

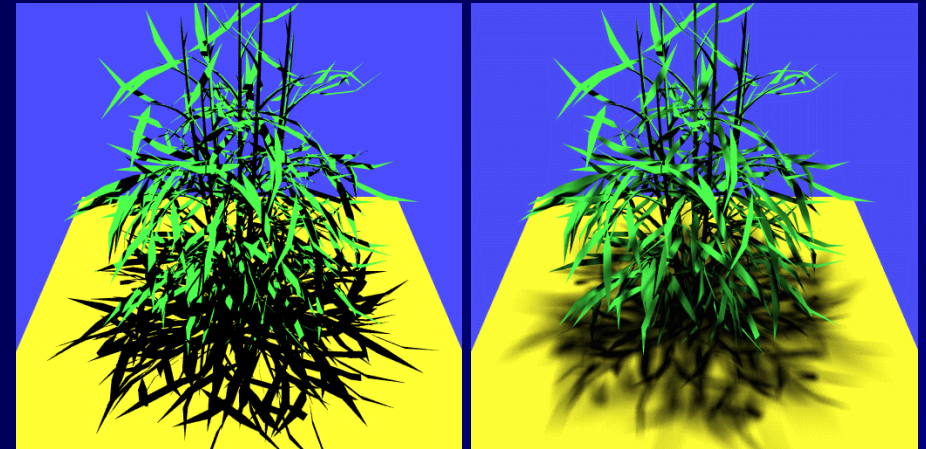
Efficient Image-Based Methods for Rendering Soft Shadows

Maneesh Agrawala
Ravi Ramamoorthi
Alan Heirich
Laurent Moll

Pixar Animation Studios
Stanford University
Compaq Computer Corporation
Compaq Computer Corporation

SIGGRAPH 2001

Hard vs. Soft Shadows



Hard Shadows

Soft Shadows

Shadow maps

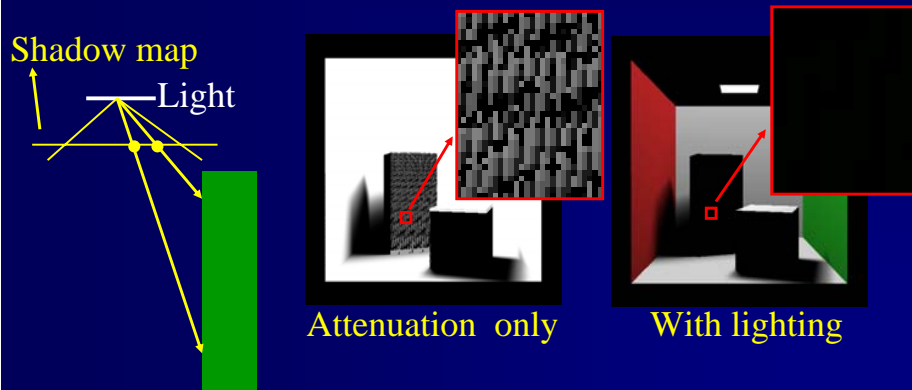
- Image-based hard shadows [Williams 78]
- Time, memory depend on image size, *not geometric scene complexity*
- Disadvantage: bias and aliasing artifacts
- Soft shadows [Chen and Williams 93]
 - View interpolate multiple shadow maps

IBR good for soft shadows

- IBR good for secondary effects
 - Artifacts less perceptible
- IBR works well for nearby viewpoints
- Shadow maps from light source
 - Light source localized area
 - Poorly sampled regions are also dimly lit

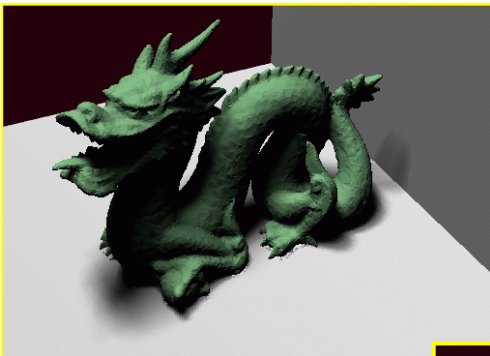
IBR good for soft shadows

- Poorly sampled regions are also dimly lit



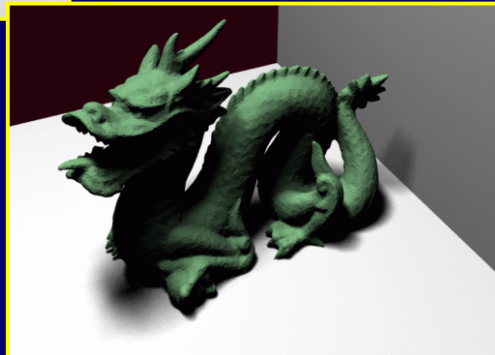
Contributions

- Extend shadow maps to soft shadows
- Image-based rendering especially suitable
- Two novel image-based algorithms:
 - *Layered attenuation maps (LAM)*
 - *Coherence-based raytracing (CBRT)*



• LAM

- Display: 5-10 fps
- Some aliasing artifacts
- Interactive applications
 - Games
 - Previewing



