Lecture 17: Shadows

Fall 2004

Kavita Bala

Computer Science

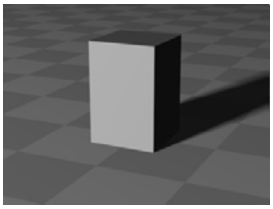
Cornell University

Projects

- Proposals due today
- I will mail out comments
- Grading HW 1: will email comments asap

Why Shadows?

- Crucial for spatial and depth perception



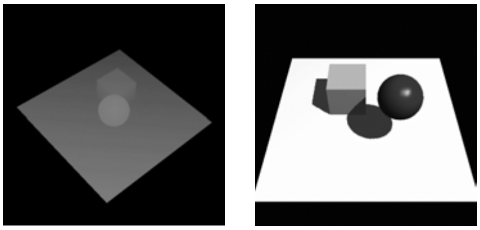
Shadows

Methods for fast shadows:

- Shadow Maps
- Shadow Volumes

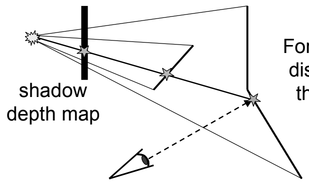
Shadow Maps

- Introduced by Lance Williams (SIGGRAPH 1978)
- Render scene from light's view
  - black is close, white is far



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

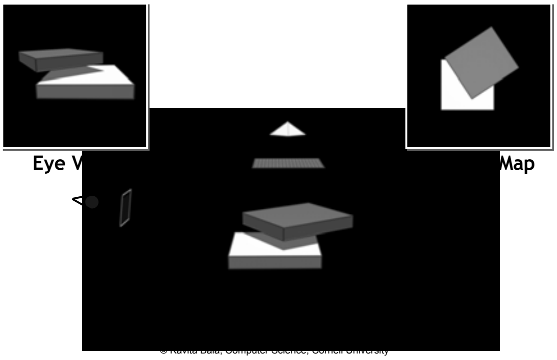


For each pixel, compare distance to light ✫ with the depth ✫ stored in the shadow map

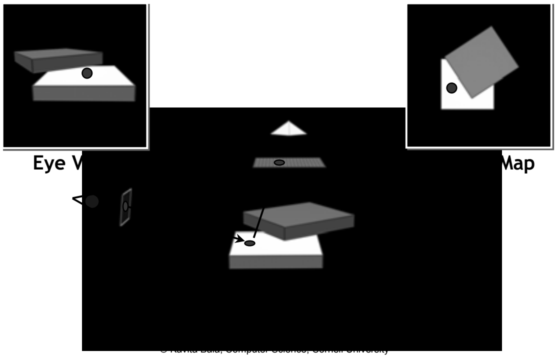
Shadow Mapping: Pass 1

- 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

How Shadow Maps Work



How Shadow Maps Work



Shadow Mapping: 2nd pass

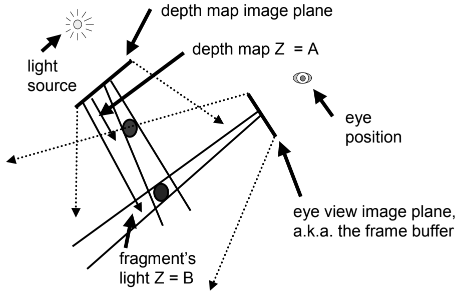
- Second, render scene from the eye’s point-of-view
- For each rasterized fragment
  - determine fragment’s XYZ position relative to the light
  - this light position should be setup to match the frustum used to create the depth map
  - compare the depth value at light position XY in the depth map to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

Shadow Mapping: Comparison

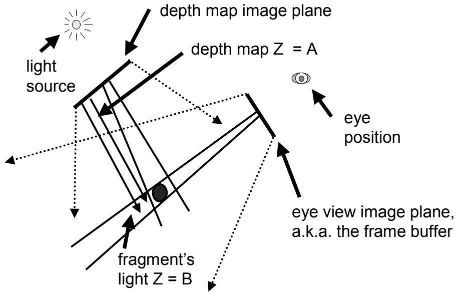
- Two values
  - A = Z value from depth map at fragment’s light XY position
  - B = Z value of fragment’s XYZ light position
- If (B > A),
  - There must be something closer to the light than the fragment
  - So, fragment is shadowed
- If A and B are approximately equal, the fragment is lit

