Hair Photobooth: Geometric and Photometric Acquisition of Real Hairstyles

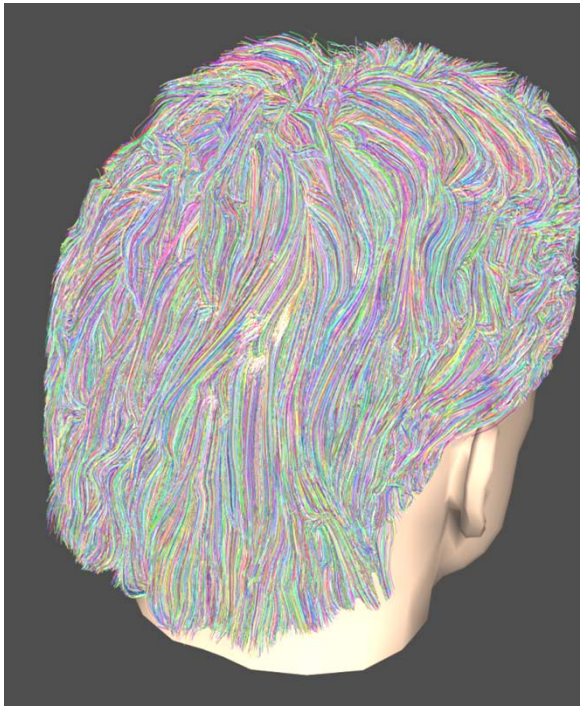
Sylvain Paris[1], Will Chang[2], Wojciech Jarosz[2], Oleg Kozhushnyan[3], Wojciech Matusik[1], Matthias Zwicker[2], and Frédo Durand[3]

[1]Adobe [2]UCSD [3]MIT CSAIL

Capturing Real Hairstyles

Useful for special effects, simulation, cosmetics…

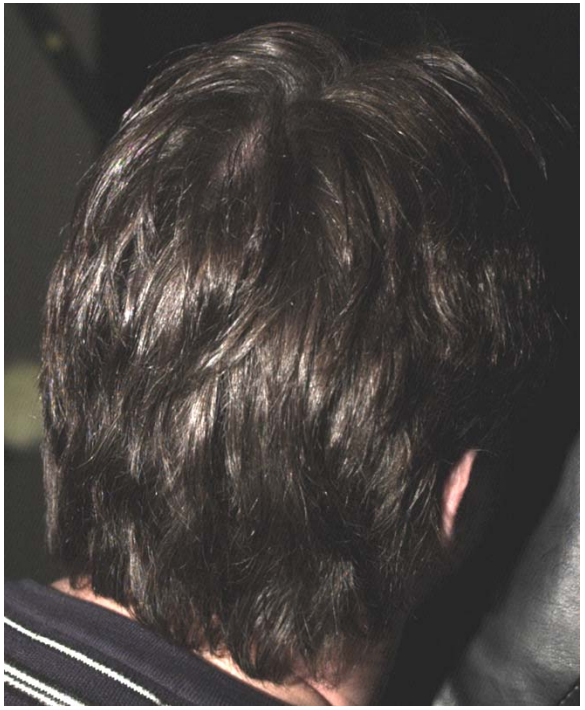
3D geometry
(about 100,000 strands)



reflectance
(image-based rendering)

our result

reference photograph
(not in the input data)



Previous Work

Hair Modeling

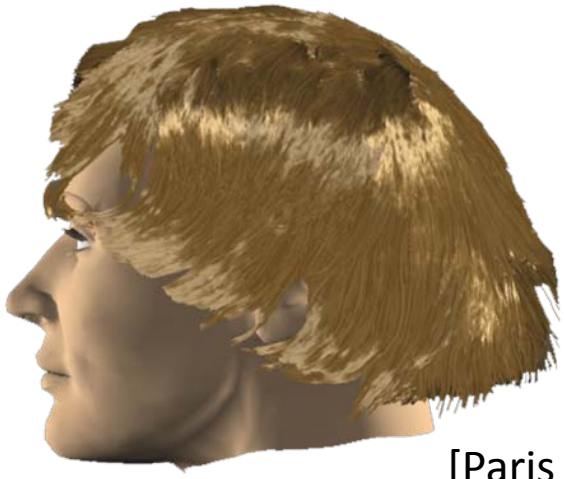
- Toolboxes for artists
  [Hadap 01, Kim 02…]

- Hard and tedious to match someone's hairstyle

[Hadap 01]

Hair Capture

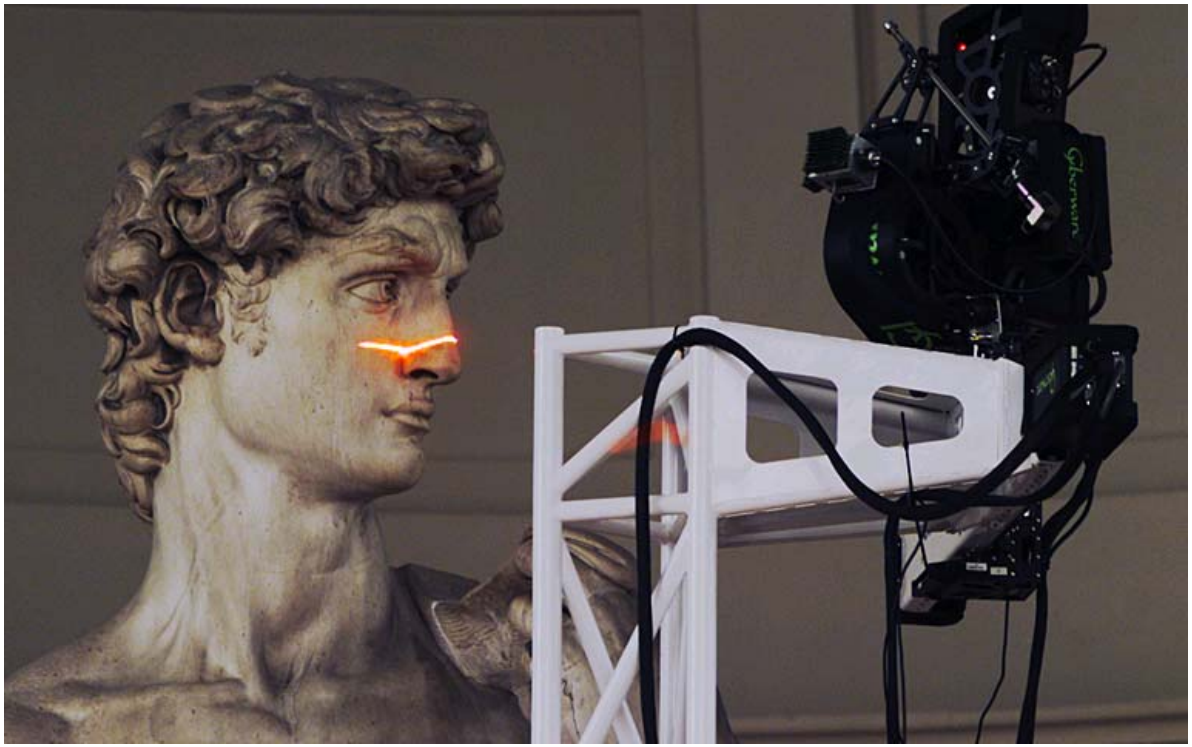
- Lightweight setups to capture whole head of hair [Paris 04, Wei 05]
- Limited accuracy because of moving parts
- No reflectance



[Paris 04]

Triangulation Scanning

- Accurate [Curless 95 & 97, Pulli 97, Levoy 00…]
- Robust to complex environments [Hawkins 05, Narasimhan 05]
- Never used for unstructured material like hair
  - Hair does not have a smooth surface.

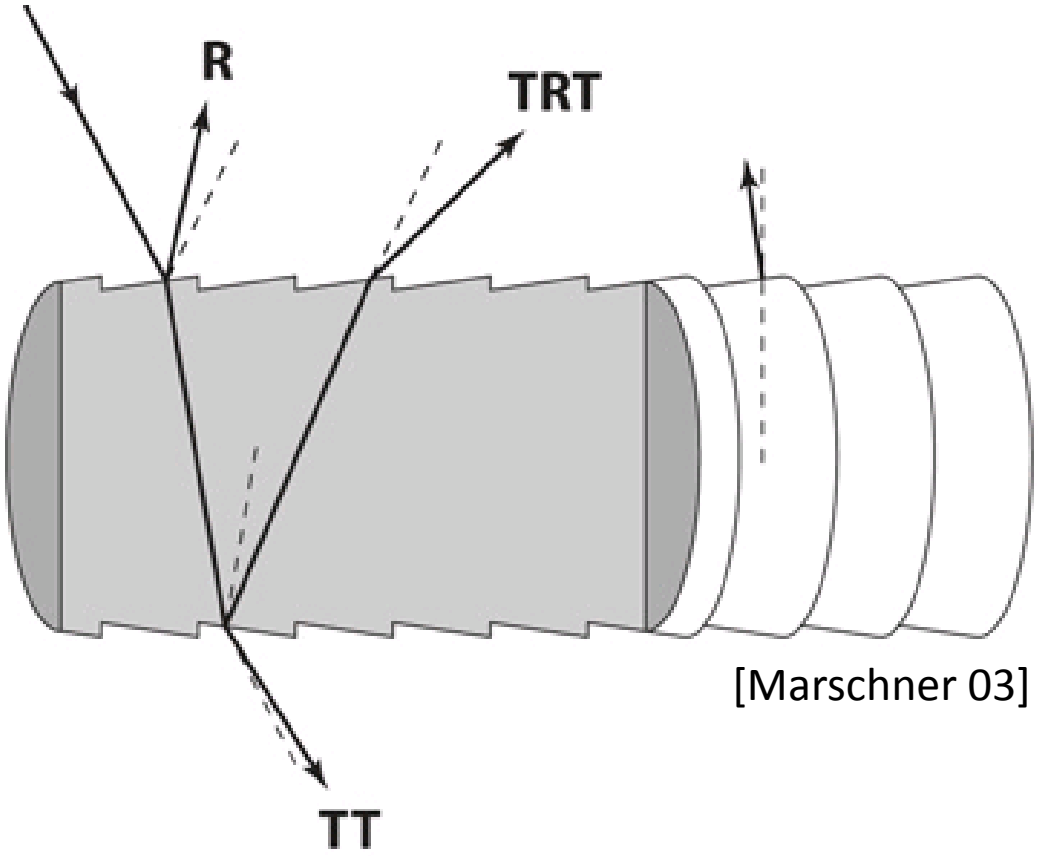


[Levoy 00]

