VGP352 – Week 6

- Agenda:
  - Fur rendering 3 ways
    - Goldman's “fake fur”
    - “Shells and fins” fur
    - Banks BRDF on large hairs

12-February-2008

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fakefur

- Developed by Dan Goldman at ILM
  - A *much* faster version of the “realfur” algorithm used at ILM for close-up shots

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fakefur

- Developed by Dan Goldman at ILM
  - A *much* faster version of the “realfur” algorithm used at ILM for close-up shots
- Makes several simplifying assumptions:
  - Geometry of individual hairs is not visible
  - Hairs are truncated cones
  - The length of each cone is much greater than the radius of either end
    - Can't be used to render 5 o'clock shadow!
  - Radius of the base is greater than the radius of the other end
  - All hairs in an area have identical geometry

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Algorithm Overview

- Compute average hair geometry in sample area
- For each light:
  - Compute hair-over-hair shadow attenuation
  - Compute reflected luminance of hair
  - Compute hair-over-skin shadow attenuation
  - Compute reflected luminance of skin
  - Compute hair / skin visibility ratio
  - Blend skin and hair reflected luminances using hair / skin visibility ratio
- Sum per-light calculated values

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Illumination Function

$$\Psi_{diffuse} = K_d \sin(T, L)$$
$$\Psi_{specular} = K_s \left((T \cdot L)(T \cdot E) + \sin(T, L) \sin(T, E) \right)^p$$
$$\Psi_{hair} = \Psi_{diffuse} + \Psi_{specular}$$

- Why is sin used instead of the usual cos?

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Illumination Function

$$\Psi_{diffuse} = K_d \sin(T, L)$$
$$\Psi_{specular} = K_s \left|(T \cdot L)(T \cdot E) + \sin(T, L)\sin(T, E)\right|^p$$
$$\Psi_{hair} = \Psi_{diffuse} + \Psi_{specular}$$

- Why is sin used instead of the usual cos?
  - A hair is an infinitesimal cylinder and has infinite normals
  - The tangent pointing along the length of the hair is used instead
  - N and T are 90° out of phase, so cos(N, L) = sin(T, L)

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- How can we calculate sin(T, L)?

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- How can we calculate sin(T, L)?

$$\frac{a \times b}{|a||b|} = \sin\theta\, \hat{n} \rightarrow \left| \frac{a \times b}{|a||b|} \right| = \sin\theta$$

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- What's the problem here?

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Illumination Function

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$$\Psi_{hair} = \Psi_{diffuse} + \Psi_{specular}$$

- What's the problem here?
  - Lacks directionality – hairs are fully lit even if L is opposite E
  - Fix this by adding some new attenuation factors

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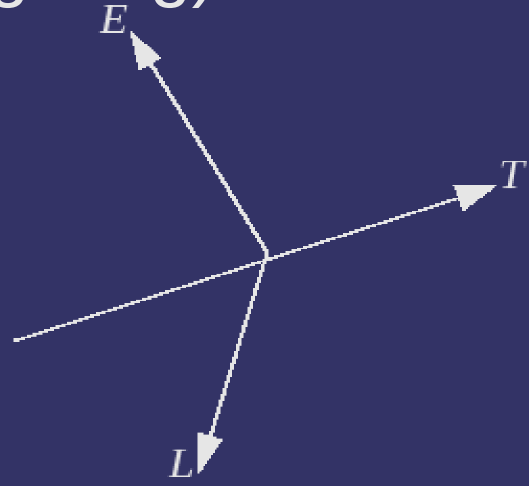
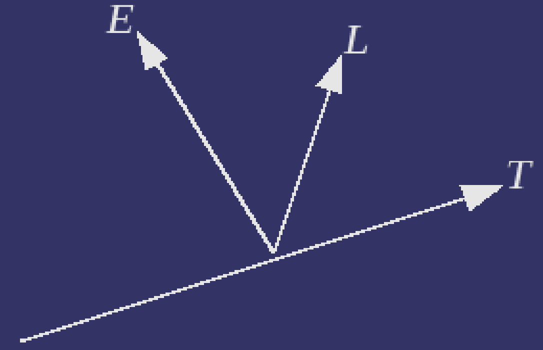
Relative Directionality

$$\kappa = \frac{(T \times L)(T \times E)}{|T \times L||T \times E|}$$

- $\kappa > 0$ when L and E are on the same side of the hair (frontlighting)
- $\kappa < 0$ when L and E are on opposite sides of the hair (backlighting)



