
Rendering Fur in
*Life of Pi*
Ivan Neulander
Google
Toshi Kato
Kevin Beason
Rhythm & Hues Studios


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# Over the years...

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Coca Cola Polar Bears (1993-1996)

# Over the years...

# Over the years...

Cats & Dogs (2001)

# Over the years...

# Over the years...

Garfield, Garfield 2 (2004, 2006)

Rhythm&Hues

# Over the years...

# Over the years...

Chronicles of Narnia (2005)


Over the years...
Rhythm&Hues

# Over the years...

Life of Pi (2012)

# Technical Advancements for Life of Pi

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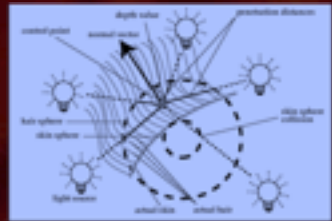
1. Hair Shading
   - Extensive use of area lights, ray tracing

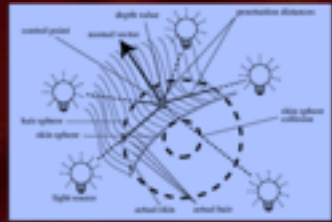
# Technical Advancements for Life of Pi

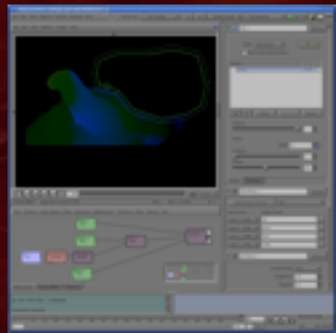


1. Hair Shading
   - Extensive use of area lights, ray tracing
2. Renderer Optimizations
   - Reduced render times & maintained quality

# Technical Advancements for Life of Pi

1. Hair Shading
   - Extensive use of area lights, ray tracing
2. Renderer Optimizations
   - Reduced render times & maintained quality
3. Postprocessing
   - Moved operations from renderer into 2D





# 1) Hair Shading: Area Lights

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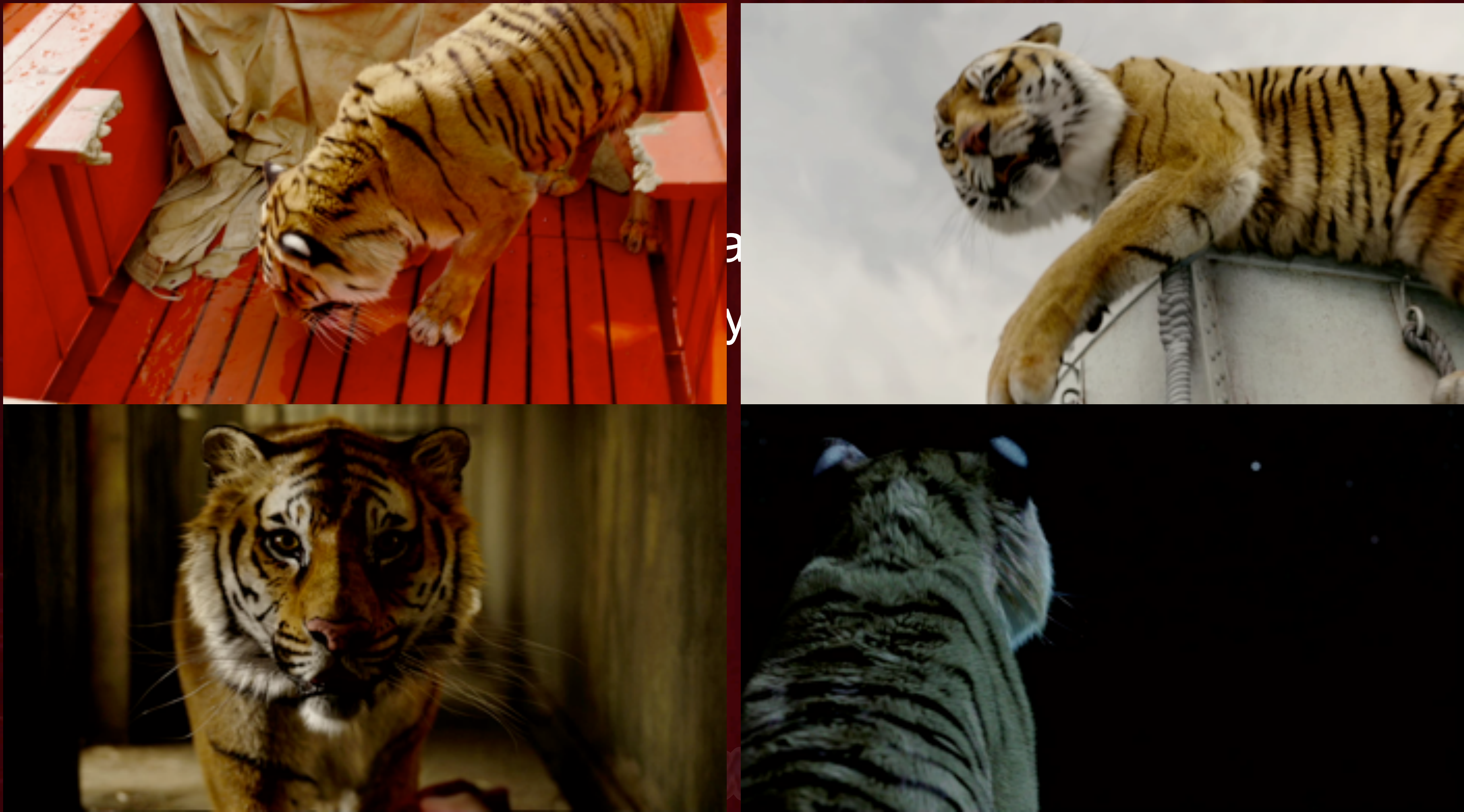
# Area Lights

- First show to use area lights almost exclusively



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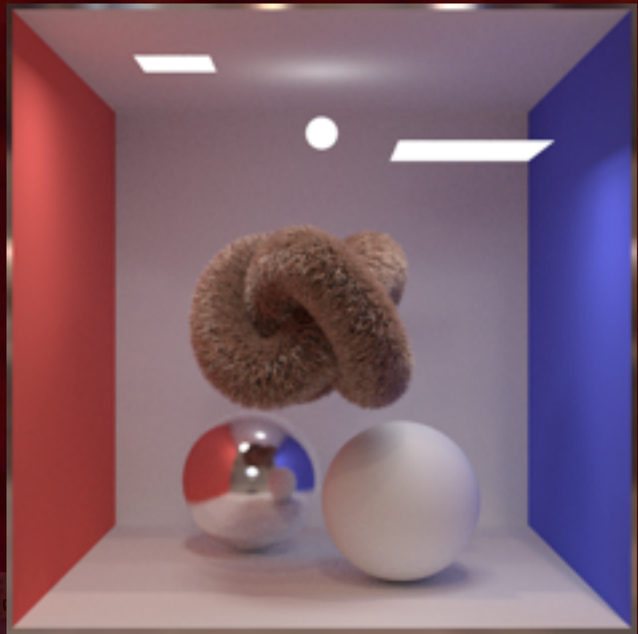
- How to deal with them efficiently
  - Good Importance Sampling:



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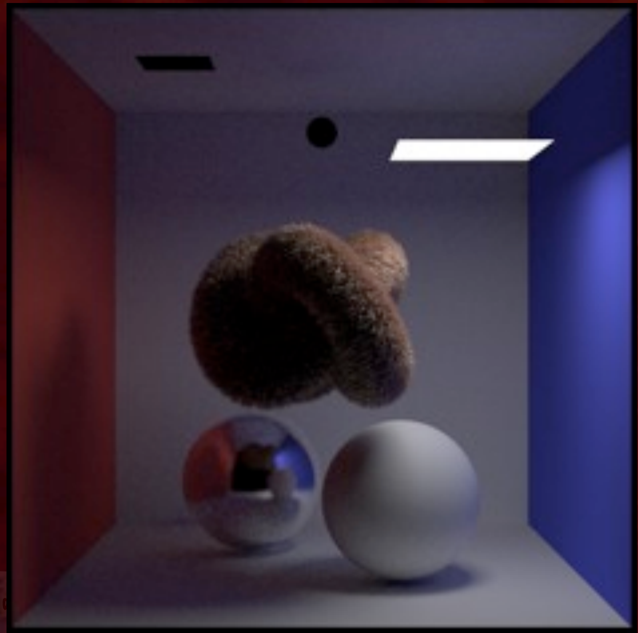