• CBRT

- Render: 19.83 min
- Speedup: 12.96x
- Production quality images

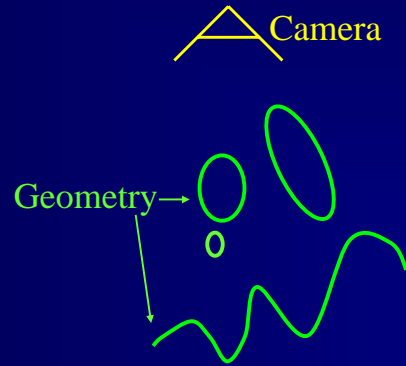
Preliminaries

$$E = \int_{A_{light}} \left[\frac{L \cos \theta_i \cos \theta_l}{\pi r^2} \right] V dA$$

$$ATT = \frac{1}{A} \int_A V dA$$

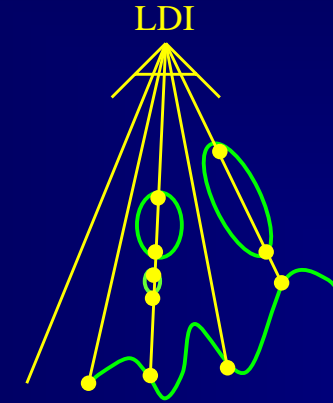
Refresher: LDIs

- Layered depth images [Shade et al. 98]



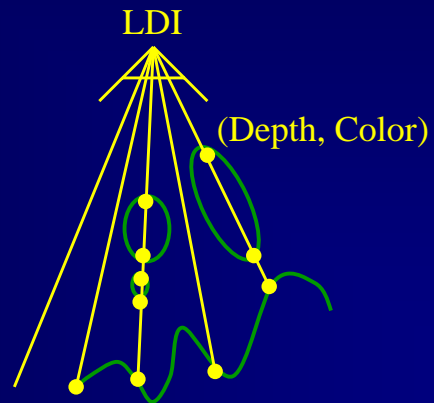
Refresher: LDIs

- Layered depth images [Shade et al. 98]



Refresher: LDIs

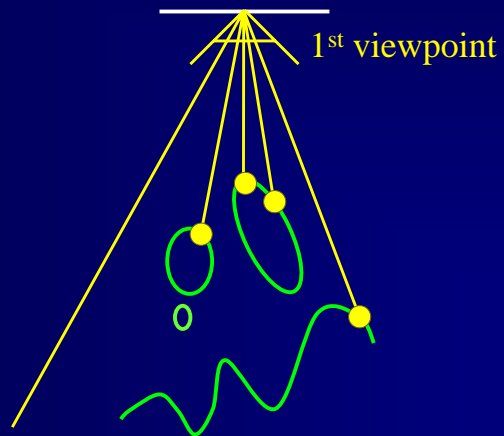
- Layered depth images [Shade et al. 98]



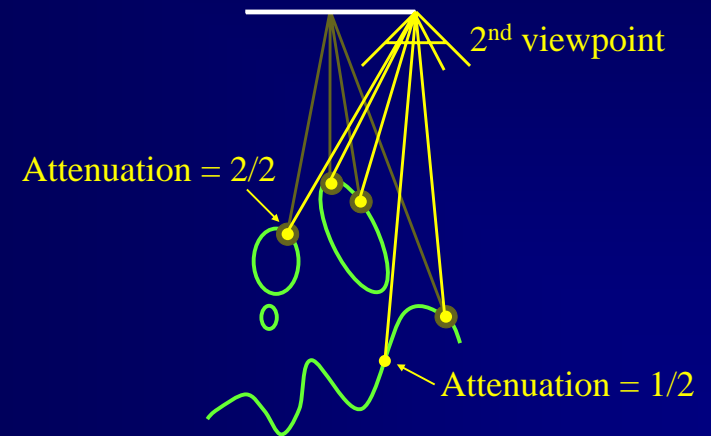
Precomputation

- Render views from points on light (hardware)
- Create layered attenuation map (software)
 - Warp views into LDI
 - Store (depth, attenuation)
- Objects in LAM visible in at least 1 view

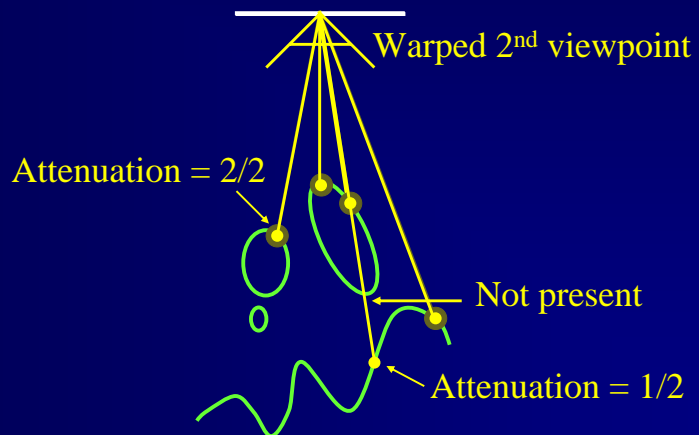
Precomputation



Precomputation



Precomputation

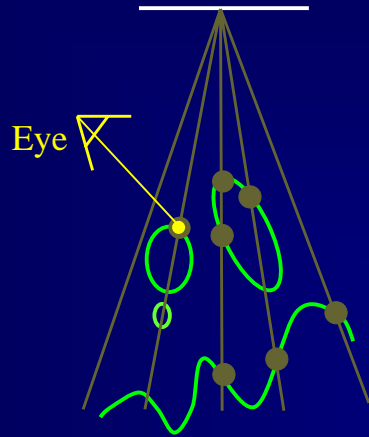


Display

- Render scene without shadows (hardware)
- Project into LAM (software)
 - Read off attenuation
 - Attenuation modulates shadowless rendering

