SIGGRAPH2004

# Practical Real-Time Hair Rendering and Shading

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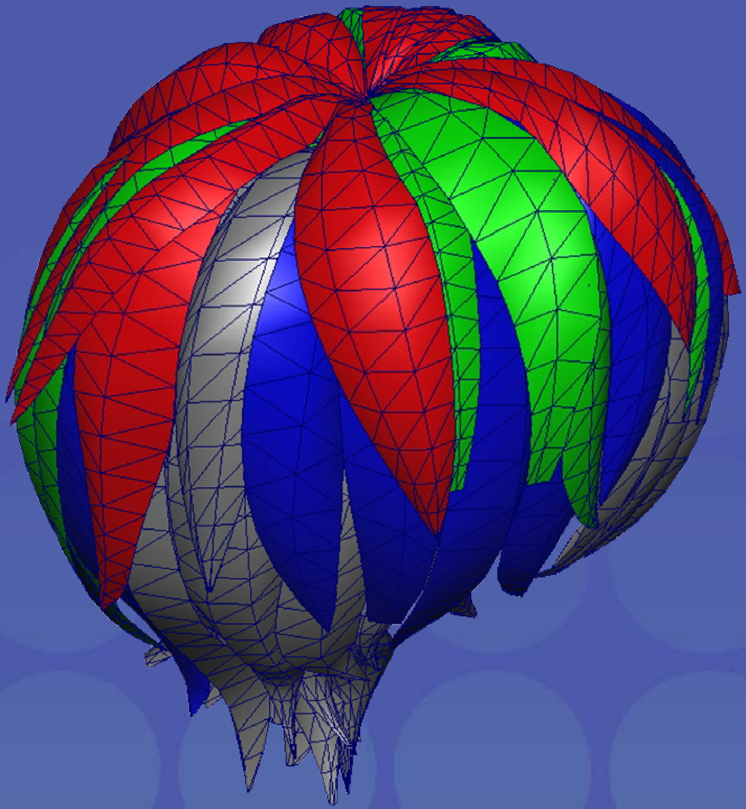
ATI Research

# Outline

- Art assets
  - Hair model
  - Textures
- Shading
  - Kajiya-Kay
  - Marschner
- Depth sorting
  - Early-Z culling optimization
- Demo

# Hair Model - Geometry

- Several layers of patches to approximate volumetric qualities of hair
- Per-vertex ambient occlusion term to approximate self-shadowing



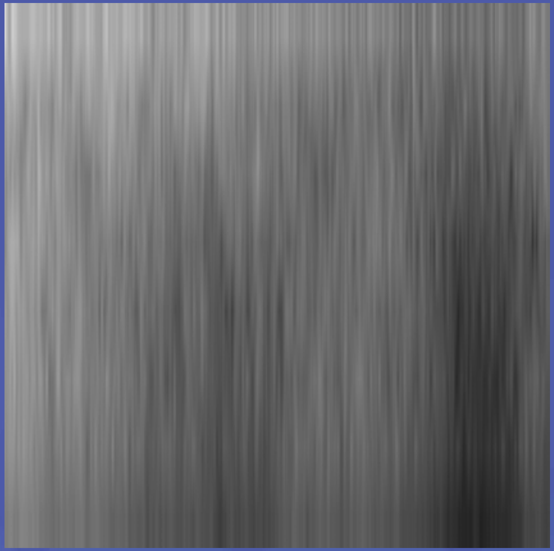
# Hair Model

Reasons for using a polygonal hair model:

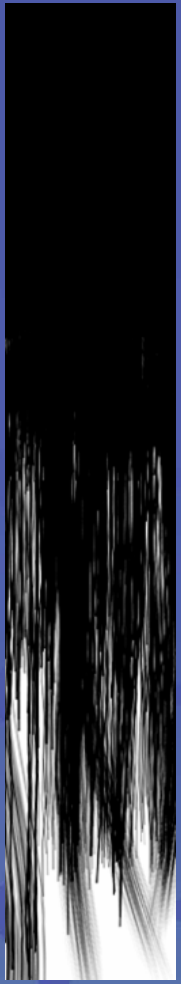
- Lower geometric complexity than line rendering
  - Makes depth sorting faster
  - Pretty much a necessity for real-world use on current graphics hardware
- Integrates well into our art pipeline