# 1) Hair Shading:
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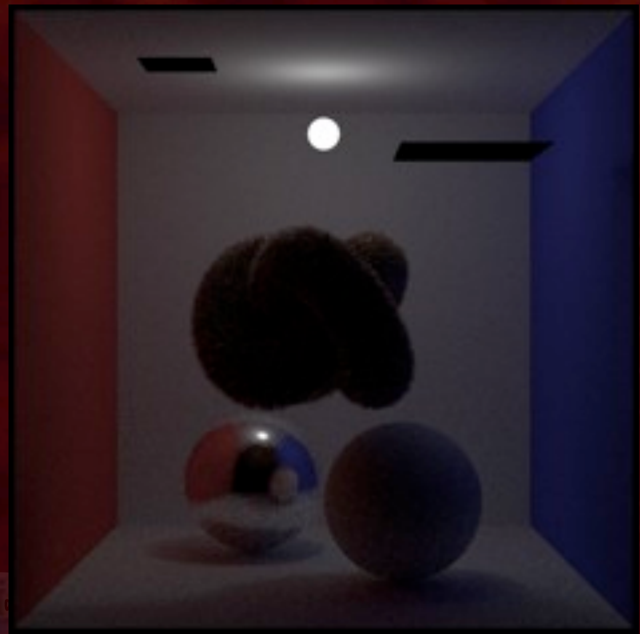

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- How to deal with them efficiently
  - Good Importance Sampling:
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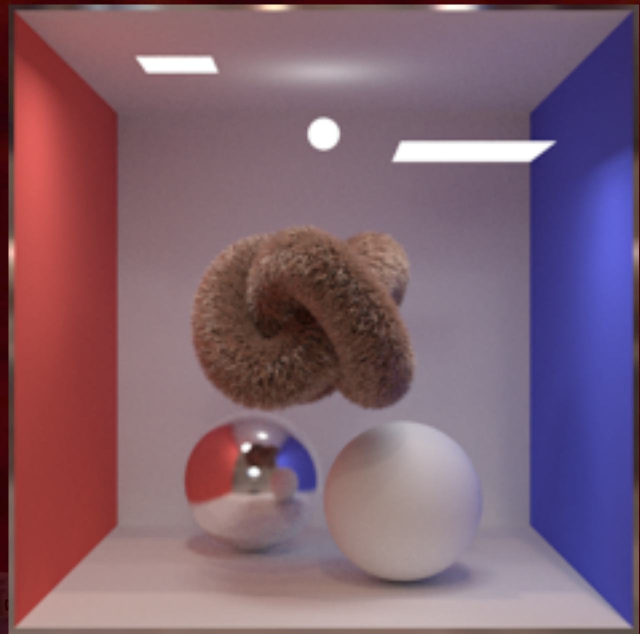
    - Environment lights
    - Ray Magnets
      - shapes that attract light rays to geometry



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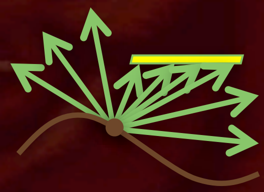
- Multiple Importance Sampling (MIS) [Veach97]:
  - BSDF vs Light Importance



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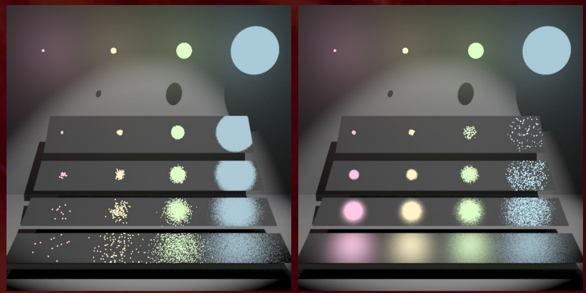

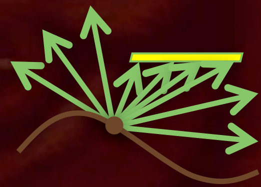

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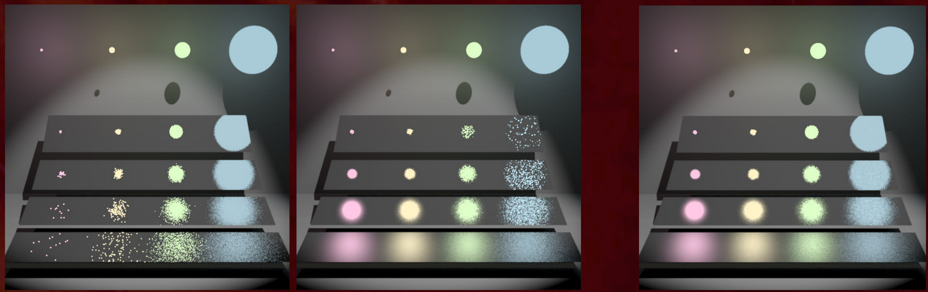

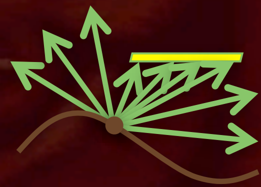

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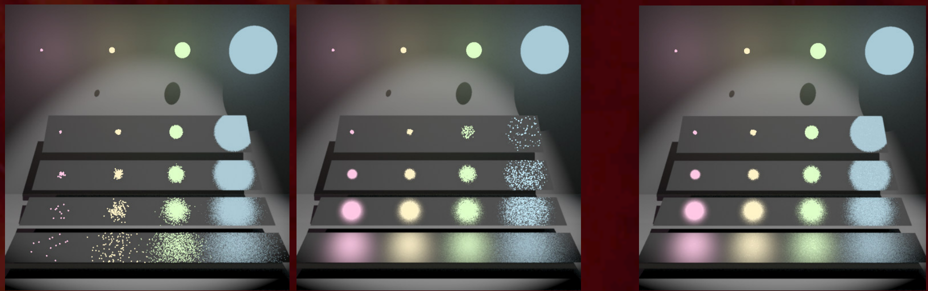

- Stochastic light selection

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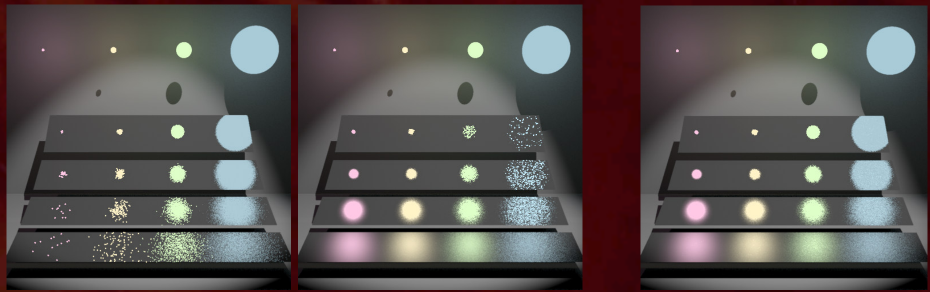

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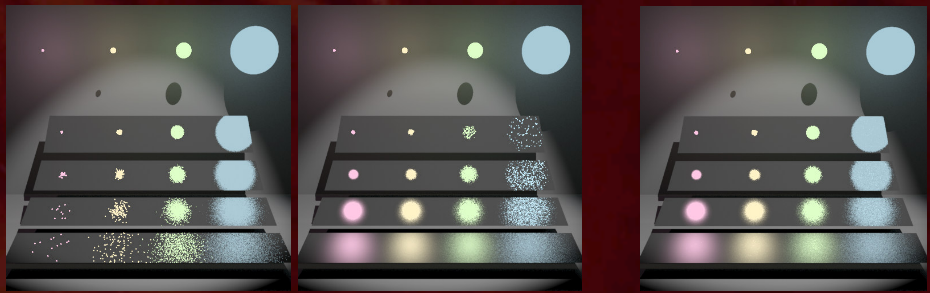

- Stochastic light selection
  - based on solid angle, average radiance
  - also uses MIS

