Percentage-Closer Soft Shadows

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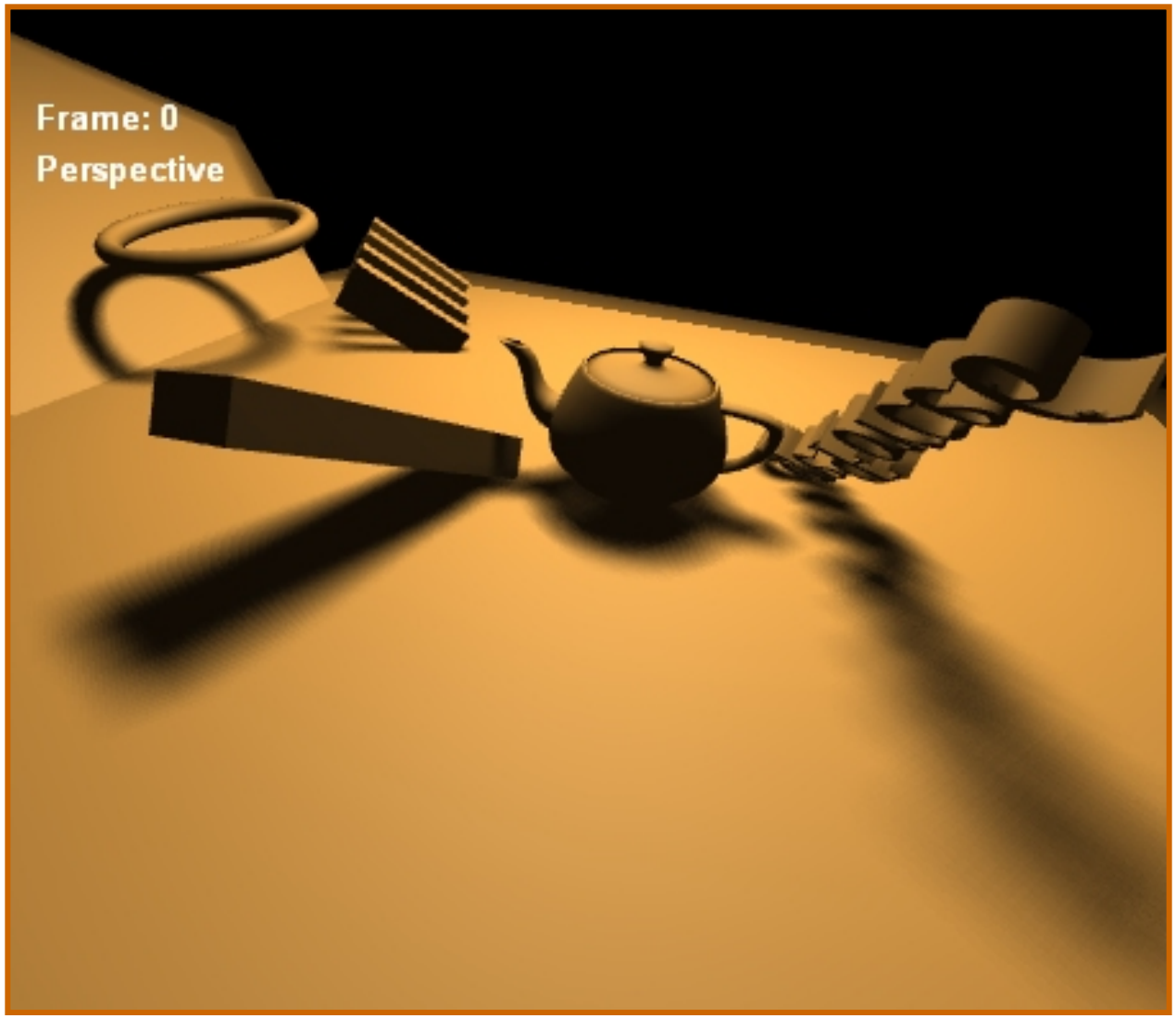
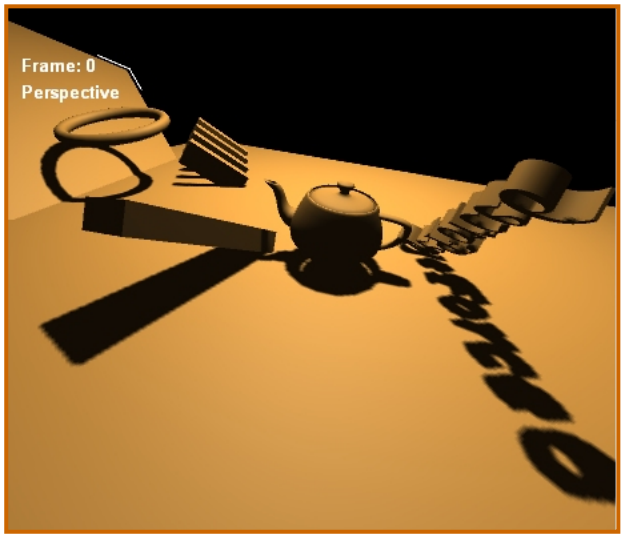
Demo

