

Computer Aided Ferret Design

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Abstract

In this paper, we explore several extensions to surface pasting. In particular, using the task of modelling a ferret as a driving force, we improved the user interface for cylindrical pasting; we looked at methods for reducing the distortion of pasted features; and we created a method for pasting trimmed features to allow for features that do not have the rectilinear shape of standard pasting.

1 Introduction

Ferrets are the only domesticated member of the mustelid family [7]. Because they need to be able to turn easily in extremely confined spaces, they are long and narrow, with a body that can assume almost any curved shape. Thus, splines are the natural tool for modelling their bodies (Figure 1). Of course, modelling the ferret’s limbs and masked face is equally important, because they express the ferret’s personality. Surface pasting is the natural method for adding them to a spline-defined body. Considering the large range of expressive postures a ferret can assume, modelling and animating the ferret is an ideal challenge problem for spline-based surface pasting.



Figure 1. Birch, a ferret? A spline?

Surface pasting is one of many tools used by artists in the time-consuming task of creating 3D models. It is conceptually similar to modelling in clay; features, like arms, are added to a basic shape, like a torso; the process is pro-

gressive, as hands are added to arms, and fingers to hands. The physics of clay imposes a subtle dependence between feature and basic shape, which evolves as the artist refines the model. Surface pasting provides a model with very similar properties, which leverages the artist’s extensive training and experience with clay. Let us now compare surface pasting to modelling in clay.

Modelling a ferret in clay we begin by constructing a tubular body, with the head added to one end and the tail to the other. The legs are then modelled as elongated tubes and attached to the body. Other features, like eyes and ears are progressively added, until the ferret is complete.

When modelling the same ferret using surface pasting, we expect to follow a similar process. First, we create a tubular body with a generalized cylinder as the base surface on which to stick features. With patch pasting, features are limited to rectangular bumps, not the ideal shape for modelling arms, legs, eyes or ears. The underlying rectangular structure of the features is often visible as well. Each feature warps to the curvature of the surface it is pasted on, so that the result is not always predictable. Figure 2 shows a ferret model made using patch pasting. Note the rectangular shape where the hind legs join the body and the awkwardness of limbs model with bumps. The singularity of the ferret face appears where the end curve of the base cylinder was shrunk to a point.

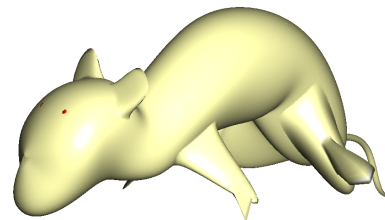


Figure 2. A patch pasting ferret model.

Based on the deficiencies we just described, we set out to improve surface pasting as follows: find a better way to create tubular shapes such as arms or legs; allow arbitrary shaped bumps as features; and maintain better control over

the warping of the features. With the introduction of cylindrical pasting [6], arms and legs could be modelled more easily. However, the user interface aspects of making and pasting cylinders need further exploration before this technique becomes useful as a modelling tool.

With these goals in mind, we made the following changes:

- First, we created a new user interface for cylindrical pasting. While the old interface required the user to manipulate surface domains, with the new user interface the user works entirely in the range space. Further, we added techniques for manipulating the spine of the cylinders, giving us a form of generalized cylinder.
- Second, we modified the patch pasting method to reduce the amount of distortion in the pasted patch.
- Third, we applied the cylindrical pasting technique to paste trimmed surfaces. The original pasting technique was restricted to rectilinear patches; with our extension to trimmed patches, the feature surfaces can have boundaries of arbitrary shape.

In the next section, we explain the basics of surface pasting and discuss what had been done with regards to patches and cylinders. Section 3 discusses world space cylindrical pasting. Section 4 shows how we took the changes we made to cylindrical pasting and apply them to pasting patches to reduce warping. Section 5 look at how we extend rectangular patch pasting to allow pasting of arbitrary shaped surfaces. Section 6 puts together all the tools we have created for building ferrets. We end with our thoughts on this project in section 7.

2 Surface pasting basics

Surface pasting, a technique developed by Bartels and Forsey [1, 2], consists of adding a tensor product B-spline surface, called a feature, onto a tensor product B-spline surface hierarchy, known as the base surface.

There are three categories of control points to be pasted: boundary control points, second layer control points, and interior control points. Each category is pasted to achieve a different goal. The boundary points are pasted to achieve C^0 continuity between the base and the feature surface. The second layer of control points are pasted to achieve C^1 continuity between the base and the feature. And the remaining interior control points are pasted to give the pasted feature a shape that reflects the shape of both the unpasted feature and the base surface. Regardless of the pasting method (patch pasting or cylindrical pasting), the control points need to be pasted with these goals in mind.

