NPR Hair Modeling with Parametric Clumps

Kunio Yamamoto
Department of Artificial Intelligence
Kyushu Institute of Technology
Iizuka, Fukuoka 820–8502, Japan
Email: kunio@ai.kyutech.ac.jp

Toma Shimosoyama
Graduate School of Computer Science
and Systems Engineering
Kyushu Institute of Technology
Iizuka, Fukuoka 820–8502, Japan

Tsukasa Noma
Department of Artificial Intelligence
Kyushu Institute of Technology
Iizuka, Fukuoka 820–8502, Japan
Email: noma@ai.kyutech.ac.jp

***Abstract*—This paper presents a modeling method for NPR hair composed of parametric 3D clumps. The clump parameters are not only for modifying a single clump but also for modifying all or large part of clumps similarly and simultaneously, and then a user can create a hairstyle only by adjusting the parameters. Our experiments show that even naive users can model a variety of hairstyles with little effort.**

1. Introduction

For many years, much attention has been paid to hair modeling due to its importance for the appearance of human characters. While most of the research has been on realistic hair modeling, NPR hair (cartoon hair) has also received considerable attention in the last 15 years, with the increasing interest in comics, cartoons, and games.

In most of the existing approaches of NPR hair modeling, users can model the hairstyle with easy to handle inputs such as overall shape [1], silhouette lines [2], skeletons [3], and 2D image [4]. Once a hairstyle is completed, however, it is hard to change its shape except for minor modifications in [2] and [4]. It means that, to obtain many variations of hairstyles, their design work should be repeated as many times as the number of variations.

Recent virtual communities and games have more and more characters/agents/avatars. To populate such virtual worlds effectively, an efficient hair design method is essential since hair is a key feature for distinguishing among different characters.

This paper presents a modeling method for NPR hair composed of parametric clumps. The clump parameters are not only for modifying a single clump but also for modifying all or large part of clumps simultaneously. All the clumps change their shapes similarly, and a user can thus change the hairstyle after completion by adjusting the parameters, and then instantly produce many variations of hairstyles.

The existing approaches use various models for NPR hair, for example, 3D volume [1] [5] [3], 3D polygon [2], billboard model [6], and 2.5D model [4]. We adopted a hair model composed of clumps as 3D volume. As shown later, our hair model can represent from normal hairstyles to spiky ones, that frequently appear in comics, animations, and games[1]. Our hair model is discussed in Section 4.1.

In our hair model, each clump is modified in shape via four parameters; The FORM parameter transforms the cross section of the clump, as pointiness variable in [1] or thickness/width in [5]. The other three parameters controls the overall shape of the clump; LENGTH, CURL, and PULL lengthens/shortens, rolls/unrolls, and pulls the clump, respectively. They are discussed in Sections 4.1 through 4.4.

The parameters are designed to work similarly for all the clumps so that all the clumps to which the parameters equally applied look natural. The user can thus greatly change the appearance of hairstyle only by adjusting the parameters of all or large part of clumps. This will help users to mass-produce variations of hairstyles. As shown later in the experiments, various hairstyles are created from a single hair model only by adjusting the above parameters. It means that our approach will change the workflow for creating multiple characters.

This paper is organized as follows: Section 2 overviews related research on NPR hair. Section 3 gives an overview of our approach. Section 4 elaborates our approach and, in particular, discusses how our parameters work. The experiments are discussed in Section 5, and finally Section 6 concludes this paper with some comments on future work.

2. Related Work

NPR hair has been studied mainly in three aspects: modeling, rendering, and animation.

In modeling, Noble and Tang [1] modeled clumps of hair from a NURBS volume representing overall hair shape. Cassol et al [5] generated strands from parameters. Sakai and Savchenko [3] proposed blobby hair model from skeletons. These works used 3D volumes as hair clumps/strands.