# Hair Model - Textures

- Base texture
  - Stretched noise
  - Hair color set in a shader constant
- Alpha texture
  - should have fully opaque regions
- Specular shift texture
- Specular noise texture



Base Texture



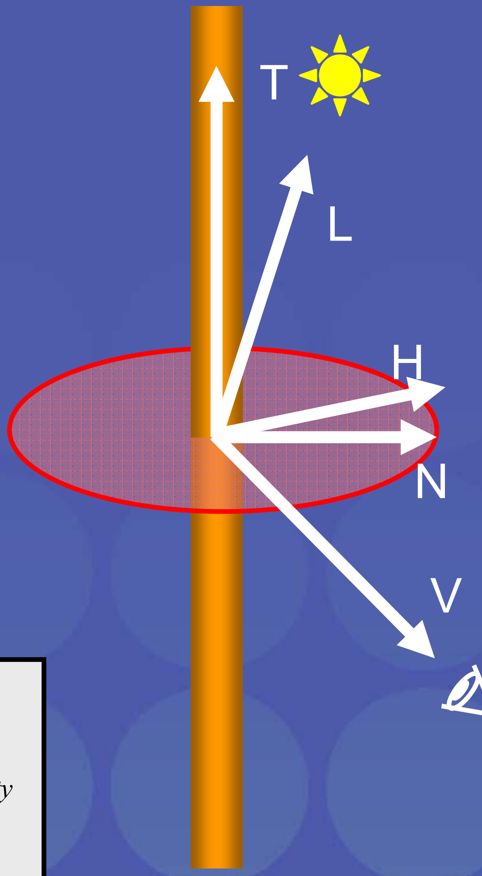
Alpha Texture

# Hair Lighting: Kajiya-Kay

- Anisotropic strand lighting model
- Use hair strand tangent $T$ instead of normal $N$ in lighting equations
- Assumes hair normal to lie in plane spanned by $T$ and view vector $V$
- Example: Specular $N{\cdot}H$ term

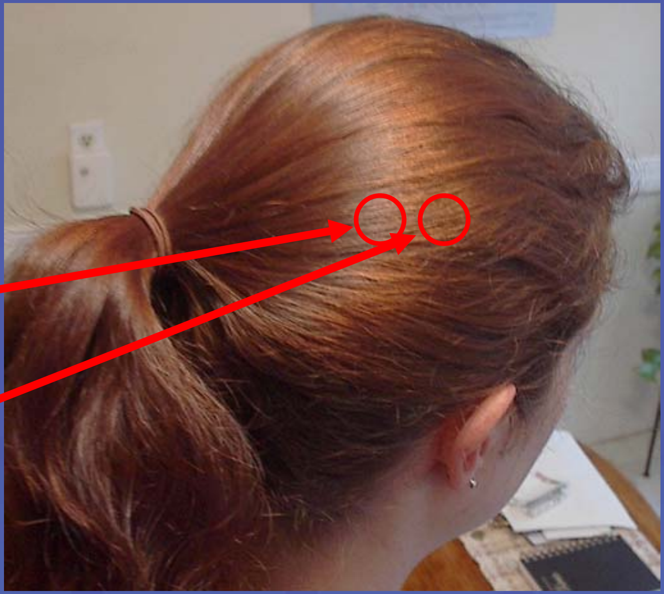
$$\cancel{\mathrm{dot}(N,H)^{specularity}}$$

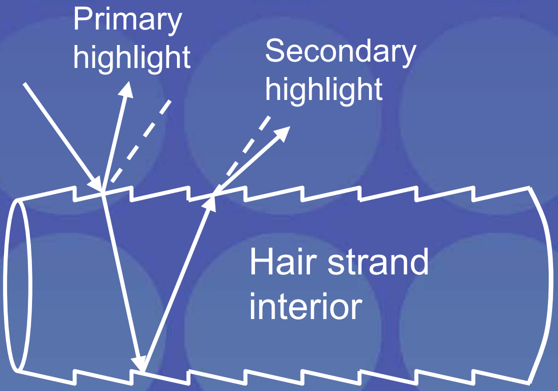
$$\sin(T,H)^{specularity} = \sqrt{1-\mathrm{dot}(T,H)^2}^{\,specularity}$$



# Hair Lighting: Marschner

- Based on measurements of hair scattering properties
- Observations
  - Primary specular highlight shifted towards hair tip
  - Secondary specular highlight
    - Colored
    - Shifted towards hair root
    - Sparkling appearance
- For simplicity we’re trying to match these observations phenomenologically