In standard surface pasting, the feature surface is represented as a Greville displacement surface using a diffuse

coordinate system [2]. In a Greville displacement, the domain is embedded in the range space. Each control point $C_{i,j}$ of the feature is expressed as an origin and a displacement vector with respect to its own local coordinate frame $F_{i,j} = \{P, \vec{i}, \vec{j}, \vec{k}\}$. The origin of each control point is its corresponding Greville point of the feature domain. Pasting is done by first mapping the feature domain into the base domain. For each transformed Greville point in the feature, we evaluate its corresponding location on the base surface, which is used as the new origin for its control point. The frame basis for the local coordinate frame is constructed from the partial derivatives evaluated at the Greville point. Figure 3 illustrates basic patch pasting.

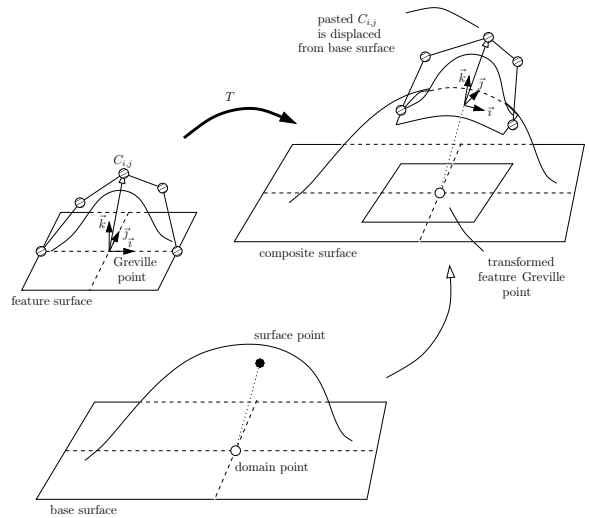


Figure 3. Standard surface pasting.

Surface pasting is an approximation technique only. When the boundary control points have $\vec{0}$ displacements, they lie exactly on the base surface and the boundary of the feature is approximately on the base. For a feature to mold itself to the base, we can achieve approximate C^1 continuity by also giving the inner layer of control points $\vec{0}$ displacement.

In the initial standard pasting user interface, the feature was pasted onto the base via manipulation of the domain. This method has been extended to a more direct user interface (projective surface pasting) by Chan [4] and Side Effects [8]. In projective surface pasting, instead of mapping the feature domain directly onto the base domain, we start by projecting the four corners of the rectangular feature onto the base surface. By inverting the surface points, we form a quadrilateral in the base domain from which the feature domain is mapped via a bilinear transformation. Projective bilinear pasting not only provides a more intuitive user interface, but extends surface pasting by allowing for skewed feature domains.

A variation of pasting patches is pasting cylinders [5, 6], a method that integrates techniques of parametric trimline-base blending into surface pasting. A cylindrical tensor product B-spline surface is the feature to be pasted. One of the two edges of the feature domain is mapped onto a circle in the base domain. This edge represents a layer of control points at one end of the cylinder. For a smoother join, the next layer of control points is mapped onto an inner circle for approximate C^1 continuity.

3 Projective cylindrical pasting

The first thing we investigated was creating a more flexible cylindrical pasting paradigm. The ferret’s long, sinuous body and tail, as well as its limbs, can be more closely represented by generalized cylinders [3] than by bumps. Each cylinder is built around a 3D spine curve. We devised a method to paste the feature cylinder onto a base surface in world space using a single point on the base and the cylinder’s spine as guides. The feature cylinder is pasted on to the base by projection in world space rather than domain pasting. Figure 4 illustrates the following pasting process:

1. First, the user clicks on a surface B , the base surface for pasting. The location of the surface point where the user clicked, $P = B(u, v)$, is determined by intersecting a ray, from the eye point to the coordinates corresponding to the selected pixel, with the spline surface.

An initial coordinate frame $F = \{P, \vec{i}, \vec{j}, \vec{k}\}$ is built such that

$$\begin{aligned} \vec{i} &= \frac{\partial B}{\partial u} \\ \vec{j} &= \frac{\partial B}{\partial v} - \left(\frac{\partial B}{\partial v} \cdot \vec{i} \right) \times \vec{i} \\ \vec{k} &= \vec{i} \times \vec{j}. \end{aligned}$$

The set of equations used to build the vectors ensure that they form an orthogonal frame, which we normalize to get an orthonormal frame. An orthonormal frame is needed so we can use it to match the coordinate frame, also an orthonormal frame, on the feature cylinder’s spine. The default direction for pasting is \vec{k} , which is normal to the surface at point P .

