Modelling and Animating Cartoon Hair

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ABSTRACT

In this paper we present a technique for the modelling and animation of cartoon hair based on its tendency to be drawn and animated in clumps. In our approach the primary shape and motion of the hair is defined by an animated NURBS surface, thus allowing animators greater artistic control. The basis of the hair clumps is formed by key hair curves that are generated along the isocurves of the originating surface and which follow its motion. Profile curves of the hair are then extruded along the length of the key hairs to create the geometry details of the hairdo. A layer of particle dynamics is attached to each individual key hair to achieve some of the animation of the hair automatically. The finished animated hairdo is rendered non-photorealistically in cartoon style shading.

Keywords
Hair modelling, physically-based computer animation, non-photorealistic rendering, cartoon shading.

1. INTRODUCTION

Hair modelling and animation has long been a major obstacle in computer graphics and most recent techniques often leave animators and modellers with little control over the final shape of the character's hairdo. Similarly, when simulating the dynamic properties of hair, control is taken away from the animator and handed over to a set of physics equations. Cartoon hair is often long and flowing and does not always obey the laws of physics. This lack of control inhibits the whole style of the animation and constrains animators' artistic expressions for characters. As it would be impractical to animate every strand of hair on a character's head, or even clumps of hair, the solution proposed by Montoya-Vosmediano and Hammel [Mon02a] was to use a NURBS volume to define the shape and motion of the hair. This would give the modellers and animators control over the final overall shape of the hairstyle without them having to worry about each individual strand of hair.

Whereas the Disney system attempts to fill the volume with realistic looking hair, this paper presents a system that fills it with clumps of hair geometry and renders it non-photorealistically. This will not only drastically reduce rendering time but also give a stylised look to the hair that can be adjusted by a set of design utilities and the shading parameters built in our system.

2. BACKGROUND

Cartoon Hair

Figure 1. Examples of Disney hair (© Disney)

While computer graphics often struggles to cope with hair, artists and animators have long been able to convey the complexity of hair with relatively simple imagery [Tho92a] as shown in Figure 1. These non-photorealistic images are also often more evocative than ones that try to perfectly replicate reality [Kal02a] [Kow99a]. The long, flowing stylised hair that we were interested in is exemplified by the heroines in most animated Disney films [Tho92a]. Although the overall style often varies, the hair is always very clumpy. That is, it seems to consist of a number of clusters of adjoining hairs. These clumps obviously simplify matters for the animators in that they have fewer features to animate but they also simulate the hairs' natural tendency to stick together and form clumps due to static attraction [Kim02a].

There are many different styles in terms of shape but the shading of 3D cartoon hair is quite consistent. They are nearly always shaded with areas of flat colour with highlights and lowlights and an outline. However, the number of different shades of the hairdo varies; Disney usually has one or two whereas other cartoons [Lee78a] often have more and some even have specular highlights.

The animation is perhaps the most interesting aspect of long cartoon hair. Again, animated Disney films give the best examples of this; the use of hair as a dramatic tool. The heroine's hair often swirls around to enhance the action and is almost as important in conveying her emotions as her facial expressions. Bearing this in mind it is no surprise to learn that cartoon hair doesn't obey precisely the laws of physics. If defying gravity serves a theatrical purpose then the animators will keep it floating as long as they need.

Research of traditional cartoon hair led to the following conclusions:

- The implementation should endeavour to preserve the clumpy look of cartoon hair.
- It requires simple flat shading – cartoon shading.
- The animator needs overall control. Animating the hair will be more important than the correctness of the dynamic properties assigned to it.

Computer Generated hair

The creation of convincing human hair is integral to the creation of convincing human characters and the pursuit of achieving realistic hair occupies all aspects of computer graphics; modelling, animation, and rendering.

There are many impressive examples of computer generated hair, [Anj92a] [Ban03a] [Cha02a] [Kim02a] [Ran96a] but these techniques are not applicable to cartoon hair. They are concerned with the problem of how to control hundreds, if not thousands, of hairs while, in our animation system, we have relatively few hair clumps.

Again, there are many different methods of simulating the mechanics of hair. Anjyo [Anj92a] uses projective differential equations while others have used particles connected by rigid springs. Within this area there is the added problem of inter-hair collisions. Most systems do not try to account for this due to the number of hairs involved but there have been a number of papers that propose acceptable approximations [Anj92a] [Ban03a].