Back lighting



Front lighting

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Directional Attenuation Factor

$$f_{dir} = \frac{1+\kappa}{2}\rho_{reflect} + \frac{1-\kappa}{2}\rho_{transmit}$$

- ρ_{reflect} and ρ_{transmit} are parameters of the hair on the range [0, 1]
- White and gray hairs have ρ_{reflect} and ρ_{transmit} equal or nearly equal
- Colored hairs have $\rho_{\text{reflect}} > \rho_{\text{transmit}}$

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- White and gray hairs have ρ_{reflect} and ρ_{transmit} equal or nearly equal
- Colored hairs have $\rho_{\text{reflect}} > \rho_{\text{transmit}}$
- Unless you're a kitten...

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Self-Shadowing

- Controlled by a second attenuation factor and 3 new parameters:

$$f_{surface} = 1 + \rho_{surface}\left(smoothstep(N \cdot L, \theta_{min}, \theta_{max}) - 1\right)$$

  - $\rho_{surface}$ controls the amount of self-shadowing
  - θ_{min} is the minimum angle where shadowing occurs
  - θ_{max} is the angle beyond which there is total occlusion

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Fur Opacity

- How much of the surface *below* the fur can be seen through the fur

$$\alpha_f = 1 - \frac{1}{e^{D A_h g(E,T,N)}}$$

$$g(E,T,N) = \frac{\sin(E,T)}{E \cdot N}$$

$$A_h = l_{hair}(r_{base} + r_{top})/2$$

  - D is the local hair density
  - A_h is the projection of the surface area of a hair onto the view plane

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Putting it all together

- Put the attenuation factors together with the opacity and skin color:

$$\Psi_{hair} = f_{dir} f_{surface} (\Psi_{diffuse} + \Psi_{specular})$$

$$\lambda_{skin} = K_{light} (1 - \alpha_f) \Psi_{skin}$$

$$\lambda_{hair} = K_{light} \left(1 - \frac{\alpha_f}{2}\right) \Psi_{hair}$$

$$f = \alpha_f \lambda_{hair} + (1 - \alpha_f) \lambda_{skin}$$

  – Ψ_{skin} is calculated by some other means

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Break

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Volumetric Fur

- Close-up, fur appears as a volumetric effect
- Kajika and Kay presented an algorithm at SIGGRAPH '89 implementing fur via 3D textures
  - Volumetric textures are *very* memory intensive
  - Kajika and Kay's model involves several computationally expensive steps
- Not practical for real-time
  - There has to be a different way!

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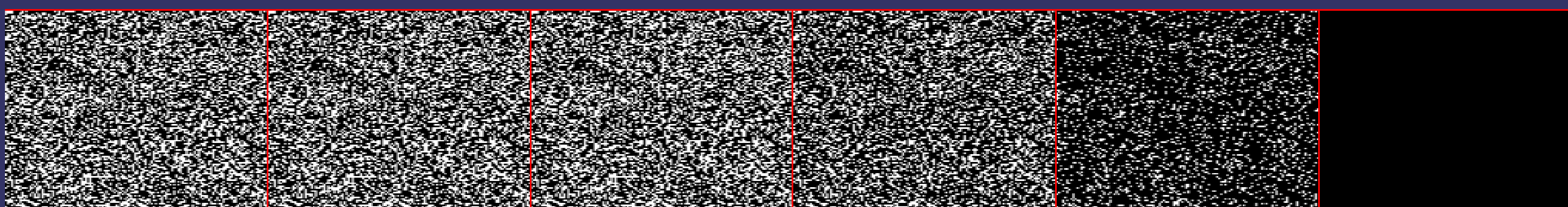
Shells and Fins

