Methods for creating hair for realtime rendering

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Methods for creating realistic hair for realtime rendering

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Abstract
Hair is one of the first noticeable aspects of our appearances and will convey many indirect first impressions. Grooming and decorating hair is something that have been with humans since documented history. It is a unique human trait that can symbolize religion, occupation, social status, identity or even health itself. Hair colors are conceived with a certain personality to them and throughout the world there exists several different genetic attributes to hairs structure and texture.

When working with storytelling, the hair is thus a very important part of the design, and if done well can live beyond the character in the story. In the world of computer graphics there are many ways in which an artist can create the parts necessary for an approach to realistic looking hair. What looks realistic can be very individual to the viewer, each visual trait looking somewhat different to each pair of eyes, and each method will also probably produce a different result. In the end, it is up to the artist to learn how to control the methods available and to create a hairstyle in line with the artistic vision.
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1 Intro

1.1 Introduction
Whether you were born into modern society, the Roman Empire\(^1\), Mesopotamia\(^2\) or the ice age\(^3\), it is likely that you have cared for your hairstyle. Our hair is one of our main visible features, be it hidden, shaved or carefully arranged, it is always present. Unlike other grooming mammals with fur, humans tend to alter their hair in ways of removing and cutting. These habits of physically tending and decorating appearance are contemplated to be an essential part of what it means to be human.\(^4\)

The way an individual may choose to wear their hair is often seen as a personality indicator, even haircolor has an attenuated personality to it. Redheads are hot tempered, blonds are seductive and/or stupid. In contrast, dark hair has the implication of intelligence.\(^5\) As these preconceived notions have been prevalent for at least hundreds of years, designing the hair for a character is crucial for genuinity. Some hairstyles have been so characteristic as to be given the name of the person wearing it. The Rachel is one of those haircuts. It stems from the haircut Jennifer Aniston wore when portraying the character Rachel in the American TV series Friends.\(^6\) Another hair to be associated with the original wearer are the locks of child star, Shirley Temple.\(^7\) In movies and theater, hair often comes with the actor, however, when dealing with CGI, the artists themselves must recreate the hair digitally.

Entering this course, I’ve also been taking my first steps into the industry. One subject that I’ve felt that I know the least about, and finding little information about, has been the creation of hair. Unlike other production pipelines, I’ve found hair to be ambiguous with many approaches. Many studios are using in-house tools for specifically this task, making it difficult to get an insight in process. Thus, I wanted to look at some methods to do this, and discover if it’s possible to tell them apart in the final image.

1.2 Background
Hair has always been tricky to simulate digitally and there is a clear gap between offline and realtime rendering in pursuit of recreating it realistically. As technology evolves, so does the capability of computer graphics. Back in 1995 offline rendered hair was coarse and rough\(^8\), however, it was still many steps above realtime renders.\(^9\) Today digital arts have grown into a large industry and

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\(^2\) Ibid p.261
\(^3\) Ibid p.333
\(^4\) Ibid p.x
\(^5\) Ibid p.147-152
\(^6\) Ibid p.38
\(^7\) Ibid p.370
\(^8\) See Appendix “Toy Story (1995)”
\(^9\) See Appendix “Duke Nukem 3D (1996)”
its capability has grown manifolds. Disney’s Moana has been pushing the fronts of creating hair through offline rendering, and on the realtime side Naughty Dog have done the same with their work on Uncharted 4.

Hair is a biological polymer, 10 percent water and 90 percent protein, called keratin. The strong chemical bonds that hold the keratins make hair a durable material, so far as to be one of the final remnants in tomb, as most of the body has decomposed.