As cartoon hairdos do not necessarily obey physical laws, a physically accurate simulation was not a priority. By offering the animator design utilities, the majority of the motion of the hair could be controlled with the quickest rather than the most accurate techniques. The animator would also have maximum control over the motion of the hairstyle and consequently hair interaction and collision detection between hair and character's body becomes an integrated part of the design process.

Non-photorealistic Rendering

The term Non-Photorealistic Rendering (NPR) covers any rendering technique that produces images that do not set out to imitate reality [Gol99a]. Cartoon or cel shading allows 3D animation to be rendered to look like traditional 2D animation. The use of 3D computer graphics in the production of 2D cartoons is becoming more and more common in film and television.

Although there are several different variations on cartoon shading the most commonly used is one called hard shading. This is a two-tone approach that uses standard shading algorithms such as Gouraud shading [Fol96a] to determine two shades of colour; one for the lit part of the object and one for the shaded part. These two shades are calculated in advance and stored as a one-dimensional texture map. The runtime calculation for the shade of any particular vertex then depends on the cosine of the angle between the light and normal vectors [Lak00a]. This method is extremely quick and real time applications of it are now used in computer games.

3. CARTOON HAIR GENERATION

The original SIGGRAPH sketch [Mon02a] presented by Disney described a technique whereby NURBS [Fol96a] volumes are created and shape animated, then filled with instanced hairs based on evaluating the positions of key hairs within the deforming surface. Rather than fill the volume with hair we propose a two-stage approach to generate cartoon hair: that profile curves could be extruded along the length of these key hairs to form new 3D volumes. The basis of the hair clumps is formed by the key hair curves that are generated along the isocurves of the surface and which follow the motion of the originating surface. Profile curves are then extruded along the length of the key hairs to create the geometry details of the hairdo and this geometry would emulate the clumpy look that hand-drawn cartoon hairdos usually possess. Once cartoon rendered, these overlapping clumps would appear to meld together to form a coherent surface. This hair clump geometry would follow the animation of the original NURBS volume but also have a layer of dynamic simulation added to enhance realism.

NURBS Surface Model

The modelling and animation of the NURBS volume that is to be filled with hair is essential to the system. Their importance cannot be underestimated as without a good initial model the generated hairdo will not be convincing and, as the motion of the surface model determines the primary motion of the hair, the same applies to the animation. Although a layer of dynamics is applied, the motion of the originating NURBS volume must mimic hair movement. As such, the skill of the animator would make large contribution to the success of the final animation.

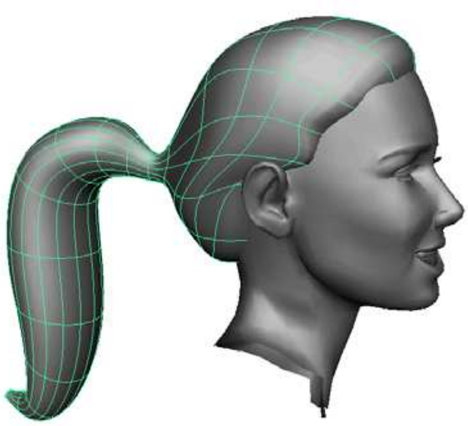

Figure 2. Example hairdo modelled with NURBS surfaces

Figure 2 shows an example hairdo modelled with a NURBS surface. Any type of animation technique to control the NURBS surface can be used, including basic keyframing or shape animation. Although the animation of the NURBS volume is not a simple task, it takes care of the collision detection process, which is one of the major obstacles of computer-generated (CG) hair: Preventing CG hair from passing through a character's head is a highly computationally expensive process that is unnecessary in our system because the initial NURBS surface modelling and animation would simply avoid it.

Key Hair Generation

This process creates the desired number of key hairs along the isocurves of a NURBS surface [Rog90a] defined by:

$$S(u,v) = \frac{\sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)w_{i,j}P_{i,j}}{\sum_{i=0}^{m}\sum_{j=0}^{n} N_{i,p}(u)N_{j,q}(v)w_{i,j}}$$

Where $N_{i,p}$ and $N_{j,q}$ are the B-spline basis functions, $P_{i,j}$ are control points and $w_{i,j}$ is the weight.

