Creating soft shadows

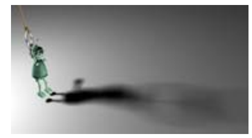
Soft vs. hard shadows

Common sense: binary status of shadow

But it looks very unrealistic

Real picture

Why?

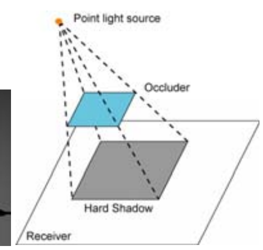


Soft vs. hard shadows.

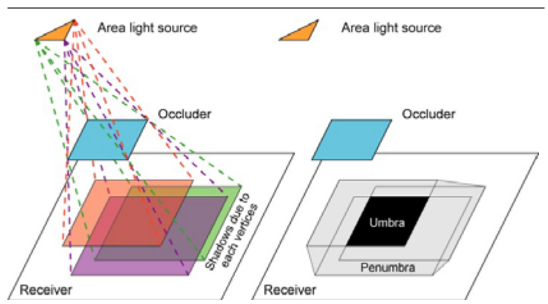
In real life light sources are not points.

Hard shadow creation

For every pixel light source is either visible or occluded



Soft shadow creation



Soft Shadows

Caused by extended light sources

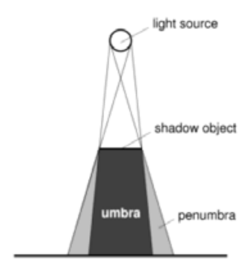
Umbra

source completely occluded

Penumbra

Source partially occluded

Fully lit



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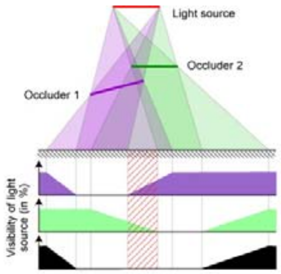
Some assumptions

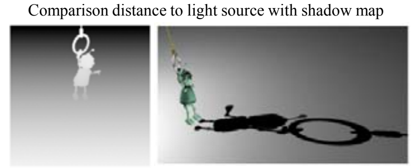
One light source
Monochromatic light source
No special objects (clouds, hair)

Many occluder shadows



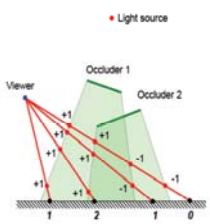
Shadow map algorithm

Point of view of the light source
Method:
- Z-buffer from light source is stored to shadow map buffer
- Z-buffer from spectator
- Comparison distance to light source with shadow map



Shadow volume algorithm

Geometrical representation
Extruding of silhouettes creates shadow volume
Method:
- Find silhouettes of occluders
- Extruding silhouettes to shadow volumes
- For every pixel number of crossed faces of shadow volumes counted
- If number of total number of faces if positive we are in shadow



Soft shadow algorithms

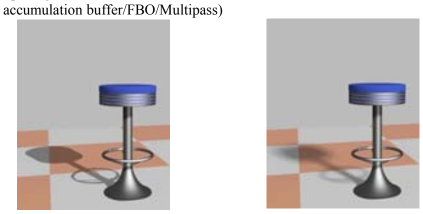
Image-based approach (based on shadow map algorithm)
Object-based approach (based on shadow volume algorithms)

Image-based approach

Combining some shadow maps from point samples
Layered shadow maps instead of shadow map
Some shadow maps take from point samples and computing percentage of light source visibility
Using standard shadow map with techniques to compute soft shadow

Sampling the Light Source

Use arbitrary hard shadow algorithm
Select point sample on area light source
Render hard shadows
Sum up weighted result
(e.g. accumulation buffer/FBO/Multipass)



single hard shadow   accumulated hard shadows -> soft

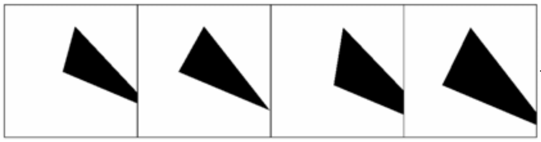
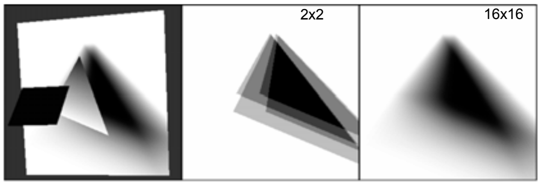


Figure 1: Hard shadow images from 2×2 grid of sample points on light source.