Some authors adopted simpler/more planar geometric models from the features of cartoon-like images. Mao et al [2] sketched silhouette lines of hair, generated cluster lines, and then represented hair as cluster polygons. Shin et al [6] created billboard strand model from particles. Since planar models have no 3D geometry, sorting of strands can be a

1. Dragon ball and Yo-kai Watch are typical examples.

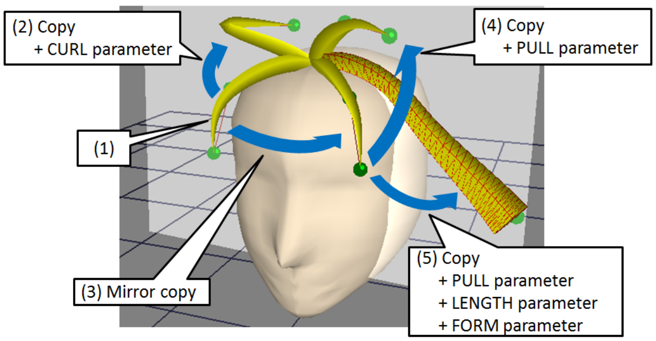

Figure 1. Parameters applied to a clump and their effects.

critical issue. Yeh et al [4] automated layering of strands from a cartoon image for 2.5D modeling of hair.

In rendering, Côté et al [7] and Shin et al [6] proposed methods for specular reflection characteristic of NPR hair. In animation, Sugisaki et al [8] developed a motion retrieval method from a user's sketch.

Parameters have been widely used in modeling hairs and strands from the early stage of hair modeling research (e.g. [9]). To modify completed hairstyle, selected cluster lines were displaced in [2], and length editing and braiding of hair strands were allowed in [4].

To the best of our knowledge, however, parameters appropriate for both local and overall modification of hairstyles have not been proposed yet.

3. Overview

Our hair model is represented as a set of 3D clumps. Figure 1 illustrates how the parameters work on a clump; A user first models a clump (1). Applying CURL parameter to a clump copied from (1), then the new clump curves upward like (2). Next, he/she makes a mirror copy (3) from (1). Applying PULL parameter to a clump copied from (3), the new clump (4) is pulled upward, and if PULL, LENGTH and FORM parameters are applied, the clump is transformed as (5). Note that the user never directly manipulate the control points. He/she adjusted the parameters only.

In our approach, the parameters applied to the clumps work similarly and simultaneously, and then we can control overall hairstyle with the parameters.

4. Method

4.1. Clump and FORM Parameter

A clump is formed along its skeletal curve, whose control points are specified by a user. The skeletal curve of a clump is a piecewise cubic Bezier curve that passes through $\boldsymbol{P}_0, \boldsymbol{P}_1, \boldsymbol{P}_2, ..., \boldsymbol{P}_n$; $\boldsymbol{P}_0$ is fixed at the center of the head, $\boldsymbol{P}_1$ is specified on the scalp, and $\boldsymbol{P}_2, ..., \boldsymbol{P}_n$ are positioned in the air (Figure 2)[2].

2. $\boldsymbol{P}_0$ makes the clump almost perpendicular from the scalp at its root, and the part between $\boldsymbol{P}_0$ and $\boldsymbol{P}_1$ is invisible.

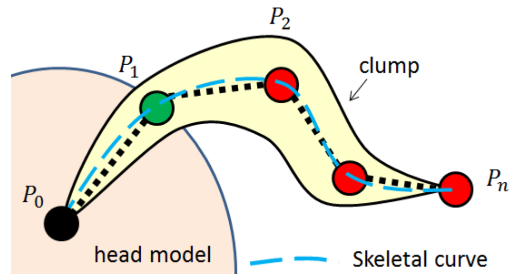

Figure 2. Clump and its skeletal curve.