The hair generation algorithm takes two optional arguments: the number of hair curves to be created, *n*, and the number of control points each hair curve should have, *p*. These two user-defined variables are used in conjunction with the parametric range (the *u* and *v* values) of the surface to determine the control points of the key hair curves. The incremental step sizes for *u* and *v* are calculated and used to loop through the parametric range to generate the key hair curves. The following algorithms demonstrate the calculation process.

$$vIncr = \frac{(vMax - vMin)}{(n-1)}$$

$$uIncr = \frac{(uMax - uMin)}{(p-1)}$$

Where parameters *vIncr* and *uIncr* are the increment along *v* and *u* respectively, while *vMax*, *uMax*, *vMin* and *uMin* are the maximum and minimum values of *v* and *u* respectively.

For each increment of *v* between *vMin* and *vMax*, new control points are created, defined as:

$$CP_v(u) = S(u,v)$$

Where *u* ranges from *uMin* to *uMax* in steps of *uIncr* and *v* is constant. These control points form the basis of the new key hair curves and are recalculated at every keyframe so they follow the animation of the originating NURBS volume exactly. The length of each key hair curve can be adjusted by altering the *uIncr* parameter. Figure 3 shows the key hair curves generated from the NURBS surface in Figure 2.

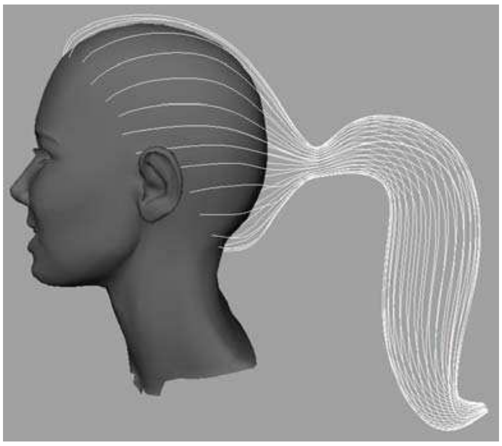

Figure 3. Generated key hair curves

Dynamics

A layer of dynamic simulation not only adds some realism, but also enables the hair clumps to move independently of the original NURBS surface and create a more cartoon-like jagged-edged image. What is traditionally the simplest method is utilised; A particle-spring system where hair is represented as chains of particles. In this method, each control vertex (CV) of a key hair is represented by a particle that has a position, a velocity, a mass, and a goal weight. During the animation, simple Newtonian mechanics [Col80a] are applied to the particles, to create the secondary motion of the hair.

Hair Clump Geometry

Profile curves are extruded along the length of the key hair curves to form hair clumps. The shape of the profile curve is extremely influential on the overall look of the hair. Flatter, more elliptical profile curves give the final hairdo a more coherent surface appearance.

The creation of the hair clump geometry is achieved using the key hair curve as its basis and the corresponding normal vectors of the originating NURBS surface.

Figure 4 shows the three vectors used at each point on the key hair curve to generate the hair clump geometry. *N* is the normal vector of the original NURBS surface, *D* is the direction of the hair curve, and *R* is the cross product of the first two. Therefore the vectors *D* and *R* are calculated as:

$$D = CV_{n+1} - CV_n$$
$$R = N \times D$$

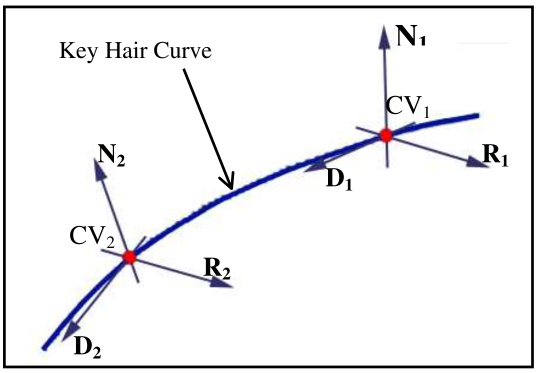

Figure 4. Key hair curve vectors

Using the vectors above and two user-defined parameters, *vr* and *hr*, the calculation of the surface geometry of the hair clump is a simple process. Each new surface control point is the result of moving the original curve in the direction of one of the two vectors *N* or *R*. The distance in the *N* or *R* direction the point is moved is determined by the *hr* and *vr* attributes that represent the vertical and horizontal radii of the profile curve.