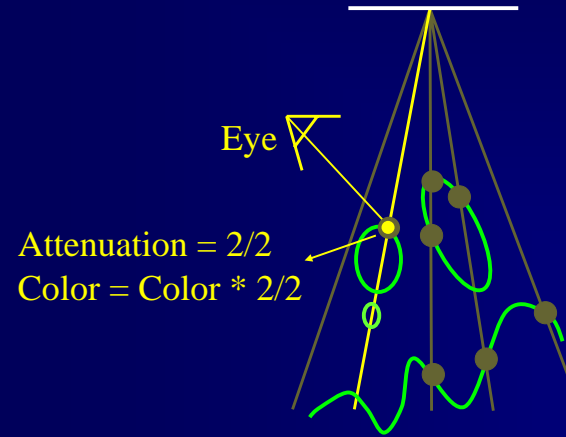
Display

LAM (center of light)



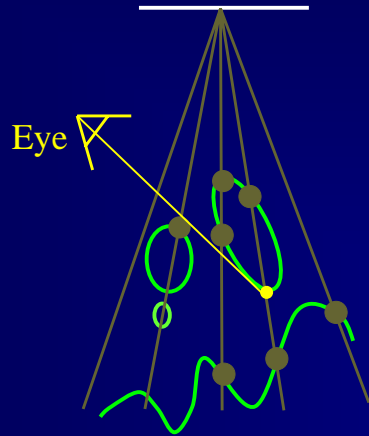
Display

LAM (center of light)



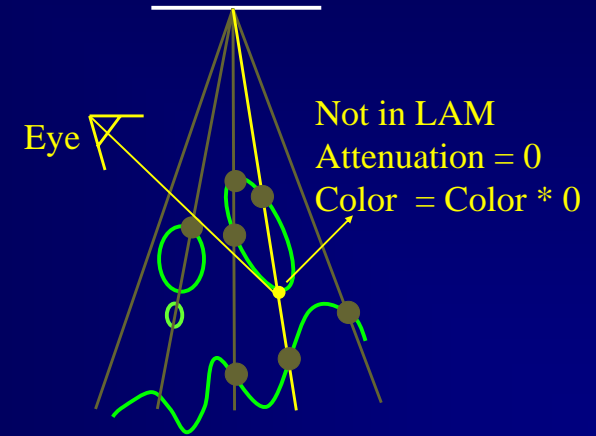
Display

LAM (center of light)



Display

LAM (center of light)

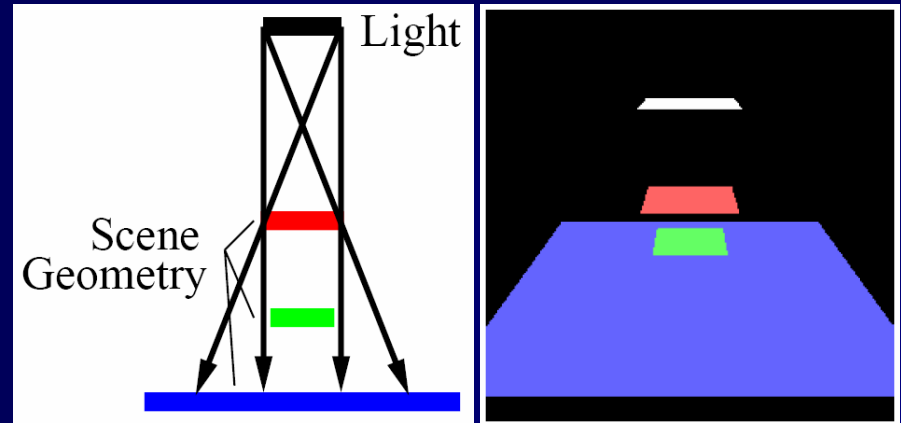


Precompute algorithm

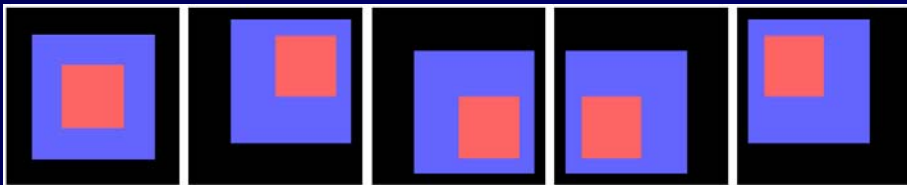
procedure Precompute

```
1 foreach light sample  $l_i$ 
2    $Viewpoint \leftarrow l_i$ 
3   Render(SCENE)
4   foreach pixel  $(x, y)$ 
5      $(x', y') \leftarrow \text{WarpCenter}(x, y, z(x, y))$ 
6     Insert( $(x', y'), z, \epsilon$ )
7   Process Attenuation Maps
```