- Instead of a 3D texture, fur can be implemented with a “stack” of 2D textures
  - Each layer in the stack represents the fur at a different depth



  - Draw each layer in a progressively larger “shell” around the original object geometry

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Shells and Fins

- Drawing loop:
  - Draw base object with inner-most (call it level 0) fur texture
    - Disable alpha blending
    - Enable z-testing
    - Enable z-writing
  - Draw base geometry moved out some small step along the normals
    - Enable alpha blending
    - Enable z-testing
    - Disable z-writing

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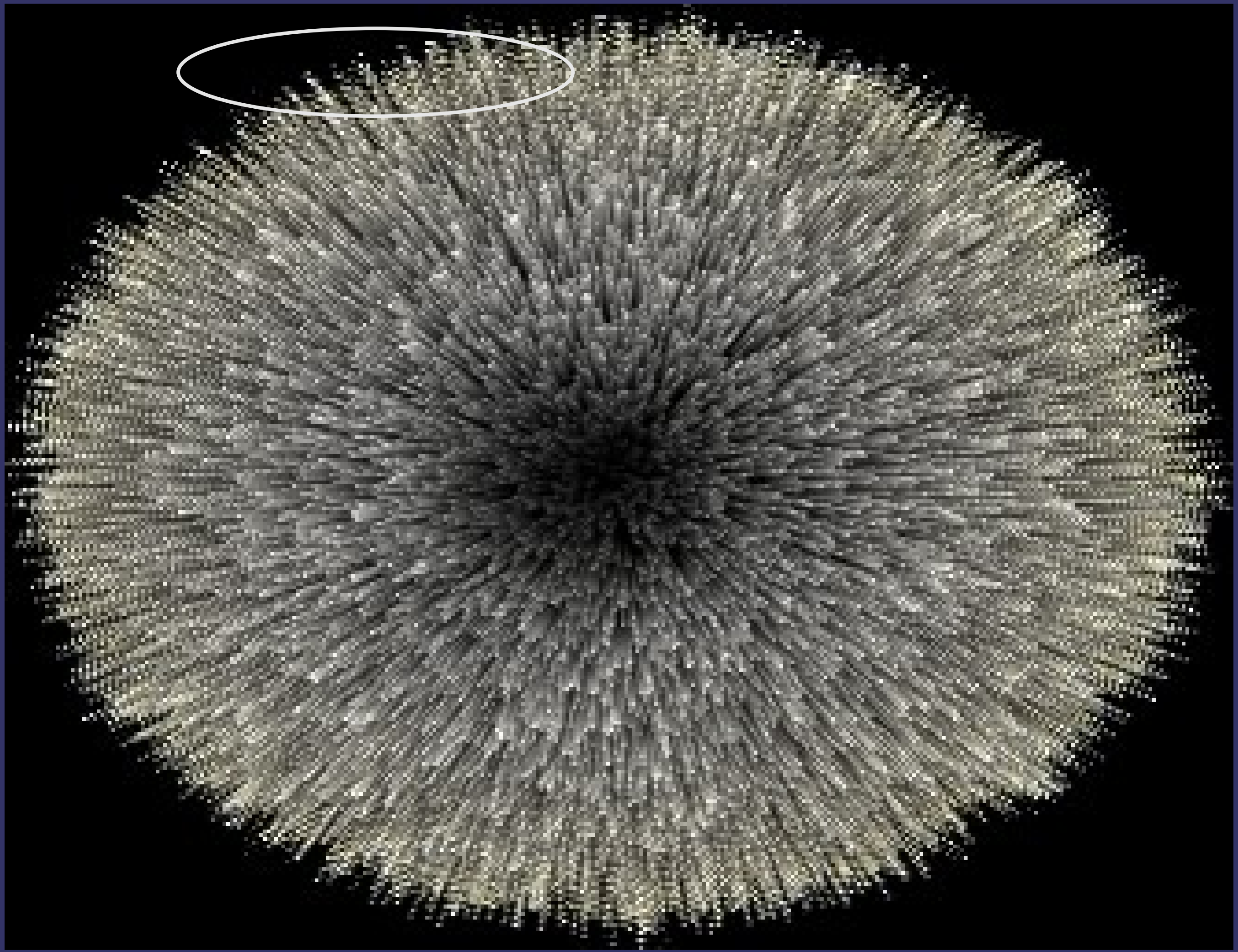
Shells and Fins