Example: Shadowed

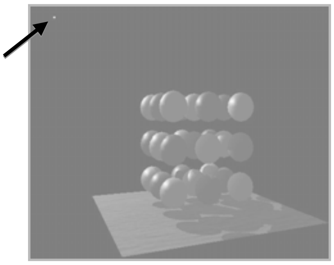
The A < B shadowed fragment case



Example: Visible

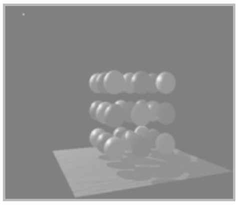


Example

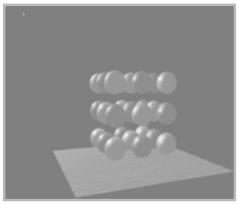


the point light source

Example



with shadows



without shadows

Shadow Map Issues

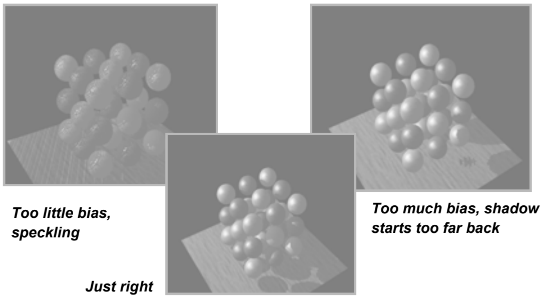
- Can only cast shadows over a frustum
  - Use 6 (like a cube map)
- Get speckling because of floating point errors
  - Use triangle ids
  - Use bias
    - If (B > A+bias) p in shadow

Shadow Map Issues

- Use triangle Ids
  - Meshes?
- Bias
  - If (B > A+bias) p in shadow
  - If b is large?
  - If b is small?

Bias Issues

- How much polygon offset bias depends



Too little bias, speckling

Just right

Too much bias, shadow starts too far back

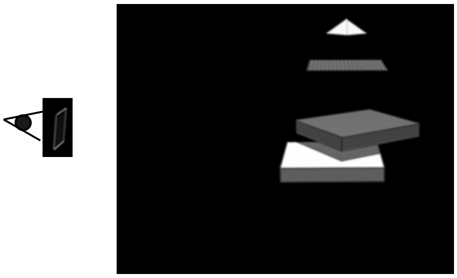
Shadow Maps on Hardware

- Shadow Maps use projective textures
- Treat texture as a light source (slide projector)
  - Do not need to specify texture coordinates explicitly
  - Spotlights

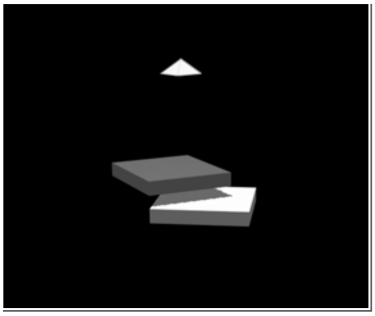
Properties of Shadow Maps

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

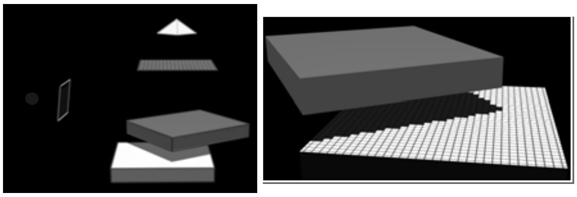
Aliasing (Distant)



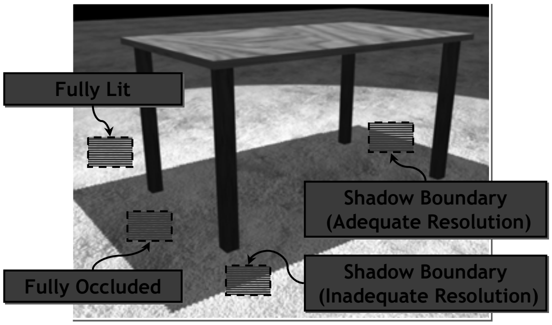
Aliasing in Eye View (Distant)



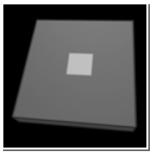
Aliasing (Close)



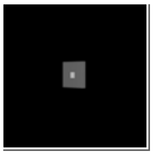
Where does aliasing occur?