# 1) Hair Shading:
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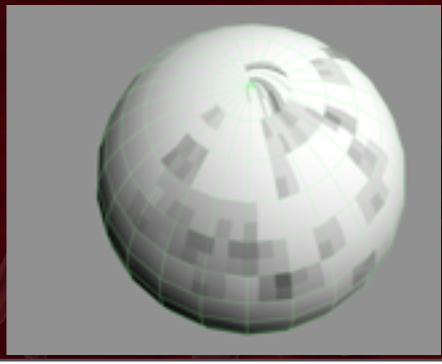
- Adaptive Importance Sampling [Neulander11]
  - Sampled ray directions are rated for contribution
  - Poorly rated directions are rejected in the future



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- Ada… Neulander11]
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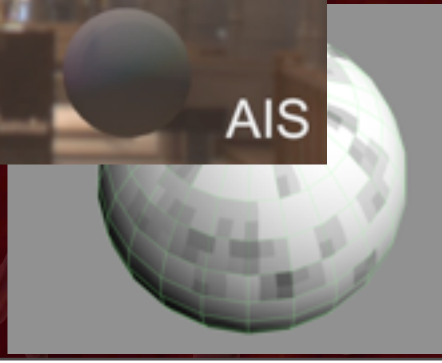
  - P… ed in the future
  - R…

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- Cone-Shell BSDF [Neulander10]

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x &= \sqrt{1-z^2}\cos(2\pi\xi_2) \\
y &= \sqrt{1-z^2}\sin(2\pi\xi_2) \\
z &= \cos\theta_{max} + \xi_1\left(\cos\theta_{min} - \cos\theta_{max}\right) \\
weight &= z\cos\theta_{mid} + \sqrt{1-z^2}\sin\theta_{mid}
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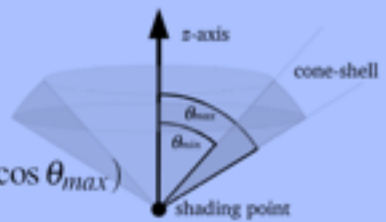

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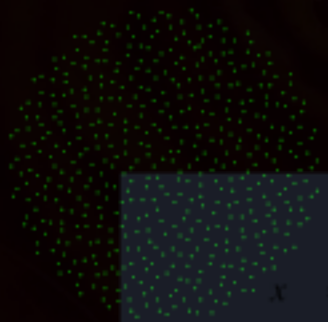

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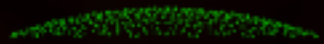

uniform sampling ; overhead view

uniform sampling ; side view

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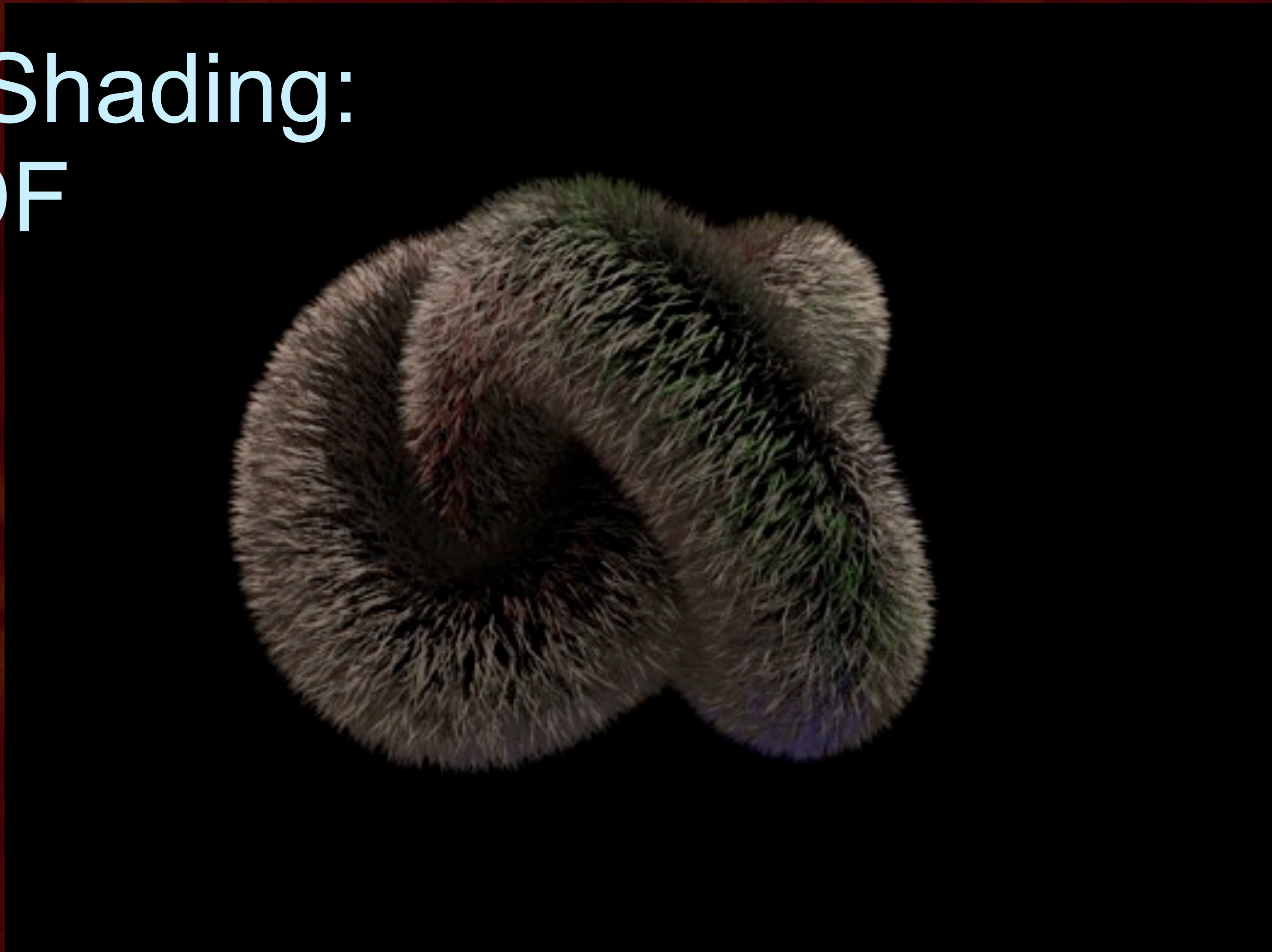

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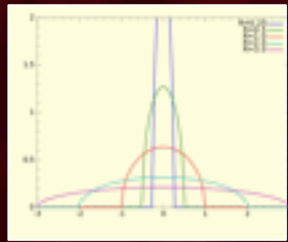
- Wigner Semicircle Importance Sampler



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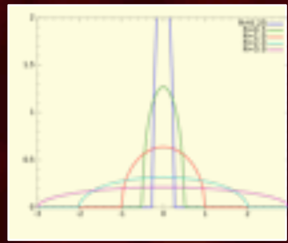
  - Closer to optimal than previous model



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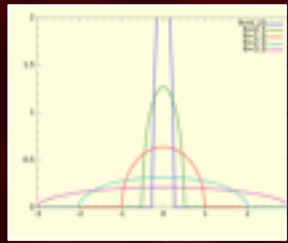

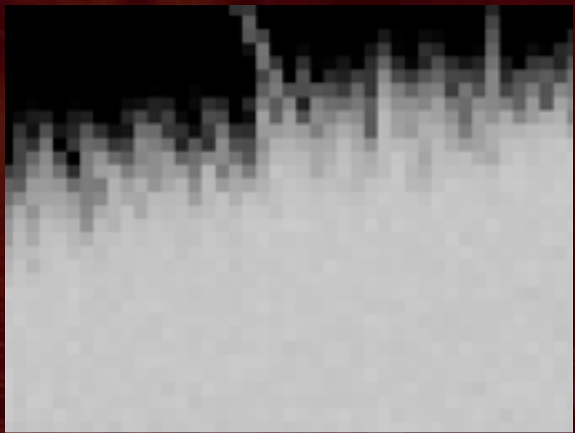

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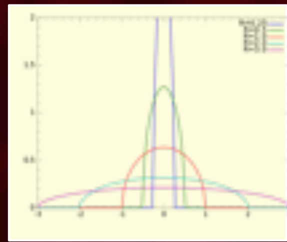