Parametric Reflectance Models

- Inspired by physics [Kajiya 89, Marschner 03, Moon 08, Zink 08…]

- Parameters are hard to set



[Marschner 03]

Image-based Rendering

- Reproduce complex effects [Debevec 00, Matusik 02…]
- Challenged by high-frequency BRDF like hair

[Matusik 02]

Our Approach

A Hardware-intensive, Data-rich Approach

Acquisition: many cameras, many lights, many projectors

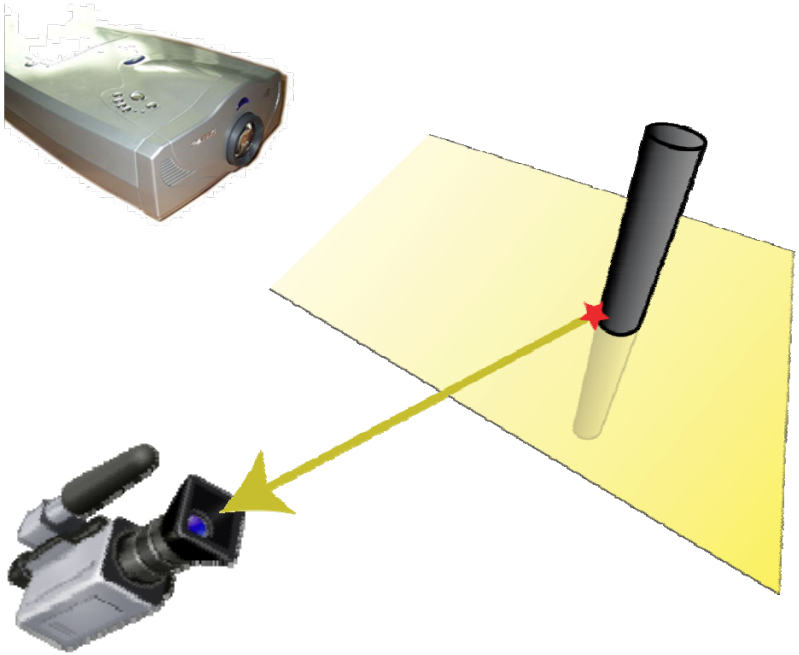
Geometry: triangulation of position and orientation

Rendering: model-driven image-based rendering

Camera-Projector Triangulation

- Redundancy important for occlusions and highlights
  - Each point lit by 1-2 projectors
  - Each point viewed by 3-6 cameras

⇨ Many projectors and cameras

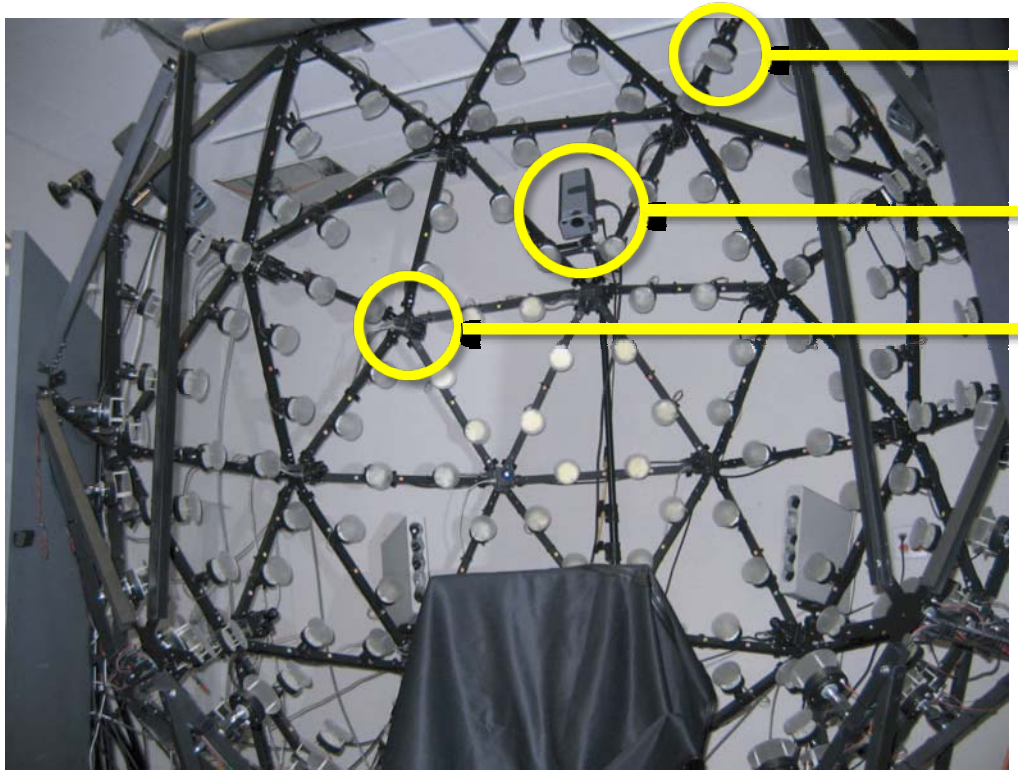


Reflectance Field

- Sampling view and light directions
  - Cameras every ~30 degrees
  - Lights every ~15 degrees

sample input views

Acquisition Setup



150 LEDs

3 video projectors

16 video cameras

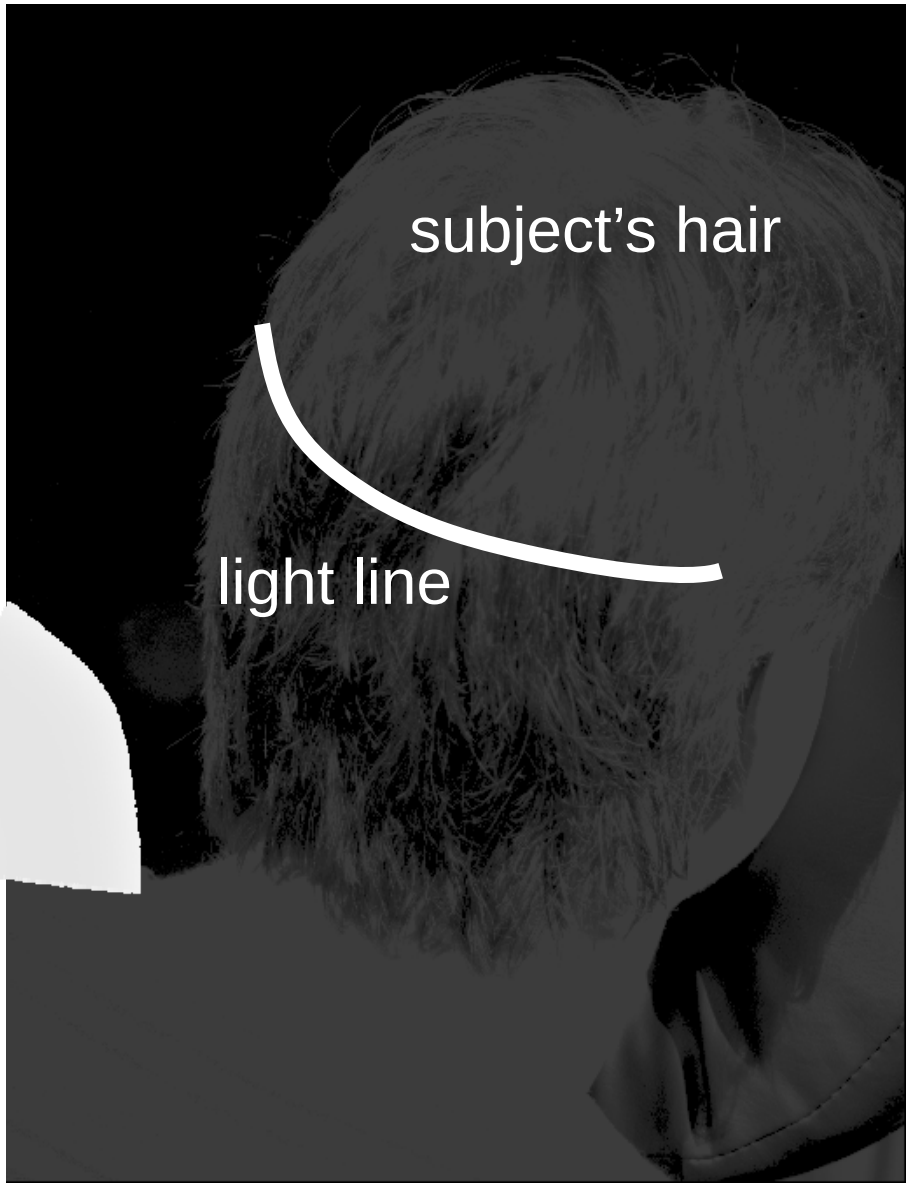
Everything is fixed and accurately calibrated off-line.