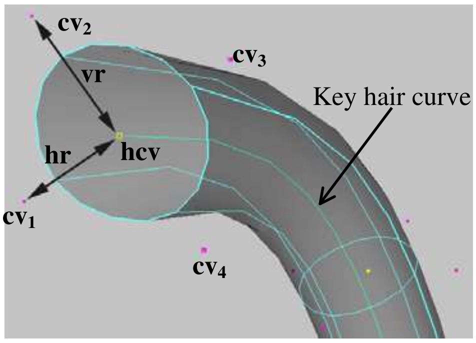

Figure 5. Generated hair clump geometry

Figure 5 shows generated hair clump geometry. As the *N* and *R* vectors are normalised, the *hr* and *vr* parameters are the actual distance that the curve point is moved.

An interface is provided that allows the user to define the *pointiness* of the hair clump, which controls end shape of the hair clumps. The design allows the user to decide where the point begins. It also allows the clump to have no point at all and end in a flat shape.

The *pointiness* variable, *p*, is a double data type between 0 and 1, representing a fraction of the hair's total length. This fraction defines where along the hair curve the point begins. So a *pointiness* of 0 would mean no point, while a *pointiness* of 1 means the point starts at the base of the hair clump, as shown in Figure 6.

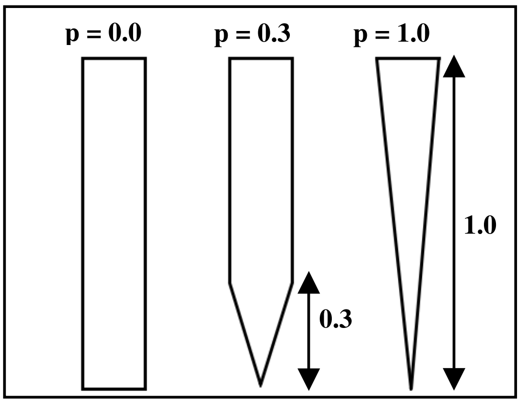

Figure 6. Control of hair clump pointiness

Attribute	Range	A	B	C	D	E
hairLength	0.0 – 1.0	1.0	1.0	1.0	1.0	0.4
numHairPoints	> 3	16	16	16	30	8
vertRadius	> 0.0	0.1	1.0	1.0	1.0	1.0
horizRadius	> 0.0	1.0	1.0	2.0	1.0	1.0
pointiness	0.0 – 1.0	0.0	1.0	0.2	0.2	0.2

Table 1. Hair clump attributes

Figure 7 shows five different variations of hair clump all generated from the same key hair curve using the parameter values shown in Table 1.

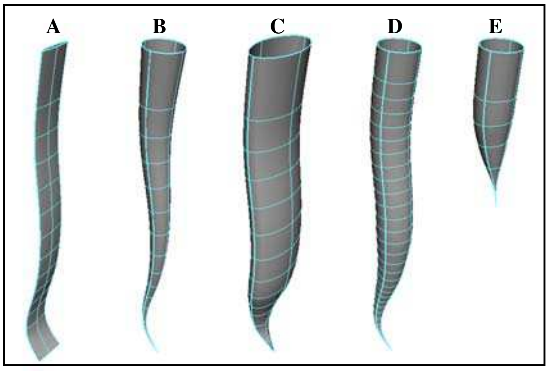

Figure 7. Hair Clump Examples

The bottom image of Figure 8 shows the finished hair clump geometry created from the key hairs shown in the top image, which moves with the animation of the original NURBS surface and also a layer of dynamics.