Combining point light sources

The simplest method by Herf (1997)

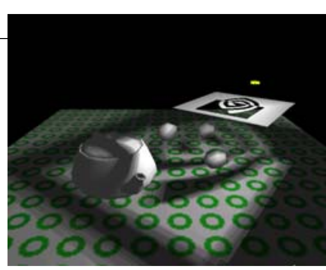
Method

- For every sample compute binary occlusion map
- Computing attenuation map storing for every pixel how many light source samples occluded

Combining point light sources

- Time complexion (NsNp for attenuation map)
- With fewer than 9 samples user sees number of hard shadows
- Parallelizable

Heckbert & Herf



Mark Kilgard

Sampling the Light Source

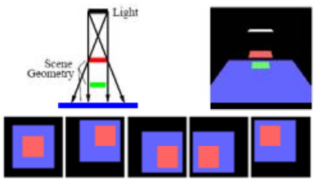
Example: Ground plane shadow texture

```
1. Initialize FB (white)
2. For each sample point do
   2a. Render scene
   2b. Subtract 1/N from FB
       only once for each
       pixel (stencil) !
```

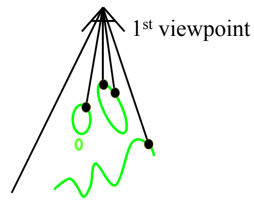
Image from ATI Developer's Site

Layered shadow map

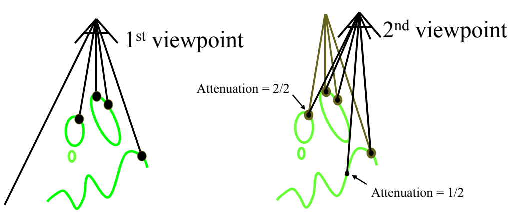
- Extension of previous method
- Method
  - Z-buffer for light point samples
  - Warp to center of light source



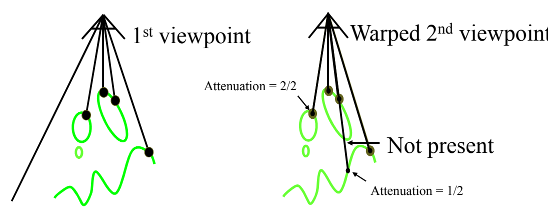
Precomputation



Precomputation

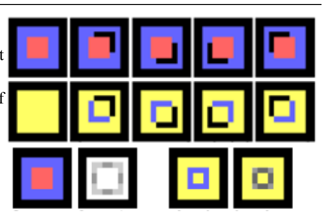


Precomputation



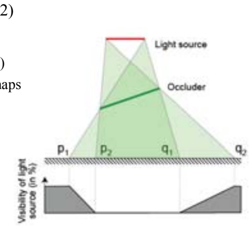
Layered shadow map

- Build attenuation map
- Store layer and distance to light source in shadow map
- While rendering render color of pixel according to layer and attenuation map



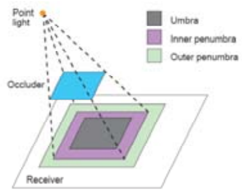
Visibility channel

- For linear light sources by Heifrich (2000)
- For polygonal sources by Ying (2002)
- Method
  - Low number of samples (usually 2)
  - Detect discontinuities in shadow maps
  - Polygon linking
  - Gouraud shading: 1 for farthest
    0 for closer



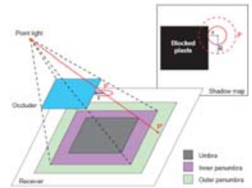
Single sample soft shadow

Parker (1998) – Inner penumbra
Brabec (2002) – Outer penumbra



Single sample soft shadow

Method:
- Standard shadow map from center of light source
- While rendering
  - If pixel is lit, find nearest shadowed pixel
  - If pixel is shadowed, find nearest lit pixel
- Calculating f
- Intensity of light:
  0.5*(1+f) for outer penumbra limited to [0.5, 1]
  0.5*(1-f) for inner penumbra limited to [0, 0.5]



$$f = \frac{\mathrm{dist}(\mathrm{Pixel}_{\mathrm{Occluder}}, \mathrm{Pixel}_{\mathrm{Receiver}})}{RS z_{\mathrm{Receiver}} |z_{\mathrm{Receiver}} - z_{\mathrm{Occluder}}|}$$