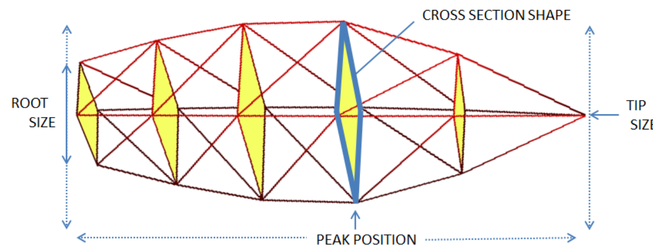

Figure 3. Clump shape and FORM parameter.

A clump has a similar quadrilateral cross section along the skeletal curve. The shape of the cross section (positions of its four vertices) are specified via CROSS SECTION SHAPE parameters. The size of the cross section is continuously scaled along the skeletal curve; it increases from the clump root, maximizes at user-defined PEAK POSITION and then decreases to the clump tip. The scale factors at the clump root ($\boldsymbol{P}_1$), at the clump tip ($\boldsymbol{P}_n$) are given via ROOT SIZE and TIP SIZE parameters, respectively (Figure 3). The above parameters are called FORM parameter.

4.2. LENGTH Parameter

The LENGTH parameter changes the total length of a clump. In designing our system, we considered how the clump shape should be when lengthened/shortened. To shorten the clump, the shape of its root side should be kept the same. On the other hand, to lengthen it, the extension part should reflect the direction around its tip, and also hang down naturally (via gravity). While the above rule may not always be ideal, it is a simple and natural solution.

Suppose that $\boldsymbol{P}_0, \boldsymbol{P}_1, \boldsymbol{P}_2, ..., \boldsymbol{P}_n$ form a skeletal curve, and we call each line segment $\boldsymbol{P}_i\boldsymbol{P}_{i+1}$ a skeletal segment. Let D_k be the length sum of skeletal segments from the hair root $\boldsymbol{P}_1$ to $\boldsymbol{P}_k$: $D_k = \sum_{i=1}^{k-1} |\boldsymbol{P}_i\boldsymbol{P}_{i+1}|$. D_n is thus the length from the root to the tip.

The LENGTH parameter l $(-1 \leq l \leq 1)$ means the ratio of extended/removed part; If $l = -0.5$, the clump length is halved, and if $l = 1$, it is doubled.

We first find the index of the tip control point of the lengthened/shortened skeletal curve:[3]

$$n' = \arg\min_k (D_k > (1 + l)D_n) \quad (1)$$

3. If $l > 0$, n' is obtained while computing $\boldsymbol{P}_j$s with Equation 3.

If $l < 0$, the clump is shortened. A new control point $\boldsymbol{P'}_{n'}$ is defined as:

$$\boldsymbol{P'}_{n'} = \boldsymbol{P}_{n'-1} + \frac{(1+l)D_n - D_{n'-1}}{|\boldsymbol{P}_{n'-1}\boldsymbol{P}_{n'}|}(\boldsymbol{P}_{n'} - \boldsymbol{P}_{n'-1}) \quad (2)$$

Then $\boldsymbol{P}_0, \boldsymbol{P}_1, \boldsymbol{P}_2, ..., \boldsymbol{P}_{n'-1}, \boldsymbol{P'}_{n'}$ are the control points for the skeletal curve of the shortened clump.

If $l > 0$, the clump is lengthened. Control points are added as if they are plotted on a projectile motion curve where the initial speed is the vector between the last two control points $\overrightarrow{\boldsymbol{P}_{n-1}\boldsymbol{P}_n}$. New control points $\boldsymbol{P}_{n+1}, \boldsymbol{P}_{n+2}, ..., \boldsymbol{P}_{n'-1}$ are defined as:

$$\boldsymbol{P}_j = \boldsymbol{P}_n + (\boldsymbol{P}_n - \boldsymbol{P}_{n-1})(j-n) - \begin{pmatrix} 0 \\ \frac{1}{2}g(j-n)^2 \\ 0 \end{pmatrix} \quad (3)$$

where g is a gravitational acceleration. At the tip of the lengthened clump, $\boldsymbol{P'}_{n'}$ is added as a control point:

$$\boldsymbol{P'}_{n'} = \boldsymbol{P}_n + (\boldsymbol{P}_n - \boldsymbol{P}_{n-1})(j'-n) - \begin{pmatrix} 0 \\ \frac{1}{2}g(j'-n)^2 \\ 0 \end{pmatrix} \quad (4)$$

where

$$j' = n' - 1 + \frac{(1+l)D_n - D_{n'-1}}{|\boldsymbol{P}_{n'-1}\boldsymbol{P}_{n'}|} \quad (5)$$

