Surface Manipulation Using a Paper Sculpture Metaphor

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ABSTRACT

The creation of 3D computer models is essential for many applications in science, engineering and arts and is frequently performed by untrained users. However, creating an intuitive mapping between 2D input and 3D models is a non-trivial task and is reflected in the difficulty novices have in using current 3D modelling software. Using metaphors of paper sculpture and pen sketching, our gesture based modelling tool simplifies this interaction mapping. More intuitive object manipulation means that an otherwise complex model can be rapidly created by an inexperienced, non-artistic user. To demonstrate this, we have chosen to model orchid flowers as they offer considerable challenges to the artist due to their complexity of shape and detail, especially the petal surfaces which vary a great deal in curvature.

1. INTRODUCTION

Traditional 3D modeling applications offer tools powerful enough to model a diverse range of creations but, unfortunately, many potential users can be overwhelmed by the enormous flexibility associated with them. One of the difficulties of these tools for novice users is that they are not based on any real world metaphor. Pencil and paper sketching, for example, is one of the most simplest yet effective ways to exercise some artistry, yet few modelling tools support digital pens (styluses) to any significant degree. Other metaphors, such as paper sculpting, can provide an interaction that makes it easier for users to predict the results of an action. We are exploring a blend of paper sculpting and sketching (where sketched lines represent paper cutouts) using a stylus, as an aid to novice 3D modelling interaction.

The proposed interface combining sketching and paper sculpting has the goal of easing the transition from the initial conceptual design into the final 3D model. This proposal is supported by two observations: first, many users find it hard to create 3D shapes which correspond to multiple 2D views and second, they find it difficult to understand the relationship between a surface's parameters (controls) and the resulting shape.

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2D sketching is a quick, intuitive and easy way to indicate 3D shapes. Using this input and mapping it automatically into a 3D shape will help users who do not have sufficient artistic skills or find it difficult to mentally conceptualise 3D shapes. In order to provide a similar intuitive way for modifying the resulting 3D shape we extend the metaphor of sketching on paper and allow the user to interact with it as if sculpting paper. This is a natural process children perform from an early age and it facilitates the mental transition from a 2D to a 3D object since the paper used in this metaphor is a 2D object.

A mixture of drawing and sculpting metaphors allows the user to intuitively interact with the model because they subconsciously predict the effect their actions would have on the model based on their real world experiences. To realise this idea we have chosen to model orchid flowers as they offer great challenges to the artist due to their complexity of shape and detail, especially the petal surfaces which vary significantly in curvature.

2. RELATED WORK

Our orchid modeller draws on work from three main areas of research: sketch based modelling, flower modelling and surface deformation.

Sketch-based tools have been explored for a number of 3D modelling domains such as transformation from sketch to structured CAD projects. SKETCH [15] was an early research project that turned a conceptualised sketch into a digitised 3D scene. It exploits the ease of design afforded by sketching and the ability to change viewing angles with the 3D digital medium. 3D primitives are constructed with basic pen strokes which are then extended to basic 3D objects. Complex objects are constructed using a combination of primitives.

A common strategy for creating free form 3D objects from sketch input is to create simple objects and then either combine or deform them into other shapes. Igarishi's Teddy application created a 3D object by inflating 2D sketches based on the width of the 2D object [4]. With a combination of cutting gestures and combining objects together, it is possible to create complex, inflated (blobby) shapes. Further research projects using similar inflation metaphors join objects smoothly together and afford shape alterations by re-sketching parts of the silhouette [8] or by inferring 3D geometry by interpreting overlapping sketch lines [9].

Other authors [12], [3] have shown that complex 3D objects can be edited using stylus strokes that retrace an object's silhouette. The modification of a model's silhouette subsequently rescales it so that it remaps itself to the new silhouette.

An algorithmic approach to modelling plants is suggested by Prusinkiewicz and Lindenmayer whereby plant structures are constructed using rule based logic [14]. This abstract, bottom up is, however, non-intuitive and difficult to control without extensive experience, so alternative sketch-based modelling of plants has been explored [11], [1]. Constraints can help with automatically creating a 3D structure, such as the assumption that branches seek to be as far away from their neighbour branches as possible [13]. Ijiri et. al. have shown that an effective way of creating a realistic flower is to sketch and then edit each individual flower component (petals, flower head etc), and then combine them together to form the complete flower model [6].