A strand of hair has an inner cortex surrounded by a layered cover. This is made of a scale-like material called cuticle and human hair typically have 6-8 layers surrounding the cortex. Each hair grows from a follicle and it is in there that the material and color is created. On average, the human scalp has around 100 000 - 150 000 follicles. Each of these operate independently, giving some color variety to hair and hinder the hair to shed all at once. Follicles work in regenerative cycles, giving a strand of hair a lifespan of around 4-7 years. Hair continues to grow throughout the lifespan, with age it changes color, growth, texture and density. Gray hair, thinning hair and baldness are visible signs of ageing. However, hair does not only age chronologically but also in relation to factors like hereditary genes, stress, nutritional state, overall health, exposure to sun or chemicals.

A hair type can be a telltale about gene heritage of said bearer since caucasians, asians and africans have some significant differences in hair aesthetics. Thickness, straightness and color is all divergent, just like skin color and other physical appearances.

More than physical and genetic traits, hair has also served as symbolic indicators in a variety of social aspects. Coming of age ceremonies around the world have involved the cutting or altering of a person’s hairstyle, as in braiding or covering, to show that the person has now traveled to a new chapter in life. Same practices are found in other ceremonies, to show a newly gained marital status or time of mourning. A Hairstyle can signify religious beliefs, identity, group membership and social status. In religious customs, sacrificing hair has been a common practice as hair has been said to have a certain amount of power.

The indication of it possessing power may come from its significance in identification and its ability to regenerate, but even its placement on the top of the head has its importance. Being the part closest to the heavens have said to give it a strong relationship to our souls. Some religions shave it to eliminate a source of vanity, but removal of one’s hair have also been used as a mean of

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10 See Appendix “Moana (2016)”
13 See Appendix “Uncharted 4 (2016)”
15 Ibid p.94
16 Ibid p.325
degradation and punishment. Slaves and prisoners in different societies were shaved bald as a mean to subjugate and demean them. After the second world war the french women who had been found to have cooperated with nazi soldiers were publicly shaved to show their affiliation with the enemy but also to shame them. \textsuperscript{17}

In political conflicts a hairstyle can identity to which side you belong. During the French revolution, the high and fancy hairdos of the rich became the reason for the resistance to dow themselves in simple and modest styles instead. Aristocrats who had survived the bloodshed cut their hair short to avoid any attention or possible violence.\textsuperscript{18} Whether deliberate or not, hair communicates a variety of social messages, and while it is largely seen as aesthetic trait, strong norms remain still today.\textsuperscript{19}

Due to the complexity of hair, its high number of follicles and dynamic attributes, it is difficult to digitally recreate. Yet it is very important and it is easy to tell when the job is done bad. Something that will quickly destroy any immersive feelings. Offline rendering has it easier, because it has more power and time to utilize compared to real time. A big difference right now between them is that offline hair simulates follicles and strands, while real time uses polygon strips to build up volume and lets a combination of textures give the illusion of strands. However, \textit{Nvidia hairworks} and \textit{Witcher 3} is an example of more advanced real time rendered hair.\textsuperscript{20}

\subsection*{1.3 Problem description}

Hair is such an important key feature for a genuine and realistic character, yet something few students know much about. As technology advances, so does the ability to digitally recreate hair. Due to complex nature that is hair, a realtime renderer can’t handle the number of unique hairstrands that a hairdo consists of, and so several methods have been developed to fake a natural look.

\subsection*{1.4 Thesis}

The \textit{Methods for creating realistic hair for realtime} will examine and compare different methods that can be used to create computer graphics with the goal to be as visually akin to real hair as possible. Said graphics is also to be viewed through a realtime renderer. Three different methods will be used to mimic a curly hairstyle. A visual reference will be the point of reference for the final visual judgement.\textsuperscript{21} A survey will ask participants what differences they can find between the final results, and which method that mostly resembles the point of reference. Participants in the survey will favourably inhere from both inside and outside the CG industry.