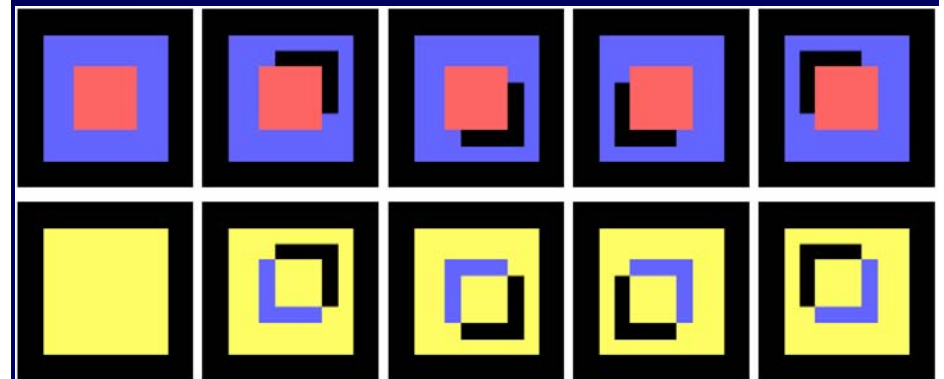
Illustration



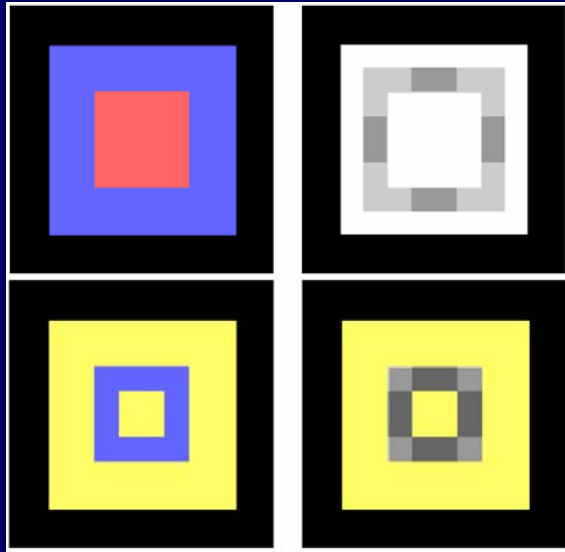
Rendered images from light



Layered images



Layered attenuation map

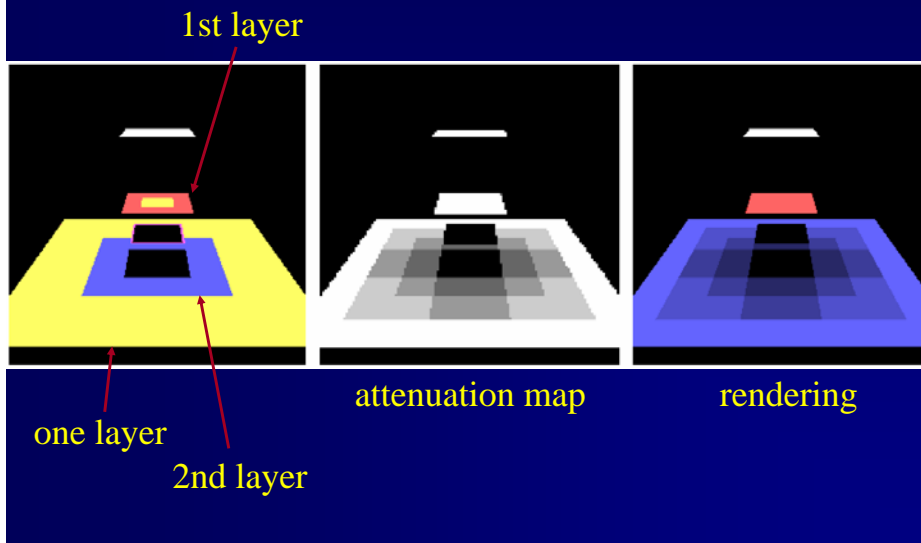


Display algorithm

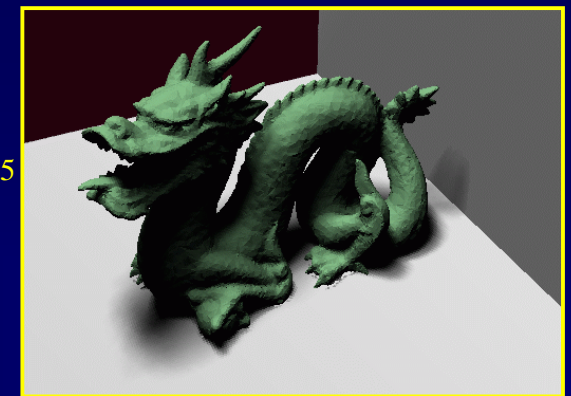
procedure Display

```
1  RenderWithLightingAndTextures(SCENE)
2  foreach pixel  $(x, y)$ 
3     $(x', y', z') \leftarrow \text{WarpLDI}((x, y, z(x, y)))$ 
4     $layer \leftarrow \text{Layer}((x', y'), z', \epsilon)$ 
5     $color \leftarrow color * \text{AttMap}((x', y'), layer)$ 
```

