A Surface-based Appearance Model for Pennaceous Feathers

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Motivation

The appearance of a feather is the result of the complex light interaction with its **multi-scale biological structure** including the central shaft, branching barbs and interlocking barbules of those barbs. These complex hierarchical structures can produce complex appearance effects such as spectacular **iridescent** colors, astonishing **structural blue** colors, **pigmentation** or **combination** of all of them.

Compared to other biological appearances such as skin, hair [1], or fur [2], rendering of feathers, and in particular of pennaceous feathers, is a relatively unexplored area in computer graphics, with some notable exceptions baked **bidirectional texture function** [3], iridescent rock dove neck feathers [4], or expensive curve-based representations for the barbs with simplified scattering functions [5]. **Modeling the barbs as explicit curves** [4, 5] is a flexible fine-detailed representation of feathers and explicitly accounts for geometric effects such as visibility, but it **might become prohibitively expensive** for scenes with too many feathers.

Our Approach

We propose a **far-field** surface-based appearance model for pennaceous feathers encoding the geometric complexity of the feather with **lightweight textures**. We also account for the geometric attenuation of barb and barbules via an **analytical masking term** and the inclusion of a **diffuse medulla** inside the barbs (see Fig. 1).

Fig. 1: Comparison between a surface-based rendering using a hair model [1] (Center) considering only attenuation, our BSDF (Right) accounting for an accurate masking and barbs with medulla interactions and a reference photograph (Left) of an Amazon Parrot wing.

Reflectance Model

In Fig. 2 we show an illustration of the **multi-scale** feather structure, while Fig. 3 represents a schematic of the occlusions modeled by our **masking term**, which we validate against Monte Carlo simulations. Fig. 4 introduces the **coloration mechanisms** represented by our reflectance model.

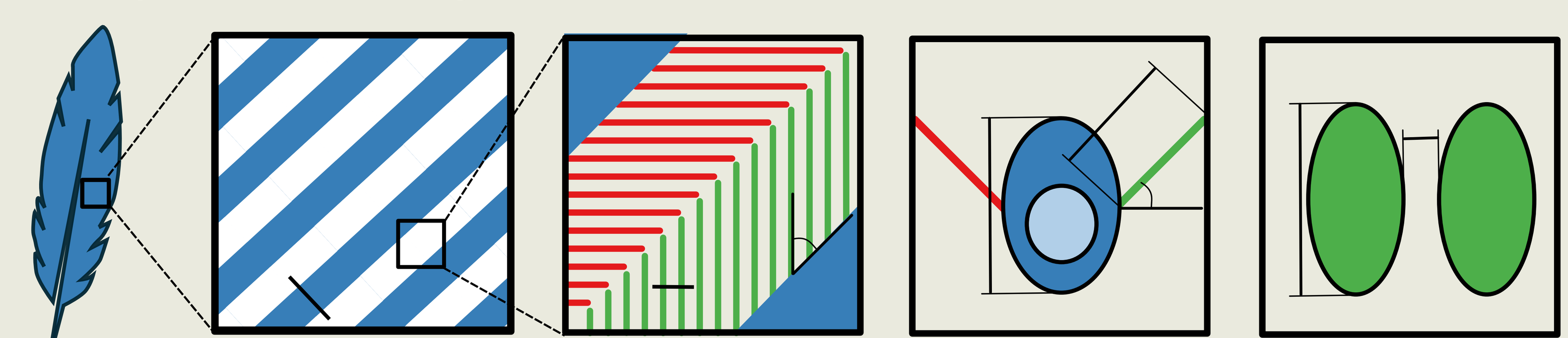

Fig. 2: (a) The appearance of the feather's vane depends on its **underlying hierarchical structure**. (b) Parallel barbs emerge from the rachis. (c) Each barb branches into two sets of barbules, proximal and distal. (d) Barbs are modeled as infinite cylinders with elliptical cross section with an inner medulla. (e) At a smaller scale, barbules are also cylinders with an elliptical cross-section form, and can occlude each other. The relative space between them can be treated as a **partial transparency** at the barb scale.