\textsuperscript{17}Victoria Sharrow, Encyclopedia of Hair: A Cultural History, USA: Greenwood press, 2006 p. 317-318
\textsuperscript{18}Ibid p.137
\textsuperscript{19}Ibid xx-xxv
\textsuperscript{20}Nvidia, "NVIDIA HairWorks | NVIDIA Developer", 2017, (13-05-2017)
\textsuperscript{21}See survey: https://drive.google.com/open?id=1oh-AArfkXc_wn6z9r_K_1pIH26iFuk2b2l-S-Nruwls
Hair has certain visual characteristics and there exists a series of tools that allow an artist to find a way to recreate these. Out of a large variety of possible ways to work, three distinct methods have been chosen.

**Method 1** will be the most manually created, as in mostly dependent by the artist’s own work by hand.

**Method 2** will be the method to use mostly generated material from values and parameters, using only guiding curves and scripted tools.

**Method 3** will be a somewhat mix between the two, where an artist first creates an approximate by hand and then use a script to finalize.

**1.5  Demarcations**
The results from each method will be put through the same shader, only have different textures, and renderer, and will compete solely based on color and form. Naturalistic hair movement and other dynamics will not be examined in this essay, along with complex shader networks compiled through code and procedurals.
2 Terminology and definitions

**Polygon strip** - A segmented plane of geometry in form of an elongated square.
**Mesh** - A geometrical object.
**Geometry** - One or several surfaces built from corner points. Each surface is called a face, each point on the surface is called a vertex and the lines connecting them, and consequently surrounds the face, are called edges.
**Zbrush** - A digital sculpting software.\(^{22}\)
**GMH** - Geo to Maya Hair, Maya plug-in.\(^{23}\)
**Maya** - A digital entertainment suite.\(^{24}\)
**UVs** - Texture coordinates on a mesh.
**Normal map** - Texture map where each RGB pixel represents a vector.
**Normal** - A vector that is perpendicular to a given object, e.g. the direction of a 2D surface.
**Albedo** - Texture map where typically the base color is stored.
**Alpha** - Grayscale texture map where each pixel value represents an amount of transparency for said pixel.
**Photoshop** - A 2D digital painting, design and editing software.\(^{25}\)
**Texture** - A 2D image used to determine appearance of object.
**Marmoset** - A Realtime renderer software.\(^{26}\)
**Real time rendering** - Creating images fast enough so that the viewer can interact with a virtual environment.
**CGI** - Computer generated images.
**Offline rendering** - Creating high-quality renderings non-interactively.
**Baking** - Transferring information, usually from one or more objects to either another object or an image.

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3 Methodology

Three sets of curly hair were rendered using varying methods for creating geometry and textures, however, UV maps, renderer and shaders were basically the same.

The softwares used throughout this paper are:
- Maya 2017, latest update as of March 2017, with Maya bonus tools.
- Photoshop version CC 2015.0.0 release
- Zbrush version 4R7 P3
- Geo to Maya version 2.6
- Marmoset toolbag 3.02
- Mental Ray Nvidia 2017
- Knald 20161227001

3.1 Method 1

3.1.1 Geometry

In Zbrush use a custom created brush\(^{27}\) to paint out polygonstrips on the scalp. The painted geometry will snap to a surface, so to create the twisting curls use some cylindrical shaped geometry to wrap the stripes around.\(^{28}\) Vary with strips of different sizes. Use Move brush to tweak placement of the polygonstrips. Paint them as the hair would fall, when there are enough for a base it is also possible to paint on the already created polygonstrips. Merge vertices and split up to parts to separate all hair strips into subtools for easier manipulation. Use Tool>Deformations>Smooth to ease out some ugly deformations resulting from manually adjusting the geometry too much with the move tool.