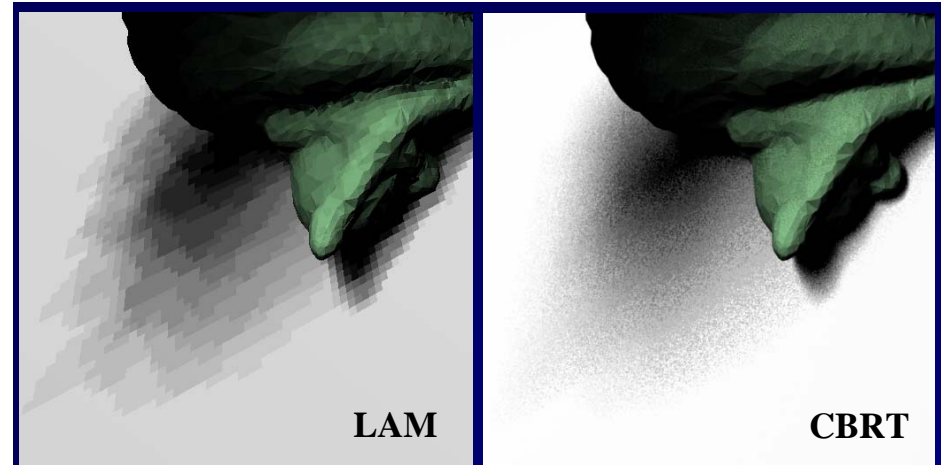
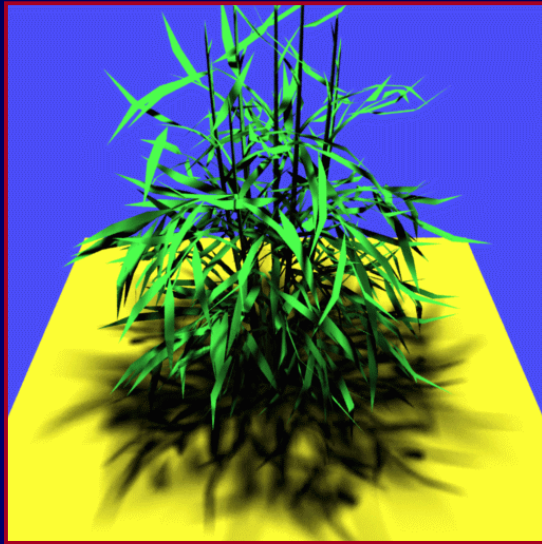
Attenuation map and rendering



- LAM size: 512 x 512
- Avg num depth layers: 1.5
- Precomp:
 - 7.7 sec (64 views)
 - 29.4 sec (256 views)
- Display: 5-10 fps



- LAM size: 512 x 512
- Avg num depth layers: 2
- Precomp:
 - 6.0 sec (64 views)
 - 22.4 sec (256 views)
- Display: 5-10 fps

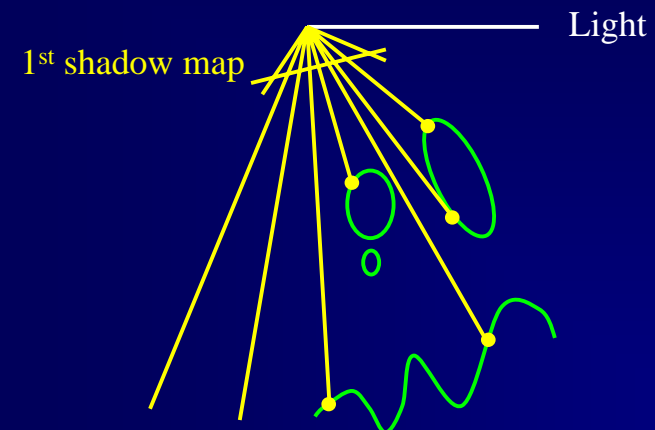


- Layered attenuation maps – fast, aliases
- Coherence-based raytracing – slow, noise

Coherence-based raytracing

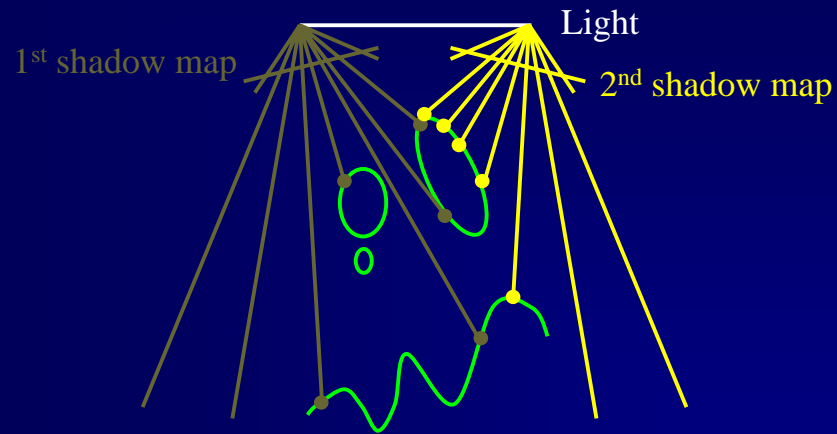
- Hierarchical raytracing through depth images
 - Time, memory decoupled from geometric scene complexity
- Coherence-based sampling
 - Light source visibility changes slowly
 - Reduce number shadow rays traced
- Also usable with geometric raytracer

Image-based raytracing



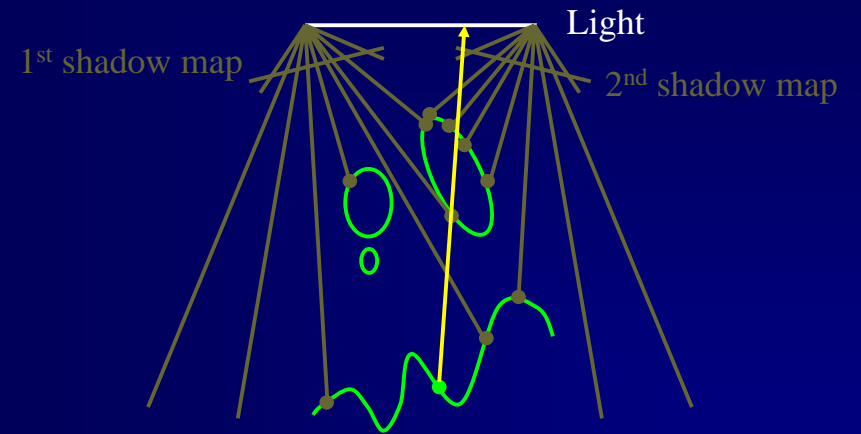
- Represent scene with multiple shadow maps