Single sample soft shadow

Disadvantages:
- Bottleneck: to find nearest lit/shadowed pixel
- Doesn't depend on size of light source, only from distances

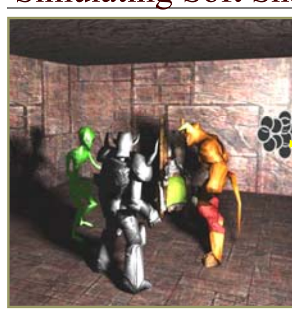
Object based approach

Combining some hard shadows
Extending shadow volume by heuristic
Computing penumbra volume for each edge

Combining hard shadows

The simplest method to produce soft shadow
Method:
- Several light source samples
- Build shadow volumes for each sample
- Average received pictures

Stenciled Shadow Volumes for Simulating Soft Shadows

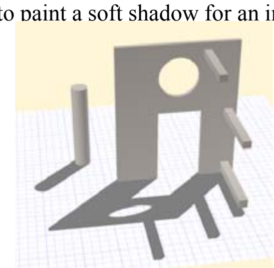


Cluster of 12 dim lights approximating an area light source. Generates a soft shadow effect; careful about banding. 8 fps on GeForce4 Ti 4600.

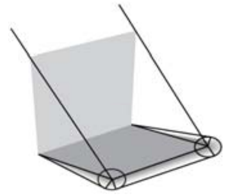
The cluster of point lights.

Plateau Soft Drop Shadows

Say we want to paint a soft shadow for an image.



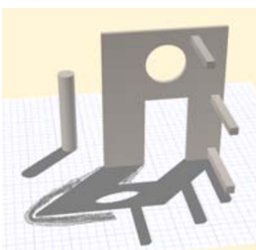
Soft planar shadows



- Haines (2001)
- Planar receiver
- Method
  - Standard shadow volume algorithm
  - Vertices of silhouette turned to cones
  - Building edges around cones
- Disadvantages:
  - Planar surfaces
  - Spherical light source
  - Outer penumbra
  - Penumbra depends only from distance occluder-receiver

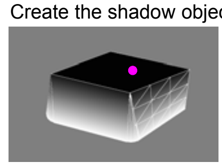
Plateau Idea

"Paint" each shadow's edge, blurring it as its height from the plane increases.

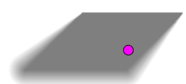


Forming Plateaus

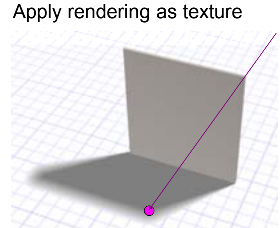
Create the shadow object



Render from above

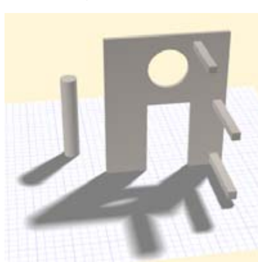


Apply rendering as texture



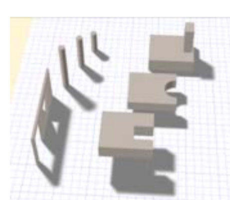
Plateau Result

Soft shadows, at the cost of finding the silhouette and drawing cones & sheets.

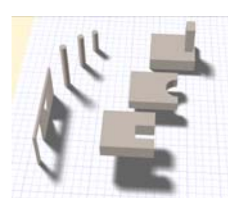


Plateau Limitations

Overstated umbrae, penumbrae are not physically correct.



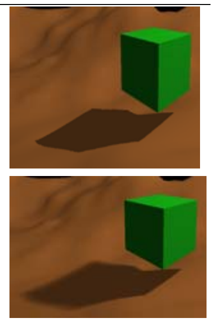
Plateau Shadows (1 pass)



Heckbert/Herf (256 passes)

Penumbra Maps

- Builds on simple idea of "shadow plateaus" introduced by Haines ('01)
- Plausible soft shadows
- Hard upon contact, soft with distance
- Simple implementation on graphics hardware
- Hides some aliasing
- One sample per pixel



Penumbra Map Assumptions

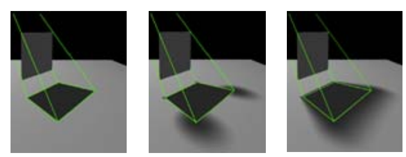
- A hard shadow is a reasonable approximation for a shadow's umbra
- Object silhouettes remain constant over light's surface