3.1.2 Textures

With photoshop paint a few different lengths of hair and let a couple vary in breadth. First paint a fairly thin, dark layer with a denser hairbrush. Continue with lighter and more sparse strands of paint to layer the hair. For every new color or size of brush, create a new layer in photoshop for maximum control. Lastly, with a small round brush, paint distinct, single strands of different


\(^{28}\) See image 3.1.1
colored hairs. The texture painted\textsuperscript{29} are to be used for albedo, normal and alpha maps. The painting information is used as a mask to create the alpha texture and the normal map,\textsuperscript{30} which is baked using a software.\textsuperscript{31}

3.1.2 Method 2

3.2.1 Geometry
Create a Collection of Descriptions with Xgen, with the settings \textit{Splines, Placing and shaping Guides} and \textit{Randomly across the surface}. Three guides are enough to enable the preview function. Set length and rebuild the curves so that they can be shaped as if they were curled around something. Move tool is used to shape the guides. Set \textit{output to guides}\textsuperscript{32} and then convert all guides to curves.\textsuperscript{33} Make curves \textit{dynamic} and create a \textit{hair system}. Assign a \textit{paint effect brush} to the hair syusym. Output curves can be deleted and the PFX to \textit{output meshes}. Set settings to \textit{flat planes}, thinning, random width and length to assimilate real hair.\textsuperscript{34} Use \textit{Curve ramp} to twist geometry along the curles.\textsuperscript{35}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{3.2.1}
\caption{3.2.1 Method 2}
\end{figure}

\textsuperscript{29} See image 3.2.1 a
\textsuperscript{30} See image 3.1.2 b
\textsuperscript{31} https://www.knaldtech.com/
\textsuperscript{32} See image 3.2.1 a
\textsuperscript{33} See image 3.2.1 b
\textsuperscript{34} See image 3.2.1 c
\textsuperscript{35} See image 3.2.1 d
3.2.2 Textures
In Zbrush, set up a square document that will serve as texture size. Use the curve brush, with tweaks, and draw out curves that'll shape out geometry for the hair strands. Draw three sets of densities and heights. Render an image pass, depth pass, shadow pass and ambient occlusion pass with Zbrush, using a MatCap Gray material. Fill the hair with white polypaint and the background with black, apply a Flat Color material and render an image. Render one more time but with a NormalRBGMaT shader. Comp the first batch of textures in Photoshop, use multiply, overlay and screen operations on passes along with Gradient Maps and Color Fill.

3.3 Method 3
3.3.1 Geometry
Create basic shapes in the form of the curly hair. Using the GMH plug-in, create a GMH system - polygonal style, and apply the curl geometry to it. Set flatness to 1 and rotate according to hair flow. Set some randomness to length and width and

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37 See image 3.2.2 a
38 See image 3.2.2 b
add some thinning to the system. Using complex shapes to generate from creates artifact geometry where edge loops cross.\textsuperscript{39} Under \textit{GMHPolyStyleSystem > SecondCurl_surfaceGrp > Shape_GMHSurface > Shape_strokeGeoGrp}, select the geometry you want and middle click and drag them somewhere else in the outliner to get rid of them.\textsuperscript{40}

Create a new system for each base geo. Assign output geometry to a UV system with three slots. Assign the polygon strips that are closest to the scalp to the first third of the UV space, the middle section to another and the top ones to the last third.

3.3.2 Textures
Still working in Maya, create three planes in a new scene, the geometry needs to have edge loops top and bottom to set the effect distribution by the system correct. Create a \textit{GMH system} for each, also \textit{poly style}. Set \textit{Flatness} to 0, some randomness to width and length and add some noise. In the shader, create a faint gradient similarly to the hair color for the final result. Vary the density and length for each system.\textsuperscript{41} Assign to the three parted UV space. Match the thickest hair with the geometry closest to the scalp, middle to middle, and top to thinnest. Bake textures using GMH plug-in, but the normalmap separately, with the offset setting on so the the plane doesn’t cross the \textit{GMHsystem}.