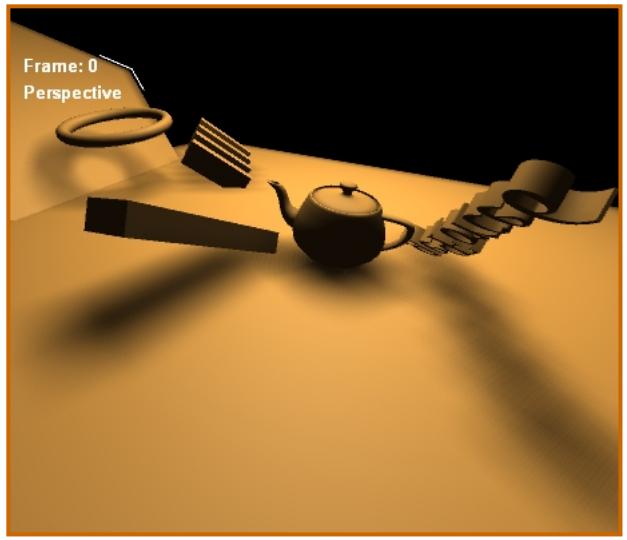


Algorithm Comparison



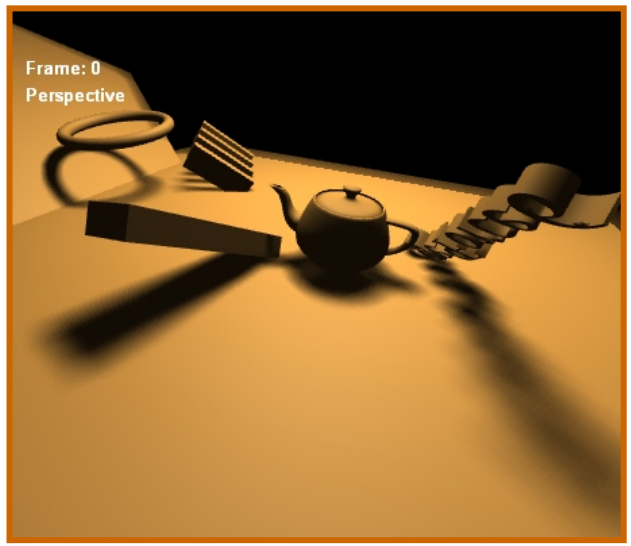
Regular Shadow Maps

- Always hard
- Noticeable Aliasing



Uniform Soft Shadows

- Always soft
- Aliasing is hidden



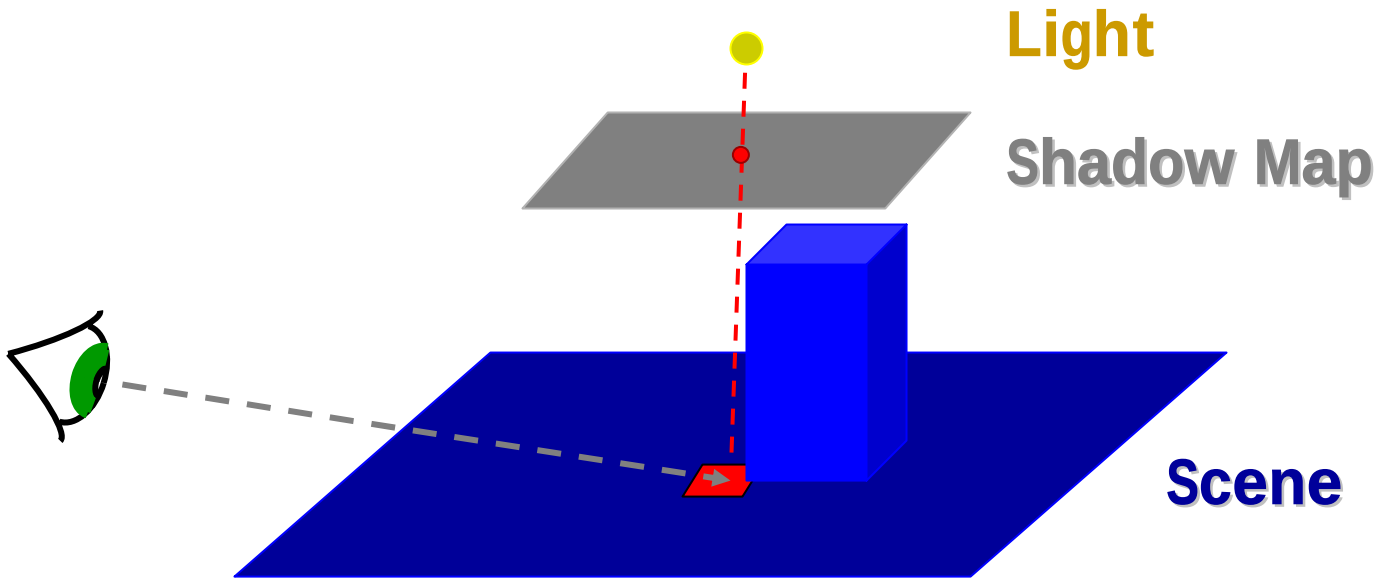
Percentage-Closer Soft Shadows

- Shadows harden on contact
- Aliasing is hidden

Features

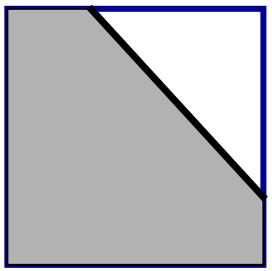
- Perceptually-correct soft shadows (good visual cues)
- Artifacts vary smoothly (no popping)
- Benefits from shadow mapping features
  - Independent of geometric complexity
  - Works with alpha testing, displacement mapping, etc…
- Integrates easily
  - Single floating-point shadow map and one shader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

Ordinary Shadow Mapping

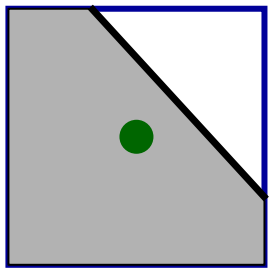


Percentage-Closer Filtering

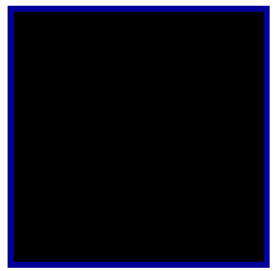
- **Extension to shadow mapping**
- **How Percentage-Closer Filtering (PCF) works:**



