06 Shadow Mapping

Thanks to previous instructor Kavita Bala

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Shadows as depth cue
Shadows as anchors
Before we get into more complex methods...

- if a shadow is just needed to help anchor an object to a plane, very simple techniques can suffice
- classic: project shape of object, blur, use as mask to darken floor

Shadow baking

- a more principled approach
- establish texture coordinates on floor
- for each texel compute irradiance
- perfectly accurate for diffuse receivers when the light and all geometry are static
Shadow maps
Main idea: reuse the z-buffer mechanism to test for light source visibility

• introduced by Lance Williams in 1978
• very widely used approach for point-like lights

Shadow testing and visibility testing are similar problems

• given a point on a surface, is it visible to an { observer | light } at a fixed location?
• for visibility: interpolate screen-space (x,y,z); consider depth buffer value stored at screen-space (x,y); z <= buffer(x,y) implies visible
• for shadow: compute light-space (x,y,z) of fragment; z <= buffer(x,y) implies illuminated

Some serious differences in practice

• most notably: fragments do not line up with depth buffer samples (they are scattered irregularly in light space)
[Möller et al. RTR]
Shadow Map Issues

- if A and B are approximately equal?
- Speckling
Mark Kilgard
first try at shadow mapping
shadow mapping with constant bias
shadow mapping with slope-dependent bias
closed surfaces and slope-dependent bias
Shadow map sample rate—bad case

Light behind object

Light’s “view direction” almost opposite the eye’s view direction

“Dueling frusta”
Cascaded shadow maps (aka. parallel-split SM)

Figure 7.18. On the left, the view frustum from the eye is split into four volumes. On the right, bounding boxes are created for the volumes, which determine the volume rendered by each of the four shadow maps for the directional light. (After Engel [430].)
Cascaded shadow maps

Idea: split the view volume

- cut into several slabs by depth
- handle shadows in each slab with a separate shadow map
- compute shadow frusta to exactly bound each piece
- use fragment depth to decide which map to sample

Design choices

- how to split the depth range (often logarithmically)
- set near distance with great care (has big effect on resolution of shadows)
- can be smarter about bounds: only need to bound objects, not whole view volume…
Single shadow map, 2048x2048

Four 1024x1024 shadow maps (equal memory)
Filtering shadow maps

Shadow map lookups cause aliasing, need filtering

As with normal maps, pixel is a nonlinear function of the shadow depth
  • this means applying a linear filter to the depth is wrong

We want to filter the output, not the input, of the shadow test
  • what fraction of samples pass the test
  • samples pass the test if they are closer than the shadow map depth
  • therefore “percentage closer filtering” or PCF
Percentage Closer Filtering

- Soften the shadow to decrease aliasing
  - Reeves, Salesin, Cook 87
  - GPU Gems, Chapter 11
closed surfaces and slope-dependent bias
adding percentage-closer filtering
Soft shadows from small sources

Main effect is to blur shadow boundaries
  • PCF can do this
  • …but how wide to make the filter?

Real shadows depend on area of light visible from surface
  • this can vary in complex ways
  • example: sun viewed through leafy trees

Useful approximation: convolution
  • shadows are convolutions when the blocker and source are parallel and planar
  • occluder fusion: approximating some occluding geometry as a planar blocker
Soft Shadows

Completely lit

Umbra

Penumbra

 Completely lit
Shadow Hardening on Contact
Percentage-Closer Soft Shadows

1. Blocker search
Percentage-Closer Soft Shadows

1. Blocker search
2. Penumbra width estimation

\[ w_{\text{penumbra}} = \frac{p_z^s - z_{\text{avg}}}{z_{\text{avg}}} w_{\text{light}} \]
Percentage-Closer Soft Shadows

1. Blocker search
2. Penumbra width estimation
3. Filtering

Filter region (size $\approx w_{\text{penumbra}}$)
Percentage-closer soft shadows