- *But* this looks bad along the silhouette



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Shells and Fins

- Add fin geometry to each polygon
  - Create fin textures to look like side-on view of fur
  - Draw fin after drawing all shells
    - Enable alpha blending
    - Enable z-testing
    - Disable z-writing
- Generate fin geometry in the vertex shader:
  - Draw each vertex *twice*
    - Once with w = 0
    - Once with w = 1
  - Use the w value to determine whether or not to extrude the vertex in the normal direction
  - Draw the vertices as a quad in the order 0, 1, 1, 0

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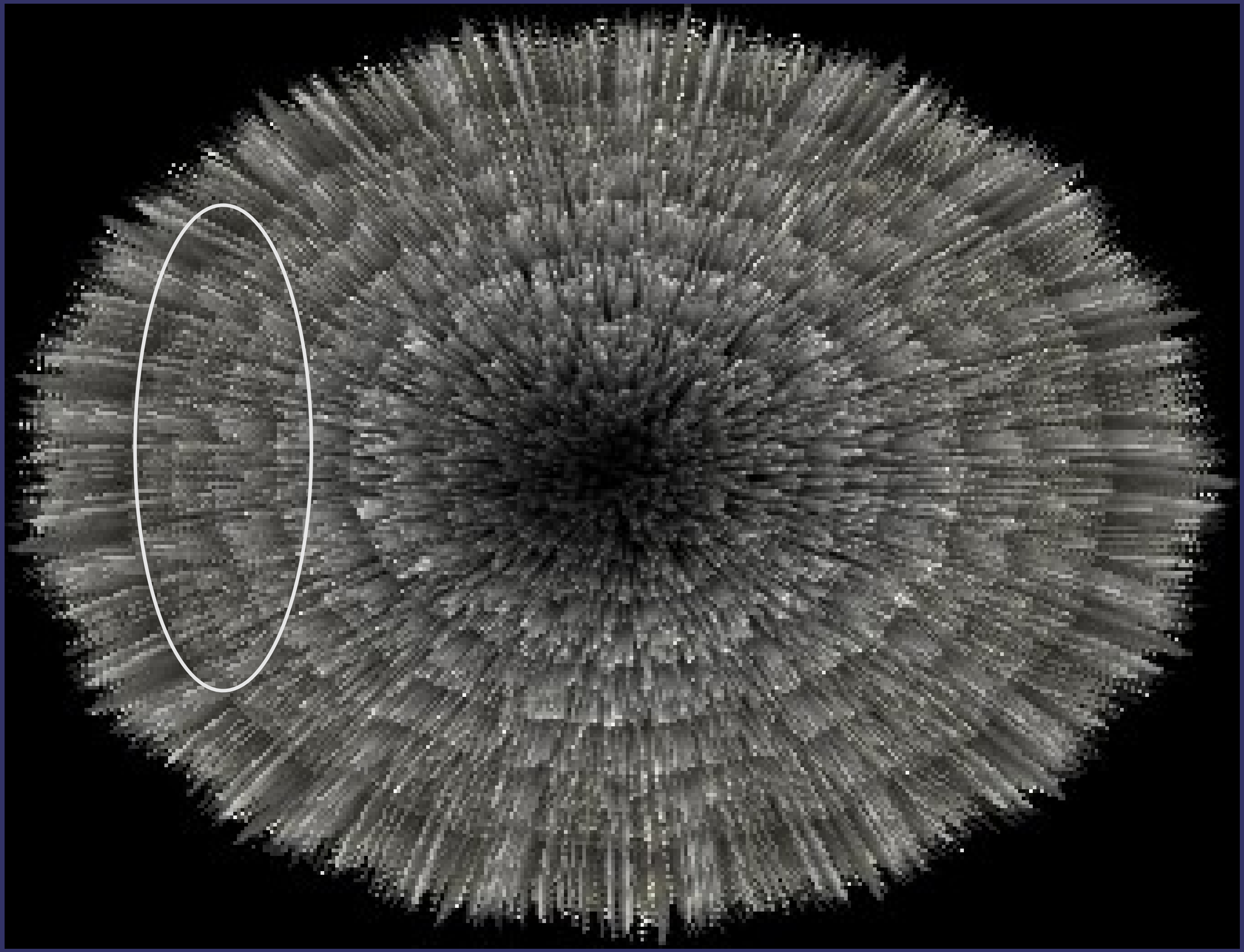
Shells and Fins