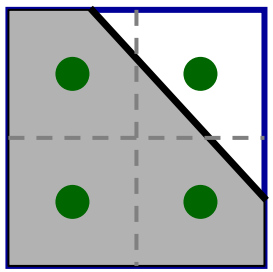
Pixel to be Shaded



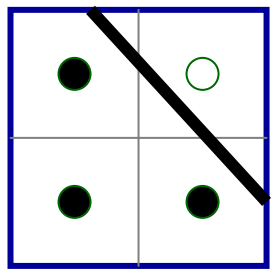
Typical Shadow Map Test



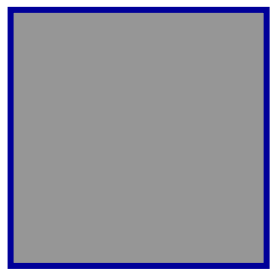
Shaded Pixel (Black or White)



4-Sample PCF



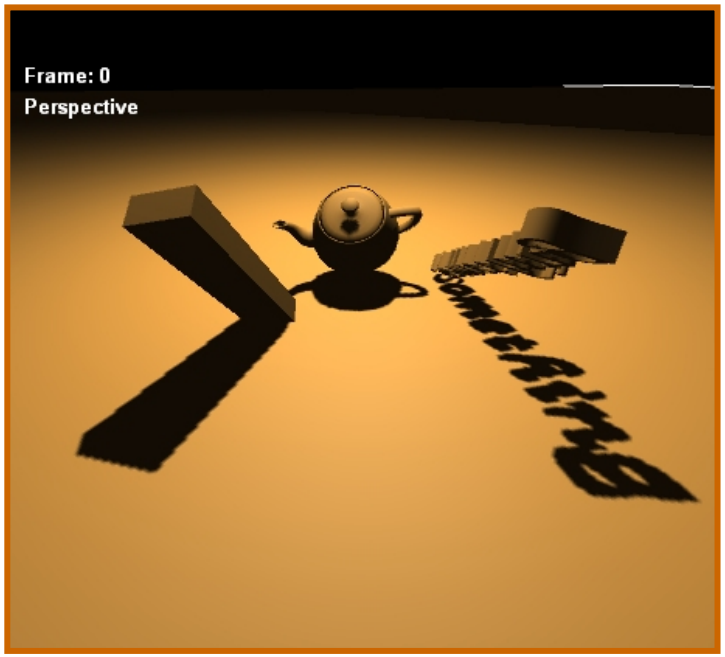
Perform 4 Depth Tests

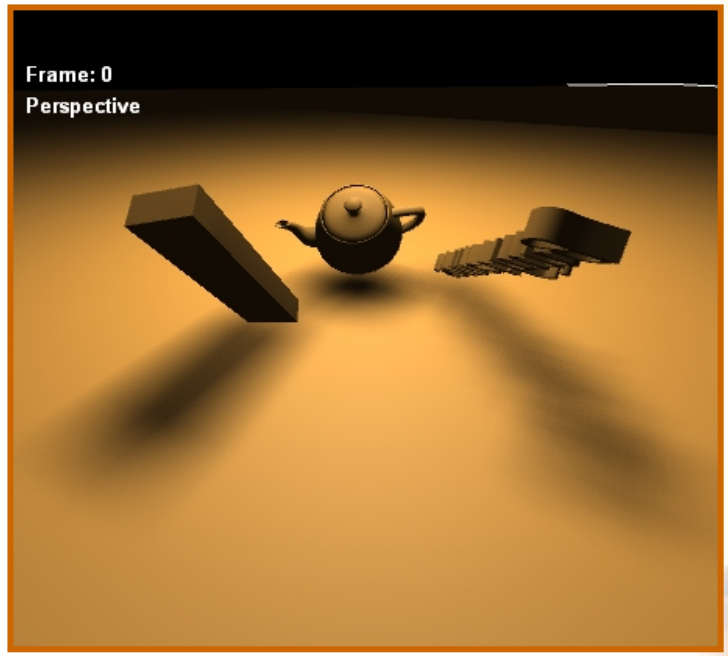


Shaded Pixel (0, 0.25, 0.50, 0.75, 1.0)