Hardware intensive [Debevec 00, Weyrich 06…]

– Movie / special-effect studios

Acquisition: Triangulation Step

- Sweep the hair volume with a white line
  - once with each projector
- Current system slow
  - bottleneck: network
  - about 17 minutes for full hair
  - video sped up 10x
- Full light every 10 frames for motion tracking (cf. paper)



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Position Triangulation

calibrated
projector

subject's hair
(unknown position)

known
plane of light

image
plane

known
ray of light

calibrated
camera

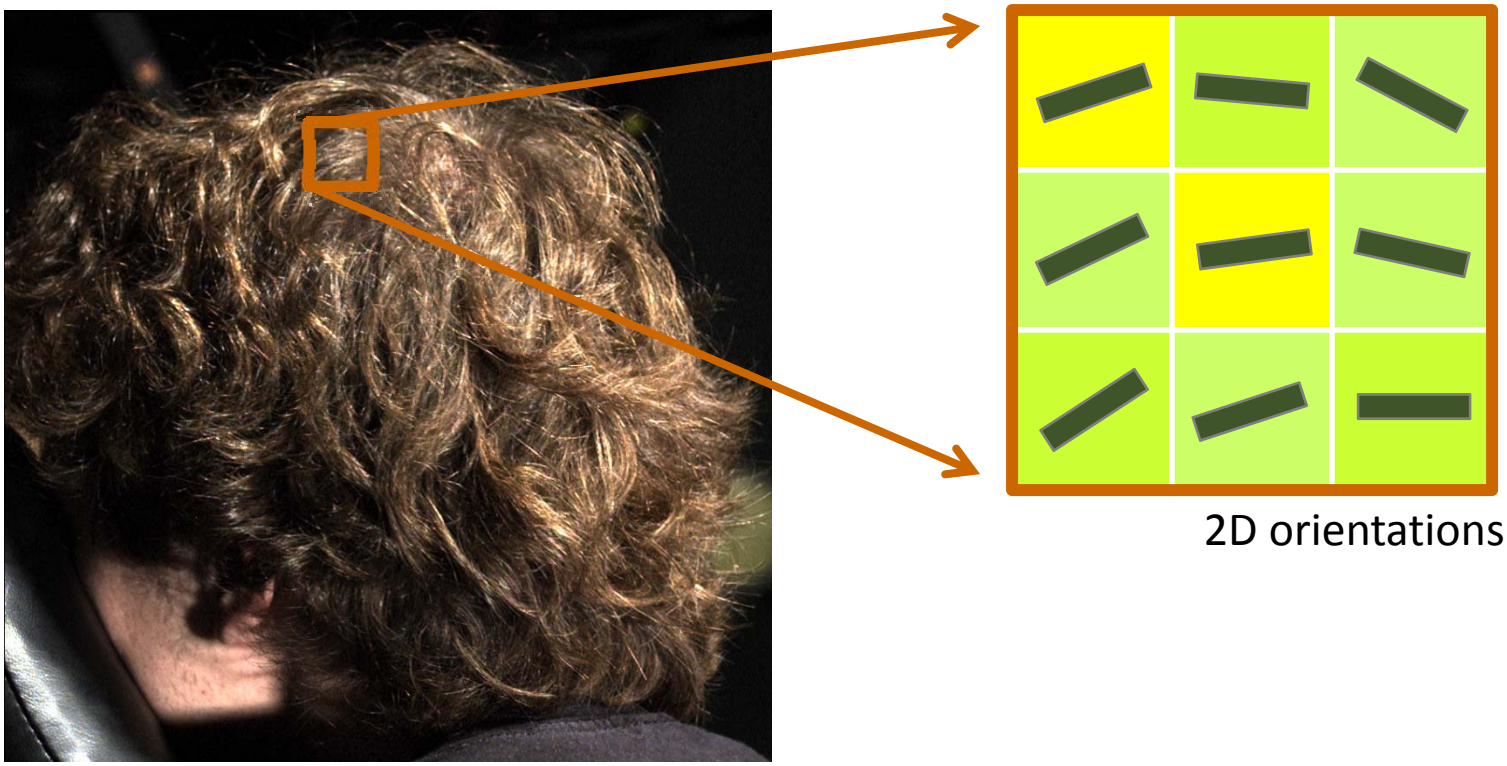
Hair 3D position =
classical line-plane intersection in 3D

Triangulation Output

- Occupancy volume
  - more accurate than visual hull [Paris 04, Wei 05]
  - remaining holes are filled later

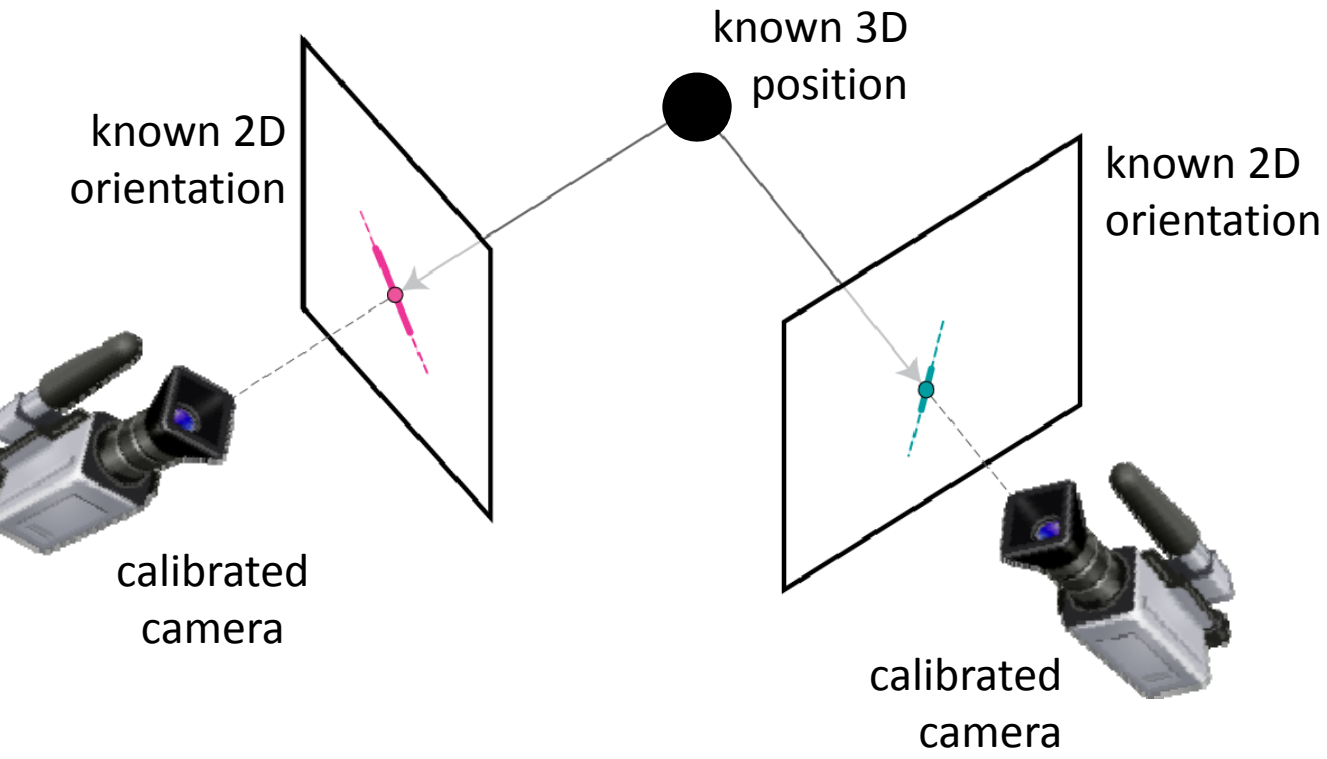
Orientation Triangulation

- 1st step: 2D orientation per pixel [Paris 04]



Orientation Triangulation

- 2nd step: triangulation from 2 cameras [Wei 05]