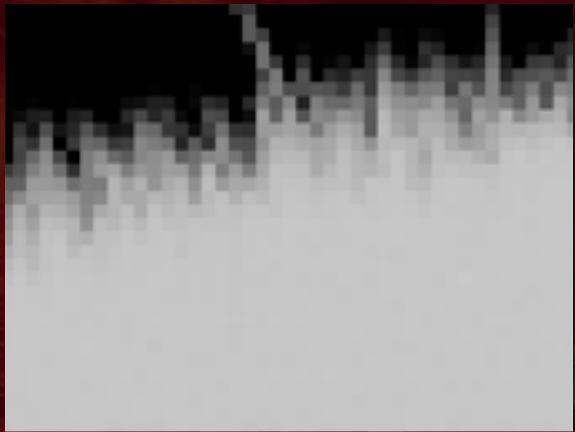

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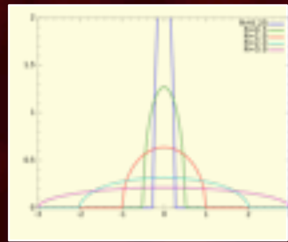

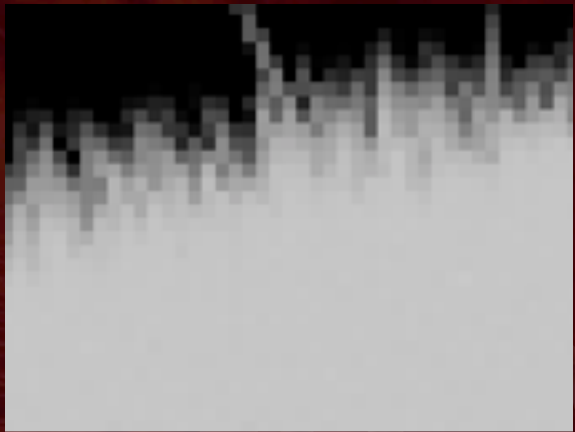

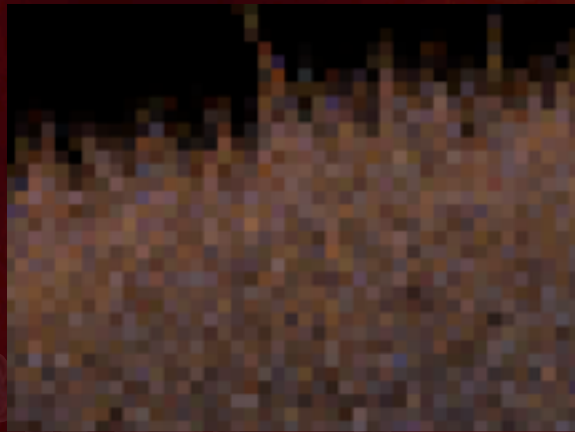

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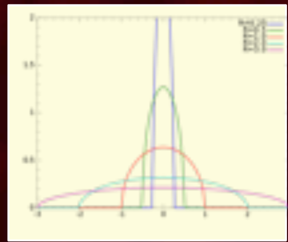
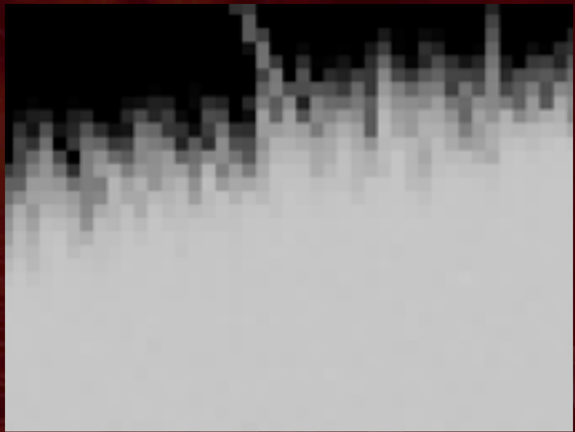
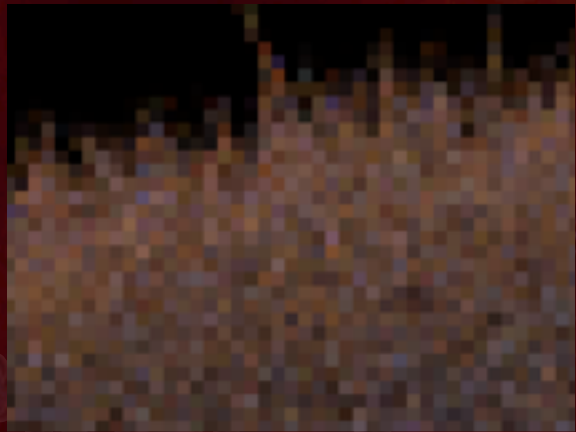
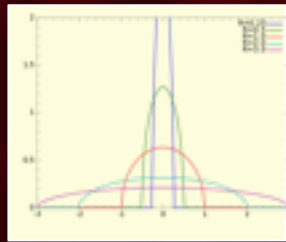






# 1) Hair Shading:
# BSDF

- Wigner Semicircle Importance Sampler
  - Closer to optimal than previous model
  - Implementation:
    - inverse CDF table, interpolate between entries



# 2) Renderer Optimizations: Skin Occlusion

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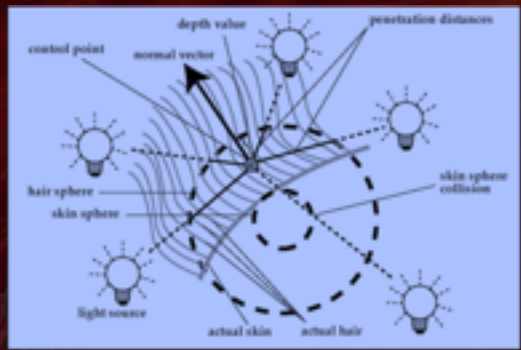
- Based on volumetric occlusion model




Rhythm&Hues

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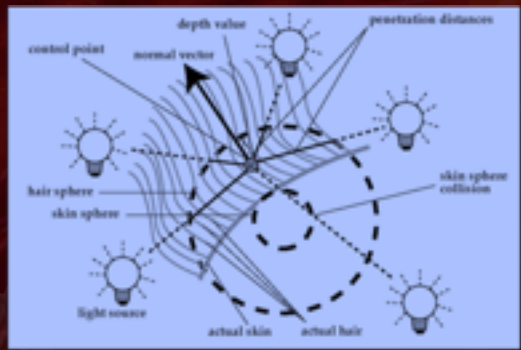

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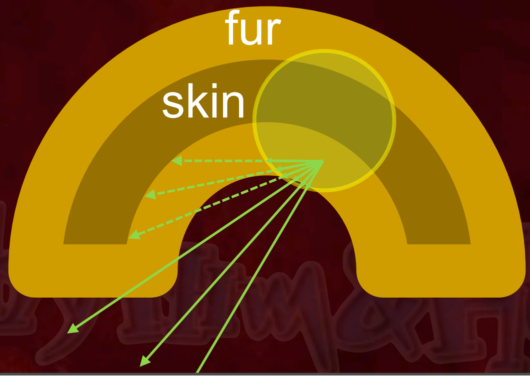


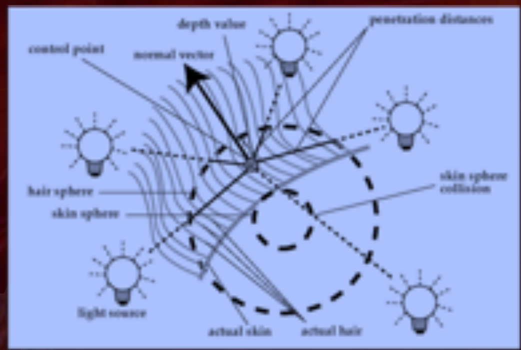

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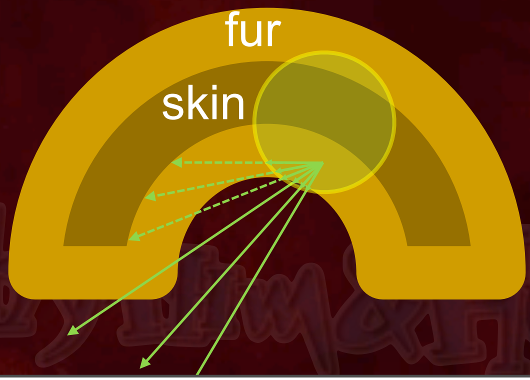