Basic Idea

- Soften shadows by varying PCF kernel width





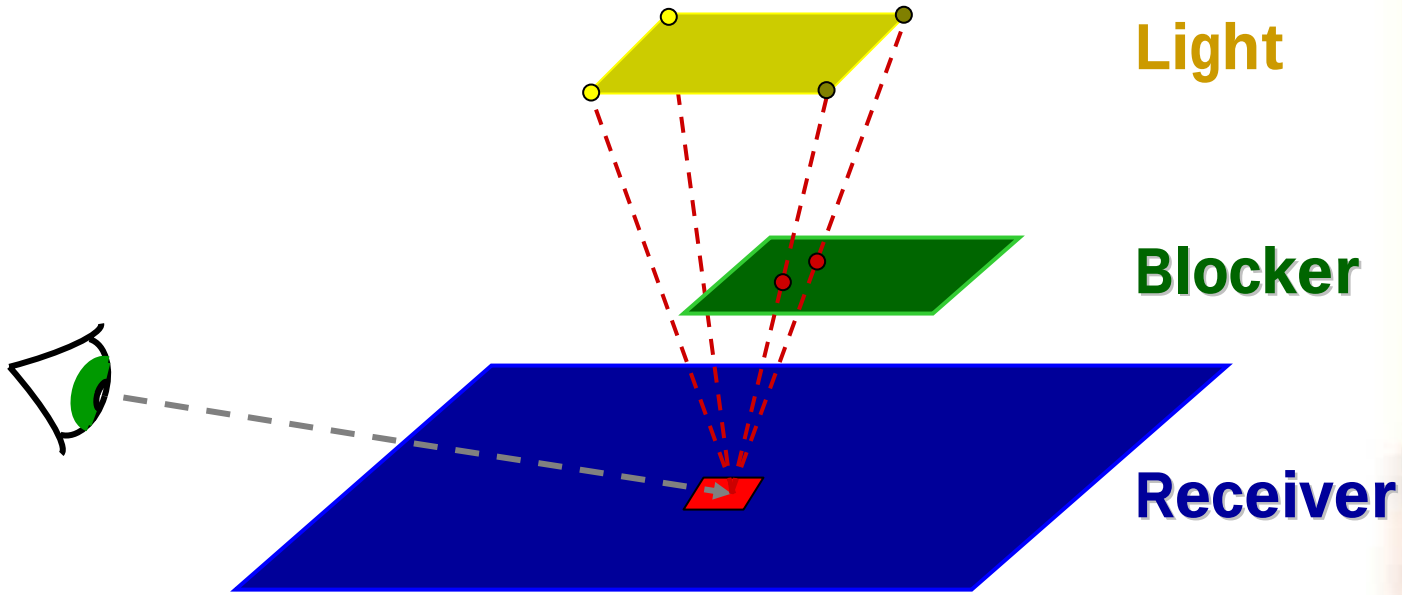
Small Kernel
(Narrow Filter)

Large Kernel
(Wide Filter)