# Hair Shader Implementation

Vertex Shader

- Just passes down tangent, normal, view vector, light vector, ambient occlusion term

Pixel Shader

- Diffuse Lighting
- Two shifted specular highlights
- Combines lighting terms

# Diffuse Lighting Term

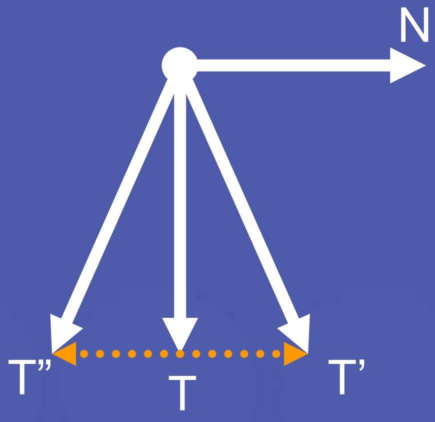
- Kajiya-Kay diffuse term $\sin(T, L)$ looks too bright without proper self-shadowing
- Instead, use scaled and biased $N{\cdot}L$ term:

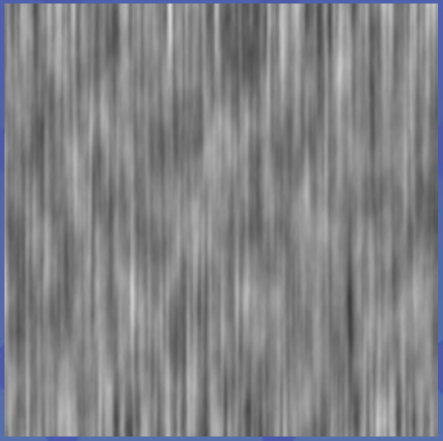
$$diffuse = \max(0, 0.75 * N \cdot L + 0.25)$$

- Brightens up areas facing away from the light when compared to plain $N{\cdot}L$ term
  - Simple subsurface scattering approximation
- Softer look

# Shifting Specular Highlights

- Move tangent along patch normal direction to shift specular highlight along hair strand
- Assuming $T$ is pointing from root to tip:
  - Positive shift moves highlight towards tip
  - Negative shift moves highlight towards root
- Look up shift value from texture to break up uniform look over hair patches

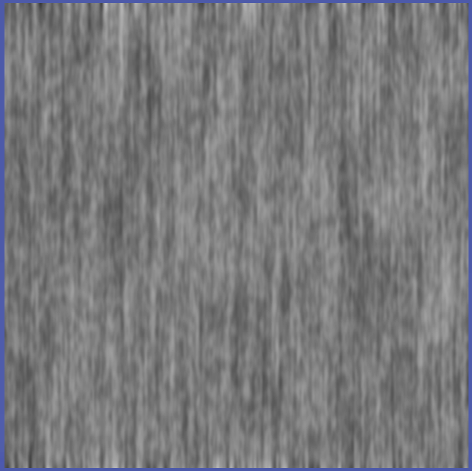




Shift texture

# Specular Strand Lighting

- Specular strand lighting using half-angle vector
- Compute two highlights with
  - Different colors
  - Different specular exponents
  - Differently shifted tangents



Specular Noise Texture

- Modulate secondary highlight with noise texture
- Specular highlights are attenuated by scaled and biased $N \cdot L$ term to account for lack of true self-shadowing

# Combination of Lighting Terms

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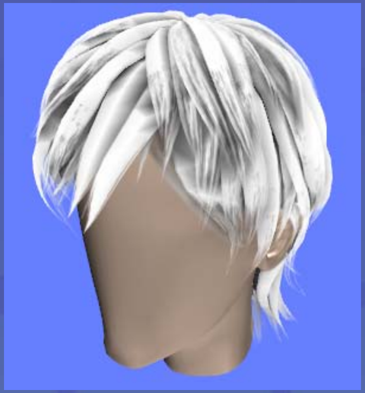
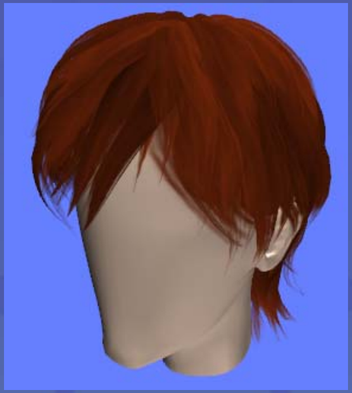
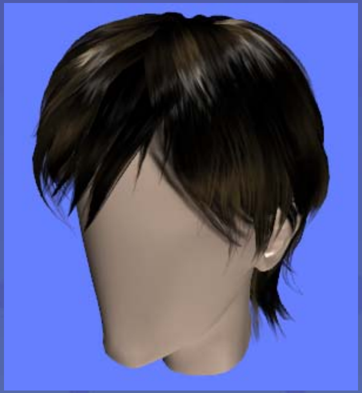
$$finalColor = (diffuse + specular_1 + specular_2) * baseTexture * ambientOcclusion$$



