Percentage-Closer Soft Shadows

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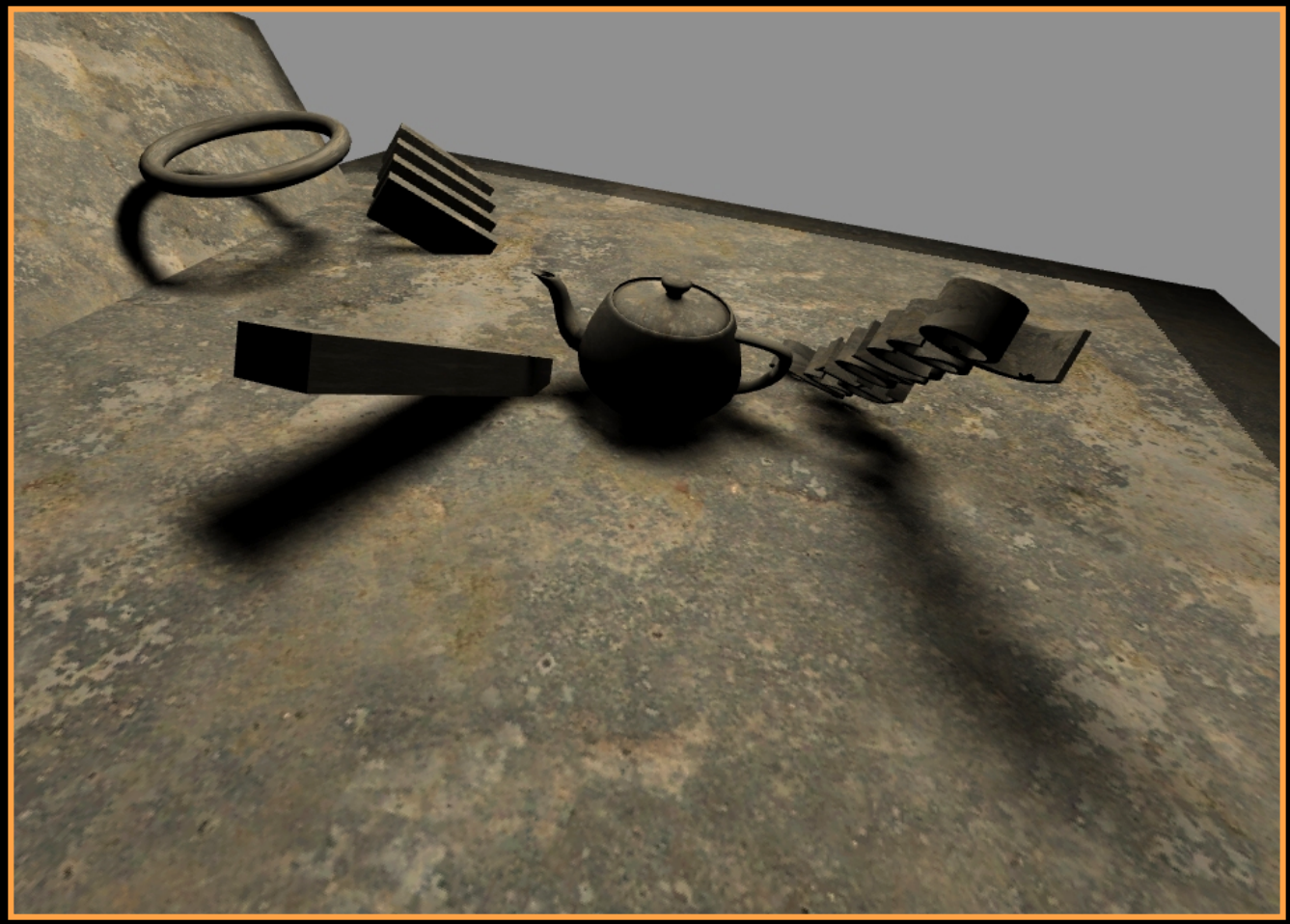
Demo