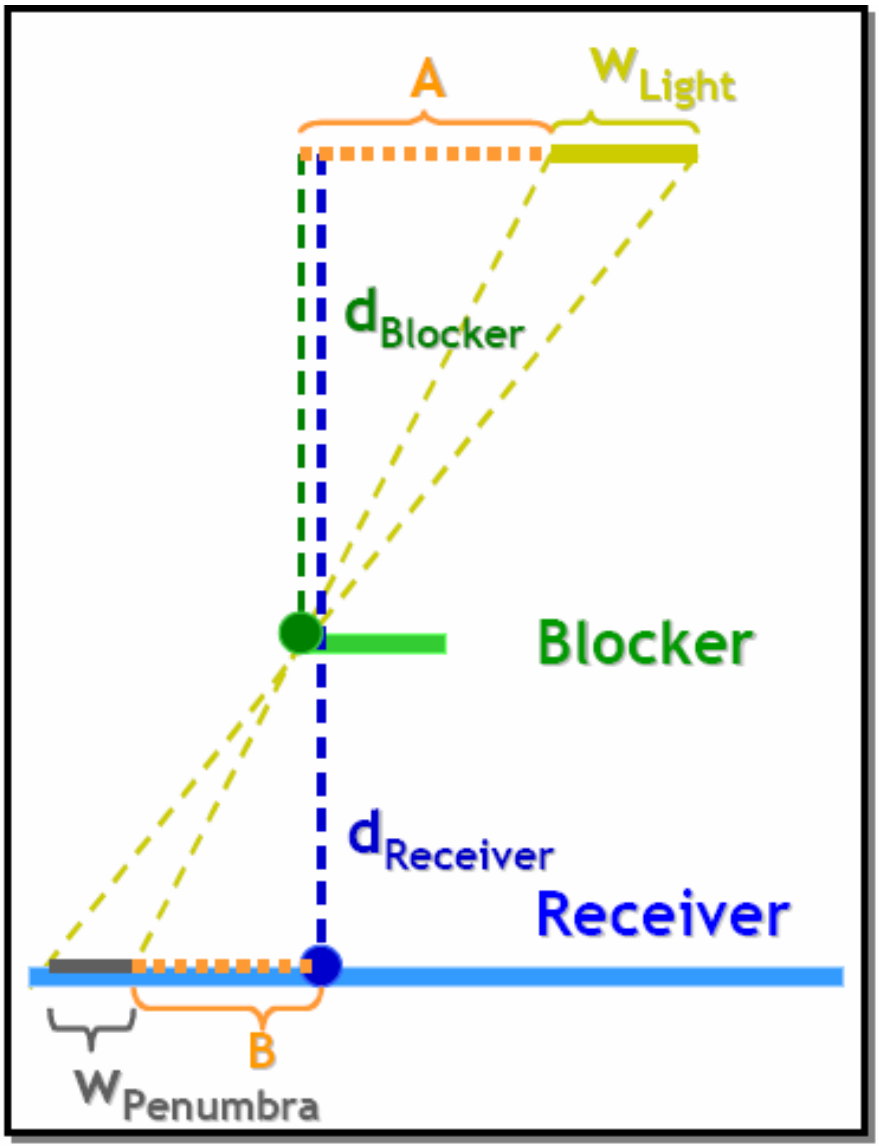
Penumbra Estimation

- **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

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

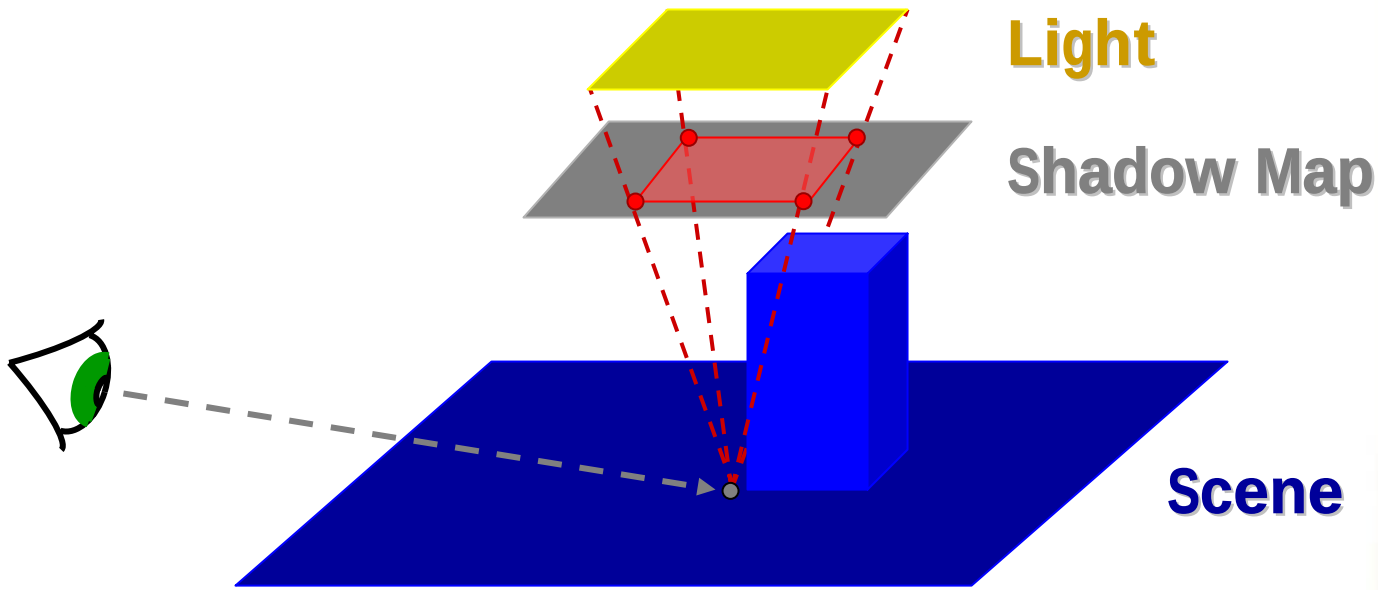
- **We need:**
  - **Distance from blocker to light source**
    - **Don't know this… yet.**
  - **Distance from receiver to light source**
    - **Depth of the point we're shading**
  - **Light size**
    - **Uniform input to the shader**