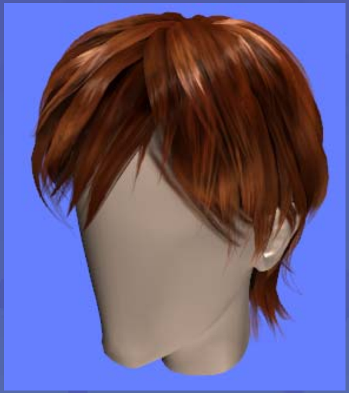
Ambient Occlusion



Diffuse Term

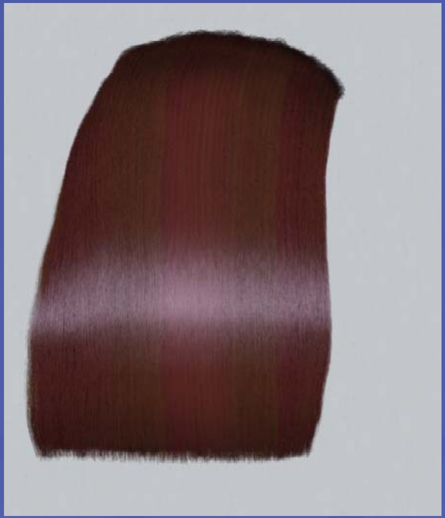


Specular Terms

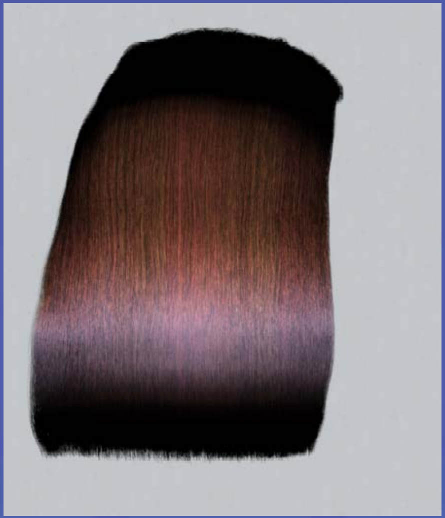


Combined

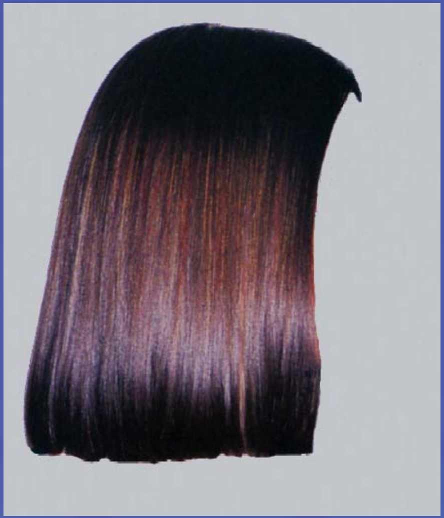
# Comparison



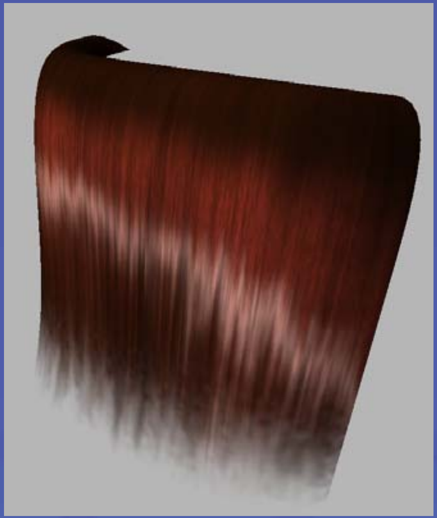
Kajiya-Kay



Marschner et al.