- *But* this looks bad in non-silhouette areas



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Shells and Fins

- Gradually blend in fins as they approach the silhouette

$$\alpha_{fin} = max\left(0, 2\left|\cos\left(V, N_{fin}\right)\right| - 1\right)$$

- We don't really have a fin normal...what to do?

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Shells and Fins

- Gradually blend in fins as they approach the silhouette

$$\alpha_{fin} = max(0, 2|\cos(V, N_{fin})| - 1)$$

- We don't really have a fin normal...what to do?
  - The surface's normal is the fin's tangent

$$\alpha_{fin} = max(0, 2|\sin(V, N_{surface})| - 1)$$

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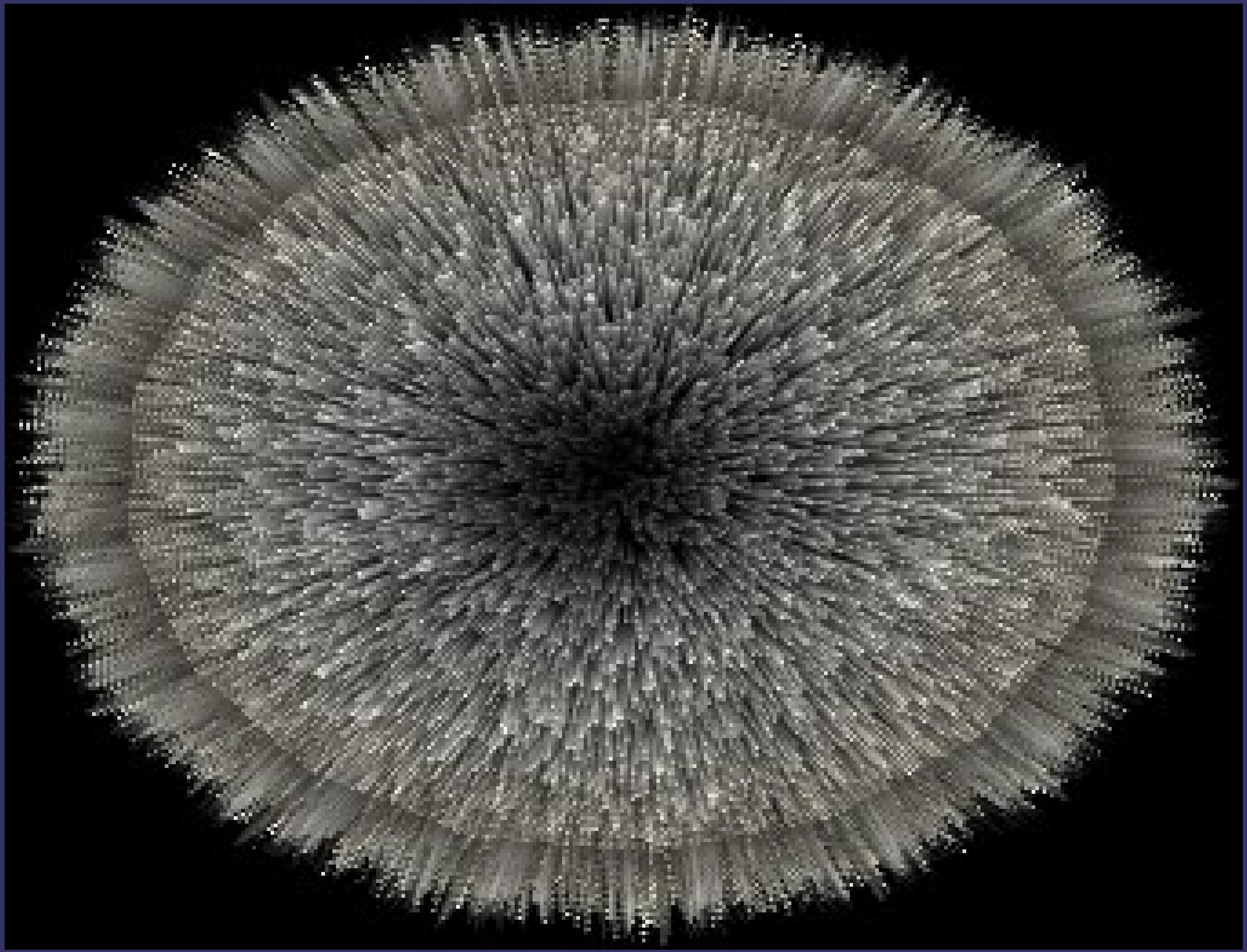
Shells and Fins