Image-based raytracing



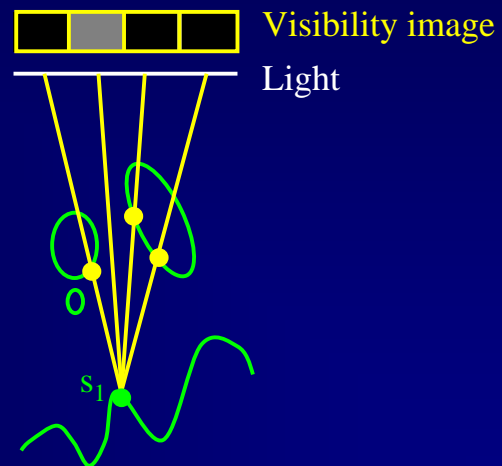
- Represent scene with multiple shadow maps

Image-based raytracing

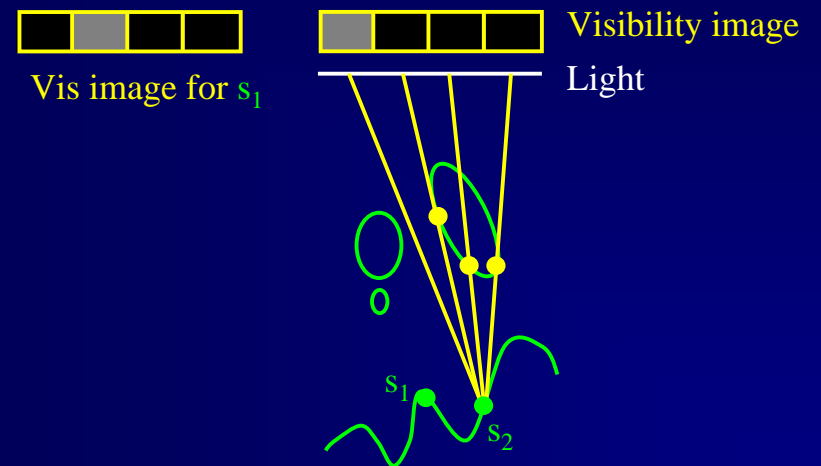


- Trace shadow ray through shadow maps

Light source visibility image



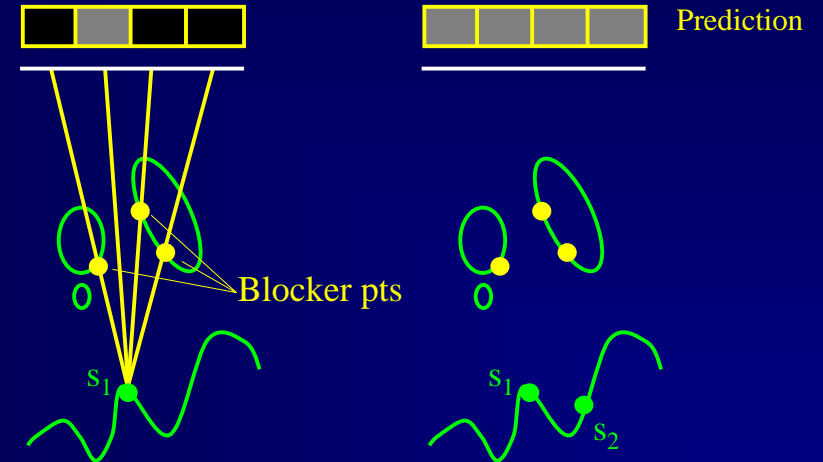
Light source visibility image



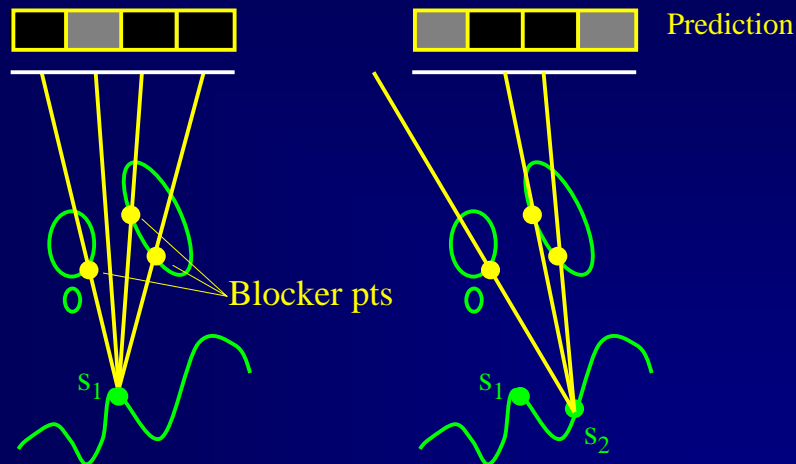
Coherence-based sampling

- Compute visibility image at first point s_1
- Loop over following surface points s_i
 - Predict visibility image at s_i from s_{i-1}
 - Trace rays where prediction confidence low