2. Next, the user clicks on one end of a cylinder. The cylinder is transformed by aligning the tangent vector T at its spine’s selected end to the coordinate frame’s basis vector \vec{k} on the base surface, and the remaining basis vectors for the spine’s end frame are aligned with \vec{i} and \vec{j} . If we are pasting the end of the cylinder, the spine’s frame will have to be negated before alignment.

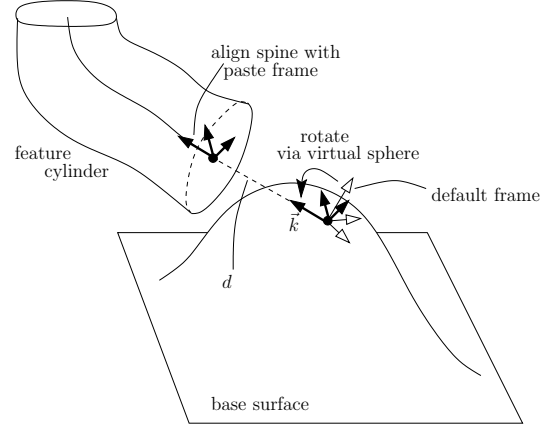


Figure 4. Projective cylindrical paste.

3. The initial frame F is built only as a guide; it can be rotated via a virtual sphere interface. The cylinder’s selected end is aligned with the paste frame as it is rotated. The user can also specify a distance d at which the cylinder end is displaced from the surface. See figure 4 for details.
4. Finally, we project the end layer of control points onto the base surface along the direction of the paste vector \vec{k} and find the points on the base that intersect with the projected lines. This last layer of control points is then moved to the intersection points to achieve an approximate C^0 paste.

The paste may fail for a number of reasons. If any of the projected lines do not hit the base surface, then the paste fails. We also require the intersection point to be at a positive distance from the feature boundary point. The displacement parameter d can be adjusted to meet this condition.

We achieve a smoother paste by modifying the next layer of control points. For each control point in the inner layer, we project it along the paste direction and intersect it with the tangent plane at the pasted location on the base surface for its corresponding boundary control point. The control point is then moved to the intersect location. How smooth the blend appears is determined by the user. If the inner layer of control points lie in the paste direction, the blend will appear to have an approximate C^0 join. For a smoother looking join, the boundary layer of control points should be moved further away from the inner layer. Figure 5 shows the result of a projective cylindrical paste.

4 Centroid projective patch pasting

In standard patch pasting, the feature surface is warped to take on the shape of the base surface. While usually this is

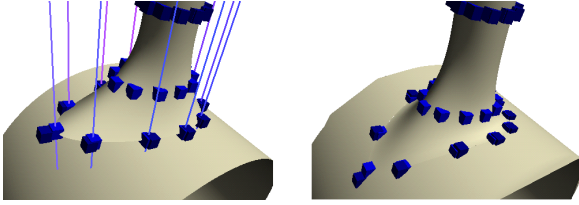


Figure 5. Left: the projected cylinder. Right: the cylinder pasted with C^1 continuity.

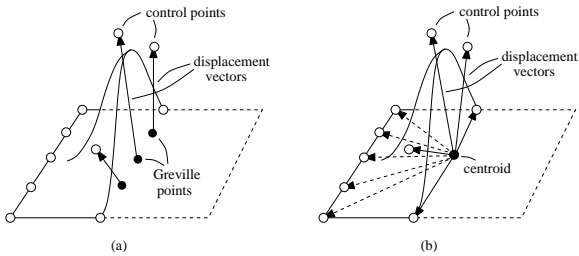


Figure 6. (a) Greville displacement; (b) Centroid displacement

the desired effect, the warping can be excessive when pasting onto a region of high curvature. To minimize distortion in pasting patches, we took the ideas for cylindrical pasting and applied them to patch pasting.

Instead of representing patches as Greville displacement surfaces, we displace their control points from a single central point, and use it as a guide; both methods are illustrated in Figure 6. This pasting interface is similar to the one we use for projective cylindrical pasting. The user selects a paste point and orients its coordinate frame on the base surface. The centroid for the patch is aligned with this coordinate frame. All the boundary points are moved to their projection on the base surface. Since the interior control points of the feature are not mapped with respect to its domain, but displaced according to the pasted centroid, the feature shape only changes at the border. We can also create patches that have irregular borders for pasting, since the entire border is projected.

Figure 7 illustrates the difference between a bilinear projective paste and a centroid projective paste.