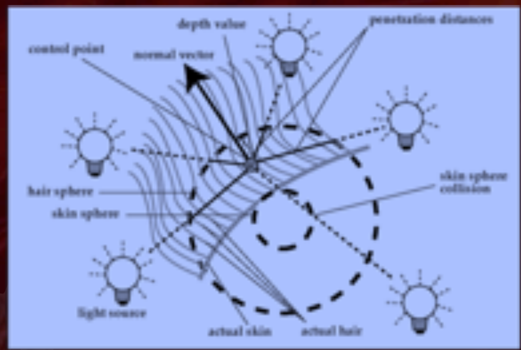

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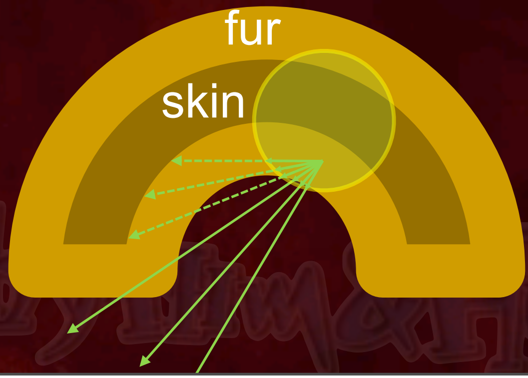


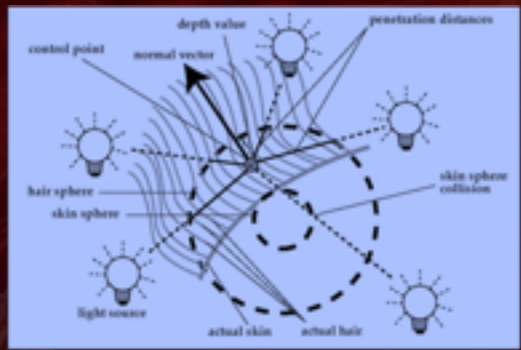

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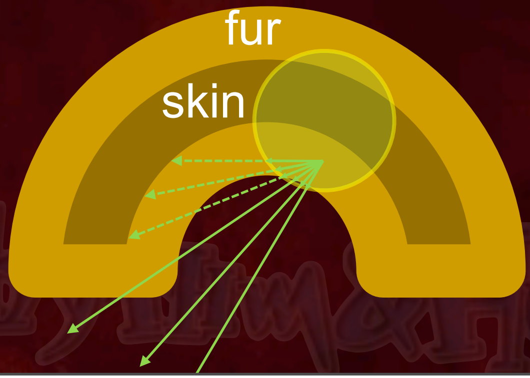


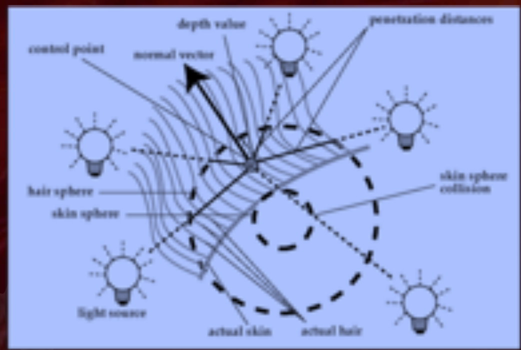

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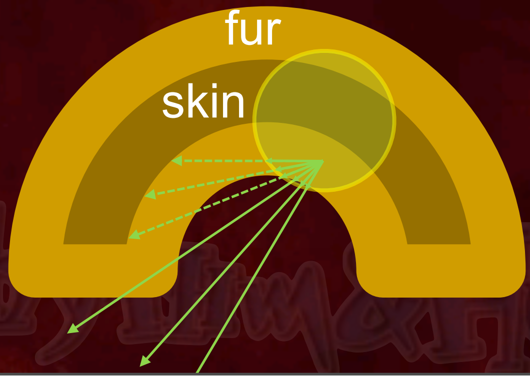


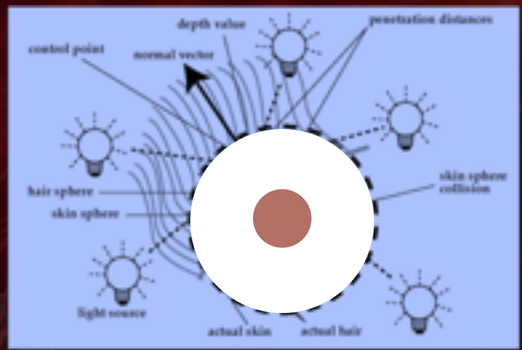

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- Significant speedup (~50%)
- Minimal image difference
- Controllable speed/quality

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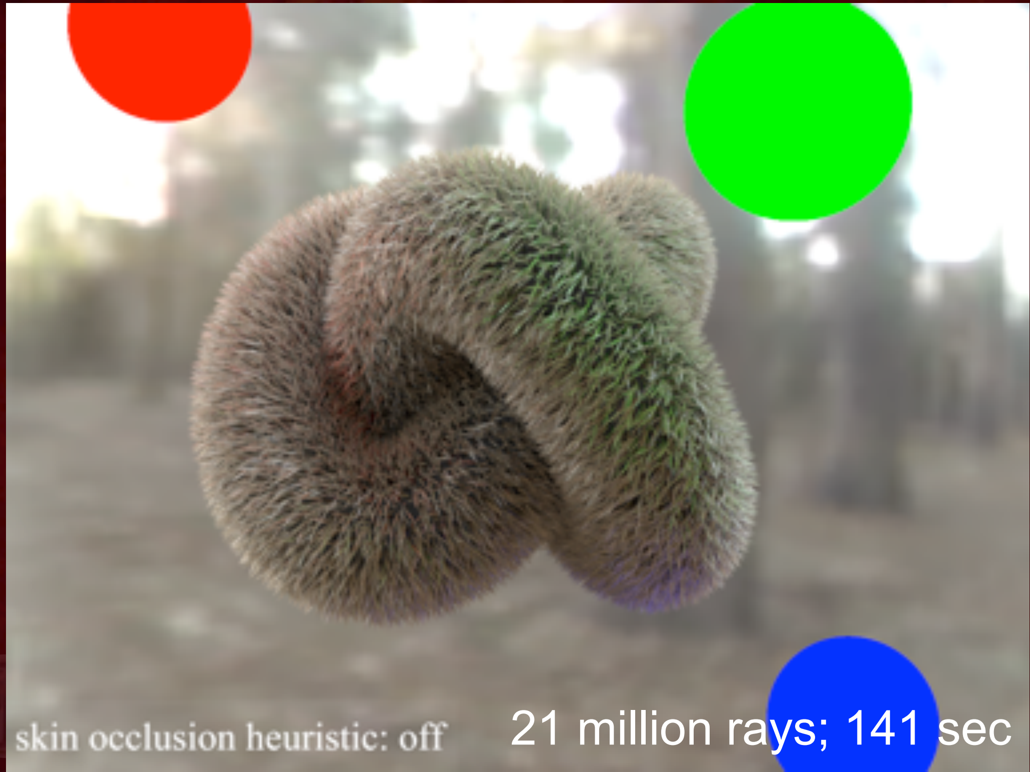

