


Fig. 5: The curve of centroids remains unaffected by the transformation, but the points of the selected cross sections are scaled around their centroids. **Top Left:** The initial model, with the selected cross sections inflated. **Top Right:** The transformation: From  $C_1$  to  $C_2$  the cross sections are completely scaled. From centroid  $C_0$  to  $C_1$  and from  $C_2$  to  $C_3$ , scaling is applied proportionally. **Bottom Left:** The inflated model. **Bottom Right:** For  $s < 1$  the operator causes deflation.

The curve of centroids may also be replaced by a user-specified **parametric curve** (Fig. 6). In this case the entire model is reshaped according to the given curve. The details of the surface are preserved.

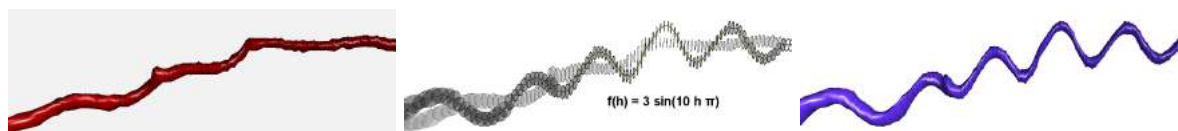


Fig. 6: Editing the cross sections with a parametric function. Each cross section is positioned on a path defined by a mathematical expression according to its index in the selected region. Here the curve of centroids is placed on a sine function. **Left:** The initial model. **Center:** The transformation. **Right:** The edited model.

To validate the quality of the results of our editing tool-set, we tried to apply similar modifications on our model, using 3ds Max. Figure 7 illustrates such an example, in which we tried to apply a  $\sin(\theta)$  function, which is actually a translation of each cross section and creates the effect of a large wave. The problem in 3ds Max is that the translation is actually performed by dragging the selected control points with the mouse. This may seem a user friendly solution, but it lacks in accuracy of the results. There is an option for setting specific transformations on the selected control points, but this option requires the manipulation of individual points. In any case, 3ds Max does not offer a direct tool for applying a proportional transformation, such as the one we have developed. Therefore, our editing tool offers a powerful feature, which allows for applying parametric transformations with a single deformation.

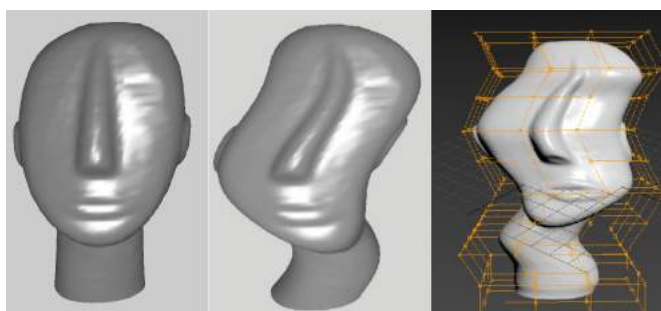


Fig. 7: Comparison with 3ds Max. **Left:** A Model of a Cycladean idol, **Center:** The model edited with our method using a parametric function  $\sinh$ , **Right:** The model edited by hand in 3ds Max.

A video with a visual demonstration of the operators described in this paper is also available here: <https://www.youtube.com/watch?v=JeW-bh0k-GA?vq=hd720>

### Conclusions:

We have introduced a toolset of editing operators for modifying free-form models of cross sectional datasets addressed to various applications, such as medical simulations. The modifications performed on the model resemble the deformation of the arterial tissue in a bypass or angioplastic surgery. Our editing operators are suitable for such applications, because they make use of a high level property we extract from the sliced point cloud, i.e. the interpolating curve of centroids. This curve is a key feature on models such as arteries, which are used as input datasets in the respective medical applications.

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