4.3. CURL Parameter

The CURL parameter rolls/unrolls a clump. Considering how to specify the appearance of hair curl, the CURL parameter has curling degree d_c and position-dependent weight w_c, specifying which side (root or tip) bends more.

The CURL parameter (d_c, w_c) is prepared for each of x, y, and z axes in the head coordinate system. In the rest of this subsection, the clump is supposed to be curled around x axis (or its parallel line).

For each control point $\boldsymbol{P}_i$ of a skeletal curve, vector $\overrightarrow{\boldsymbol{P}_i\boldsymbol{P}_{i+1}}$ is rotated relative to $\overrightarrow{\boldsymbol{P}_{i-1}\boldsymbol{P}_i}$ around the rotation axis, parallel to x axis and passing through $\boldsymbol{P}_i$, with an angle θ_i:

$$\theta_i = \left(w_c \frac{i}{n-1} + 1 - \frac{w_c}{2} \right) \frac{\pi}{2} d_c \quad (6)$$

where $-1 \le d_c \le 1$ and $-1 \le w_c \le 1$.

From the above equation, as (the absolute value of) d_c increases, the clump curls more. As w_c increases, the tip side bends more, and vice versa. Figure 4 illustrates how the clump shape reflects the values of (d_c, w_c).

4.4. PULL Parameter

The PULL parameter pulls a clump to a specified direction (x, y, or z). It has pulling degree d_p ($-1 \le d_p \le 1$) and position-dependent weight w_p, specifying how the clump is swollen ($-1 \le w_p \le 1$). In the rest of this subsection, the clump is supposed to be pulled in x direction.

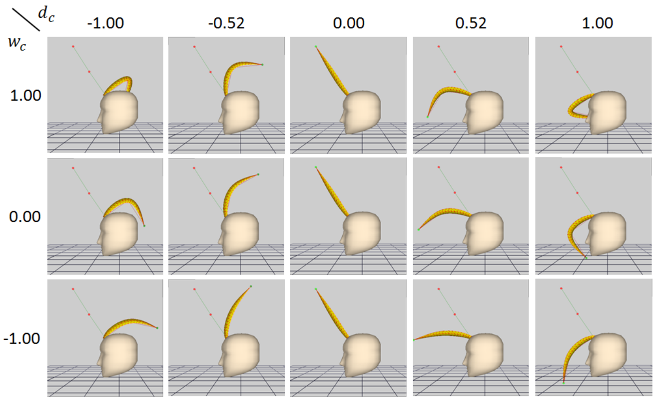

Figure 4. Effects of CURL parameter (d_c, w_c).

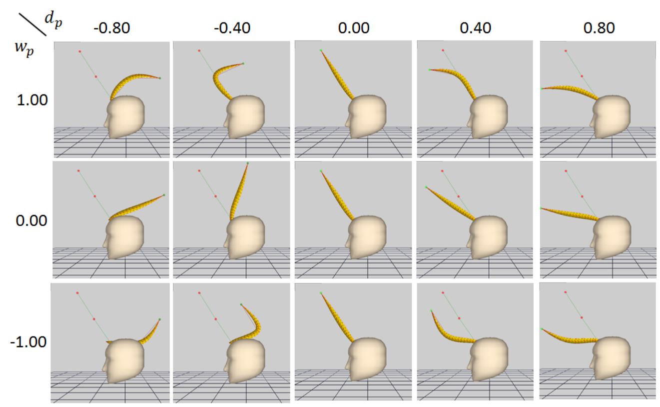

Figure 5. Effects of PULL parameter (d_p, w_p).

