Super Fast Strand-Based Hair Rendering with Hair Meshes

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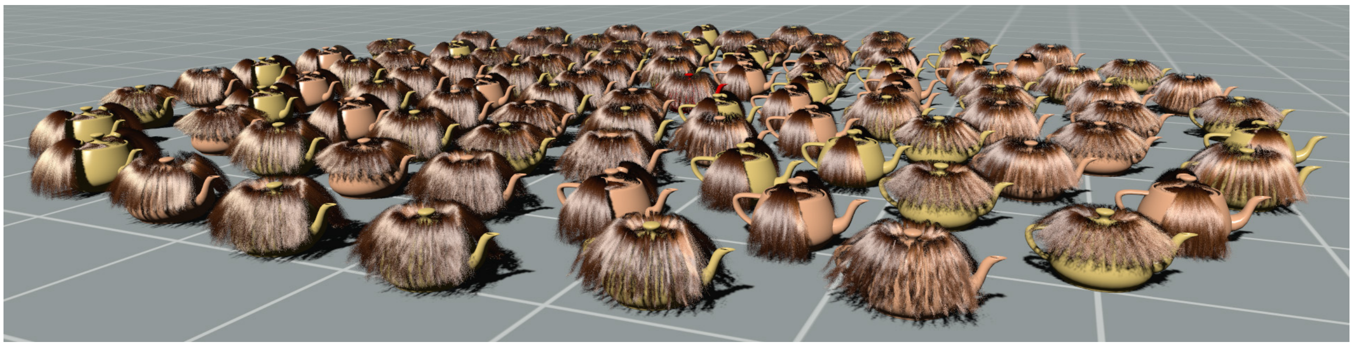

Figure 1: *A scene with 101 teapots with unique hair models and over 10 million total hair strands rendered at real-time frame rates on an NVIDIA GTX 4090 GPU using our real-time hair rendering method with hair meshes and our level-of-detail techniques.*

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Hair is one of the most important visual components of a virtual character. Yet, strand-based full hair models are often avoided in real-time graphics applications. A primary reason for this is the geometric complexity of hair. Most humans have on the order of 100 thousand hair strands. Representing each of them with a curve may require many control points, depending on the length and style. Therefore, a strand-base hair model for a single character may correspond to a large number of triangles to render. Though today's GPUs can quickly render millions of triangles needed for a single hair model, the processing needed for a dynamic hair model can easily consume a significant portion of the render time budget on high-end devices. Thus, strand-based hair rendering is reserved for a few hero characters.

We present a new real-time hair rendering approach that is more than an order of magnitude faster than standard methods, allowing us to render strand-based hair models for hundreds of characters at real-time frame rates. An example of this is shown in Figure 1.

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The speed of our method comes from the *hair mesh* representation. Hair meshes were initially introduced as an effective method for modeling hair [Yuksel et al. 2009]. A hair mesh is a volumetric structure formed by extruding polygonal faces on a scalp model. The use models the exterior surface of this volumetric structure and the interior vertices are positioned automatically. This allows precisely designing the overall shape of a hair model using the hair mesh, circumventing the geometric complexity of individual strands and bringing hair modeling close to polygonal modeling of typical surfaces, commonplace in computer graphics. The individual hair strands are generated within these extrusions, which are then modified using a collection of *styling* operations that define the geometric variations of hair strands.

Hair meshes are included in the Hair Farm software [Cyber Radiance LLC 2009] and have been used in numerous productions with offline rendering for hair and fur. We show that hair meshes can also be used for real-time graphics, achieving an unprecedented level of hair rendering performance.

Hair meshes were shown to be effective for fast hair simulation as well [Wu and Yuksel 2016]. Our system combines this approach with position-based dynamics [Macklin et al. 2016] to achieve a highly-efficient hair simulation pipeline using hair meshes.

We generate the individual hair strands on-the-fly during rendering within GPU shaders using a given hair mesh and a set of styling parameters that control the procedural functions specifying strand variations. This avoids the need for storing strand-based hair data, which can easily take hundreds of megabytes, and updating it as the hair moves/deforms. Instead, hair motion is captured by simulating the hair mesh and animating the styling parameters, reducing the amount of data to be stored and managed by several orders of magnitude.

In our system, the hair mesh structure forms a volumetric embedding for defining the styling functions. This ensures that the hair strands follow the animation of the hair mesh in a consistent and predictable manner. We use a custom texture layout for representing the hair mesh on the GPU, so that we can utilize the existing texture filtering hardware to perform a part of the computations we need for generating hair strands.

Our on-the-fly hair generation approach also allows easily supporting level-of-detail for seamlessly reducing the rendered hair count and the number of vertices per hair strand. As a result, rendering large crowds with a full-resolution unique hair model per character becomes practical for real-time graphics applications: each hair model requires minimal storage (only the hair mesh and a set of styling parameters) and the number of triangles generated is automatically controlled on the GPU by dynamically adjusting the detail level.

In addition, our approach allows further optimizations with multi-pass rendering techniques that are needed for computing hair shadows and multiple scattering. The cost of on-the-fly hair generation can be amortized by simultaneously rendering multiple passes. Also, the hair mesh itself can be used as a proxy for the strand-based hair model to accelerate the shadow passes either for the entire scene (for ultimate performance) or for distant hair models (to preserve strand-based shadow detail for close-by characters).

Our system is able to render hundreds of unique strand-based hair models (without instancing) at real-time frame rates on current GPUs, showcasing an unprecedented level of geometric complexity for real-time hair rendering.

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