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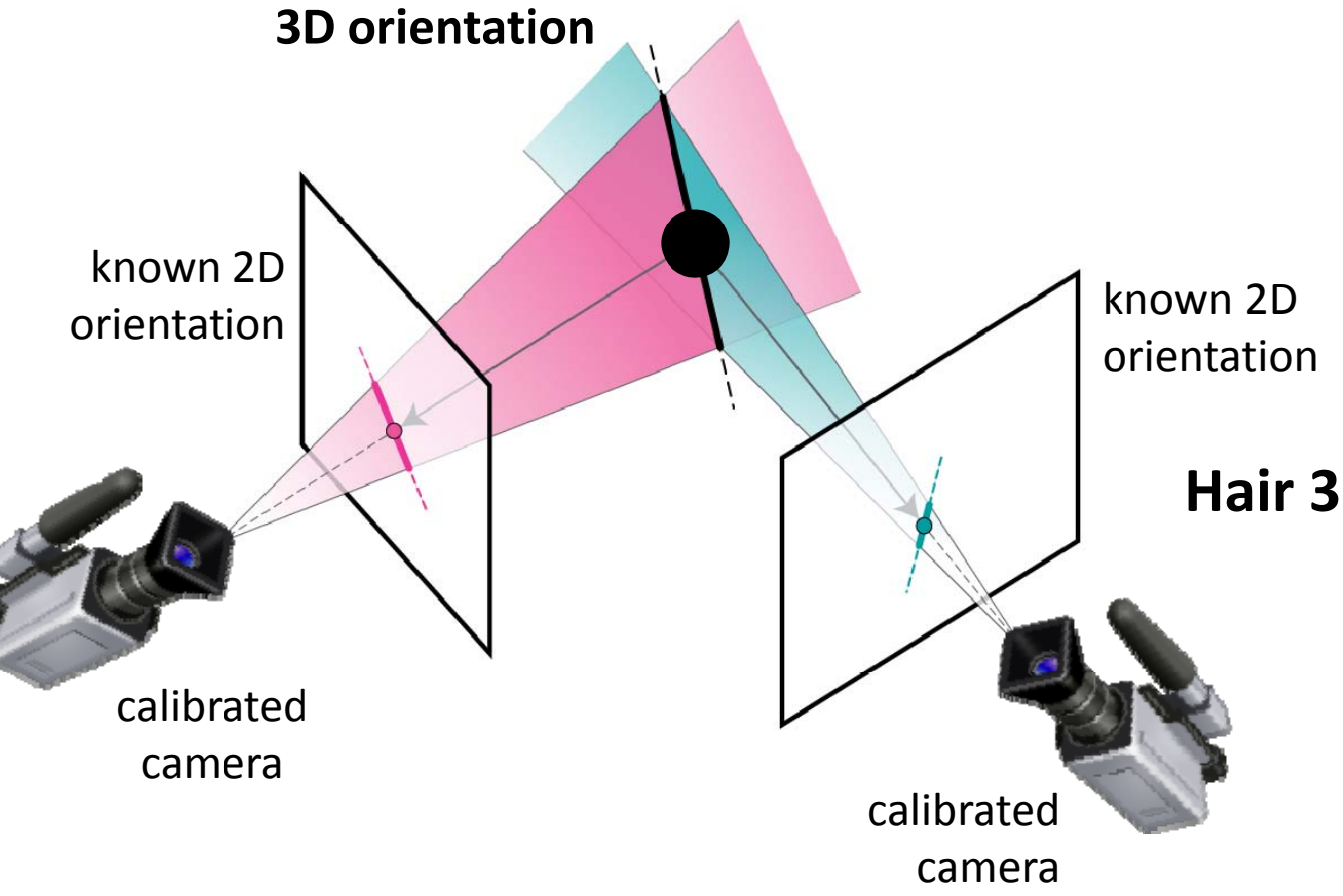
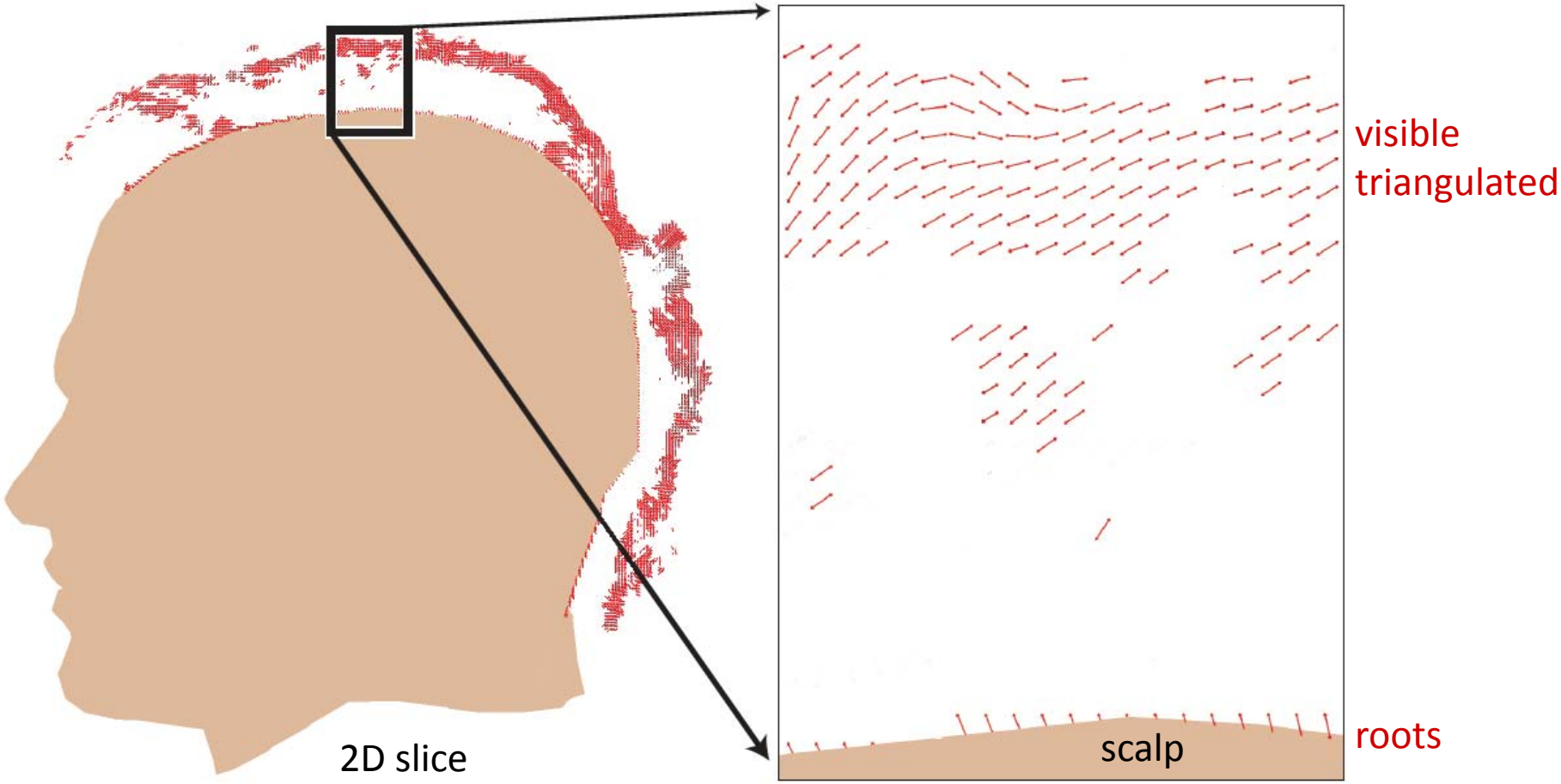


Hair 3D orientation = classical plane-plane intersection in 3D

Inferring Hidden Data

- Triangulation: only visible geometry, no connection to scalp
- Inference using *structure tensors* (see paper)



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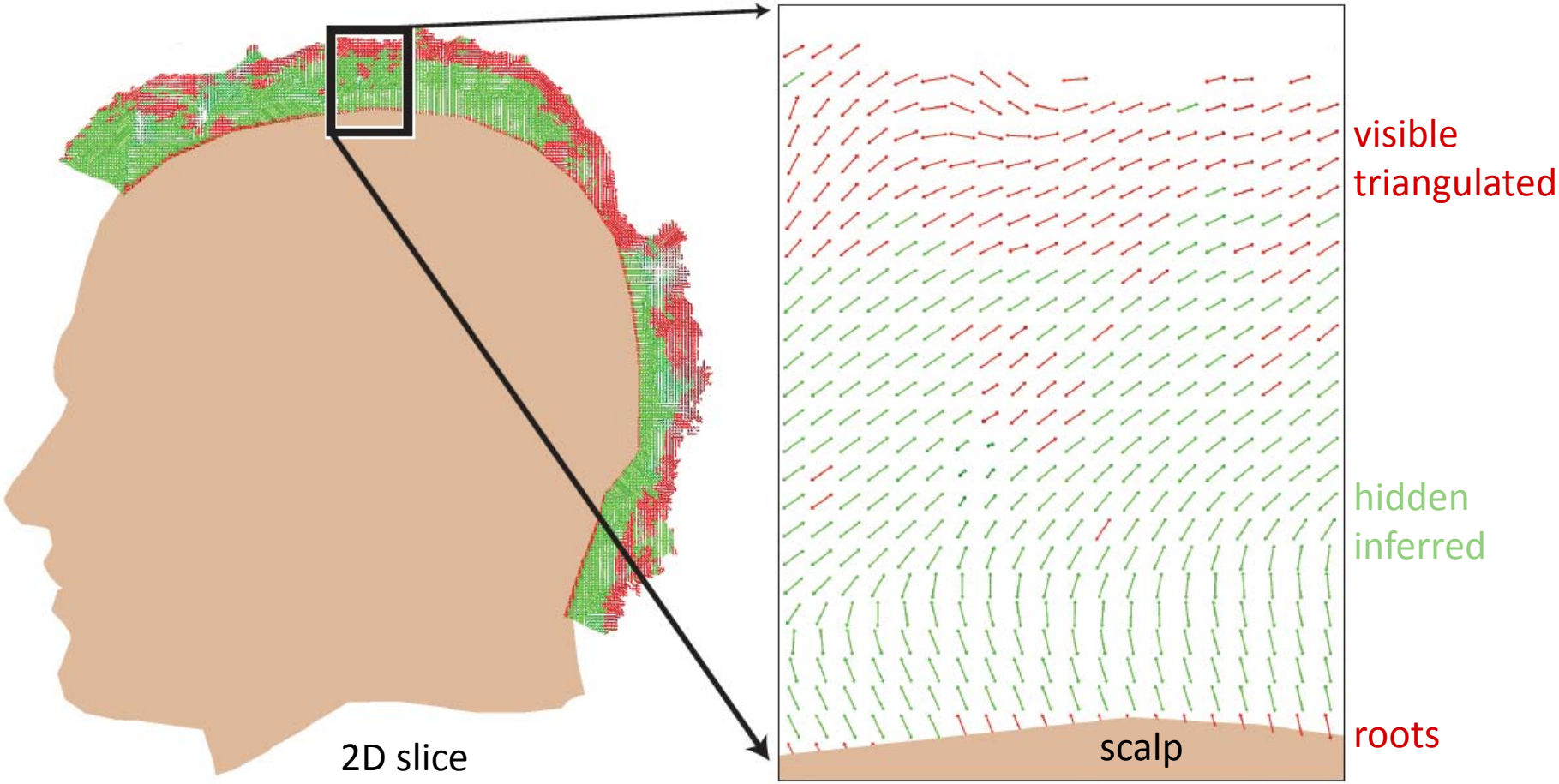
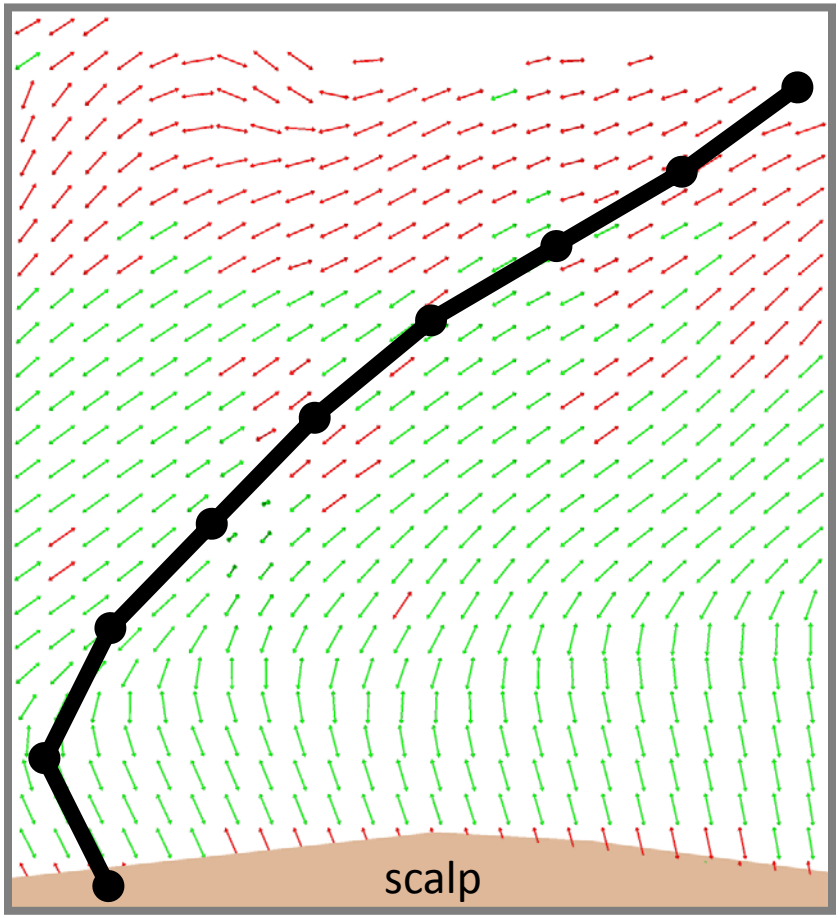