If $d_p > 0$ and the angle between $\overrightarrow{\boldsymbol{P}_i\boldsymbol{P}_{i+1}}$ and $(1,0,0)$ is $\tilde{\theta}_i$, $\overrightarrow{\boldsymbol{P}_i\boldsymbol{P}_{i+1}}$ is rotated toward $(1,0,0)$ with the angle θ_i:

$$\theta_i = \begin{cases} \min(\frac{(n-1)d_p + (i-(n-1))w_p}{(1-w_p)(n-1)+w_p}\ \tilde{\theta}_i, 0) & (w_p \ge 0, f_1 > 0) \\ \min(\frac{(n-1)d_p + (i-1)w_p}{(1+w_p)(n-1)-w_p}\ \tilde{\theta}_i, 0) & (w_p < 0, f_2 > 0) \\ 0 & (\text{otherwise}) \end{cases} \quad (7)$$

where

$$\begin{cases} f_1 = |(n-1)d_p| + (i-(n-1))w_p \\ f_2 = |(n-1)d_p| + (i-1)w_p \end{cases} \quad (8)$$

If $d_p < 0$, the vectors are rotated similarly toward $(-1,0,0)$.

From the above equation, as (the absolute value of) d_p increases, the clump is pulled more, and w_p changes the bulge of the skeletal curve. Figure 5 illustrates the effects of (d_p, w_p).

4.5. Application of Multiple Parameters

To apply four types of parameters in our approach, the LENGTH parameter is first applied. The resultant control points are processed via the CURL and PULL parameters separately. Their results are then integrated via interpolation,

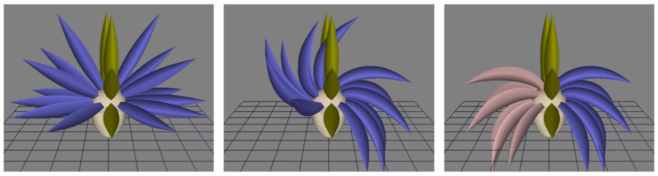

Figure 6. Applying parameter of opposite signs (base model (left), same signs (center), opposite signs (right)).

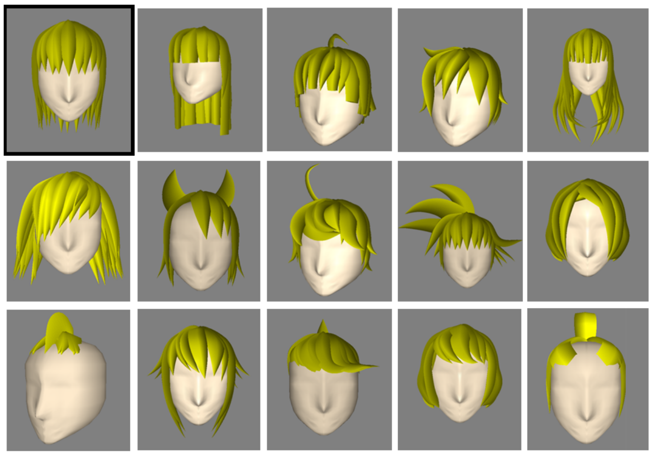

Figure 7. Various hair models created from a single model (top-left, thick-bordered) only by adjusting parameters.

and finally the volumes of clumps are generated via the FORM parameter.

In some of the parameters, their effect on the hair on the left side of the head is opposite to that on the right side. Our UI thus enables us to give parameter values of opposite signs for the left side and the right side (Figure 6).

5. Experiments and Results

We implemented a hair modeling system, where parameters are adjusted with slide bars[4]. In our experiment, to evaluate the effectiveness of our approach, test subjects created hairstyles from a single base model (top-left image in Figure 7) only by adjusting its parameters. Figure 7 shows various results by seven subjects.