Predicting visibility

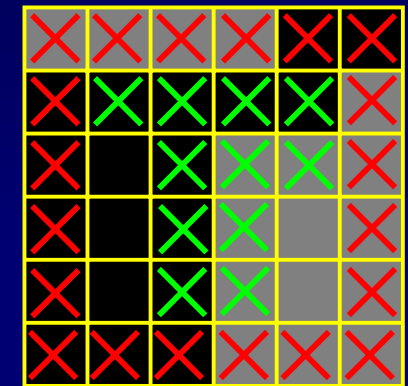


Predicting visibility



Prediction confidence

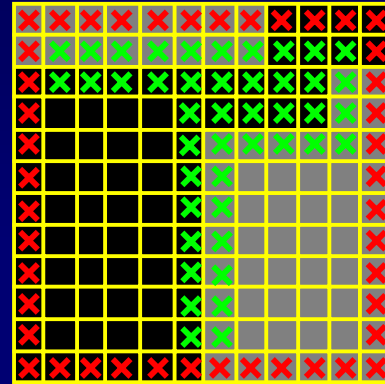
- Low confidence
- High confidence: 5
- Low confidence: 31
- Total cells: 36
- Ratio: $5/36 = 0.14$



Predicted visibility

Prediction confidence

- Low confidence
- Light source edges (X)
- Blocked/unblocked edges (X)



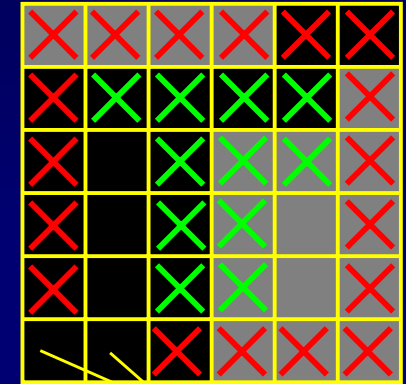
- Trace rays in all X'ed cells

- High confidence: 56
- Low confidence: 88
- Total cells: 144
- Ratio: $56/144 = 0.40$

Predicted visibility

Propagating low confidence

- If traced ray \neq prediction trace neighbor cells

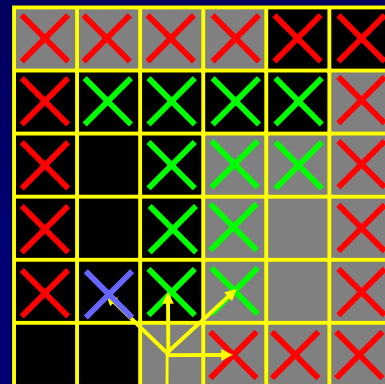


Prediction correct

- Similar to [Hart et al. 99]

Propagating low confidence

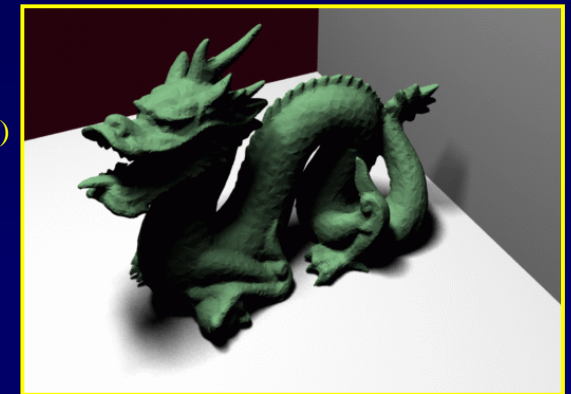
- If traced ray \neq prediction trace neighbor cells



Prediction incorrect

- Light cells: 16 x 16 (256)
- Four 1024 x 1024 maps
- Precomp: 2.33 min
- Render: 19.83 min
- Rays: 79.86

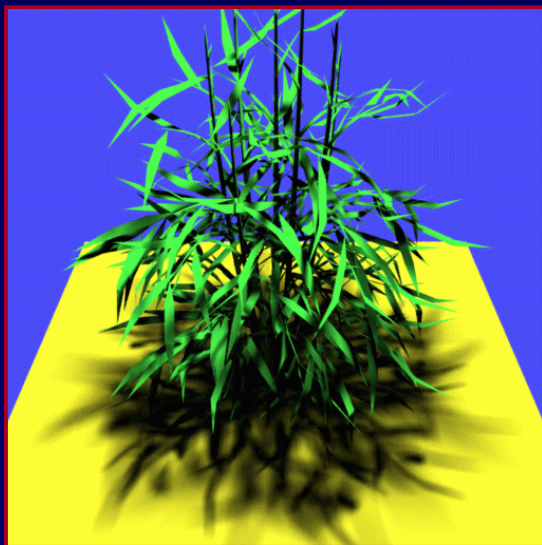
- Speedup: 12.96x
- 2.27x due to image-based raytracing accelerations
- 5.71x due to coherence-based sampling