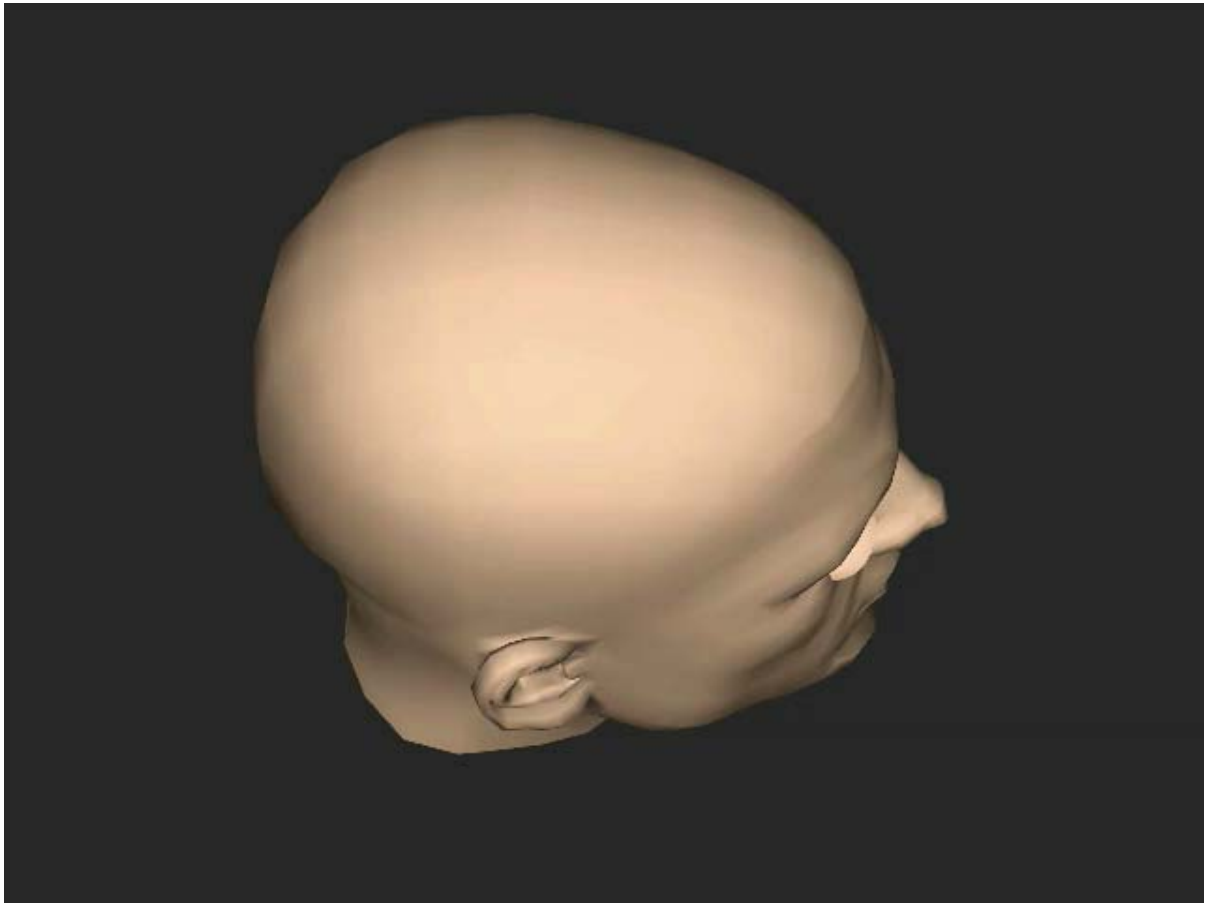
Strand Growth

- Progressive growth from scalp until outer boundary
- Strand = polyline, sampled every 0.5 mm



2D slice

Reconstructed Geometry



Hair Rendering

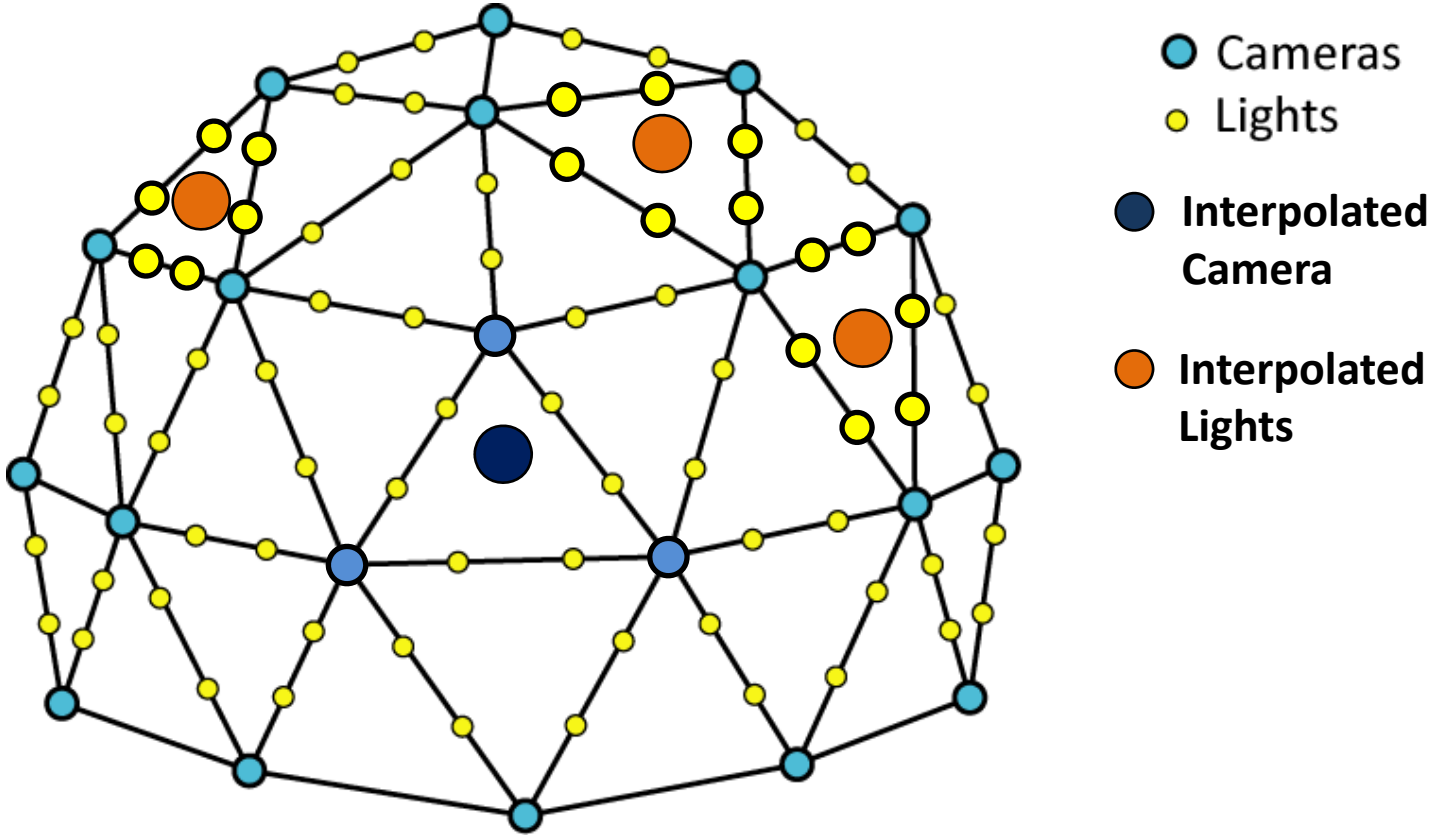
- Render realistic images of hair at any desired viewpoint and illumination
  - Match the original appearance of a hairstyle
- Our contribution: **Model-Based Interpolation**