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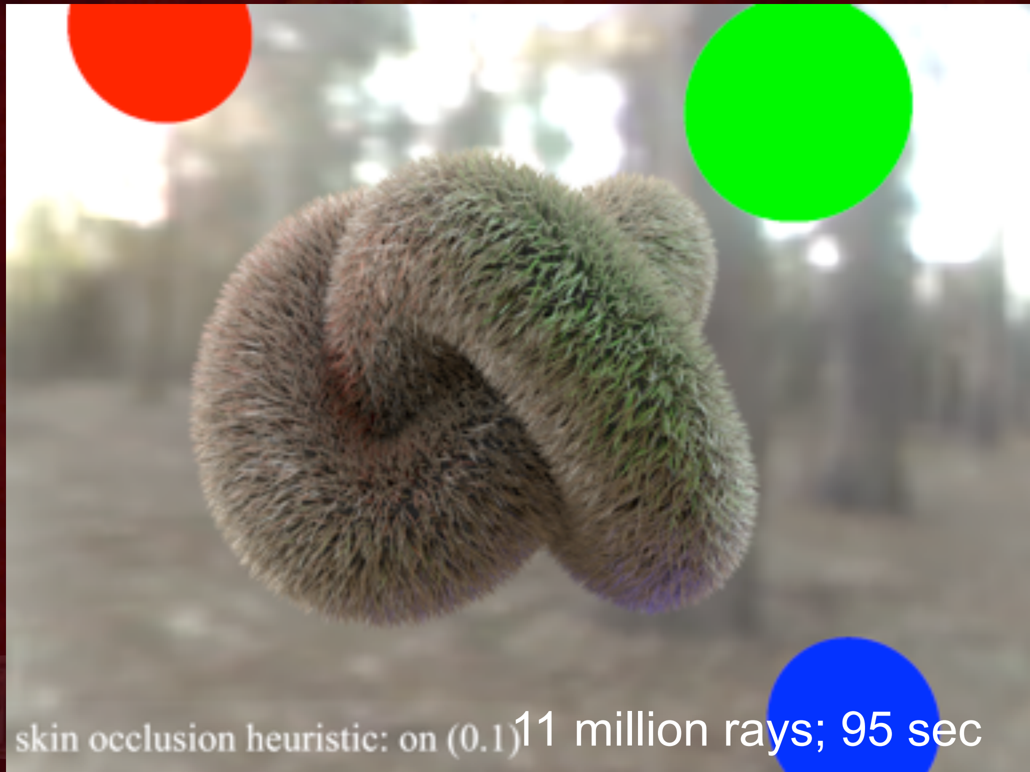

# 2) Renderer Optimizations:

## Screen Door Transparency

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- Hybrid renderer:

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- Hybrid renderer:
  - Scanline mode:
    - thick, semitransparent strands

Rhythm&Hues

# 2) Renderer Optimizations:
## Screen Door Transparency

- Hybrid renderer:
  - Scanline mode:
    - thick, semitransparent strands
  - Raytraced occlusion:
    - thinned, opaque strands (of equal coverage)
    - thickness, opacity can vary along strand

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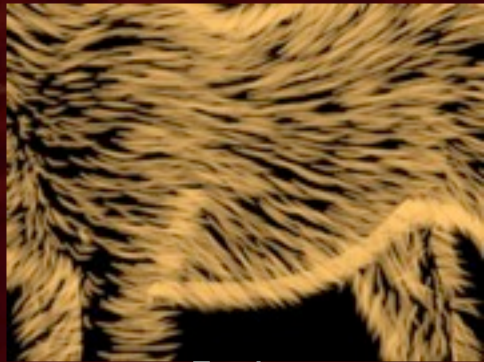

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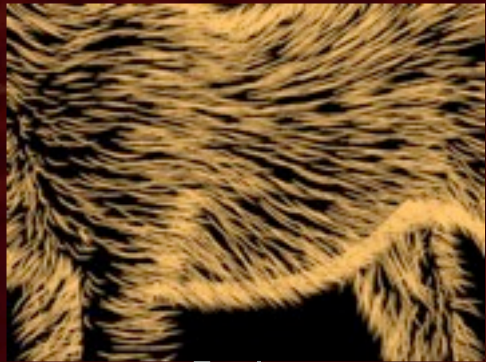

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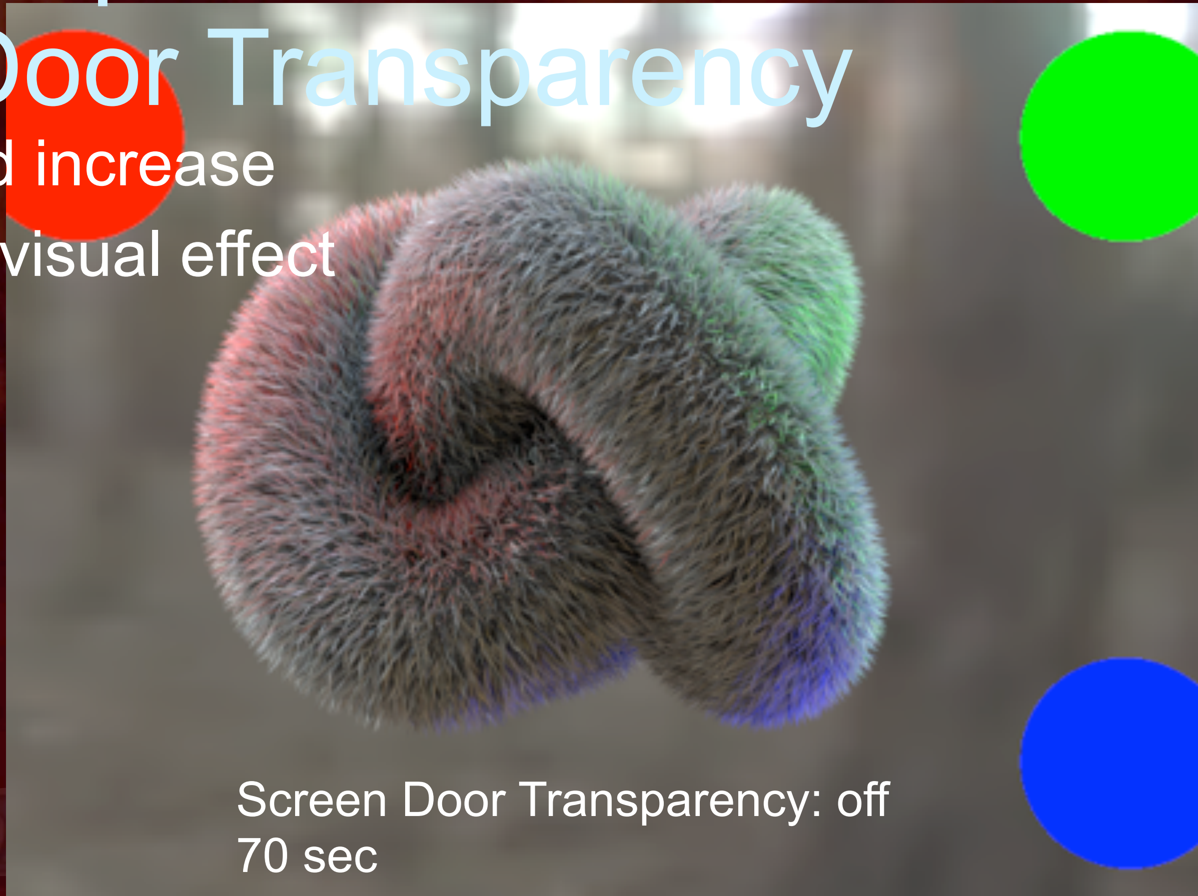

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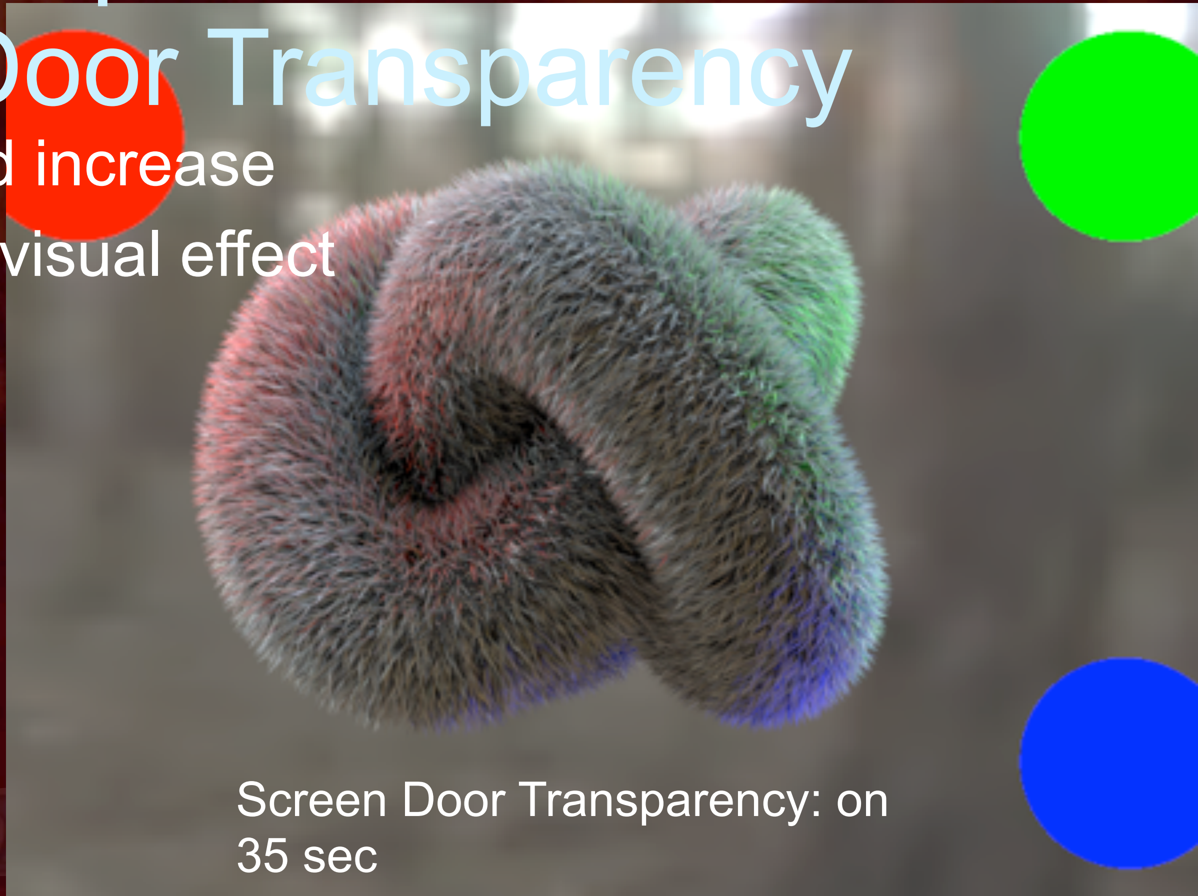

