Background

Rendering hair

Important for variety of industries

- Animation movie industry: to render realistic hairs in a physically accurate way.
- Game industry: enhance realism and visual effects.
- Clothes manufacturing industry: to render custom fabrics and to compare appearance in different lighting conditions.
- Hair styling: render hair styling products applied to the hair.

Rendering hair

Hair fiber representation

Explicit representation vs. Implicit representation

- Explicit representation represents each fiber by geometric primitives (e.g. triangles)
- Implicit representation represents fiber

There are a couple of ways to represent hair fibers:

- Connected triangle strips
- Cylindrical primitives
- Trigonal prisms
- Ribbons

Rendering hair

Rendering challenges

Human hair consists of over hundreds of thousands of hair strands. Leads to rendering challenges:

- Memory consumption: to store all fibers in memory.
- Time: rendering realistic scattering effects requires tracing many samples through the hair volume.
- Aliasing: Hair fibers are very thin, requiring additional samples to be drawn to prevent aliasing.

Mathematical notation

Radiometry

- Power (Watts): energy in Joules per second.
- Radiant intensity (steradians): power divided by the solid angle.
- Irradiance (Watts per m^2): power per unit area.
- Radiance : Irradiance per solid angle, where solid angle goes to zero (becoming a ray instead of a cone).

Scattering is represented by a bidirectional reflection distribution function (BRDF):

$$f_r(p, \omega_o, \omega_i) = \frac{dL_o(p, \omega_o)}{dE(p, \omega_i)} = \frac{dL_o(p, \omega_o)}{L_i(p, \omega_i) \cos\theta_i d\omega_i} \tag{1}$$

The BRDF is the fraction of outgoing radiance in direction ω_o related to the incident irradiance from direction ω_i.

Mathematical notation

Hair fibers

Mathematical notation

Bidirectional curve scattering distribution function (BCSDF)

- Hair fibers are rendered implicitly by 3D curves.
- Curves have no surface area. They have a length, requiring a change to the BRDF formulation.

$$S_r(\omega_o, \omega_i) = \frac{dL_o(\omega_o)}{dE_i(\omega_i)} = \frac{dL_o(\omega_o)}{DL_i(\omega_i) \cos\theta_i d\omega_i} \tag{2}$$

$$L_o(\omega_o) = D \int S(\omega_i, \omega_o) L_i(\omega_i) \cos\theta_i d\omega_i \tag{3}$$

Monte-Carlo integration

Numerical integration technique based on random numbers
Possible to integrate any definite higher dimensional integrals.

$$F_N = \frac{b-a}{N} \sum_{i=1}^{N} f(X_i) \tag{4}$$

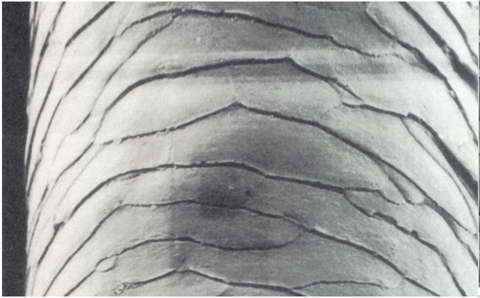
$$F_N = \frac{1}{N} \sum_{i=1}^{N} \frac{f(X_i)}{p(X_i)} \tag{5}$$

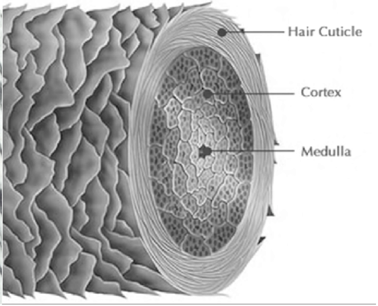
Multiple importance sampling

Related work

Structure of hair

- Hair fibers do have cuticle scales oriented at approximately 7 degrees.
- The core of the fiber (medulla and cortex) consist of pigment which absorbs specific wavelengths in the light.