Rendering

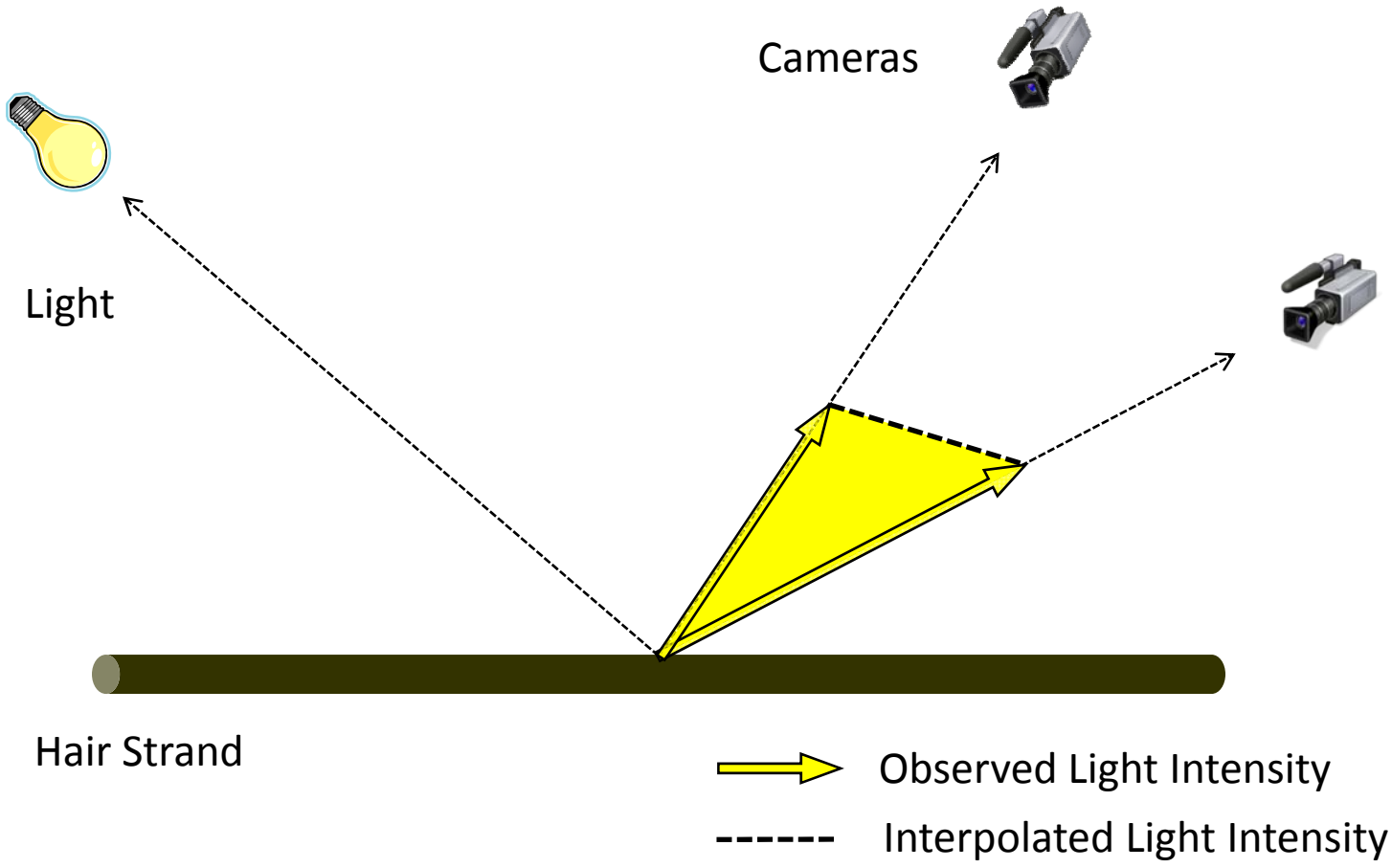
Reference Photograph

Image-Based Rendering

- Leverage acquired photometric data
- Render any desired viewpoint and illumination



