Lecture 18: Shadows

Fall 2004

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Announcements

- HW 1 graded
- HW 2 due tomorrow
  - Turn in code AND classes in jar file
  - Do NOT hard-code parameters
  - Examples with noise have been posted

Next-Event Estimation

- How does it work?

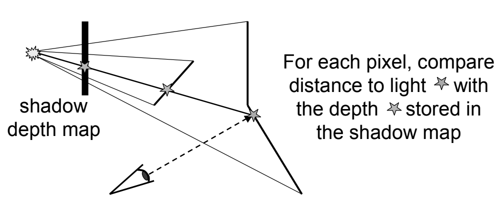
Shadows

Methods for fast shadows:

- Shadow Maps
- Shadow Volumes

Using the Shadow Map

- When scene is viewed, check viewed location in light's shadow buffer
  - If point's depth is (epsilon) greater than shadow depth, object is in shadow



Shadow Mapping: Pass 1

- Depth testing from light’s point-of-view
  - Two pass algorithm
- First, render depth buffer from light’s point-of-view
  - Result is a “depth map” or “shadow map”
  - A 2D function indicating the depth of the closest pixels to the light
  - This depth map is used in the second pass

Shadow Mapping: 2nd pass

- Second, render scene from the eye's point-of-view
- For each rasterized fragment
  - determine fragment's XYZ position relative to the light
  - this light position should be setup to match the frustum used to create the depth map
  - compare the depth value at light position XY in the depth map to fragment's light position Z

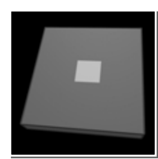
Shadow Map Issues

- Can only cast shadows over a frustum
  - Use 6 (like a cube map)
- Get speckling because of floating point errors
  - Use triangle ids
  - Use bias
    - If (B > A+bias) p in shadow

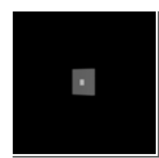
Properties of Shadow Maps

- One shadow map per light
- Render scene twice per frame
  - If static, can reuse
- Advantages
  - Fast
  - Easy to implement
- Disadvantages
  - Bias
  - Aliasing
  - Hard shadows

Why does Aliasing arise?

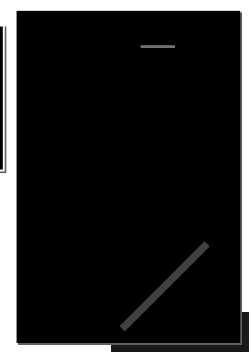


Eye View



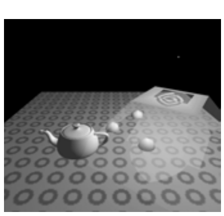
Shadow Map

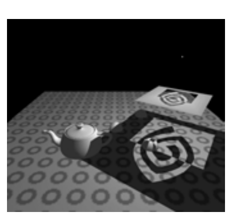
Eye View Projected Area != **Shadow Map Projected Area**



Shadow Volumes

- Clever counting method using stencil buffer
- Can cast shadows onto curved surfaces



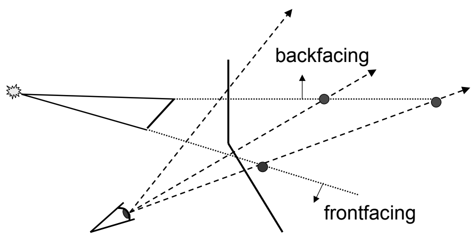


Mark Kilgard, NVIDIA Inc.

Algorithm

- Finding volumes
  - Project out shadow volumes
- Rendering
  - Render scene into z-buffer, freeze z-buffer
  - Draw front-facing volumes in front/back of pixel
    - increment stencil
  - Draw back-facing volumes in front/back of pixel
    - decrement stencil
  - If (cnt == 0) lit else shadow

Z-fail Approach



Performance

- Have to render lots of huge polygons
  – Front face increment
  – Back face decrement
  – Possible capping pass
- Uses a LOT fill rate
- Gives accurate shadows
  – IF implemented correctly
- Need access to geometry if want to use silhouette optimization

Comparison

- Shadow Maps
  – Adv: Fixed resolution, fast, simple
  – Disadv: Bias, aliasing
- Shadow Volumes
  – Adv: Accurate, high-quality
  – Disadv: Fill-rate limited, hard to implement robustly