In order to make the flower modelling process more an artistic exercise, it has also been shown that a user can sketch a plant in its entirety, and then have each of its sketched components replaced with 3D equivalents [5].

Although petal like surfaces can be created from the Teddy 'blobs' by creating the blob and then cutting it like a potato chip, it deviates too far from what would be intuitive to a user. The flower modellers by Ijiri et. al. offer a much better alternative but their petals are restricted to a silhouette that doesn't form large concavities; ideally a user can sketch a petal of arbitrary shape. Another limitation is that petal curvature can only be altered by a series of modifying strokes that displace the vertices. We believe that there are more intuitive ways of modifying the curvature of petal-like surfaces.

3. OUR APPROACH

Paper is thin, which makes it an ideal metaphor for 3D modelling of objects that consist of thin surfaces such as flowers. Our approach uses metaphors of paper sculpture techniques whereby the user's sketch is a paper cut out that gets sculpted by folding, crimping and indenting it.

Paper is a widely used artistic medium, not just because of its prevalence but also because of its flexibility as a modelling medium. One of the most well known paper crafts is origami, but there is more to paper sculpting than just folding hard edges.

Paper can be cut, torn either with or against the grain, creased along either a straight or curved line, coiled/rolled, cut to form textured patterns by utilizing light sources, joined together using tabbing, layered in relief, crimped (forming curves by cutting the paper and then folding it in on itself), impressing the paper and by curling edges [7]. All of these can serve as metaphors for virtual modelling.

3.1 Interaction

Many of these aforementioned paper sculpting techniques can be applied to surface manipulation to facilitate predictable user interaction. The primary techniques are the ability to cut, curve and crease paper so we have explored how these metaphors can be used for manipulating surfaces on the computer.

Besides the inherent difficulties with managing 3D objects in a 2D space, there is also the problem of working with a single mouse cursor. We are essentially paper sculpting with one hand. With one hand, we have to take a piece of paper, cut it to shape and then sculpt it by adjusting its curvature. By blending the sketching and paper sculpting metaphors together, simple interaction is achieved.

Here is an example of how the user could create a petal of an orchid. First the user draws the outline of the petal. The region enclosed by the sketch can be interpreted as a flat object cut out of a sheet of paper. Immediately the software generates and displays possible fold lines. The user selects part of the cut out with the mouse cursor and drags/pulls at it. As a result, the selected subpart will fold about an axis formed depending on the geometry of the cut out.

Since mouse input only gives 2D coordinates we must find a way to specify movements orthogonal to the screen during folding. Since a fold backwards often leads to visibility problems due to hidden surfaces our applications always interprets mouse drags as a pulling operation out from the screen rather than deeper into it.

3.2 Geometry

The user requires an intuitive way to curve their original shape. There are two generalized ways of achieving this:

1. Define a sub part of a surface to be curved and then curve it about the rest of the surface.
2. Have the program infer areas that can be curved and then curve these areas about the rest of the surface.

Both of these ideas are perfectly valid for paper sculpting. We can achieve the first technique by creasing the paper, thus creating an artificial axis from which the two areas about this axis rotate about. Creasing and folding don't have to be restricted to a straight axis either.

The second technique takes advantage of a 2D geometric property that defines these foldable axes automatically. Halverston [2] determined that silhouettes are especially important in determining objects. This is made evident when children draw the most salient silhouette of objects such as animals. By taking such a silhouette, Marr and Nishihara [10] noted that the concave sections of objects define the subparts of an object. As can be seen in figure 3, it is these subparts that define the foldable areas. The axes about which they fold is defined by the path that joins one concave curve to the other.

These geometric properties can be applied to paper sculpting. By picking up the paper from one of the subparts of the object, the subpart then naturally curves about the axis

Figure 1: This selection of images shows how the curvature of a real orchid petal (left) can be represented with paper (centre) and with a digital model that uses paper folding properties.

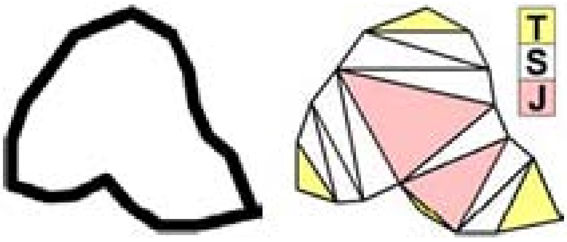


Figure 2: The triangulation strategy used by "Teddy" defines different triangles as Terminal (T), Sleeve (S) or Junction (J) depending on how many sides are shared with the silhouette [4].

defined by the concave points of the silhouette that define that subpart (figure 1).