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- Ray-hair intersection based on *Ray Tracing for Curves Primites* [Nakamaru, Ohno WSCG 2002]
  - hair CP-segment-based bbox construction
  - Surface Area Heuristic evaluation

# 2) Renderer Optimizations:
# BVH Ray Tracer

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- Recent development
  - Disk-Based storage of complete BVH
    - user-defined RAM footprint
    - computed once and stored on disk

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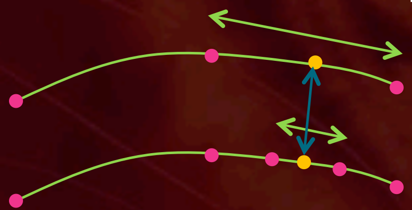
- Introduced in [Neulander10]
  - caches reflected radiance at primary rays along strand



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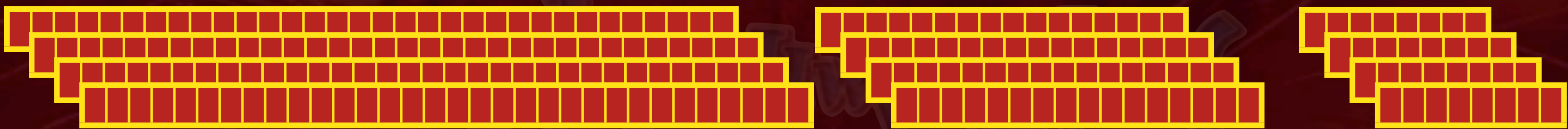

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  - Writes use Read-Copy-Update (RCU) for synchronization
    - RCU is used extensively in the Linux kernel
    - Allows lock-free cache reads

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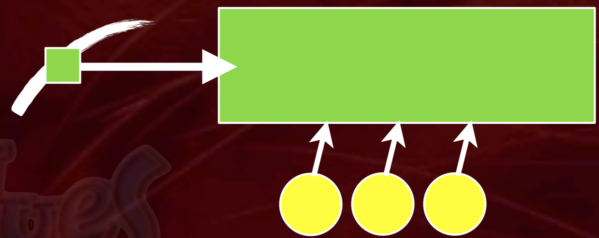

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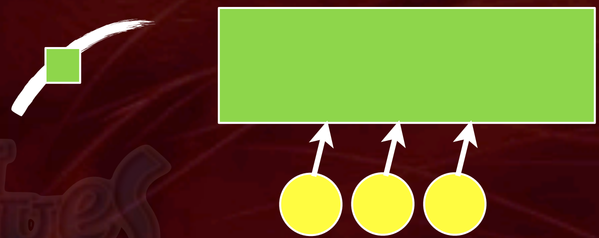

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- Improved concurrency:
  - near-linear speed (8 threads)
  - slight memory increase

# 3) Postprocessing: Motion Blur

- ***pixmotor***: pixel motion integrator [Neulander07]
    - Screen-space motion vectors, depth values output by renderer
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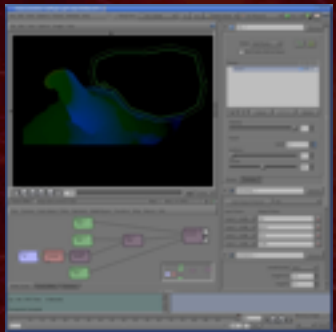

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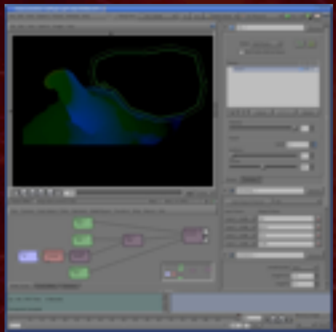

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- Use this to compute screen-space motion vectors



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 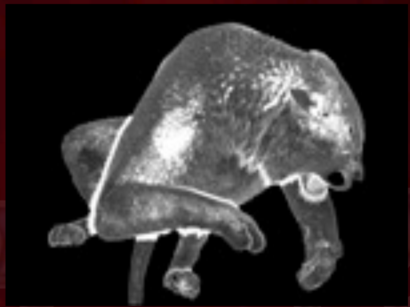 

# 3) Postprocessing: Stereo Synthesis

- Recipe:
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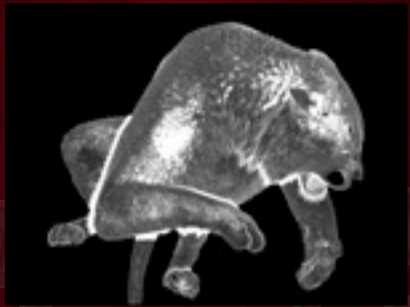
  - Fill holes using heuristics
  - Build result at 4x+ resolution, then downsample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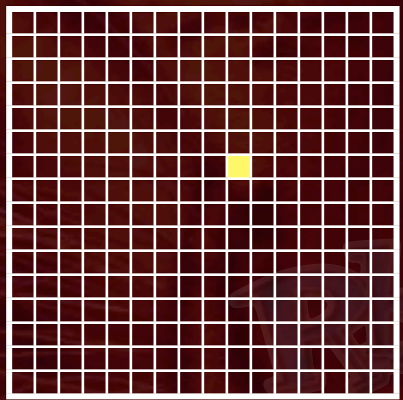

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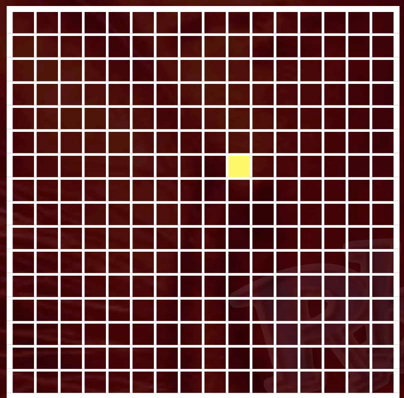

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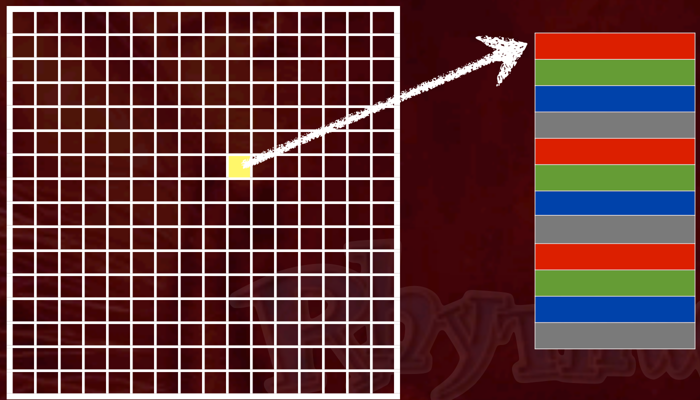