\textsuperscript{39} See image 3.3.1 a
\textsuperscript{40} See image 3.3.1 b
\textsuperscript{41} See image 3.3.2 a
Compile the baked textures in Photoshop similarly to Method 2.\(^{42}\)

\[\text{Image 3.3.2 a}\]

3.4 **Transfer normal**

In Maya, create a smooth, basic shape that matches the shape of the hair mesh for each method. Select the smooth mesh and shift click the hair mesh, go to **Mesh > Transfer Attributes** options and turn off **UV Sets** and on **Vertex normal**. Click **Transfer**.\(^{43}\)

\[\text{Image 3.4}\]

\(^{42}\)See image 3.3.2 b

\(^{43}\)See image 3.4
Before export as OBjs, duplicate the hair mesh, go to Mesh Display > Set to Face, then Mesh Display > Reverse and finally Mesh Display > Soften Edge. Scale down to 0.99. Delete all history, select both meshes and export.

### 3.5 Marmoset Toolbag 3
Import an anonymous and androgynous head mesh for hair to rest upon. Set shader attributes to have one Surface: Normals, Microsurface: Gloss, Albedo: Albedo, Diffusion: Subsurface Scatter, Reflectivity: Specular, Reflection: Anisotropic, Secondary Reflection: Anisotropic, Emissive: Emissive, and Transparency: Dither. Create a light setup to appropriately show head, specularity and shadows.

Duplicate shader and change alpha, albedo and normal map. Tweak anisotropic direction correctly for each hair mesh.

### 3.6 Survey
Send the final images from the renderer to the group of participants. Three final renders from Marmoset Toolbag and a reference photo will be included in the survey. Participants will decide on which method to look the most alike the reference and give a comment on the visual differences they can detect between the methods.\(^{44}\)

### 3.7 Methodology critique
Artistic skill might affect method outcomes, thus skewing the results. The fact that there is only one artist is an issue as it is possible to create any hairstyle of any color with them, and artists often work very differently from each other. This will make it impossible, for example, to determine if there is any specific visual trait to any certain method. Only the result from this one experiment can be judged, and not the methods.

\(^{44}\)Survey: https://drive.google.com/open?id=1oh-AArfkXC_wn6z9r_K_1pIH26iFuk2b2I-S-NruwFs
4 Empirical research

GMH needed some practice, early results had issues with geometry not flowing correctly. To solve this issue I had to recreate the meshes in Zbrush using a remesh tool to simplify them. This seemed to remove some of the abrupt mid-change of directions, however, I did get some dirty geo at beginning and ends. These artifacts were easy to delete though, and so I worked around them instead of further reworking the base geometry.

45 See image 4 a
46 See image 4 b
5 Results

5.1 Final Render
From top to bottom, Method 1, 2 and 3.
5.2 Texture maps
Albedo, alpha and normal map. Top left is from Method 1, top right Method 2 and bottom Method 3.

5.3 Survey
5.3.1 Question 1
The first question resulted in many different opinions on the visual appearance of all three methods, contradicting each other with fairly little consensus.\textsuperscript{47}

\textsuperscript{47} See Appendix Survey Result
5.3.2 Question 2

Which result was visually closest to the reference?

![Bar chart showing votes for Methods 1, 2, and 3. Method 3 has the highest votes.]

5.3.3 Question 3

1 of 8 participants have had experience with creating CGI.
6 Discussion

Method number one seems to me the one that “cuts” through itself the most noticeable, probably due to the alpha having been painted too dense. This is a difference in visual appearance as a result to my inexperience at hand painting hair textures and might not have been as visually prominent if done differently.

While aware of situations like this, I still included them in the final version for the report as they make for a difference in a handpainted texture compared to one baked from a hair system or similar. However, one could definitely argue that it is possible for a baked texture to be dense enough for it to not blend, and at the same time it is possible to paint a texture that can blend better. But I think that it is appropriate to not dwell on such arguments since they don’t really fit my thesis anyway. My thesis was to see if different methods would yield different results, not specifically to see what different results these methods could yield. It might be possible to yield more or less the same results through different methods if that was your goal.