The ability for the user to relate to this object subdivision and paper style curvature is the basis of this interaction. Using these geometric properties a predictable response will occur when the user interacts with the surfaces.

3.3 Implementation

Realisation of these subparts was achieved with Delaunay triangulation and some of the skeletonisation strategies used in the "Teddy" application [4]. The "Teddy" tool defines 3D shapes from 2D sketches by triangulating a closed sketch curve and computing a skeleton from it. The vertices of the sketch curve are then rotated around the skeleton resulting in a 3D shape whose projection is the original sketch. During the process of constructing the skeleton the triangles that make up the triangulation are defined as either a terminal, sleeve or junction triangle where each triangle type has either one, two or no shared edges to the silhouette respectively (see figure 2).

The edges that make up the junction triangle define the folding axes of a simple surface, thus isolating the sub parts of the overall surface (see figure 3). Some of the subparts become impractically small so the pruning method used in Teddy for eliminating insignificant parts of the skeleton was applied here.

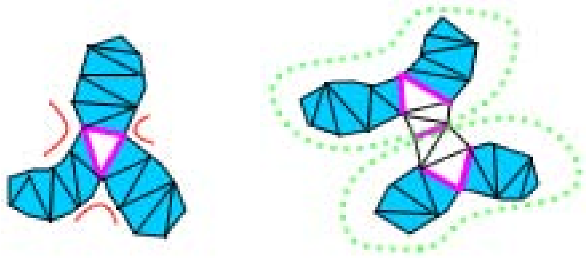
More complex shapes create complications but the solutions still draw on the geometric properties:

- If the triangulated surface contains multiple junction triangles then consider a skeleton between pairs of junction triangles. The fold axis will be the shortest line to the silhouette that is orthogonal to the skeleton (figure 3(b)).
- Sometimes the pruning algorithm eliminates all the junction triangles. However, there is usually at least one pre-pruning junction triangle that is larger and shaped closer to an equilateral. The shortest edge of this triangle is the significant fold axis. Note that size and closeness to being equilateral is a property of most of the junction triangles.
- There is a special case when a surface is a consistent width and results in no junction triangles. If the surface has no concave areas then it won't be able to utilise the geometric properties discussed in section 3.2. However, a surface in the shape of a letter S or U does have such concavities and should be able to fold about certain points. Because such shapes don't exist in orchid flowers, it has been ignored for now.

3.4 Discussion

By adopting a paper sculpture metaphor, we believe we can facilitate the task of creating and manipulating the flat surfaces required by 3D flower models. However, there are still some points that should be addressed with regards to expanding the functionality and highlighting some of the issues with the interaction strategies.

The interaction becomes less clear when the user wishes to fold a large subpart that encapsulates smaller subparts (figure 3(b)). If the user selects one of the smaller subparts with the intention of folding the larger subpart, the application



(a) (b)

Figure 3: 3(a) shows a junction triangle (purple) that stretches between concave sections (red), defining the subparts (blue). For more complex surfaces a fold axis between two junction triangles is identified as the shortest distance across the surface. The green dashed lines of 3(b) represent encapsulating subparts.

must be able to realise this. The only way to differentiate between the two areas is by the overlapping and non-overlapping regions. Expecting the user to select the non overlapping region in order to get the desired result may be optimistic. Another possible solution is to have the larger encapsulating subpart begin to fold once the smaller subpart has been folded to some critical angle.

Real orchid petals can form a curvature that is very difficult to sculpt with paper unless one was to 'collapse' the paper by crumpling it or using multiple tiny zigzag-like folds. Modelling such orchid surfaces would therefore break the paper sculpting metaphor because simple paper folds maintain surface area.

We have implemented the cutting and folding metaphors but there are a multitude of other paper sculpting techniques that can enrich the user interaction possibilities. Our next step is to conduct usability testing in order to ascertain the effectiveness of the metaphor. The eventual goal is to utilize these techniques for the rapid creation of orchid flowers, as these represent a good example of high curvature surfaces.

4. CONCLUSION

Paper sculpture is a promising metaphor to assist in the creation and manipulation of complex surfaces such as those used in flower modelling. By utilizing geometric properties and the sculptural qualities of paper, it is possible to make a more intuitive 2D to 3D mapping. Traditional 3D modelling tools are complex so such techniques go some way to assist both novice and expert users to rapidly create complex models.

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