Recorded in Real Time on a GeForce 7800 GTX

Previous Work

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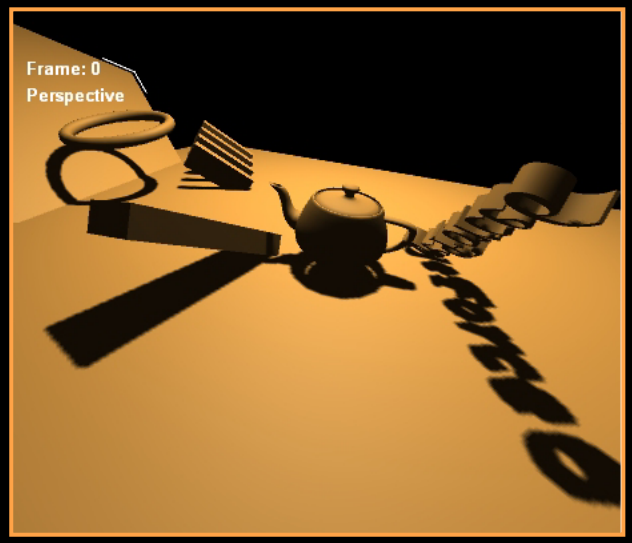
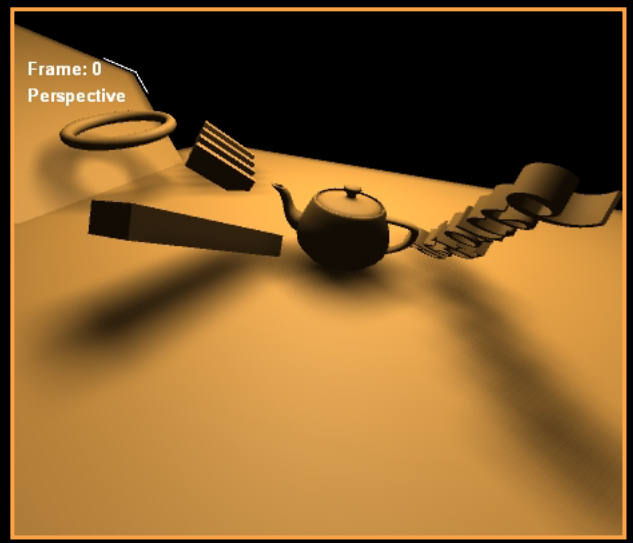
- Fundamentally based on [Williams1978] and [Reeves1987]
- Lots of previous work in this area
- Recent survey of real-time algorithms:
  - http://artis.inrialpes.fr/Publications/2003/HLHS03a/
- Related background and references in:
  - http://www.randima.com/MastersThesis.pdf