5 Trimmed patch pasting

The original pasting technique used tensor product B-splines as the feature surfaces. Tensor product B-spline patches have a rectilinear structure, and while we can move the control points around to create irregular shapes, this is an unintuitive method. Often the shapes of the features we create are not rectangular, but once pasted, the underlying

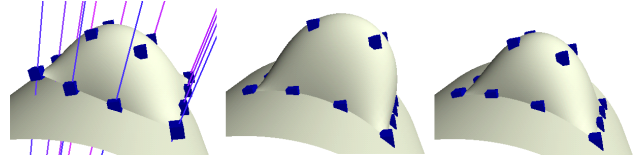


Figure 7. From left to right: unpasted surface; C^0 bilinear projective paste; C^0 centroid projective paste.

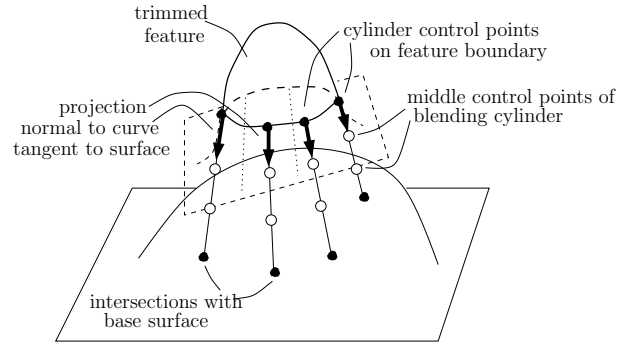


Figure 8. C^0 tangent projective paste.

rectilinear structure becomes prominent, especially at the borders.

A more intuitive way to create an irregular patch is to trim away the unwanted border bits. We can specify a trim curve in the feature domain and create an irregular patch this way. However, the border of this patch may not lie on a plane, and there are no border control points, so it is unclear how to paste this trimmed feature.

We can combine the methods we discussed earlier and use a cylinder to blend the irregular feature with its base surface. The user specifies a trim curve in the feature domain to create an irregular patch. We paste the feature as if we are pasting an untrimmed patch with C^0 continuity. There are two different approaches we can take to create the cubic blending cylinder.

In the tangent projective approach, we take evenly spaced samples along the trimmed feature's domain boundary to generate the closed curve of one end of the cylinder. For each sample s , we calculate the vector \vec{t} normal to the boundary curve that also lies on the tangent plane at s . We project s in the direction of \vec{t} and use the intersection points as the control points for the other end of the cylinder. The two middle layers of control points for the cylinder are created at equal distances between the first and last layer of control points. By construction, the blending cylinder will join with approximate C^1 continuity with the feature, and approximate C^0 continuity with the base. See figure 8 for an illustration.

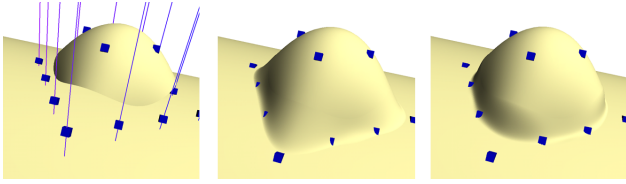


Figure 9. From left to right: unpasted trimmed surface; C^1 tangent projective paste; C^1 parallel projective paste.

To join with approximate C^1 continuity to the base, we need to create a second curve that is larger than the trimmed boundary projection. To do this, we extend s from the feature centroid by a user specified percentage before we do the projection to determine the boundary curve on the base. The next layer of control points is then determined as with a C^1 cylindrical paste.

The tangent projective paste depends on the curvature at the trimmed boundary, which may fluctuate if the control points are moved just a little. The parallel projective method avoids this problem. Instead of projecting lines normal to the feature boundary, we project in the paste direction specified by the paste frame. The blending cylinder created meets with approximate C^0 continuity at both the feature and the base. For a C^1 paste, we extend the trimmed boundary as discussed previously and set the middle layers of control points so that the blending cylinder meets both the feature and base with approximate C^1 continuity.

Figure 9 illustrates the difference between parallel projective paste and tangent projective paste.

6 Putting it all together

In standard and bilinear patch pasting, surfaces can be pasted hierarchically. The respective domains are embedded within one domain space and the relation between features and bases form a directed acyclic graph. When we add cylinders, one domain space is no longer enough. Cylinders are pasted by their ends, which represent one edge of their rectangular domain. Both ends of a cylinder can be pasted, so a graph structure can be achieved. In our implementation, we only allowed pasting where the domain relationships form a tree.