Approaches to Improve Shadows

- Hard Shadows
  – Adaptive Shadow Maps [Fernando, Fernandez, Bala, Greenberg]
  – Shadow Silhouette Maps[Sen, Cammarano, Hanrahan]
- Hard and Soft Shadows
  – Edge-and-Point Rendering [Bala, Walter Greenberg]
- Soft Shadows

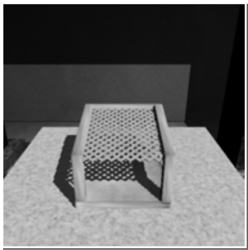
Adaptive Shadow Maps: Motivation

- Fernando, Fernandez, Bala, Greenberg [SIG01]
- Shadow maps require too much tweaking
  – Where to place light?
  – What resolution to use?
- Goals:
  – Address the aliasing problem
  – No user intervention
  – Interactive frame rate

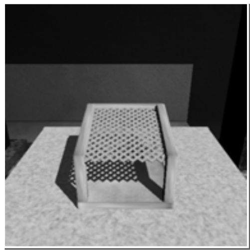
Adaptive Shadow Maps

- Idea:
  – Refine shadow map on the fly
- Goal:
  – Shade each eye pixel with a different shadow map pixel
- Implementation:
  – Use hierarchical structure for shadow map
  – Create/delete pieces of shadow map as needed
  – Exploit fast rendering and frame buffer read-backs

Results: Images (Mesh)

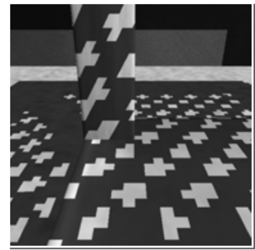


Conventional Shadow Map
(2048 x 2048 pixels)
16 MB Memory Usage

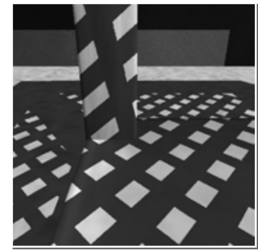


Adaptive Shadow Map
(Variable Resolution)
16 MB Memory Usage

Results: Images (Mesh Close-Up)



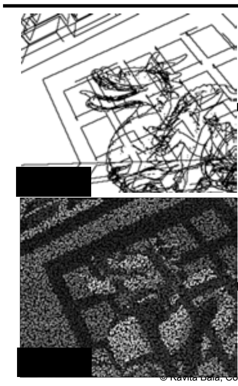
Conventional Shadow Map
16 MB Memory Usage



Adaptive Shadow Map
16 MB Memory Usage

Equivalent Conventional Shadow Map Size:
65,536 × 65,536 Pixels

Edge-and-Point Rendering [Bala03]

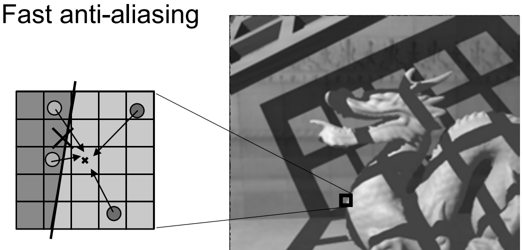


Edges: important discontinuities
- Silhouettes and shadows

Points: sparse shading samples

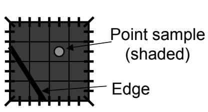
Edge-and-Point Image

- Alternative display representation
- Edge-constrained interpolation preserves sharp features
- Fast anti-aliasing



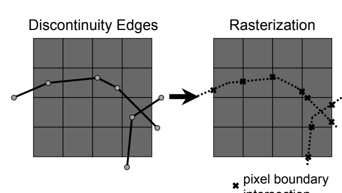
Edge-and-Point Image (EPI)

- Goal: compact and fast
  - Store at most one edge and one point per pixel
  - Limited sub-pixel precision
  - Pre-computed tables give fast anti-aliasing



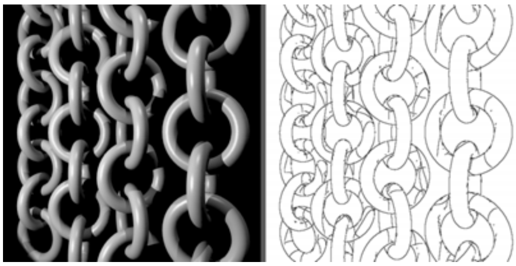
Edge Reconstruction

- Rasterize edges onto image plane
- Record their intersections with pixel boundaries
- Can handle high complexity objects