Linear Interpolation



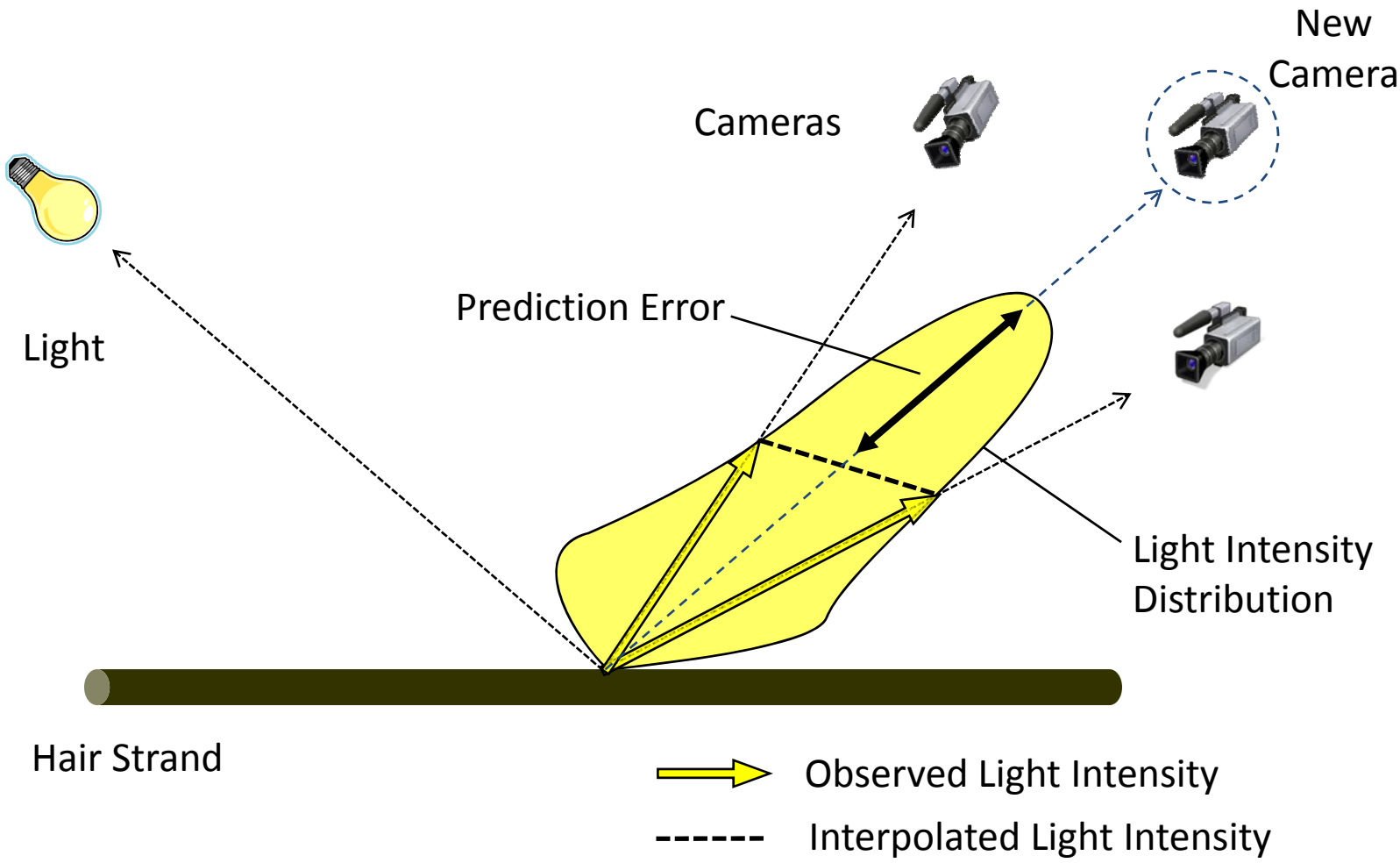
Rendering with Linear Interpolation

- Realistic hair
- Washed-out, faded appearance

Linear interpolation

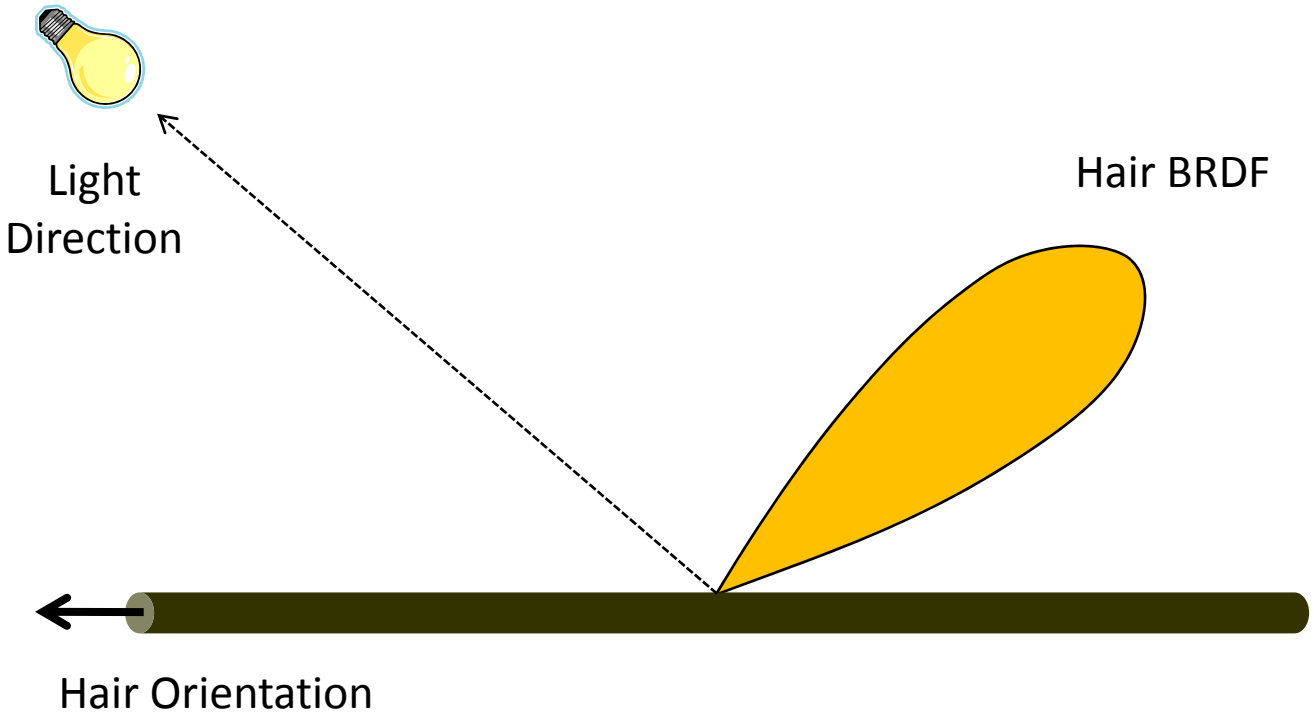
Reference Photograph

Linear Interpolation



Improving Linear Interpolation

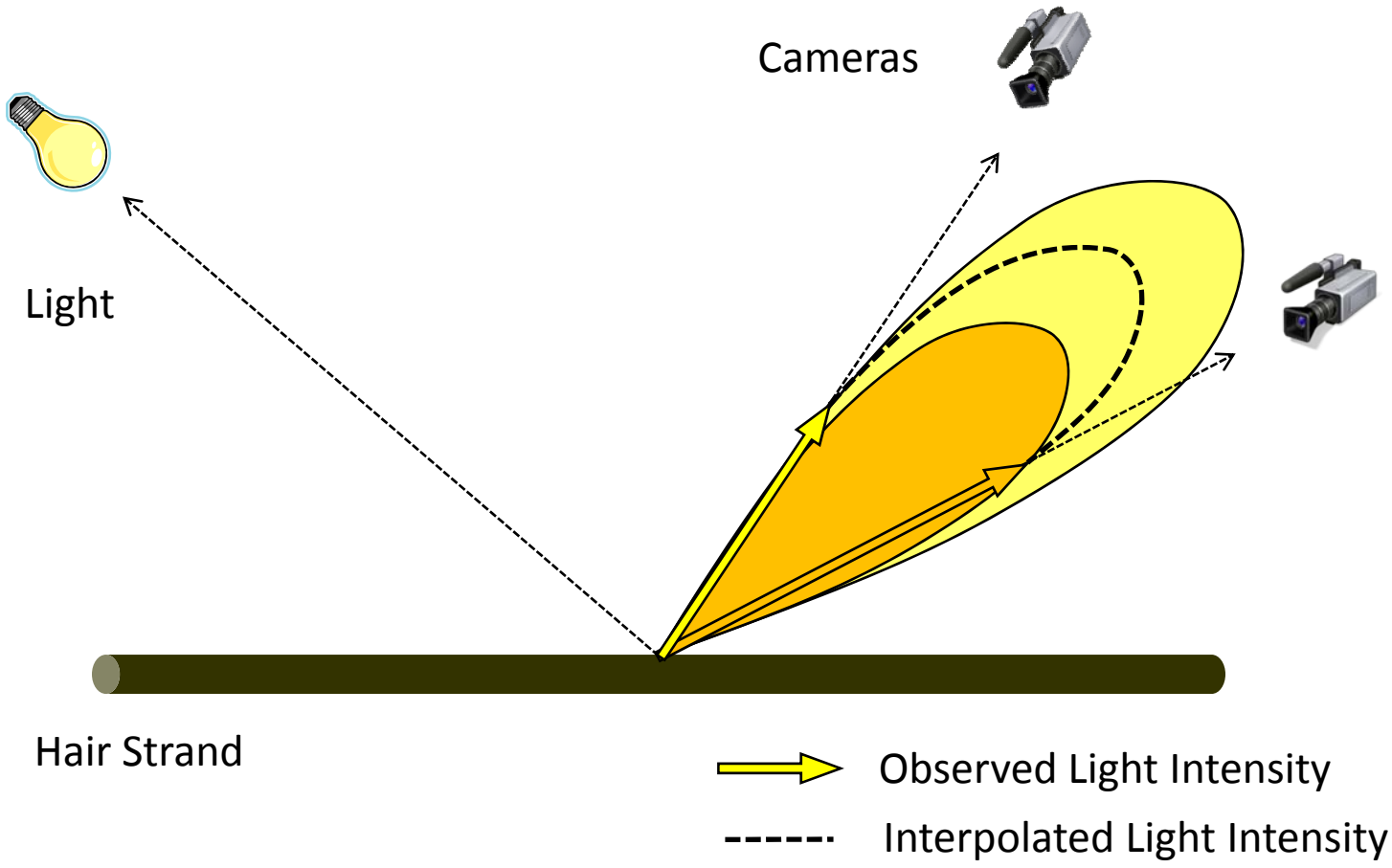
- Incorporate domain-specific information
  - Known hair BRDF + strand orientation



Model-Based Interpolation

- Parametric hair BRDF (Kajiya-Kay lobe)
  - Lobe width fit globally
  - Scaled locally to match image data
- Advantages:
  - BRDF provides sharp highlights
  - Image data reproduces hair color variation, shadows