Key Insight

- When using a hard shadow as the umbra, all of the approximate penumbra is visible from the center of the light
- Allows storage of penumbral intensity in a separate map called a *penumbra map*

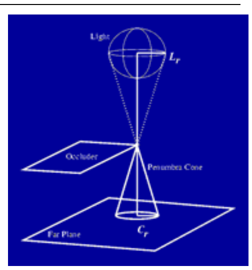
Creating Penumbra Map

- Compute shadow map (for hard shadow)
- Compute object silhouette from light's center
- Compute cones at silhouette vertices
- Compute sheets connecting vertices (along silhouette edges)



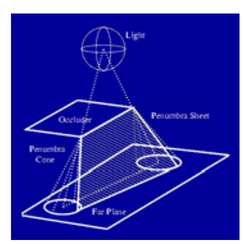
Computing Cones

- For each silhouette vertex
  - Find distance from light's center to vertex
  - Find distance from vertex to far plane
  - Using these distances and the light radius L_r compute C_r using similar triangles

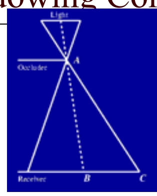


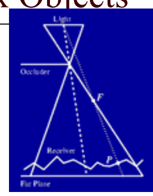
Computing Sheets

- Create quads at each silhouette edge tangent to the adjacent cones
- May not be planar
  - Subdivide significantly non-planar quads for good results



Shadowing Complex Objects



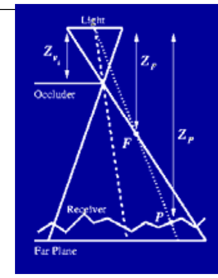


Can not just draw quad with 0 (shadowed) at A and 1 (illuminated) at C

Result depends on current fragment F on quad and point P in the shadow map

Use Fragment Program to Generate Map

$FragmentProgram(Z_{V_i}, F, S_{map})$
(1) $F_{coord} = GetWindowCoord(F)$
(2) $Z_P = TextureLookup(S_{map}, F_{coord})$
(3) $Z_F = F_{coord_z}$
(4) $if\ (Z_F > Z_P)\ DiscardFragment()$
(5) $Z'_P = ConvertToWorldSpace(Z_P)$
(6) $Z'_F = ConvertToWorldSpace(Z_F)$
(7) $I = (Z'_F - Z_{V_i}) / (Z'_P - Z_{V_i})$
(8) $I' = 3I^2 - 2I^3$
(9) $Output_{color} = I'$
(10) $Output_{depth} = I'$



Rendering

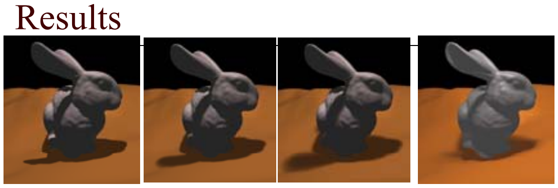
Compare fragment's depth to shadow map to determine if light is completely blocked

If not completely shadowed, index into penumbra map to determine percentage of light reaching surface

Multiple lights requires multiple shadow and penumbra maps

Video

Results



Hard shadow | Soft shadow | Double light size | Pathtraced

Framerates are ~18 Hz with 1024^2 shadow map, penumbra map, and image size

Note the pathtraced image uses the larger light

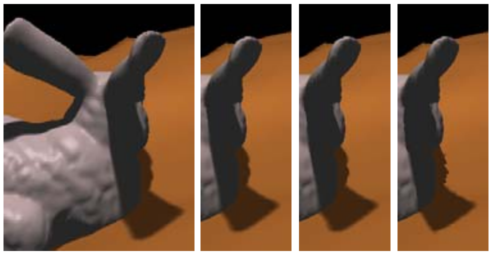
Use 10k triangle bunny to generate shadows

More Results

Shadow Map | Hard shadows | Soft Shadows | Penumbra Map

- Framerates are ~15 Hz for 1024^2 resolution

Changing Penumbra Map Size



1024^2 512^2 256^2 128^2

Problems

Shadows are not accurate

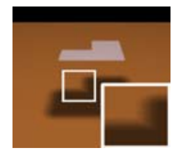
- Less accurate as occluders move further away from shadowed objects