- Alpha blended fins



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Lighting Shells and Fins

- Use the surface normal as the direction of the hair

$$K = K_d \sin(N_{surface}, L)^{P_d} + K_s \sin(N_{surface}, H)^{P_s}$$

  - P_d and P_s are diffuse and specular exponents
  - Similar to Goldman's fakefur lighting model
- A little trig-identity love gets us:

$$K = K_d (1 - \cos(N_{surface}, L)^{P_d/2}) + K_s (1 - \cos(N_{surface}, H)^{P_s/2})$$

$$K = K_d (1 - (N_{surface} \cdot L)^{P_d/2}) + K_s (1 - (N_{surface} \cdot H)^{P_s/2})$$

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Lighting Shells and Fins

- No shadowing happens!
  - Fur near the skin is occluded by the fur above it
  - Add a shadowing term to falloff to a minimum value linearly with the distance from the outermost shell

$$S = \frac{D\left(1 - S_{min}\right)}{D_{max}} + S_{min}$$

  - D is the current shell distance
    - $D = 0$ is the shell closest to the skin
  - D_{max} is the total number of shells
  - S_{min} is the minimum amount of light reaching the bottom layer

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Thorough overview of the various real-time fur methods.

Tariq, S. *Fur (using Shells and Fins).* Nvidia White Paper, Number WP-03021-001_v01. February 2007. http://developer.download.nvidia.com/whitepapers/2007/SDK10/FurShellsAndF

This article focuses on optimizing shells-and-fins using Shader Model 4 features that are currently only supported in OpenGL on GeForce8.

Kajiya, J. T. and Kay, T. L. 1989. Rendering fur with three dimensional textures. *SIGGRAPH Comput. Graph.* 23, 3 (Jul. 1989), 271-280. http://www.icg.tu-graz.ac.at/courses/lv710.087/kajiyahair.pdf

Lake, A. and Kuah, K.. *Real-Time Fur Rendering For Short Haired Creatures*. 2006. http://softwarecommunity.intel.com/articles/eng/2597.htm

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Break

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Terminology – codimension

- Given an object of dimension n in a k dimensional space with $k > n$, the *codimension*, c, is equal to n-k
  - For a surface in 3-space, n is 2 and k is 3
    - When $c = 1$, we can trivially assign a normal to the object