Fully Lit
Shadow Boundary (Adequate Resolution)
Fully Occluded
Shadow Boundary (Inadequate Resolution)

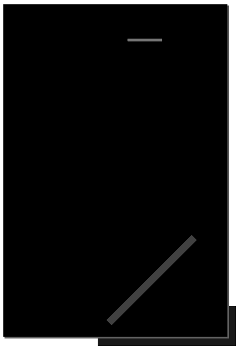
Why does Aliasing arise?



Eye View



Shadow Map



Eye View Projected Area != Shadow Map Projected Area

Shadows

Methods for fast shadows:

- Shadow Maps
- Shadow Volumes

Shadow Volumes

- Crow 1977
- Accurate shadows

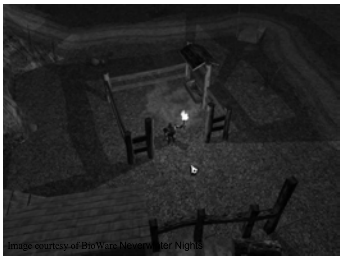
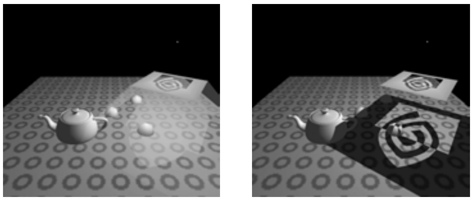


Image courtesy of BioWare Neverwinter Nights

Shadow Volumes

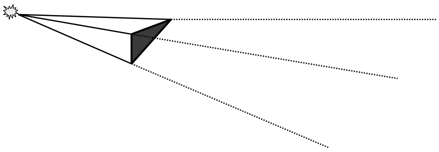
- Clever counting method using stencil buffer
- Can cast shadows onto curved surfaces



Mark Kilgard, NVIDIA Inc.

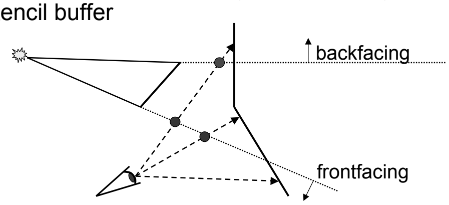
Volume Concept

- Create volumes of space in shadow from light
- Each triangle creates 3 projecting quads



Using the Volume

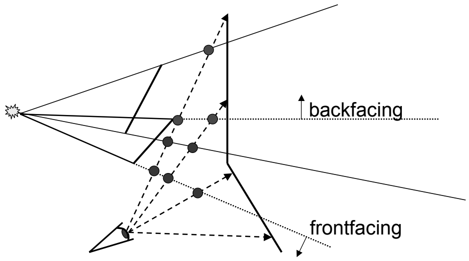
- To test a point, count the number of polygons between it and eye
- If more frontfacing than backfacing polygons, then in shadow
- Done with clever counting method using the stencil buffer



Algorithm

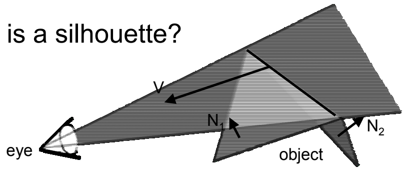
- Finding volumes
  - Project out shadow volumes
- Rendering
  - Render scene into z-buffer, freeze z-buffer
  - Draw front-facing volumes in front of pixel
    - increment stencil
  - Draw back-facing volumes in front of pixel
    - decrement stencil
  - If (cnt == 0) lit else shadow

Multiple Shadow Volumes



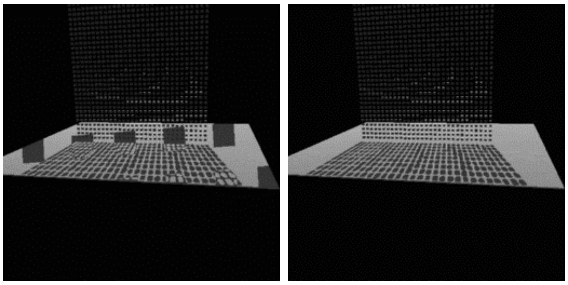
Shadow Volumes Properties

- Performance: Use the silhouette for speed
- What is a silhouette?