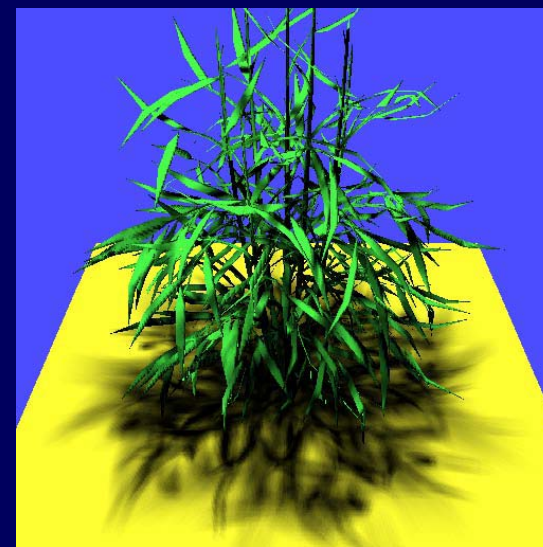
- Light cells: 16 x 16 (256)
- Four 1024 x 1024 maps

- Precomp: 3.93 min
- Render: 65.13 min
- Rays: 88.74

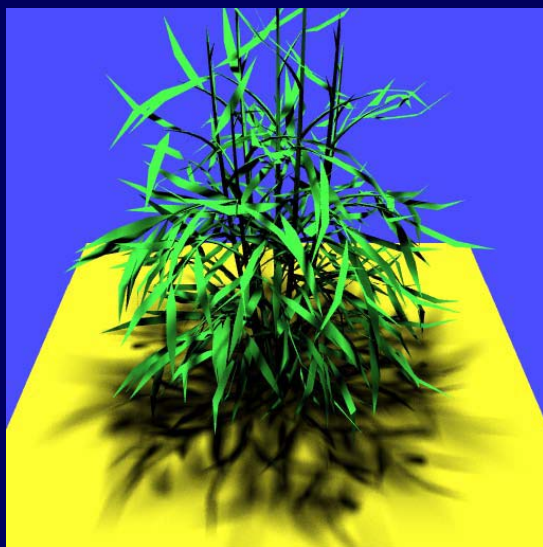
- Speedup: 8.52x
2.16x due to image-based raytracing accelerations
3.94x due to coherence-based sampling



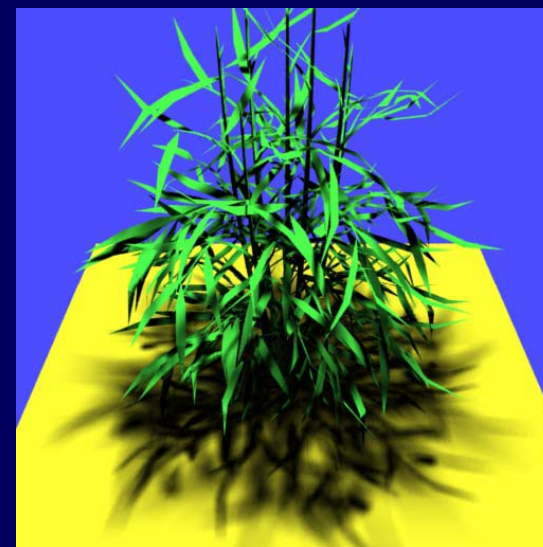
LAM

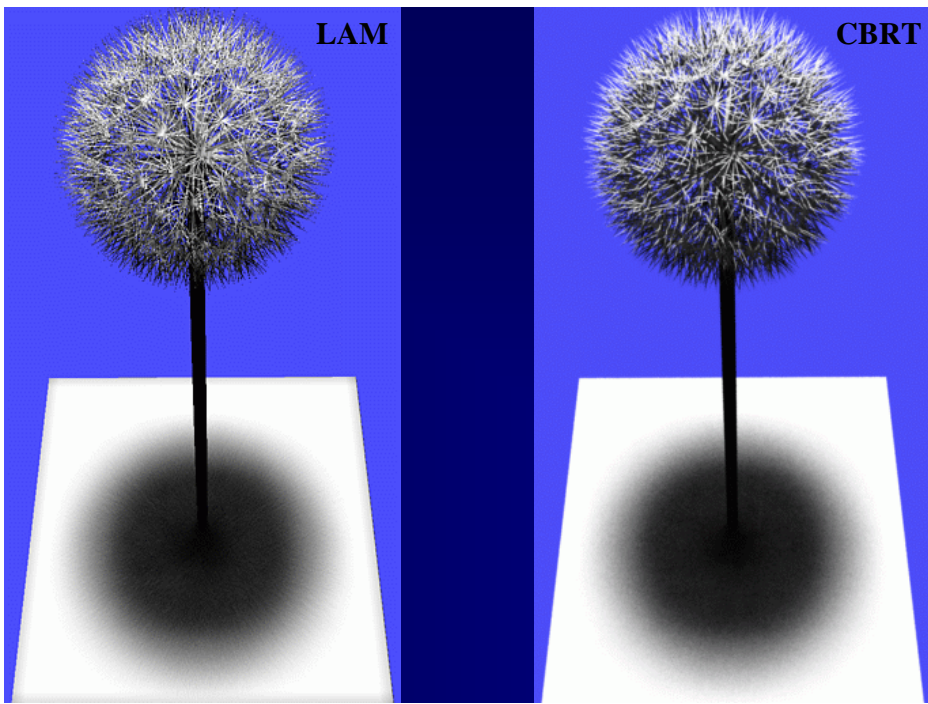


Ray tracing



CBRT





Conclusions

- Two efficient image-based methods
- Layered attenuation maps
 - Interactive applications
- Coherence-based raytracing
 - Production quality images
- IBR ideal for soft shadows – secondary effects