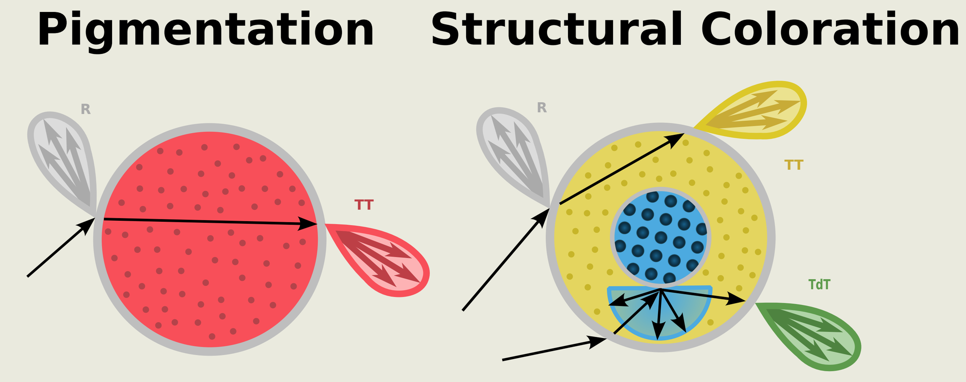

Fig. 4: Cross-section fiber schematic of the coloration mechanisms in feathers supported by our appearance model. **Diffuse structural coloration** extends the range of appearance from pigmentation coloration including a diffuse medulla inside the barbs, a reasonable approximation given the internal **spongy nano structures** inside the barbs.

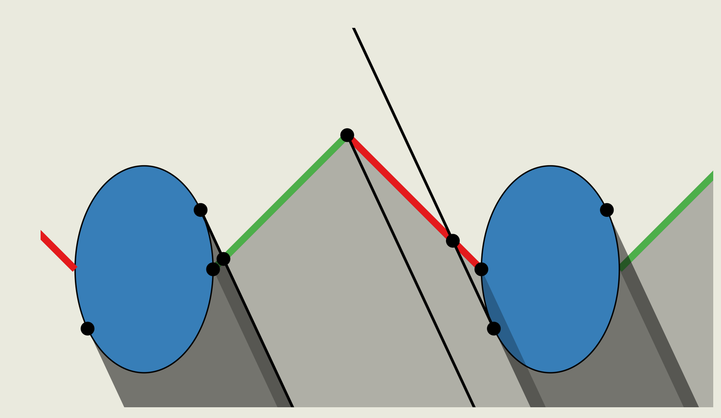

Fig. 3: Cross section of barbs, representing the **masking between barbs** at a view inclination of 25 degrees. Barbules are partially transmitting, depending on the view direction at their particular local coordinates (see Fig. 2), while barbs are considered to be opaque. Depending on the view direction, each element (barbs and barbules) totally or partially occludes the rest. The limits of such occlusions are identifying by tracing 2D rays.

Results

We perform an **ablation study** of our reflectance model (Fig. 5), where the medulla is critical to achieve similar tones to the photographs and the masking is key for **goniochromatic** and **occlussions effects**. We also show a practical example of a single goniochromatic **Amazon Parrot feather** (Fig. 6).

Fig. 5: Ablation study of our feather BSDF for a feather pelt scene. **[Only hair barbs]**: Only barb with hair BCSDF [1], **[Only masking]:** Barb and barbules with Hair BCSDF combined with our masking term similar to [5], and **[Full]:** Adding a diffuse medulla inside the Barb BCSDF. From top to bottom: northern cardinal, blue-fronted amazon parrot, electus parrot and Brewer's blackbird.