Algorithm Comparison



Regular Shadow Maps

- Always hard
- Noticeable Aliasing



Uniform Soft Shadows

- Always soft
- Aliasing is hidden

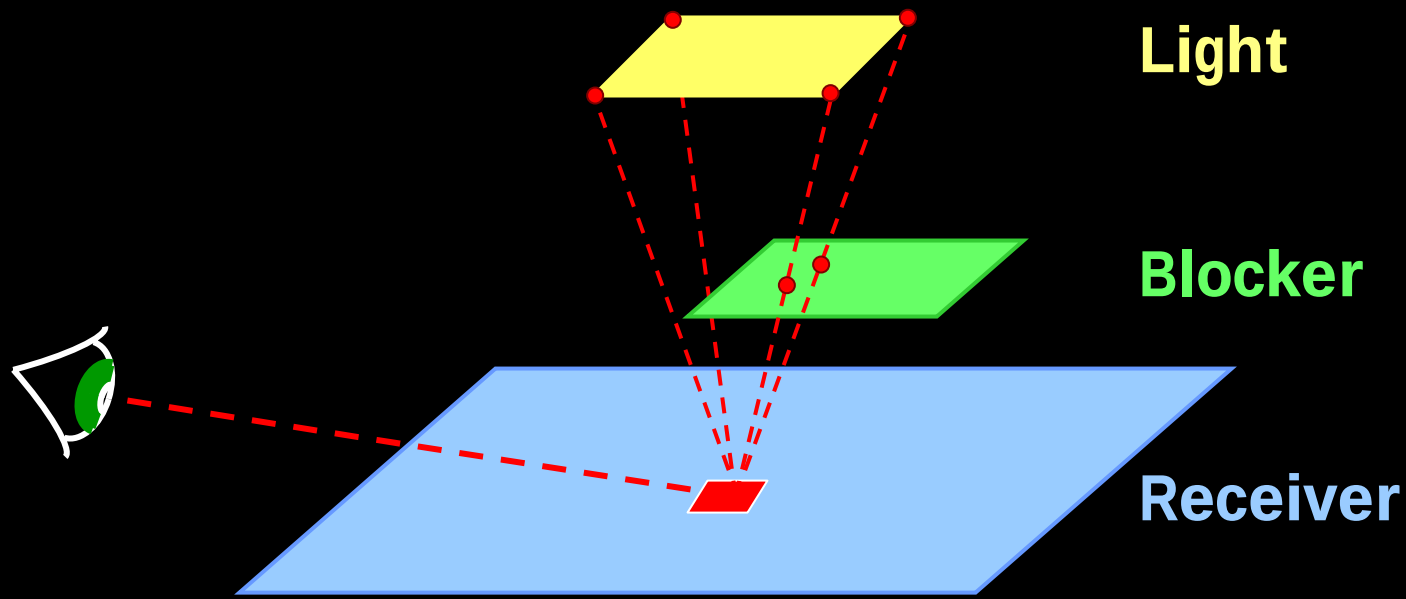
Perceptually-Correct Soft Shadows

- Shadows harden on contact
- Aliasing is hidden

Features

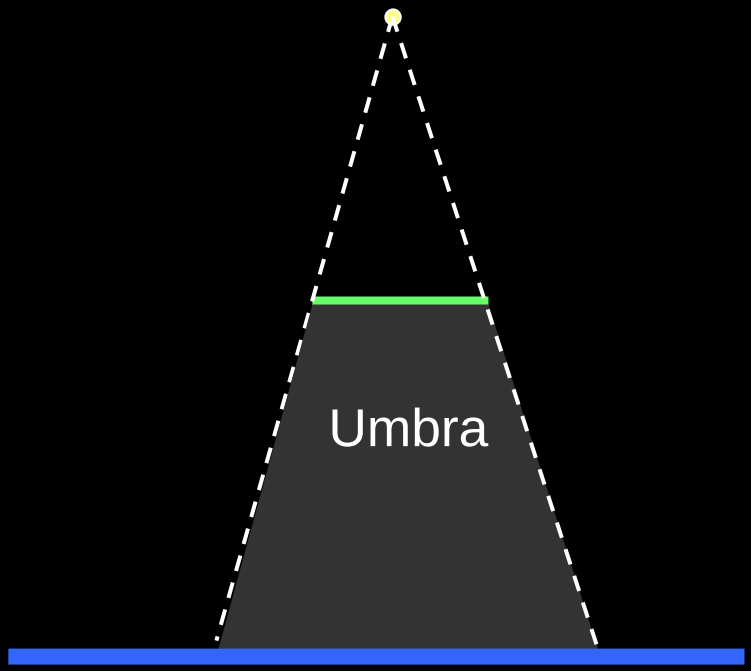
- Perceptually-correct soft shadows (good visual cues)
- Runs at real-time rates
- Artifacts vary smoothly (no popping)
- Benefits from shadow mapping features
  - Independent of geometric complexity
  - Works with alpha testing, displacement mapping, etc…
- Integrates easily
  - Single floating-point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