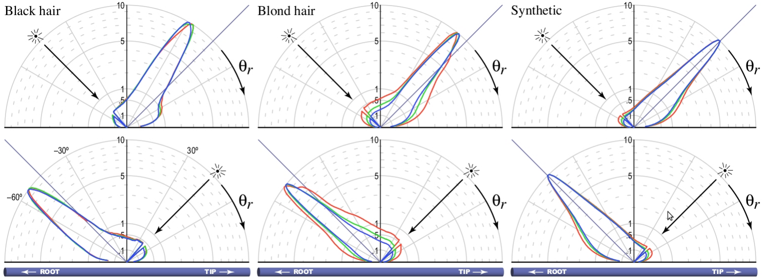




Related work

Measured scattering data

Single fiber scattering model that models three visible scattering components:



Related work

Marschner model

Single fiber scattering model that models three visible scattering components.

R reflection,
TT double transmission,
TRT transmission, reflection, transmission

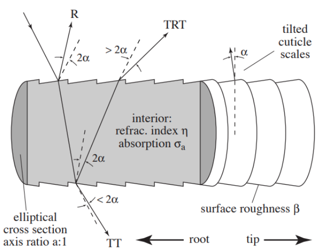


Figure: Longitudinal scattering

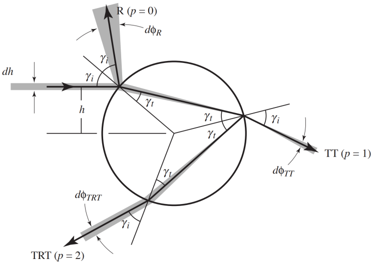


Figure: Azimuthal scattering

Related work

Dualscattering Approximation

Approach

Goals

Implementation

PBRT

Implementation

Voxel grid

Implementation

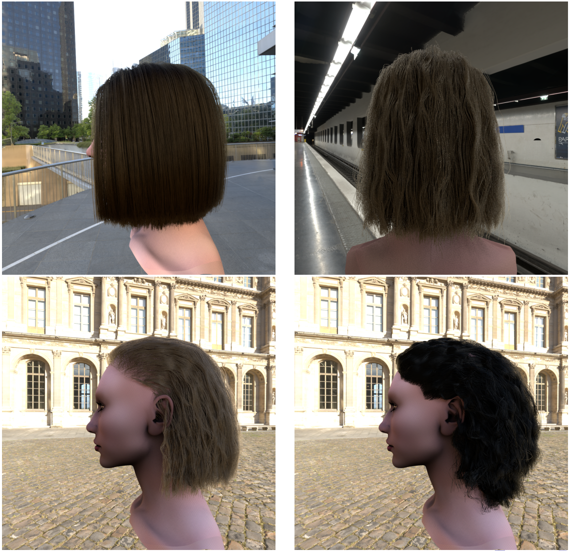
Memory and speed requirements

Results

Dual scattering approximation IS 512 samples per pixel

Results

Importance sampling results



Results

Real world scenarios (Venice)

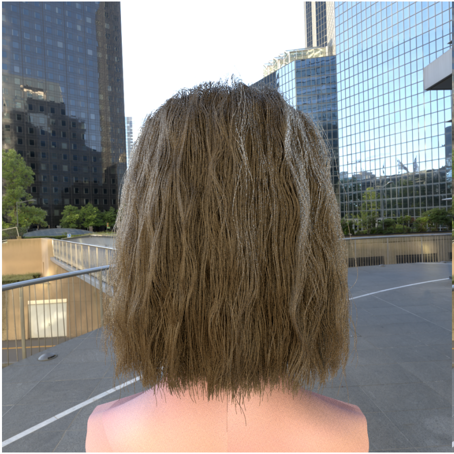
Uniform Sampling (32 spp)

Importance Sampling (32 spp)