Method 3 is pointed out to like a bit balding, yet also the thickest according to the survey. Method 1 is plane and stiff yet can be seen as voluminous. The only somewhat consecutive survey results regard the third method in that it is livid, shiny and soft.

It is interesting that the way they are created give off such a difference in “shininess” as the shader is basically the same. Intensity has not been changed, just anisotropic direction, which was to match the geometry.

It is not too surprising that the method created utilizing both artistic skill and scripts would be the most like the original hair, as, in a way, it makes it quite easy to generate a clump of polygon strips and still having a lot of control in overall shape and motions. Compared to method two, where it is easy to make a lot of geometry but more difficult to control. I would, however, have liked to be able to find good way, other than having to paint it myself, to generate more color variety in the hair textures. Since each hair follicle work independently, they don’t all produce the exact same color. Each strand of hair should look a bit more unique.

Since this paper has not been about production quality of hair, but rather any visual differences, the work itself could need improvement. To imitate the amount of hair follicles one has on one’s head, there needs to be additional levels of polygon strips. Preferable actually covering all surface of the scalp, otherwise it will not look production ready. There would also be a need to fix unnatural overlap between polygon strips, as mentioned before, most prominent in Method 1. There is also the presence of normal transfer artifacts, mostly visible in the curls. I decided to leave these imperfections as is, since I do not feel that they affect the result for the question at hand. It would take a lot of time for something that would be, essentially, irrelevant for the paper.
7 Conclusions

There would be need of a bigger crowd of artist doing these tests and see if there’d be similar traits in all methods to really scientifically determine a visual similarity to a specific method. However, I feel that it is still safe to say that, working as a beginner with each method, they did generate severely different results. Although, what each method is looking most alike is clearly debatable and they do not seem to conform to a singular look according to the survey results. Except that there’s definitely an obvious visual difference between them. Again, I can’t say that this paper can say much regarding what method will general a result that will typically look like “this”, or come with issues like “that”. I can only attest for the different outcomes from my use of the most manual, most generated and the most intermediate methods I could find.

While these results are all very different, Method 3 got the most votes as being the one method closest to the original reference, albeit not without competition. That is something I can agree to, although I am be curious as to what it would look like if further refinements to method 1 were done. The original haircut is a very advanced hairstyle, with neatly fixed curls, and the method generating geometry made it difficult to resemble that aesthetic.

To me, hair creation is very important when working with immersive storytelling. While realistic hair can be created in many ways, ways that will yield visually diverged images, in the end, the method to use is probably the one that feels the most comfortable.
8 Bibliography


9 Appendices

9.1 Toy Story (1995)
9.2 Duke Nukem 3D (1996)
9.3 Hairstyle
9.4 Moana (2016)
9.5 Uncharted 4 (2016)
9.6 Survey results

9.6.1 Survey results from a group of three
X har tjockast här Och alla tyckte det om varsin X har likast X ser blötast ut X har mest levande X har tunnad Ingen enighet alls

9.6.2 Survey results A
1. Method 1 looks to have the most volume. Method 2 is the shiniest. Method 3 looks abit balding. Method 2 looks the most like real hair. Method 3 looks the curliest. Method 2 looks the messiest. 2. Method 1 3. No

9.6.3 Survey results B
1. Hair in...Method one looks a little bit limp. Method two, the hair looks finer/thinner and wispier. Method 3, the hair looks thicker/more volume and "livlier". 2. I think Method 3 captures the hair in the photo best. 3. Nope, unfortunately I have never done rendering.

9.6.4 Survey results C
1. Method 1 feels the most grainy and dry. Feels the least realistic and very stiff. Method 2 feels more shiny and soft, but is also a bit stiff Method 3 is a bit too shiny but the texture of the hair looks the best 2. I would go with Method 2 3. No

9.6.5 Survey results D
1. B looks to be thinner than the other, all three look like they have wet hair. 2. C. 3: No

9.6.6 Survey results E