Assume silhouettes constant over light

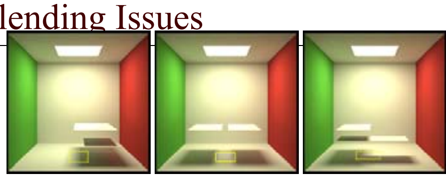
- Noticeable pops on cube
- No problems with other objects

Blending overlapping penumbrae

- Occurs on a per-pixel basis
- No geometric info in the hardware
- Artifacts at silhouette concavities



Blending Issues



In these three cases, overlapping penumbrae should be handled differently

No geometric information in the pixel program means no quick way to decide in hardware

We always choose the darkest pixel (left image)

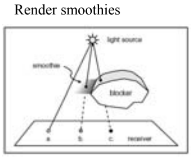
Same as Smoothies….

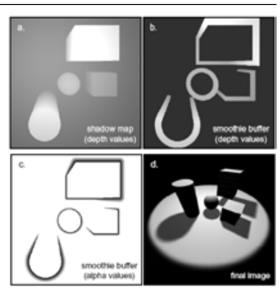
Smoothies

Chan (2003)

Method

- Shadow map
- Identify silhouette edges
- Construct smoothies
- Render smoothies

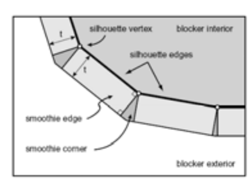




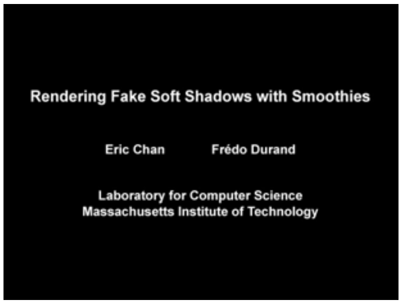
Smoothies

Disadvantages

- Outer penumbra only
- There is always umbra
- Connecting edges



Video



Video

Comparison to Penumbra Maps

Penumbra maps (Wyman and Hansen, EGSR 2003)

- Same idea, different details

	Penumbra Maps	Smoothies
Geometry:	cones and sheets	quads
Store depth:	blockers only	blockers + smoothies

Smoothie depth:

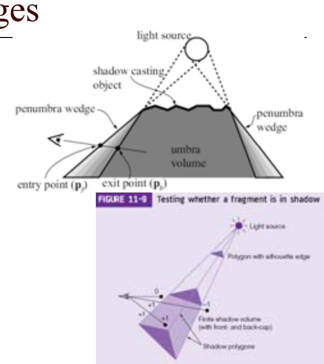
- Extra storage + comparison
- Handles surfaces that act only as receivers

Penumbra wedges

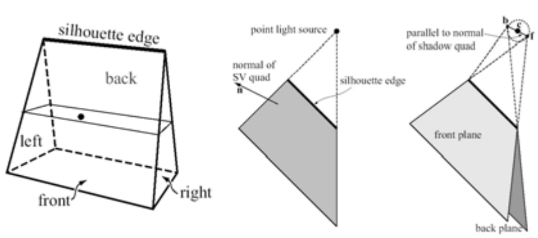
Akenine-Moller and Assarsson(2002-03)

Method

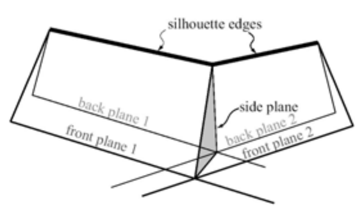
- Building silhouette from single sample
- Building penumbra wedges
- Shadow volume algorithm
- If point inside wedge algorithm uses fragment programs implemented in hardware



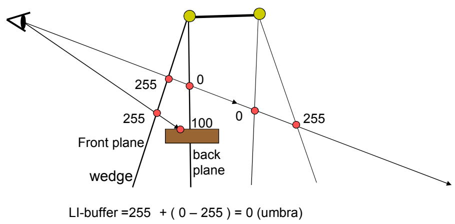
Penumbra wedges



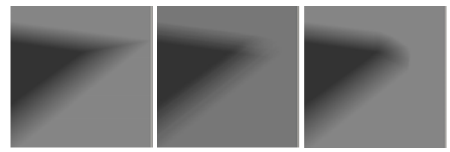
Penumbra wedges



Penumbra wedges

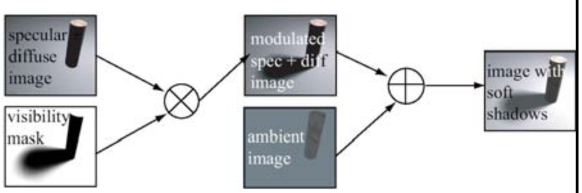


Some Issue (need to 'round' corners)