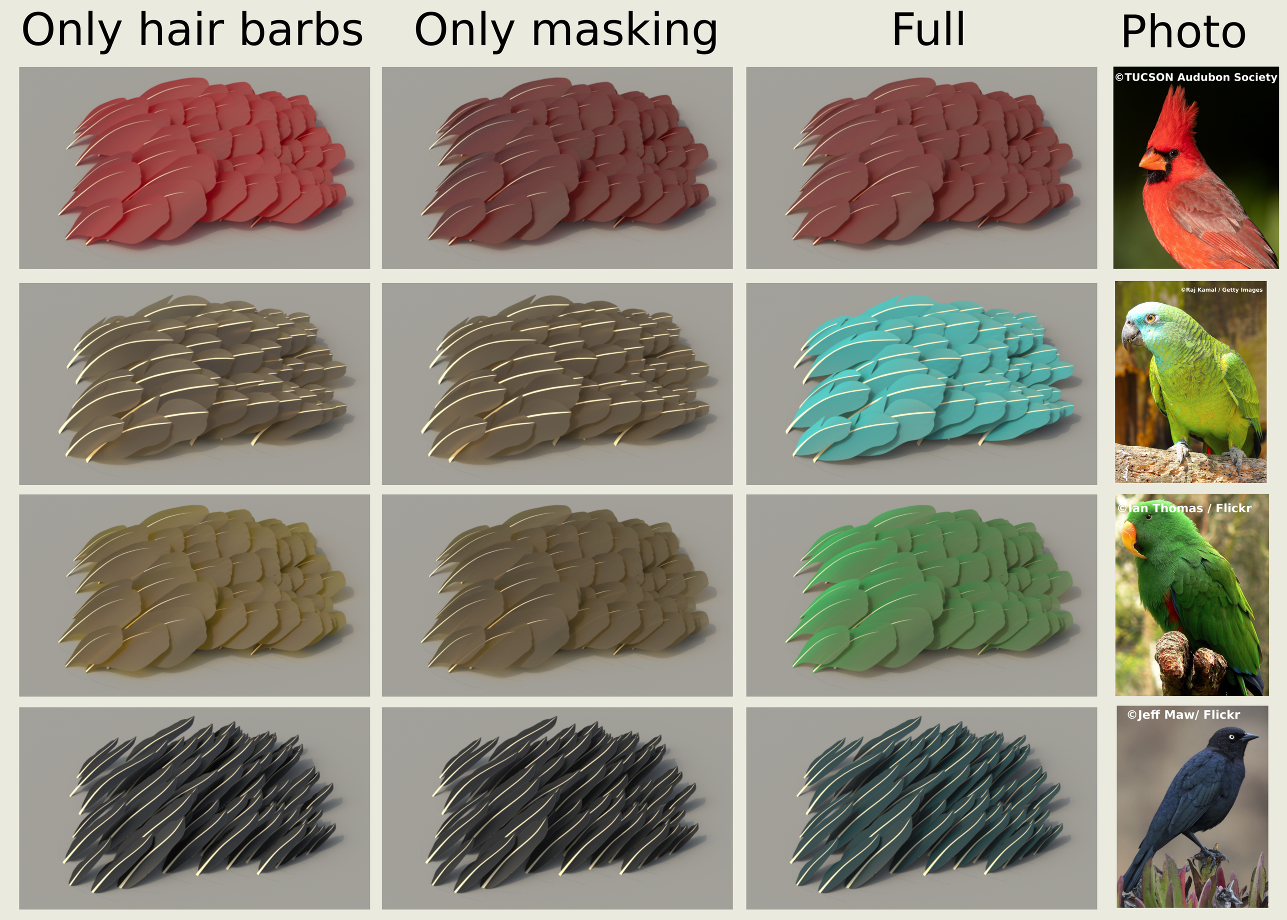

Fig. 6: Appearance matching on an Amazon parrot feather, for a frontal (top) and lateral (bottom) views. As the feather rotates, view dependent changes on the feather's color become apparent: These are produced by visibility changes between barbs (yellow) and barbules (green).

References / Acknowledgments

[1] Stephen Marschner, Henrik Wann Jensen, Mike Cammarano, Steve Worley, and Pat Hanrahan. 2003. Light scattering from human hair fibers. ACM Trans. Graph. 22, 3.
[2] Ling-Qi Yan, Chi-Wei Tseng, Henrik Wann Jensen, and Ravi Ramamoorthi. 2015.Physically-Accurate Fur Reflectance: Modeling, Measurement and Rendering. ACM TOG 34.
[3] Yanyun Chen, Yingqing Xu, Baining Guo, and Heung-Yeung Shum. 2002. Modeling and rendering of realistic feathers. ACM TOG 21, 3.
[4] Weizhen Huang, Sebastian Merzbach, Clara Callenberg, Doekele Stavenga, and Matthias Hullin. Rendering Iridescent Rock Dove Neck Feathers. 2022. In ACM SIGGRAPH 2022 Conference Proceedings.
[5] Jessica Baron, Daljit Singh Dhillon, Adam Smith, and Eric Patterson. 2022. Microstructure-based appearance rendering for feathers. Computers & Graphics 102.

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