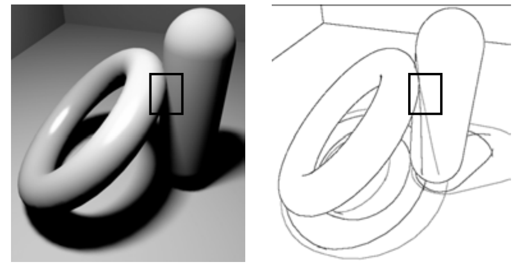
Edge Finding

- Hierarchical trees: fast edge finding
  - Fraction of a second



Soft Shadow Edges

Black: silhouettes,
Red: umbral edges, Blue: penumbral edges



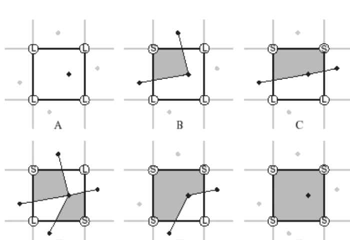
Results

- Fast edge finding
- Accurate shadow reconstruction (similar to shadow volume quality)
- Pre-computed tables give fast anti-aliasing

Silhouette Shadow Map

- Shadow maps with silhouettes for precision and low fill rate
- Silhouette map: texture map (depth + silhouette)
  - Texel represents (x,y) of point on silhouette
  - At most one pt per texel: at most 1 silhouette
- Render with silhouette map
- Overall 3 passes

Rendering with Silhouette Map



Implementation

- ATI Radeon 9700 Pro

Figure 1: (Left) Standard shadow map. (Center) Shadow volumes. (Right) Silhouette map, at same resolution as shadow map in (Left).

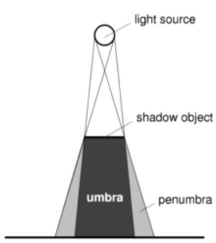
Results

- Relatively simple scenes: 1k-14k triangles
- Little slower than shadow volumes
  - but lower overdraw

Soft Shadows

Soft Shadows

- Soft shadows appear natural
- Hard to get soft shadows in hardware
- Slow in software



Heckbert and Herf

- Use accumulation buffer
- Render shadows from multiple point lights over the area light (like MC)
- Accumulate shadows

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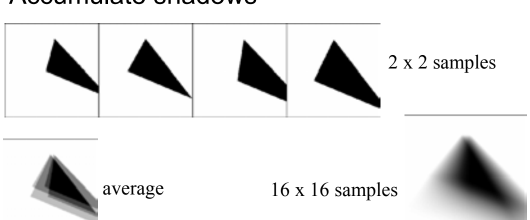
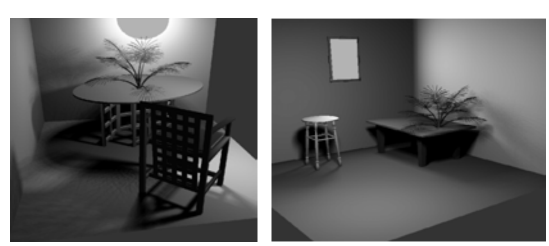


Heckbert/Herf Soft Shadows

- Advantage: gives true penumbra
- Limitations: overlapping shadows are unconvincing unless a lot of passes are made



Images courtesy of Michael Herf and Paul Heckbert

Soft Shadow Approximations

- Approximations
  - People can’t tell the difference
  - Good for games
- Convolution
- Penumbra Maps
- Penumbra Wedges

Soler and Sillion

- Shadows as convolution

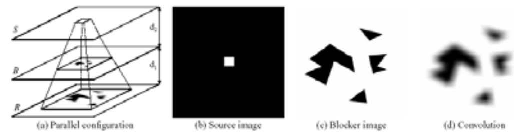
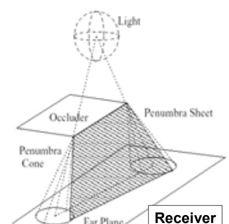
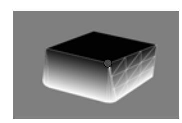


Figure 14: A single 128 × 128 shadow map was computed for the cluster of cubes, and used to obtain shadows on each individual cube according to its location in space.