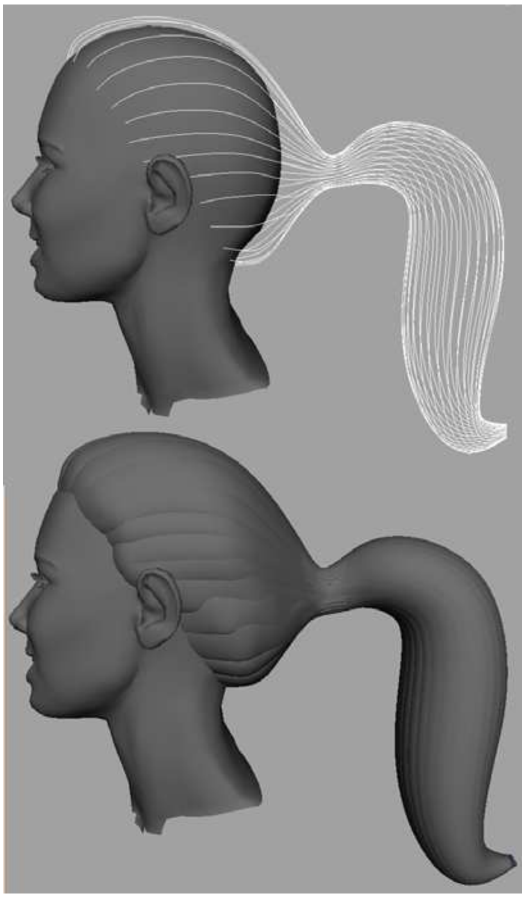

Figure 8. From key hair curves to hair clump geometry

Cartoon Shading

The last part of the implementation is to apply cartoon shading to the hair clumps. There are many styles of cartoon shading. In our implementation, we chose the basic flat shading style with a two-tone approach to highlight the hair clumps and the hairs' natural tendency to stick together, as shown in Figure 9. The complete process of modelling and animating the cartoon hair is demonstrated in Figure 10. Figure 11 and 12 show two different hairstyles animated and cartoon rendered.

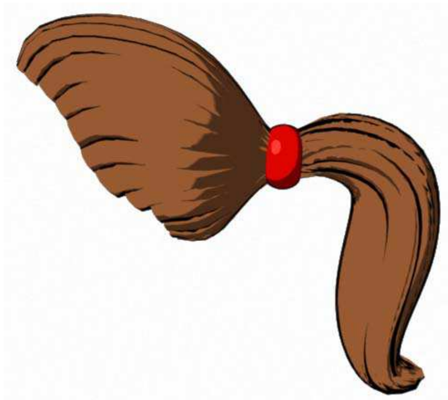

Figure 9. A ponytail hairdo with cartoon shading

4. CONCLUSION AND FUTURE WORK

This paper has presented a system to model and animate carton style hair by defining the desired final shape and primary motion using NURBS surfaces. A layer of dynamic simulation is added to enhance realism.

A simple addition to the current implementation would be a Graphical User Interface to allow the user to interactively fine-tune the hairstyle. As described above, the current implementation's emphasis is on offering a flexible design tool to the animator for cartoon hair generation but another enhancement to our system would be real-time hair animation. The techniques presented in this paper are feasible for real-time. Cartoon shading algorithms are quick enough to render the animation in real-time as done in games. Further work would be required in simplifying the geometry and dynamics sufficiently to allow real-time animation.

Currently the user can control the height, width, length, and pointiness of the hair clumps but these controls could still be improved. The profile curve that is extruded along the key hair curve is presently required to be vertically and horizontally symmetrical. More variations in the shape of this profile curve and the shape of the hair clump point would be give even greater flexibility. Ideally the system would allow the users to draw their own profile curve shape.

5. REFERENCES

[Mon02a] Ramon Montoya-Vosmediano, Mark Hammel, Stylized Flowing Hair Controlled with NURBS Surfaces, SIGGRAPH 2002 Conference Proceedings, pp 254.

[Tho92a] Bob Thomas, Disney's Art of Animation, Welcome Enterprises, Inc. 1992.

[Kal02a] Robert Kalnins, Lee Markosian, Barbara J. Meier, Michael A. Kowalski, Joseph C. Lee, Philip L. Davidson, Matthew Webb, John F. Hughes, Adam Finkelstein, WYSIWYG NPR: Drawing Strokes Directly on 3D Models, SIGGRAPH 2002, pp 755 – 762.

[Kow99a] Michael Kowalski, Lee Markosian, J.D. Northrup, Lubomir Bourdev, Ronen Barzel, Loring S. Holden, John F. Hughes, Art Based Rendering of Fur, Grass, and Trees, SIGGRAPH 1999, pp 433 – 438.

[Lee78a] Stan Lee, John Buscema, How to Draw Comics the Marvel Way, Simon and Schuster, Inc. 1978.

[Anj92a] Ken-ichi Anjyo, Yoshiaki Usami, Tsuneya Kurihara, A Simple Method for Extracting the Natural Beauty of Hair, SIGGRAPH 1992, pp 111 – 120. (4)

[Ban03a] Yosuke Bando, Bing-Yu Chen, Tomoyuki Nishita, Animating Hair with Loosely Connected Particles, Eurographics 2003, pp 411 – 418.