Photograph



Our shader

(Left three pictures from [Marschner03])

# Approximate Depth Sorting

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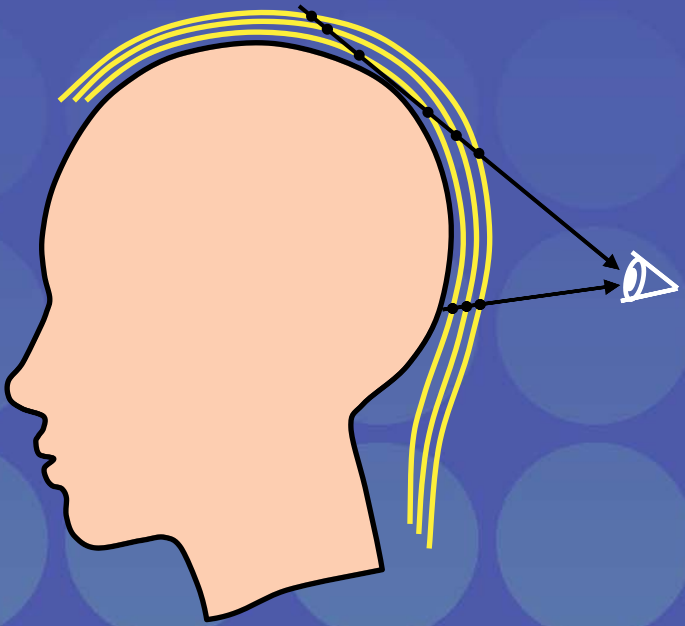
- Back-to-front rendering order necessary for correct alpha-blending
- For a head with hair this is very similar to rendering from inside to outside
- Use static index buffer with inside to outside draw order
  - Computed at pre-process time
  - Sort connected components (hair strand patches) instead of individual triangles



# Sorted Hair Rendering Scheme

- Pass 1: render opaque parts
  - Visibility resolved using z buffer
- Pass 2: render transparent back-facing parts
- Pass 3: render transparent front-facing parts

- Use alpha testing to distinguish between opaque and transparent parts in each pass

# Taking Advantage of Early-Z Culling

- Early-Z culling allows skipping pixel shader execution for fragments that fail Z test
- Helps scenes with high depth complexity like the layered hair model
- Unfortunately early-Z culling is incompatible with alpha testing on our target hardware
- Replacing alpha tests with Z tests enables early-Z culling which speeds up hair rendering

# Optimized Scheme: Pass 1

Prime Z buffer with depth of opaque hair regions

- Enable alpha test to only pass opaque pixels
- Disable backface culling
- Enable Z writes, set Z test to `Less`
- Disable color buffer writes
- Use simple pixel shader that only returns alpha

- No benefits of early-Z culling in this pass, but shader is very cheap anyway

# Optimized Scheme: Pass 2

Render opaque regions

- Start using full hair pixel shader
- Disable backface culling
- Disable Z writes
- Set Z test to `Equal`
  - Z test passes only for fragments that wrote to Z in pass 1, which are the opaque regions

- This and subsequent passes don’t require alpha testing and thus benefit from early-Z culling

# Optimized Scheme: Pass 3

Render transparent back-facing parts

- Cull front-facing polygons
- Disable Z writes
  - Z order isn't necessarily correct
- Set Z test to `Less`

# Optimized Scheme: Pass 4

Render transparent front-facing parts

- Cull back-facing polygons
- Enable Z writes
- Set Z test to `Less`

- Enabling Z writes prevents incorrect depth order at expense of possibly culling too much
- Covers up potential depth order artifacts of previous pass

# Demo

# Pros and Cons

## Pros:

- Low geometric complexity
  - Reduced load on vertex engine
  - Makes depth sorting faster
- Easy fall-backs for lower-end hardware

## Cons:

- Sorting scheme assumes little to no animation in hair model
  - Things like dangling pony tails need to be handled separately
  - Sort geometry at run-time to overcome this
- Not suitable for all hair styles

# Conclusion

- Art assets
  - Polygon hair model
  - Textures
- Shading
  - Diffuse term
  - Two specular terms
  - Ambient occlusion term
- Approximate depth sorting
- Early-Z culling optimization