Haines: Shadow Plateaus

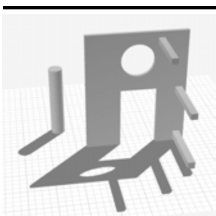
- Compute soft shadows on a plane
- Start with umbra from light’s center
- Blur outward from umbra to get penumbra





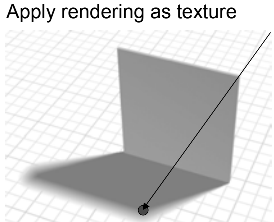
Create the shadow object

Haines: Shadow Plateaus



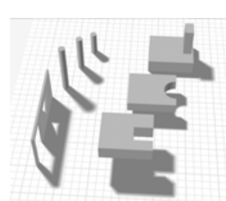
Find silhouettes and draw cones & sheets

Apply rendering as texture

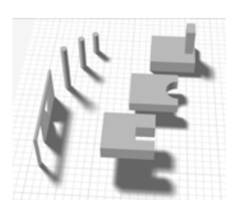


Plateau Limitations

- Overstated umbra
- Penumbra not physically correct



Plateau Shadows (1 pass)

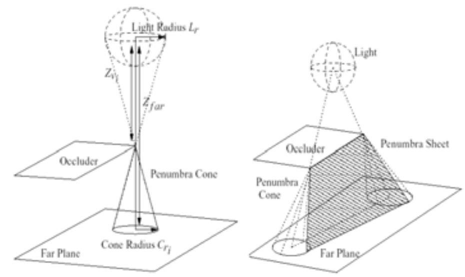


Heckbert/Herf (256 passes)

Penumbra Maps

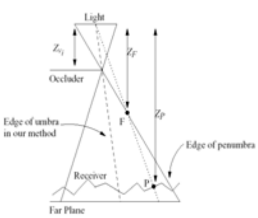
- Wyman and Hansen
- Use shadow map and Haines technique for soft shadows on arbitrary surfaces
- Penumbra map
- Stores intensity of shadow
- Overall:
  - 3 pass: shadow map and penumbra map
  - Render image using depth from shadow map and intensity from penumbra map

Method Details: Visualization



Computing Penumbra Map Values

Uses fragment program



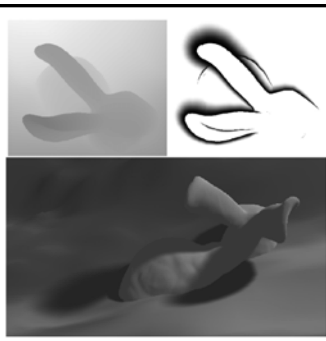
Z_{vi} Distance to vertex v_i
Z_F Distance to cone/sheet fragment
Z_P Depth of shadow map pixel
P Point in the scene
I Intensity in the penumbra map

$$I = 1 - \frac{Z_P - Z_F}{Z_P - Z_{v_i}} = \frac{Z_F - Z_{v_i}}{Z_P - Z_{v_i}}$$

Rendering

- Render from camera's viewpoint
- If occluded in shadow map, in umbra
- Else, modulate w/ value from penumbra map

Results



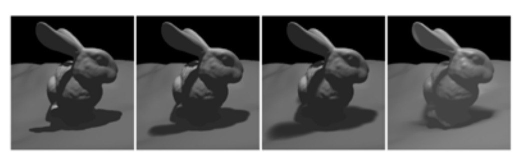


Figure 7: *Comparison of the Stanford Bunny with shadow maps (left), penumbra maps with two different sized lights (center), and a pathtraced shadow using the larger light (right). For this data set, we generate shadows using a 10k polygon model and render the shadows onto the full (~70k polygon) model.*

Figure 8: *Using a standard shadow map results in hard shadows (left), add a penumbra map to get soft shadows (right). Using a 10k polygon dragon model for the shadows and a 50k polygon model to render, we get 14.5 fps at 1024x1024.*

Assumptions

- Umbra from center is the real umbra; full penumbra visible from center
- Umbra is fixed size irrespective of size of light: over-stated umbra
- Silhouette stays fixed over light