[Cha02a] Johnny T. Chang, Jingyi Jin, Yizhou Yu, A Practical Model for Hair Mutual Interactions, SIGGRAPH Symposium on Computer Animation 2002, pp 73 - 80.

[Kim02a] Tae-Yong Kim, Ulrich Neumann, Interactive Multiresolution Hair Modelling and Editing, SIGGRAPH 2002, pp 620 – 629.

[Ran96a] John Rankin, Richard Hall, A Simple Natralistic Hair Model, SIGGRAPH 1996, pp 5 – 9.

[Gol99a] Dan Goldstein, Intentional Non-Photorealistic Rendering, SIGGRAPH 1999, pp 62 – 63.

[Fol96a] J. D. Foley, A. van Dam, S. K. Feiner, J. F. Hughes, Computer Graphics: Principles and Practice in C (2nd Edition), Addison-Wesley, 1996.

[Lak00a] Adam Lake, Carl Marshall, Mark Harris, Marc Blackstein, Stylized Rendering Techniques For Real-Time 3D Animation, Non-photorealistic Animation and Rendering 2000, pp 13 – 20.

[Col80a] C. D. Collinson, Introductory Mechanics, Edward Arnold Ltd., 1980.

[Rog90a] David F. Rogers, Alan Adams, Mathematical Elements for Computer Graphics (second edition), McGraw-Hill Publishing, 1990.

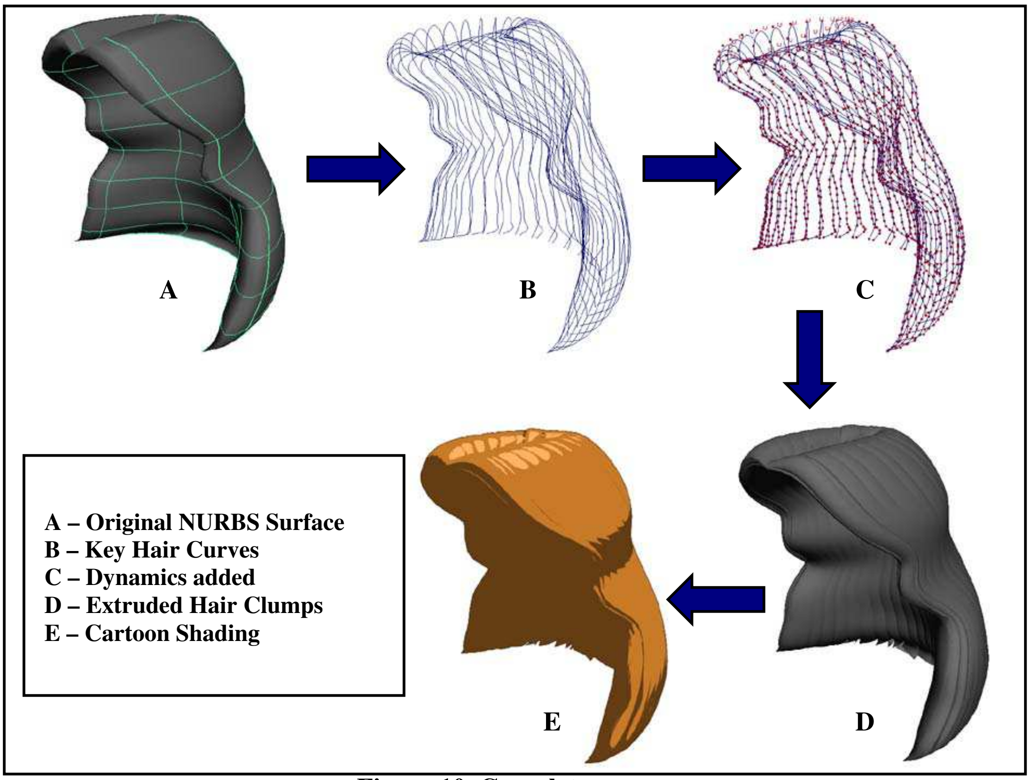

Figure 10. Complete process

Figure 11. An animated ponytail hairstyle

Figure 12. Long hair in the wind