Procedural Shading for Rendering the Appearance of Feathers

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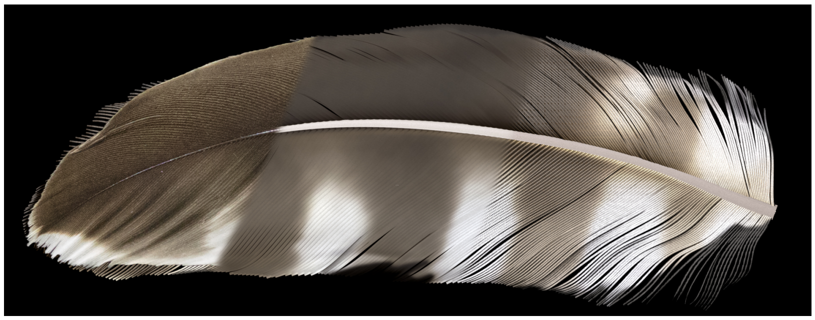

Figure 1: An osprey feather photographed (left portion) and modeled as curves and rendered as hair (middle) and with simulated microstructures using the proposed shading technique (right). Note the variation in specularity exhibited by microstructures in the photograph that the proposed technique captures in comparison with the hair-fiber approach.

ABSTRACT

The appearance of a real-world feather is the result of light interactions with complex, patterned structures of varying scale; however, these have not yet been modeled for accurate rendering of feathers in computer graphics. Previously published works have presented simplified curve models for feather appearance. Using imaging from real feathers, we suggest why these approaches are not sufficient and provide motivation for building an appearance model specific to feathers. In that vein we demonstrate a new technique that takes into account the substructures of feathers during shading calculations to produce a more accurate far-field appearance.

CCS CONCEPTS

• **Computing methodologies → Reflectance modeling**.

KEYWORDS

Appearance Modeling, Biological Modeling, Natural Phenomena, Reflectance & Shading Models

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1 INTRODUCTION

Feathers are a complex assembly of multi-scale structures where each component contributes to the appearance. Published techniques for feathers rely on simplified structures and often bidirectional curve scattering distribution functions (BCSDFs) borrowed from hair models [2016; 2010]. Here we argue that such BCSDFs do not well represent light scattering of feather substructures in most cases. Also, a physically based model of the light-surface interactions of feathers has not yet been introduced. Such a model would eventually need to account for wave-optics effects to simulate structural coloration exhibited by some feathers. Ahead of that, though, we suggest that a more fundamental model is needed for the significant effects that ray-optics can describe, and we propose a render-time method to better represent the multi-scale assembly found in nearly all feathers.

2 BACKGROUND AND RELATED WORK

A feather's hierarchical structure includes a central *shaft* and two *vanes* composed of hundreds of adjacent *barbs*, each of many *barbules* extending from a *ramus* (pl. *rami*). Barbules possess *pennulae* which act as interlocking hooks and rods [1966].

Feathers in computer graphics have been most often modeled only to the barb level [2019] and rendered as hair fibers [2016; 2010] with the Marschner BCSDF [2016; 2003; 2015] or with a BTF [2002].

Harvey et al. [2013] studied specimens of an iridescent species regarding avian visual signaling and mating. Their work did not present a scattering model but raised an important idea that we build upon – certain substructures contribute significant reflected radiance. Contrarily, the most-often used BCSDF curve representation can only represent the central ramus of each barb and not the significant substructures. We propose a substructure-based method that embodies more of the multi-scale light interactions during shading calculations.

3 APPROACH

As a preparation stage, feather specimens were imaged with scanning electron microscopy (SEM, see Figure 3) and photographed in a controlled lighting environment to observe specular highlights of the barbules and rami. We created matching geometry of the major substructures of the specimens based on procedural generation of curves [2019] and a virtual scene simulating the light conditions.

In the shading and rendering of feathers, we compare two approaches: (1) rendering only barb curves along the shaft, using a Marschner-hair BCSDF and (2) rendering the barbs with the new substructure-based technique that procedurally simulates some of the effects of the reflectance from barbules and rami. The proposed substructure-based technique incorporates the reflectance of barbules that lie within the outer simplified cylindrical representation for a given barb. (Base color in both is driven by low-frequency albedo derived from cross-polarized photography of the original feathers.)

Figure 3 depicts the aforementioned substructures that we represent at shading time using the proposed substructure-based technique. Parametric (u, v) coordinates at points sampled with path-tracing along the barb curve determine the substructure, and we simulate sampling for this substructure instead by modifying the shading frame. Radiance is calculated as if each substructure is a unique fiber, evaluating the same hair model but with eccentricity and shading orientation chosen based on which substructure. Samples from neither barbules nor ramus are evaluated as pure transparency. Parameters include barbule and ramus radii and two angles for planar rotation and lift of the barbule in respect to the barb. A geometric term applies this information along with parametric coordinates and orientation sampled along the barb curve to determine if the sample lies on a ramus, barbule, or neither.

In justification of simplifications, the Marschner BCSDF was chosen due to its common use. The ramus shape, though, differs greatly from a hair strand, and thus future work should derive better models. The shape and periodic placement of barbules are also simplified in this early work.

RenderMan was chosen for the rendering and development environment, leveraging the material interface, Maya plugin, and PxrMarschnerHair material [2015]. The substructure-based technique is implemented as a variation of PxrHair, a simplified, public version of PxrMarschnerHair.

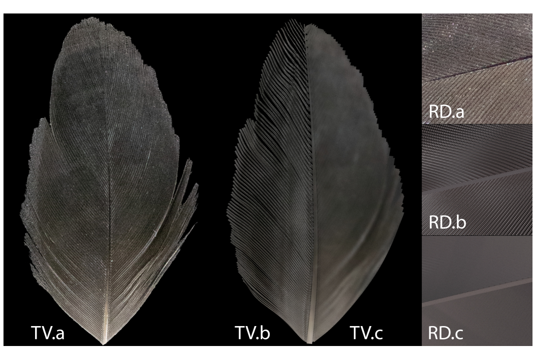

Figure 2: Turkey Vulture (TD) and Rock Dove (RD) photos (a) with new-technique (b) and hair-fiber (c) renders.

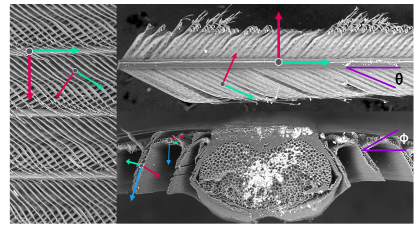

Figure 3: SEM images of interlocking barbs (left), a single barb (top), and shaft and barb cross sections (bottom). Annotations depict conventions for describing barbules.

4 RESULTS AND CONCLUSION

Figure 1 displays an osprey feather from original photo (left), barb curves shaded with hair BCSDF (middle), and new technique simulating substructures (right). Note the variation in specularity in the photo that the middle hair-fiber approach does not represent, but the proposed method demonstrates at least partially. Figure 2 provides similar visual comparison. The proposed method creates far-field glints more similar to those photographed.

We show that representing light reflected from substructures is significant for photorealistic renders. Traditionally used, a simple hair model does not accurately represent the far-field specular contributions of the barbules and rami of barbs. This is due to a large portion of reflected radiance originating from barbules that is not included. Including radiance contributions from these microstructures represents a fundamental improvement in rendering the appearance of non-structural-color feathers.

In future work we seek a more elaborate scattering distribution term that matches the non-cylindrical shapes, improved models for each feather component, a far-field aggregated BSDF, and wave-optics models.

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