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Terminology – codimension

- Given an object of dimension n in a k dimensional space with $k > n$, the *codimension*, c, is equal to n-k
  - For a surface in 3-space, n is 2 and k is 3
    - When $c = 1$, we can trivially assign a normal to the object
  - For a line in 3-space, $n = 1$, $k = 3$, and $c = 2$

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Terminology – vector spaces

- T is the tangent-space at some point on the object
  - Vector space tangent to the point on the object
  - Has dimension k (same as the object)
- N is the normal-space at some point on the object
  - Vector space orthogonal to T
  - Has dimension c (codimension of the object)

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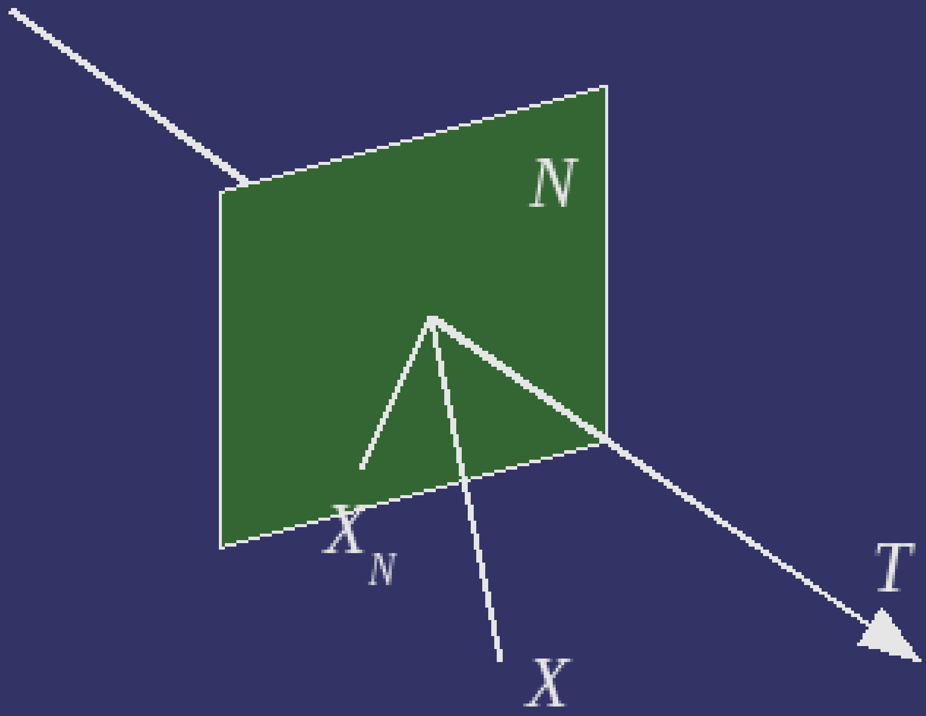
Terminology – vectors

- X_N is the projection of vector X onto $\boldsymbol{N}$
- X_T is the projection of vector X onto $\boldsymbol{T}$



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Diffuse Reflection

- Applying this terminology, diffuse reflection is calculated as:

$$I_{diffuse} = K_d \cos(L, L_N)$$

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Diffuse Reflection

- Applying this terminology, diffuse reflection is calculated as:

$$I_{diffuse} = K_d \cos(L, L_N)$$

- Since N and T are orthogonal, we can rewrite this as:

$$I_{diffuse} = K_d \sin(L, L_T)$$

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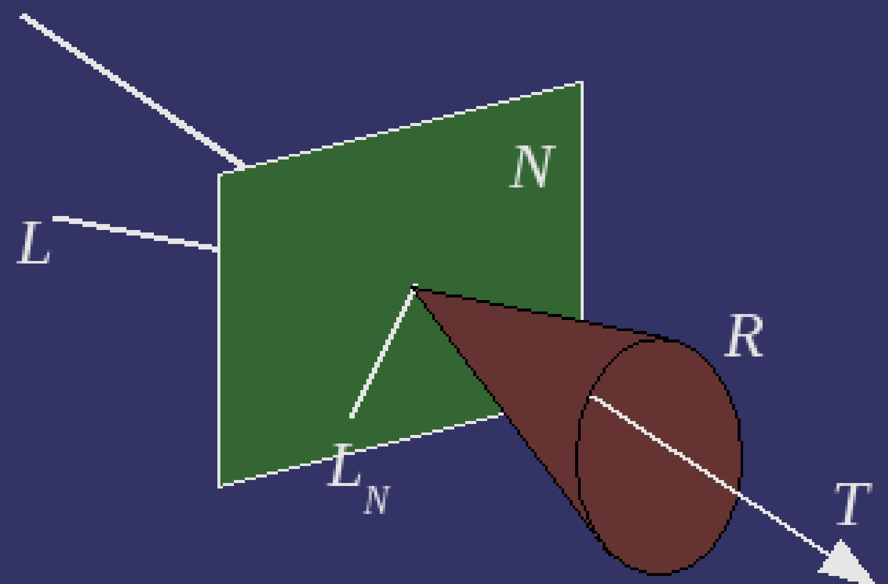
Specular Reflection

- Specular reflection is generally calculated as:

$$R = N - 2(N \cdot L)L$$
$$I_{specular} = k_s I_{light} \cos(V, R)$$

- If $c > 1$, there are infinite N vectors, so there are infinite possible R vectors



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Fermat's Principle Saves the Day

- Fermat's principle says that light travels on the shortest length path
  - This means that L, L_N, and R are coplanar
  - Skipping the derivation, this means that $R_N = L_N$
  - Skipping more derivation, we can calculate cos(V, R) as:

$$V \cdot R = V_T \cdot L_T - |V_N||L_N|$$

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Inherited Self-Shadowing

- When c = 1, the object has at most 2 sides
  - One side of the surface "self-shadows" the other, and we get that calculation for free from $N \bullet L$

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Inherited Self-Shadowing

- When $c = 1$, the object has at most 2 sides
  - One side of the surface “self-shadows” the other, and we get that calculation for free from $N \bullet L$
- Consider a surface with a 2D tangent space, $\boldsymbol{T}$, and a 1D vector field, $\boldsymbol{V}$
  - If $\boldsymbol{T}$ is used to calculate the illumination, $N \bullet L$ works
  - If $\boldsymbol{V}$ is used to calculate the illumination, there is no unique N to use

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Inherited Self-Shadowing

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- Consider a surface with a 2D tangent space, $\boldsymbol{T}$, and a 1D vector field, $\boldsymbol{V}$
  - If $\boldsymbol{T}$ is used to calculate the illumination, $N \bullet L$ works
  - If $\boldsymbol{V}$ is used to calculate the illumination, there is no unique N to use
  - If $\boldsymbol{V}$ is used to calculate the illumination, it can *inherit* $N \bullet L$ from $\boldsymbol{T}$

$$I_{conditioned} = max(N \cdot L, 0)(I_{diffuse} + I_{specular})$$

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Vector Field Shadowing

- This shadows the vector field from the surface
- If the vectors like outside the surface (e.g., fur) the vector field can obviously shadow itself and the surface
- Input light energy is attenuated by:

$$d = h / \sin(T, L)$$

$$I_{atten} = I_{source}(1 - \rho)^d$$

  - h is the distance from the surface
  - ρ is a property of the fur
    - The paper uses ρ = 0.02

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References

Banks, D. C. 1994. Illumination in diverse codimensions. In *Proceedings of the 21st Annual Conference on Computer Graphics and interactive Techniques SIGGRAPH '94*. ACM, New York, NY, 327-334. http://lmi.bwh.harvard.edu/~banks/

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Next week...

- Non-photorealistic rendering
  - Cel shading (cartoon rendering)
  - Silhouette edge rendering
  - Gooch style technical illustrations

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