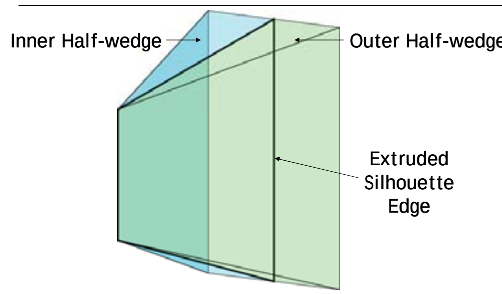


Original result Expected result [HH] PW algorithm using 6 extra wedges per acute angle

Penumbra wedges



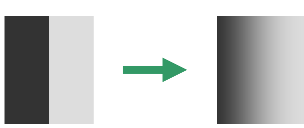
Penumbral Wedge Rendering



Soft Shadow Correction

Darken area inside outer penumbra

Lighten area inside inner penumbra



Soft Shadow Correction

Lighting pass for ordinary stencil shadows uses stencil test

0 in stencil buffer at a particular pixel means light can reach that pixel

Nonzero means pixel is in shadow

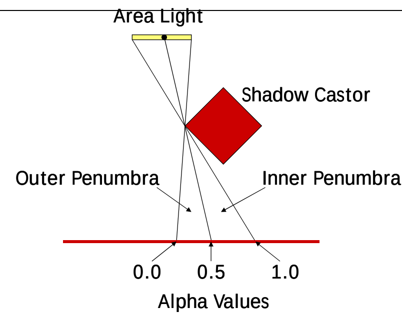
Soft Shadow Correction

For soft shadows, use alpha blending during lighting pass

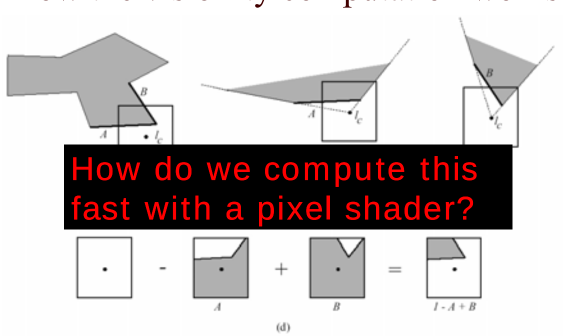
Value in the alpha channel represents how much of the area light is covered

0 means entire light source visible from a particular pixel
1 means no part of light source is visible (fully shadowed)

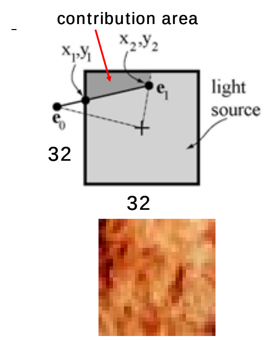
Soft Shadow Correction

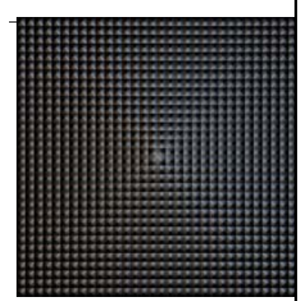


How the visibility computation works:



Precomputed contribution in 4D textures





Video

4D textures used as look-up table

Enables

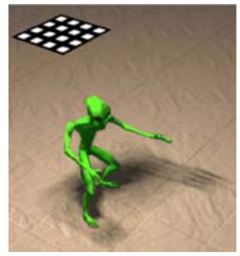
Fast computation

Textured light sources (e.g., fire)

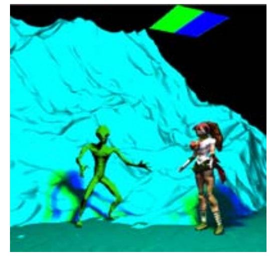
Colored shadows.

Fire video

More examples using textured lights



Texture of 16 area lights



Texture of two colors

Colored Lights

Soft Shadow Correction

Render the shadow volumes into a 16-bit floating-point render target

Penumbral Wedge Rendering

In the vertex program, we compute the three outside bounding planes of a half-wedge

Send these planes to the fragment program in viewport space!