With the improvements we have made, we can extend the pasting paradigm to model a larger set of objects more effectively. Cylinders are useful for modelling limbs and bodies. The ends of a cylinder can be sealed by pasting the cylinder onto a patch, and then trimming away the outside of the paste. For a smooth cap, the outer layer of control points can be pulled towards the centre and a C^1 paste can be used. This method of capping works well for cylinders

made up of non-convex cross sections.

Using centroid projective patch pasting, the user has more control over the warping of the pasted feature. We can adjust how much the feature warps by creating a blend between pasting with bilinear projective patch pasting, or our new method. Finally, we can reduce the visibility of the rectangular structure of the features by trimming the feature to the shape we want and then applying one of our trimmed pasting methods.

7 Conclusions and future work

We have looked at ways to improve surface pasting by using the challenging task of modelling a ferret (Figure 11 as our objective). The process of modeling with our method is illustrated in Figure 10. Initially, we start by modelling a spline that gives the overall shape of the ferret (Figure 10, left), which is then skinned to give the body of the ferret (Figure 10, middle). Pasting is then used to add legs, ear, etc. Figure 10, right, shows a partially completed ferret model, with the control points and Greville points illustrated. The final ferret appears in Figure 12.



Figure 11. Diefenbaker, posing.

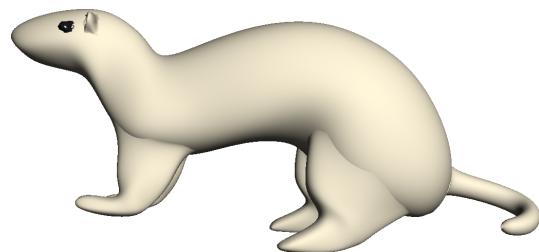


Figure 12. The ferret!

As a second example, we modelled a bone chew toy for our virtual ferret. The bone (shown in Figure 13) is modelled as a cylinder with capped ends. The actual process in modelling the bone was to start with the caps, which had non-convex boundary curves. A cylinder was then attached to the cap, with the resulting bone having non-convex cross sections similar to that of the boundary of the cap.

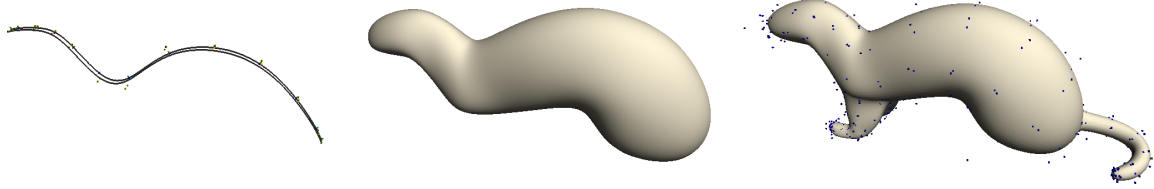


Figure 10. Partially built ferret shown with control points and surface Greville points.

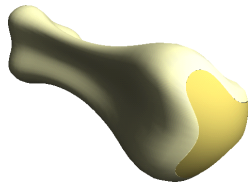


Figure 13. A bone chew toy for the ferret.

While we have focused on modelling ferrets, the modelling tools we have described can be used to model other less interesting shapes. Our projective cylindrical paste provides users with direct control via a world space interface. This method also extends cylindrical pasting to allow for arbitrary shaped domain curves when pasting. We also allow trimming either inside or outside of the base surface, so that we can cap cylinders. Capping with pasting let us closed off cylinders with non-convex surfaces smoothly.

By extending patch pasting to a centroid projective paste, and allowing for a blend with bilinear projective paste, we give users more control over how much the feature should distort according to the base surface. We also implement pasting of trimmed patches via a cylindrical blend, to allow for arbitrary shapes surfaces. Using cylindrical blends this way has an additional advantage: we can paste a simple feature on a more complex base, and smoothness can be handled by increasing the number of knots on the blend rather than the actual feature. Existing pasting methods only works well for refined features on simple bases.

There are still some problems and limitations with our implementation. We have chosen to limit our pasting hierarchy to a tree structure for simplicity, where as existing patch pasting allows for a DAG structure, i.e., each feature can be pasted where surface overlaps. Even with a simplified structure, organizing cylinders can be confusing as each cylinder feature can have two bases. Extending our pasting structure into a general graph, where self looping is allowed would make a wider range of objects possible. We would need to look at extending the spine curve of the cylinder given two paste points for its ends.

With our extensions to surface pasting, we have only created an approximate shape of a ferret. The real ferret is much more complicated and it is unclear when we can

recreate it to our satisfaction. Investigating textures and fur should be done in the future. Further, using cylinders, the models created have a skeletal structure that should aid in animation. We plan to animate the ferret to see how it works.

8 Acknowledgments

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