Model-Based Interpolation



Using Model-Based Interpolation

- Faithfully preserves specular highlights

Linear interpolation

Model-Based interpolation

Reference Photograph

Results

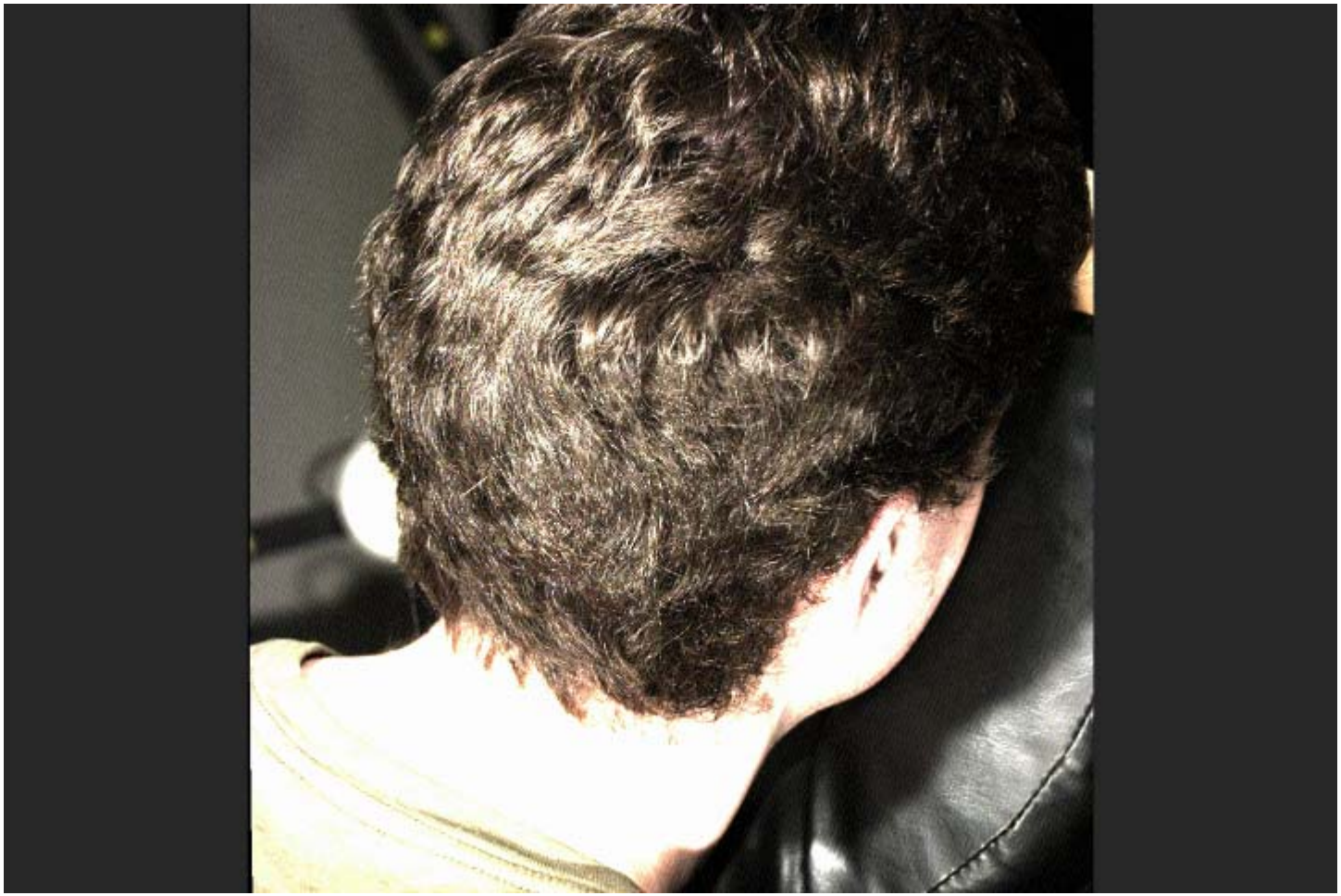
Side-by-Side Comparison

- Rendered hairstyle closely matches reference

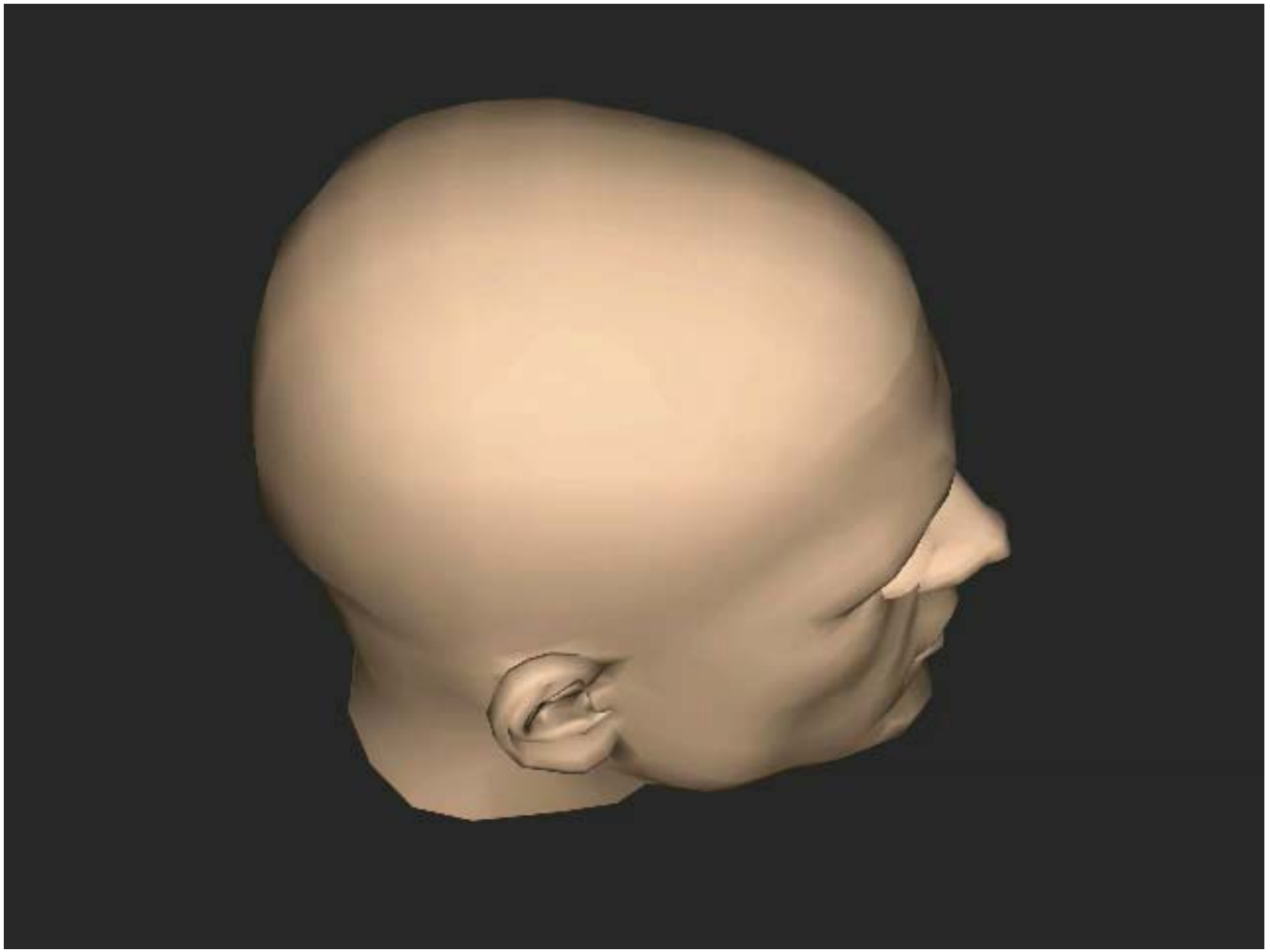
Rendering

Reference Photograph (not in data)

View Interpolation



Tangled Hair Rendering



Rendering Comparison: Linear Interpolation

Rendering Comparison: Model-Based Interpolation

Performance Statistics

- Highly Detailed Geometry Reconstruction
  - 100,000 strands and 4,000,000 vertices
  - 10 hrs on a single core
  - Bottleneck: motion tracking, triangulation
  - Intended as a one-time, offline step
- Image-Based Rendering
  - 90 to 140 seconds per frame on a single core
  - Bottleneck: accessing image data
  - Compress image data for real-time performance

Discussion

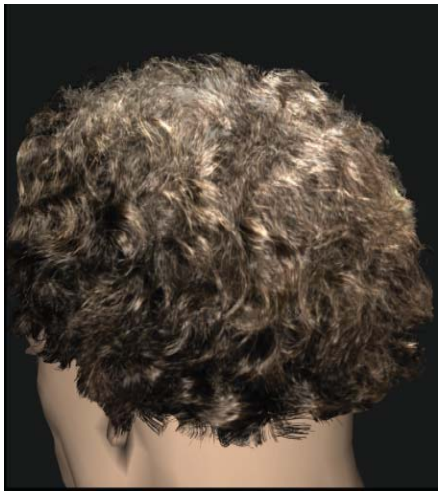
- Use of both geometric and photometric data
  - IBR is great for high-quality images
  - Geometry is great for changing viewpoints & animations
- Reconstructed hair geometry enables animation
  - Further work needed to apply IBR for animated geometry
- Hardware-heavy solution
  - Light-weight acquisition solution needed for wide-spread practical deployment
  - Higher resolution needed to observe fine-scale detail while increasing capture volume

Conclusion

- **High quality hair capture** for movies and games
  - **Triangulation scanning** for hair geometry
  - **Hole filling** to infer occluded orientation field
  - **Model-based interpolation** for specular highlight

Rendering

Reference Photograph



Rendering

Reference Photograph

Thank you!

- Janet McAndless, Peter Sand, Tim Weyrich, John Barnwell, Krystle de Mesa
- MERL, MIT Pre-Reviewers, SIGGRAPH Reviewers
- NSF CAREER Award 0447561, Microsoft Research New Faculty Fellowship, Sloan Fellowship, Adobe

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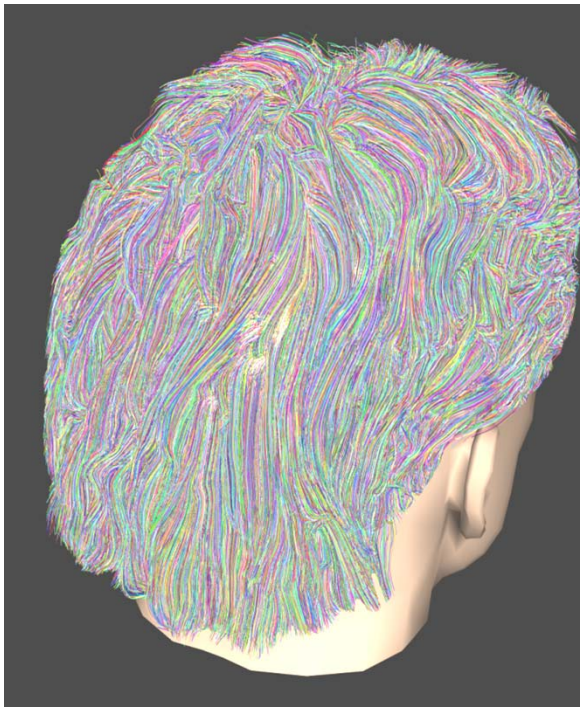

reflectance
(image-based rendering)

reference photograph
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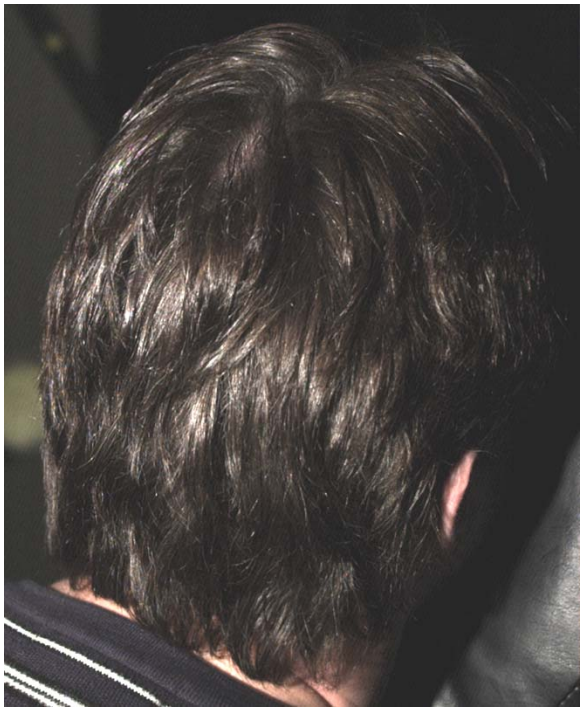

our result