Allows us to do a quick test to determine whether a viewport-space point is outside the half-wedge

Penumbral Wedge Rendering

In the fragment program, we test the viewport-space position of the point in the frame buffer against three half-wedge bounding planes

We will use the depth test to reject points on the wrong side of the extruded silhouette edge

Penumbral Wedge Rendering

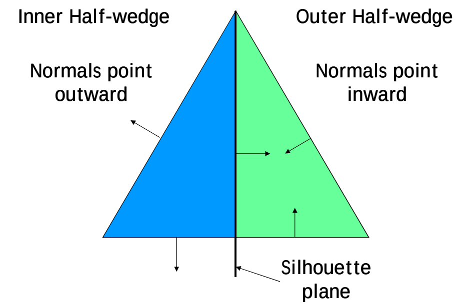
Sort half-wedges into two batches:

1) Those for which camera is on the positive side of the silhouette edge

2) Those for which camera is on the negative side of the silhouette edge

Extruded silhouette plane normal always points outward from shadow volume

Penumbral Wedge Rendering



Rendering Outer Half-wedges

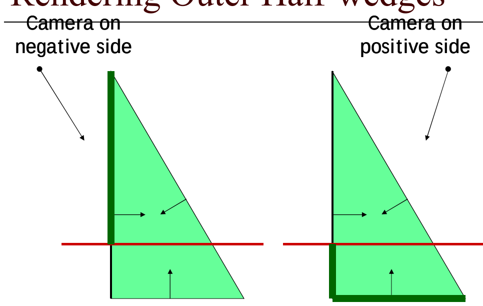
Half-wedges for which camera is on positive side of silhouette plane

Render front faces when *z* test fails

Half-wedges for which camera is on negative side of silhouette plane

Render back faces when *z* test passes

Rendering Outer Half-wedges



Penumbral Wedge Rendering

Penumbral Wedge Rendering

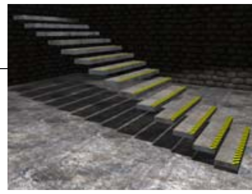
If the value was greater than one, then it's saturated to one, corresponding to fully shadowed

Then render lighting pass, multiplying source color by one minus destination alpha

```
glBlendFunc(GL_ONE_MINUS_DST_ALPHA, GL_ONE);
```

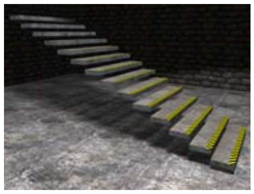
Small Light Area

Shadows sharper, rendering faster



Large Light Area

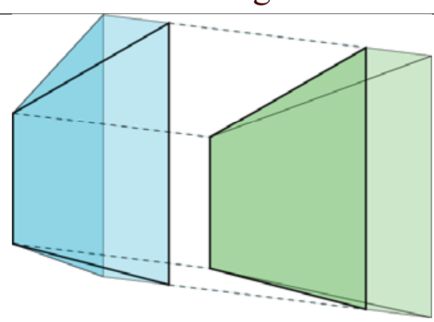
Shadows softer, interact more, rendering slower



Semi-penumbral Shadows

- Method for speeding up penumbral wedge soft shadows
- Only render outer half-wedges
- Less correct, but still looks good
- Lose the ability to cast shadows that have no point of 100% light occlusion

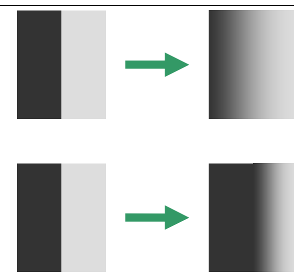
A Penumbral Wedge



Semi-penumbral Shadows

Instead of full penumbra:

Render outer half of penumbra only:



Inner and outer half-wedges rendered

Only outer half-wedges rendered

Summary

- Hard vs. soft shadows
- Existing algorithms for soft shadow creation
- Advantages and disadvantages of each algorthms

Bibliography

Maneesh Agrawala, Ravi Ramamoorthi, Alan Heirich and Laurent Moll. Efficient image-based methods for rendering soft shadows.

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J.-M. Hasenfratz, M. Lapierre, N. Holzschuch and F.X. Sillion A Survey of Real-time Soft Shadows Algorithms