Percentage-Closer Soft Shadows

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Algorithm Comparison

- **Regular Shadow Maps**
  - Always hard
  - Noticeable Aliasing

- **Uniform Soft Shadows**
  - Always soft
  - Aliasing is hidden

- **Perceptually-Correct Soft Shadows**
  - Shadows harden on contact
  - Aliasing is hidden
Features

- Perceptually-correct soft shadows (good visual cues)
- Artifacts vary smoothly (no popping)
- Benefits from shadow mapping features
  - Independent of geometric complexity
  - Works with alpha testing, displacement mapping, etc…
- Integrates easily
  - Single floating-point shadow map and one shader
  - No special steps, preprocessing, etc…
Ordinary Shadow Mapping
Percentage-Closer Filtering

Extension to shadow mapping
How Percentage-Closer Filtering (PCF) works:

Pixel to be shaded:

Typical Shadow Map Test:

Shaded Pixel (Black or White):

4-Sample PCF:

Perform 4 Depth Tests:

Shaded Pixel (0, 0.25, 0.50, 0.75, 1.0)
Basic Idea

Soften shadows by varying PCF kernel width

Small Kernel (Narrow Filter)  Large Kernel (Wide Filter)
Penumbra Estimation

- Vary amount of softening
  - Based on penumbra size

- Penumbra size estimate based on:
  - Blocker depth
  - Receiver depth
  - Light size
“Blockers” and “Receivers”
Penumbra Size Estimation

\[ w_{Penumbra} = \frac{(d_{Receiver} - d_{Blocker}) \cdot w_{Light}}{d_{Blocker}} \]

- Assumes that blocker, receiver, and light are parallel
Penumbra Size Estimation

\[ w_{Penumbra} = \frac{(d_{Receiver} - d_{Blocker}) \cdot w_{Light}}{d_{Blocker}} \]

- We need:
  - Distance from blocker to light source
    - Don’t know this... yet.
  - Distance from receiver to light source
    - Depth of the point we’re shading
  - Light size
  - Uniform input to the shader
Main Algorithm

- Generate a shadow map (as usual)

- When shading each pixel on the screen:
  - Blocker Search
  - Penumbra Size Estimation
  - Variable Percentage-Closer Filtering
Blocker Search

- **Search region** depends on light size and distance to light
Blocker Search

- Iterate through all texels in **search region**
- Do something with the depth values…
What to do with Blockers?

- **Take minimum?**
  - Artifacts when transitioning between blockers

- **Need some kind of average**
  - Average all blockers (depth < receiver)
  - Flag the case if no blockers were found
    - Fully lit – no need to perform filtering
  - Gives good results
  - Further exploration in progress…
Penumbra Size Estimation

\[ w_{Penumbra} = \frac{(d_{Receiver} - d_{Blocker}) \cdot w_{Light}}{d_{Blocker}} \]

- We have:
  - Distance from blocker to light source
  - Result of blocker search
  - Distance from receiver to light source
  - Depth of the point we’re shading
  - Light size
  - Uniform input to the shader

- Estimate penumbra per pixel
  - Change PCF kernel based on the result
Variable Percentage-Closer Filtering

Use a flexible PCF kernel that can vary:
- Filter width
- Number of samples

Vary kernel parameters based on penumbra estimate
- Actually, projection of penumbra in screen space (but not yet implemented)
Demo

Observed current performance in FX Composer (on GeForce 6800 Ultra):

- ~20 fps @ 640 x 480
  - 64 blocker search samples
  - 144 PCF samples
  - Great results (see image)
    Especially with a texture!
- ~8 fps @ 640 x 480
  - 144 blocker search samples
  - 256 PCF samples
  - For high-quality screenshots
Improvements

**Performance**
- Need to implement early exit for PCF
  - Currently very wasteful (256 samples always!)
- No profiling/tuning done yet
- Mask out umbras and fully-lit regions

**Quality**
- Better blocker-search heuristics
- Better filtering to remove banding in large penumbras
Parting Thoughts

- Algorithm is completely encapsulated in one shader file for easy integration
- Try it out – please let us know what you find
- Tweak “Near Plane Factor” and “Shadow Map Bias” to match your scene
- Applications: DCC/CAD applications, pre-visualization, future games
- Improved version, video, and slides on the way…
Suggestions/Questions Welcome

Lots of relevant references in:

Slides and code on
The Source for GPU Programming

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Thanks to Kevin Bjorke, whose basic PCF shader I based this work on.

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