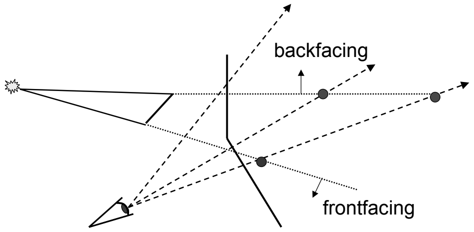
$N_1 \cdot V > 0$ (forward facing)
$N_2 \cdot V < 0$ (backward facing)

Near Plane Clip Issues



- Near plane clip discards part of shadow volume, messes up count

Z-fail Approach



But

- Far clipping plane problems?
- Use homogeneous coordinate to map to infinity

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

Summary

- Shadow maps
  - Render scene twice per frame
    - If static, can reuse
  - Uses projective texturing, requires hardware support/shaders
- Shadow volumes
  - Use stencil buffers

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
  - Next time

Adaptive Shadow Maps: Motivation

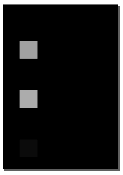
- Fernando, Fernandez, Bala, Greenberg [SIG01]
- Shadow maps require too much tweaking
  - Where to place light?
  - What resolution to use?
- Goals:
  - Address the aliasing problem
  - No user intervention
  - Interactive frame rate

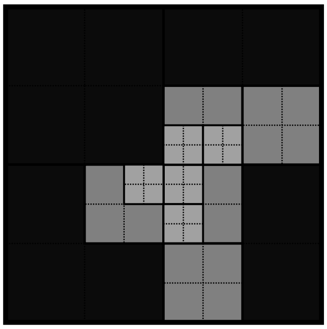
Adaptive Shadow Maps

- 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

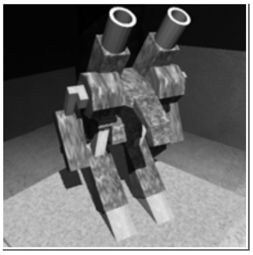
ASM Data Structure

- Simple 2D tree:

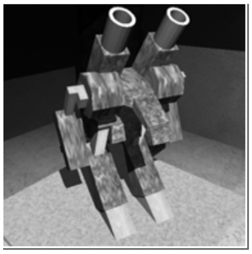




Results: Images (Robot)

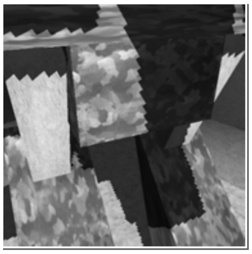


Conventional Shadow Map
(2048 x 2048 pixels)
16 MB Memory Usage

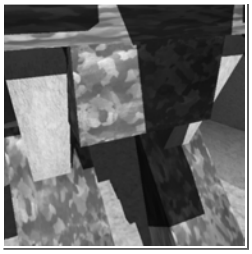


Adaptive Shadow Map
(Variable Resolution)
16 MB Memory Usage

Results: Images (Robot Close-U



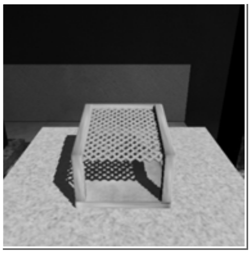
Conventional Shadow Map
16 MB Memory Usage



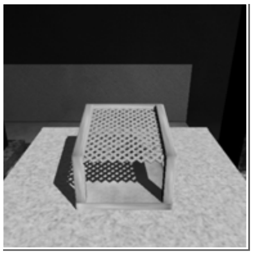
Adaptive Shadow Map
16 MB Memory Usage

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

Results: Images (Mesh)

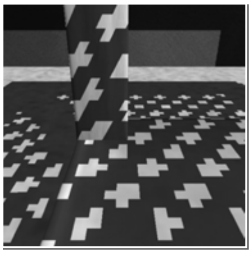


Conventional Shadow Map
(2048 x 2048 pixels)
16 MB Memory Usage

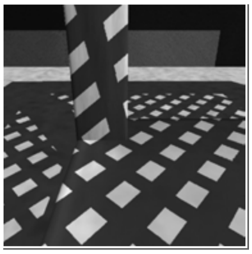


Adaptive Shadow Map
(Variable Resolution)
16 MB Memory Usage

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