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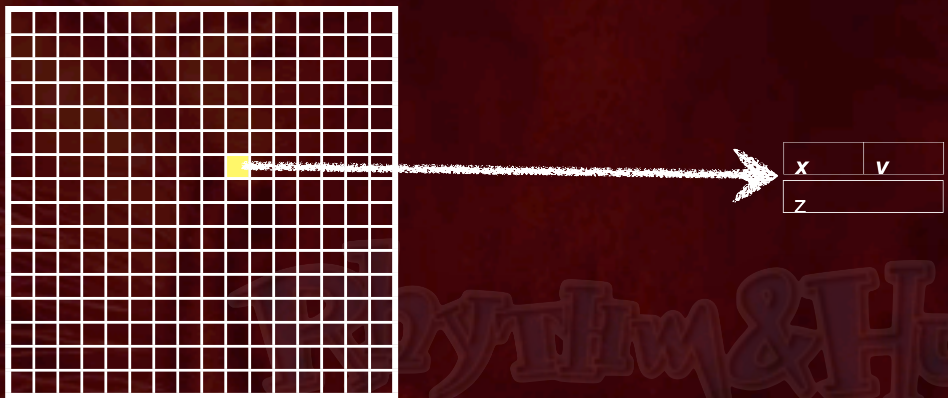

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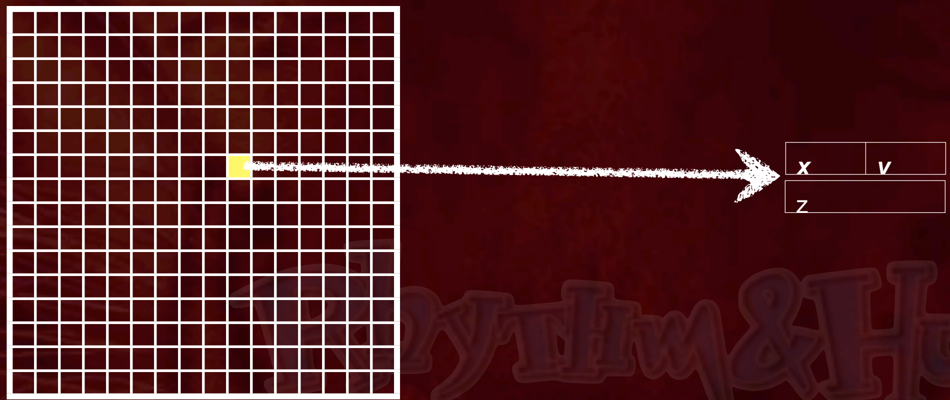
- High-res work buffer stores only pixel coords
  - pair of 16-bit coords instead of many floats (plus one float for depth)
  - faster due to lower memory bandwidth



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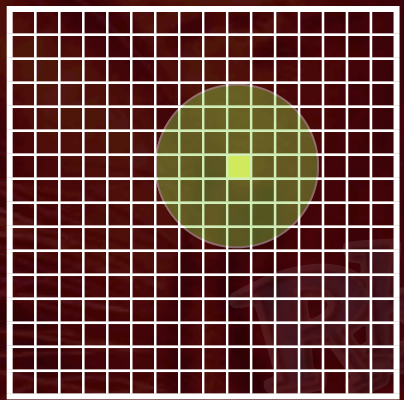

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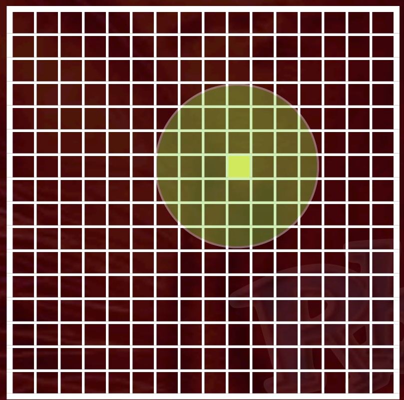

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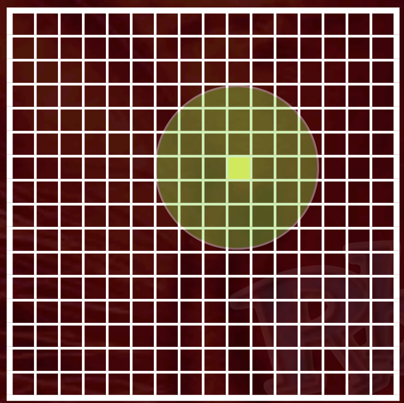

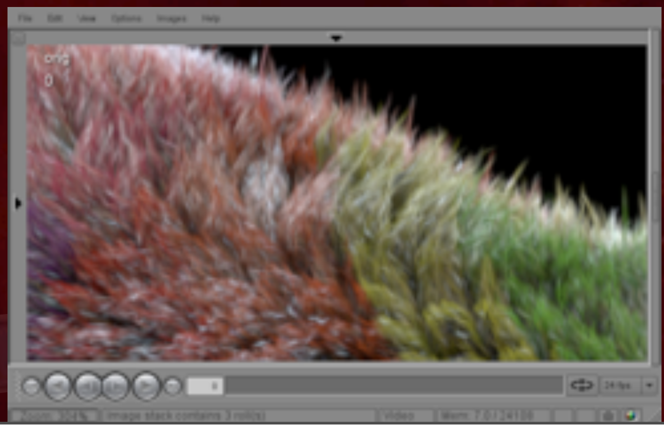

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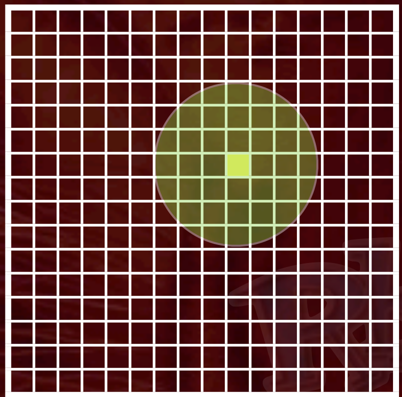

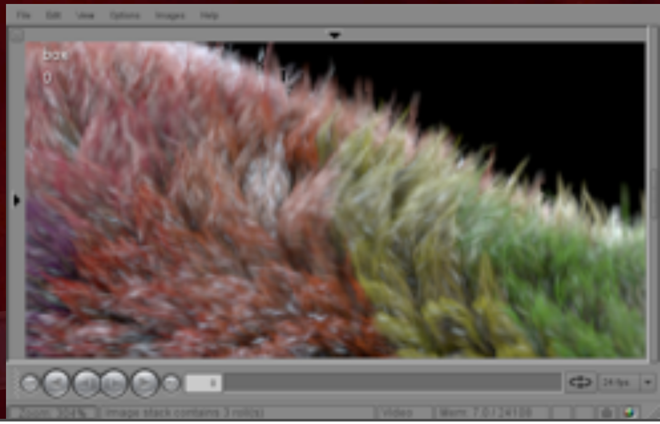

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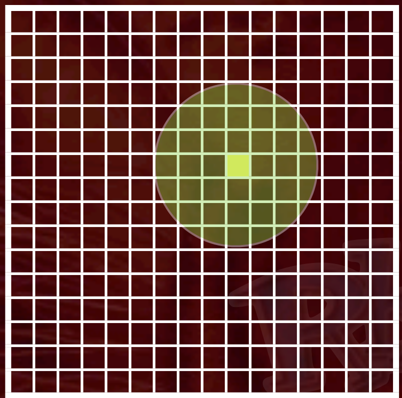

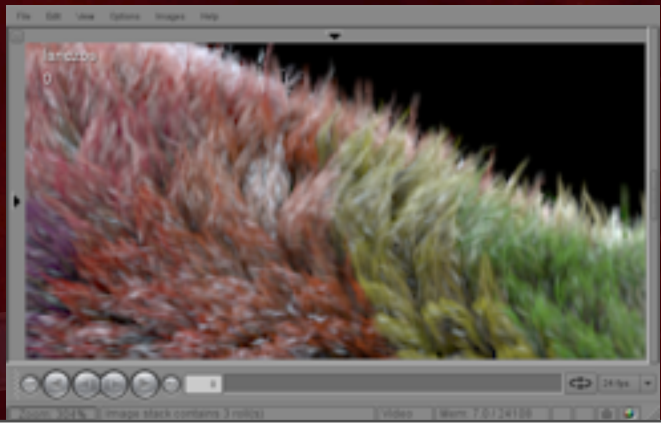

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- Future work:
  - Improve hair scattering, including multiple scatter


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