Main Algorithm

- Generate a shadow map (as usual)
- When shading each pixel on the screen:
  - Blocker Search
  - Penumbra Size Estimation
  - Variable Percentage-Closer Filtering

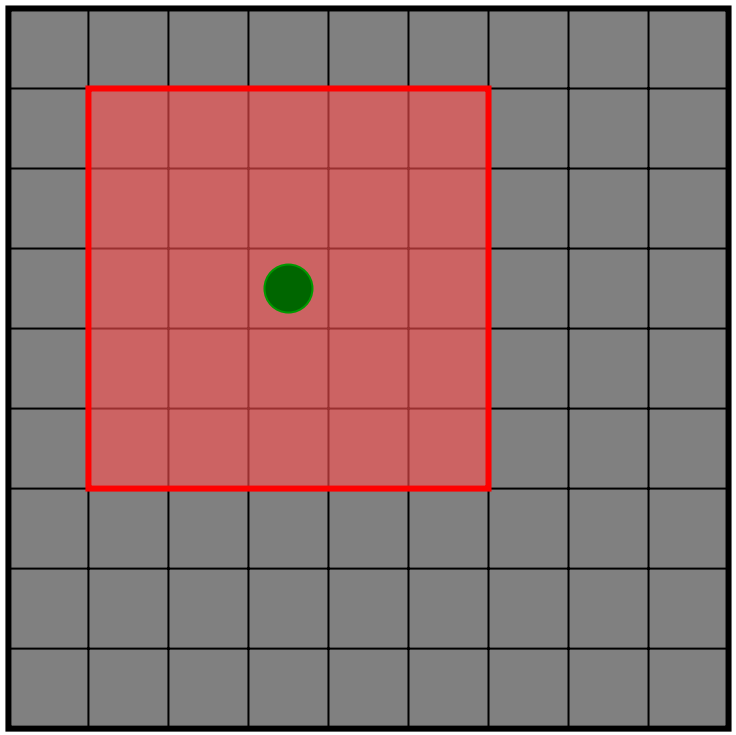
Blocker Search

- **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...