Another experiment was on easiness of modification to a target hairstyle. Five test subjects were given a base model and two target images α and β (Figure 8). After a tutorial in a few minutes, three subjects A, B, and C modeled α first and β next, while two subjects D and E modeled β first and then α[5]. As shown in Table 1, all the subjects finished their second trial quicker than the first one, and they finished the second trial in 5 minutes on average.

4. Clumps are first modeled by specifying their control points in 3D.
5. Subjects other than E have no experience using 3D modeling software.

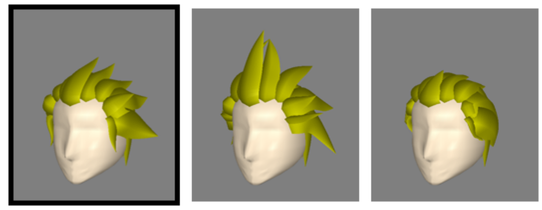

Figure 8. Base model (left) and two target hairstyle images α (center) and β (right).

TABLE 1. TIMES FOR IMITATING TWO HAIRSTYLES [MM:SS].

Subject	A	B	C
α (1st)	4:40	3:42	10:26
β (2nd)	2:41	3:12	6:18

Subject	D	E
β (1st)	9:10	6:13
α (2nd)	5:58	5:07

6. Conclusions

In conclusion, our approach enables us to model a wide variety of NPR hairstyles only by adjusting the parameters. Even naive users can learn its use and create a hair model as intended in 5 minutes. Our approach is thus appropriate for modeling variations of hairstyles with little effort.

There is much room for improvements in the parameters, which have been designed via trial-and-error. For example, CURL and PULL might be specified for a single direction rather than for x, y, and z separately. If a large dataset of hairstyles can be prepared, an appropriate parameter set may be obtained via, e.g., PCA. In addition, due to our trial-and-error development, the current approach has naive computation in, for example, curve lengths and rotation representations, which should also be improved. Our future work includes applying the parameters to realistic hair models, and then establishing a novel workflow for hair modeling in *the space of hairstyles*.

References

[1] P. Noble and W. Tang, "Modelling and Animating Cartoon Hair with NURBS Surfaces," in *Proc. CGI'04*, June 2004, pp. 60–67.

[2] X. Mao, S. Isobe, K. Anjyo, and A. Imamiya, "Sketchy Hairstyles," in *Proc. CGI'05*, June 2005, pp. 142–147.

[3] T. Sakai and V. Savchenko, "Skeleton-based Anime Hair Modeling and Visualization," in *Proc. Cyberworlds 2013*, Oct. 2013, pp. 318–321.

[4] C. K. Yeh, P. K. Jayaraman, X. Liu, C.-W. Fu, and T.-Y. Lee, "2.5D Cartoon Hair Modeling and Manipulation," *IEEE Trans. Vis. Comput. Graph.*, vol. 21, no. 3, pp. 304–314, Mar. 2015.

[5] V. J. Cassol, F. P. Marson, and S. R. Musse, "Procedural Hair Generation," in *Proc. SBGAMES VIII*, 2009, pp. 185–190.

[6] J. Shin, J. Haller, and R. Mukundan, "A Stylized Cartoon Hair Renderer," in *Proc. ACE'06*, June 2006, p. 64.

[7] M. Côté, P.-M. Jodoin, C. Donohue, and V. Ostromoukhov, "Non-Photorealistic Rendering of Hair for Animated Cartoons," in *Proc. GRAPHICON'04*, 2004.

[8] E. Sugisaki, Y. Yu, K. Anjyo, and S. Morishima, "Simulation-Based Cartoon Hair Animation," in *Proc. WSCG'05*, Jan./Feb. 2005, pp. 117–122.

[9] A. Daldegan, N. M. Thalmann, T Kurihara, and D. Thalmann, "An Integrated System for Modeling, Animating and Rendering Hair," *Comput. Graph. Forum*, vol. 12, issue 3, pp. 211–221, Aug. 1993.