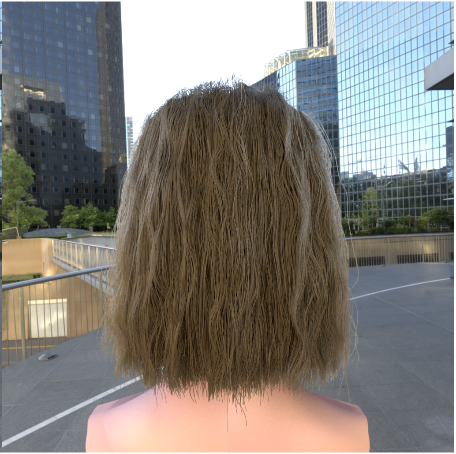
Results

Real world scenarios (Office Square)

Uniform Sampling (32 spp)



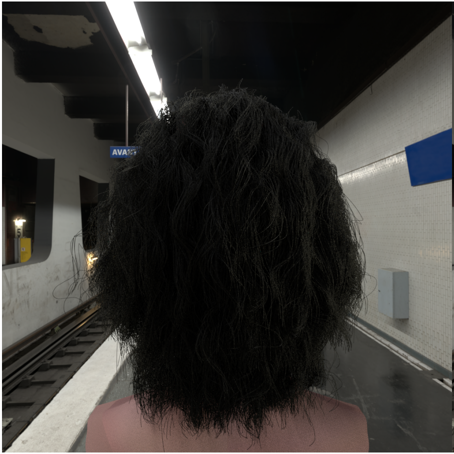
Importance Sampling (32 spp)



Results

Real world scenarios (Subway Station)

Uniform Sampling (32 spp)



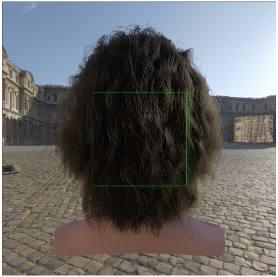
Importance Sampling (32 spp)

Results

Variance computation

- Variance V is computed for a region (w, h) of the image .
- Variance is computed by taking the average distance squared between the image to be analyzed X with the ground truth X'.
- Ground truth is assumed to be uniform sampling at 512 spp.

$$V = \frac{1}{w \cdot h} \sum_{x=0}^{w} \sum_{y=0}^{h} (X_{x,y} - X'_{x,y})^2 \qquad (6)$$



Results

Variance comparison

Results

Variance comparison

Results

Variance plot

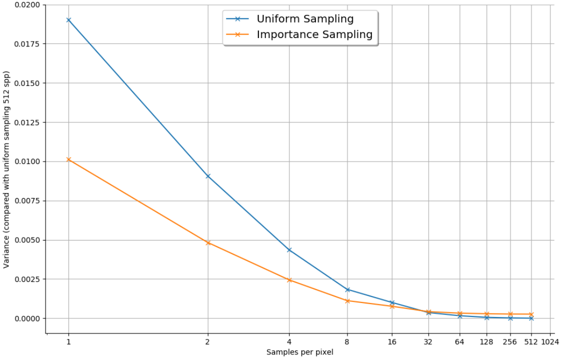


Figure: Logarithmic scale of variance that is reduced as the samples per pixel increase.

Conclusion

Theoretical Challenges

- Dual scattering model for this thesis is not fully energy conserving.
- Variance is lower for importance sampling, but not by the extend that it is clearly noticeable.
- Challenge to implement the dualscattering method in PBRT, because dual scattering makes use of an approximated volume (which does not fit a pure ray tracer).
- Involved physics and mathematical knowledge required. That was challenging to understand.

Conclusion

Practical Challenges

- Choice of rendering framework. Started from scratch, then Pixar Renderman, finally PBRT.
- Voxel grid implementation (OpenVdb) where hair fibers are assumed to be oriented in the same direction.
- Memory and speed requirements. Physics based rendering can take a long time. Feedback cycle is long.
- Non intuitiveness of Marschner model parameters.

Conclusion

Applying importance sampling for the dual scattering method does not significantly reduce the noise compared to rendering using uniform sampling.