Shadow Map

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

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

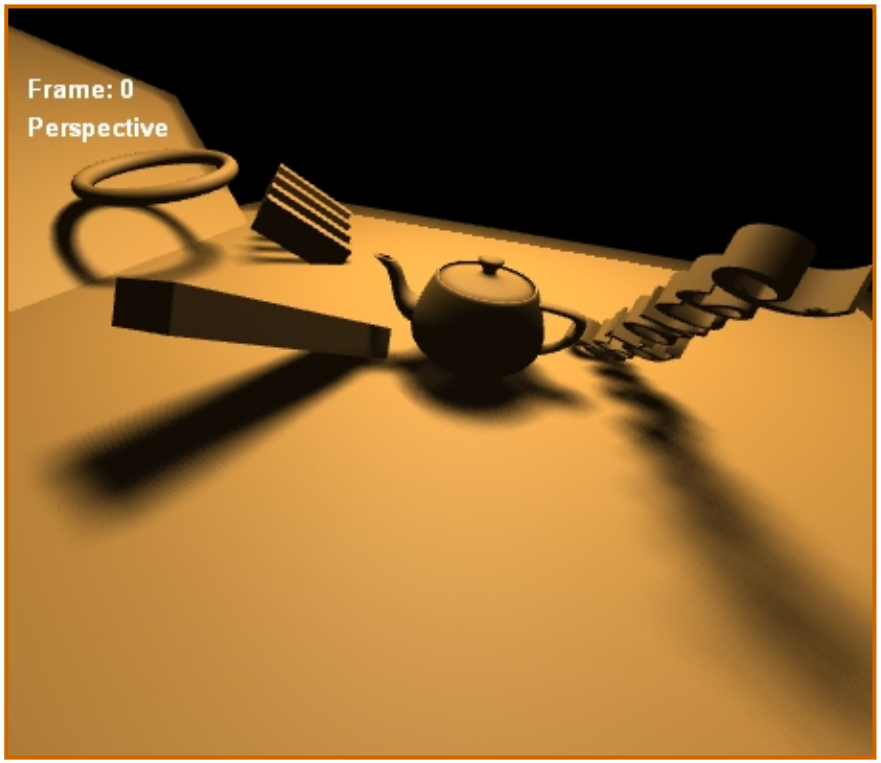
- **We have:**
  - **Distance from blocker to light source**
    - **Result of blocker search**
  - **Distance from receiver to light source**
    - **Depth of the point we're shading**
  - **Light size**
    - **Uniform input to the shader**
- **Estimate penumbra per pixel**
  - **Change PCF kernel 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:**
  - **~8 fps @ 640 x 480 in FX Composer**
  - **GeForce 6800 Ultra**



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:
  - http://www.randima.com/MastersThesis.pdf
- Slides and code on
  http://developer.nvidia.com
  The Source for GPU Programming
- E-mail: rfernando@nvidia.com
- Thanks to Kevin Bjorke, whose basic PCF shader I based this work on.
- Thanks to Chris Maughan and FX Composer for making shader development so easy.

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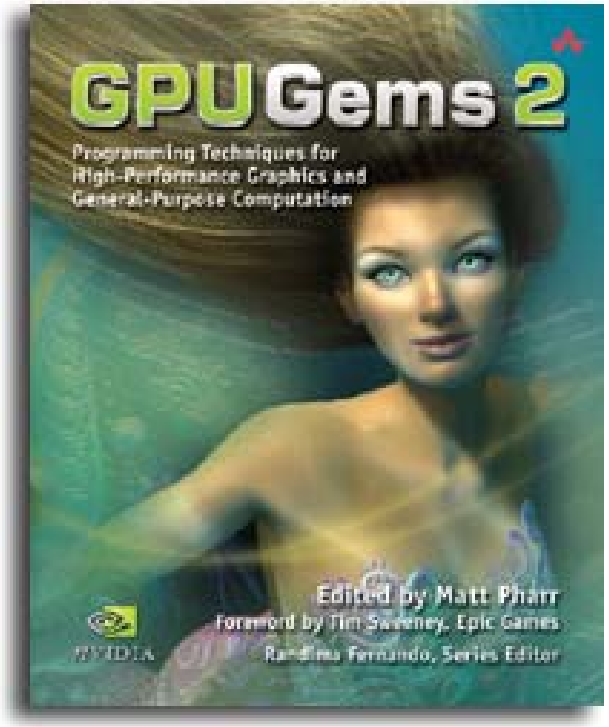

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