A Simple Scene

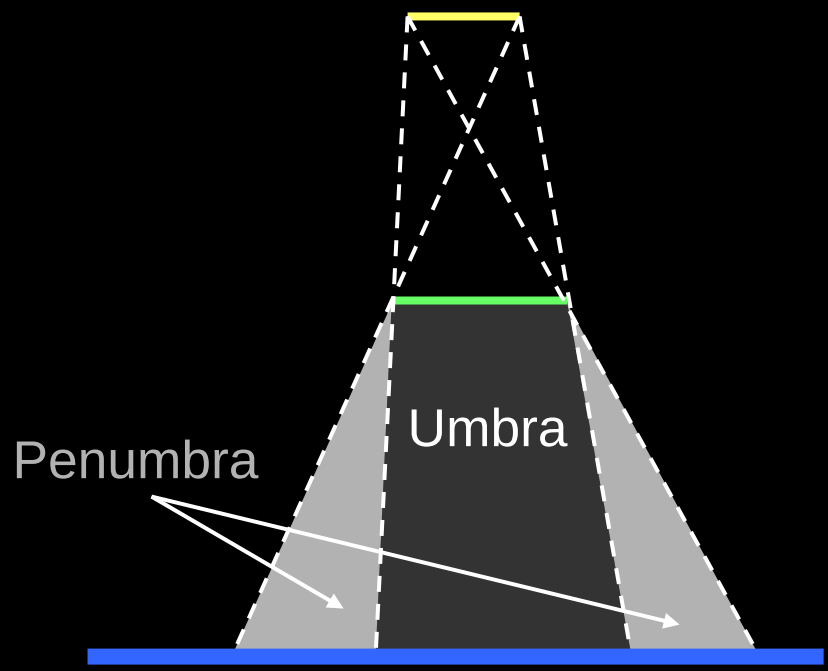


Point Light vs. Area Light

SIGGRAPH2005



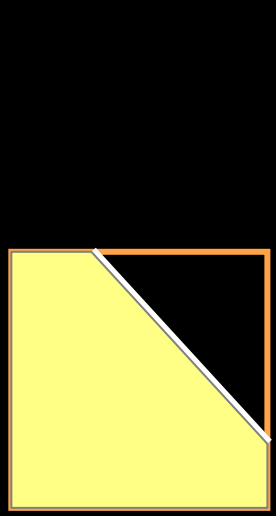
Point Light



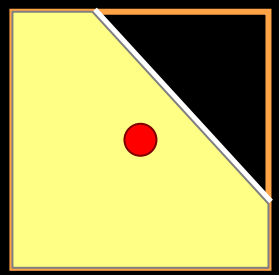
Area Light

Percentage-Closer Filtering

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

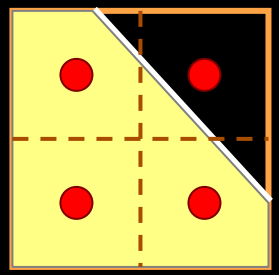


Pixel to be Shaded

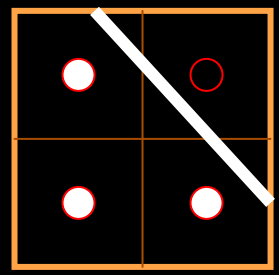


Typical Shadow Map Test

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

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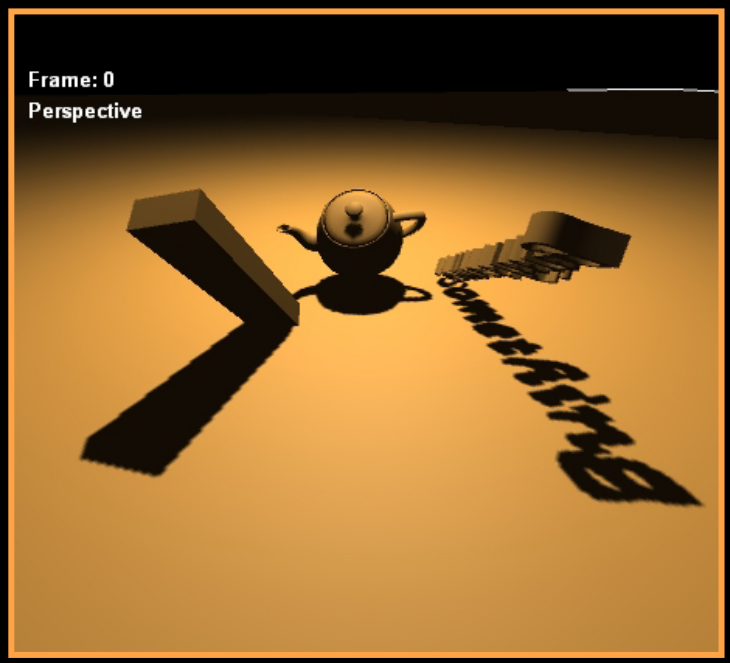
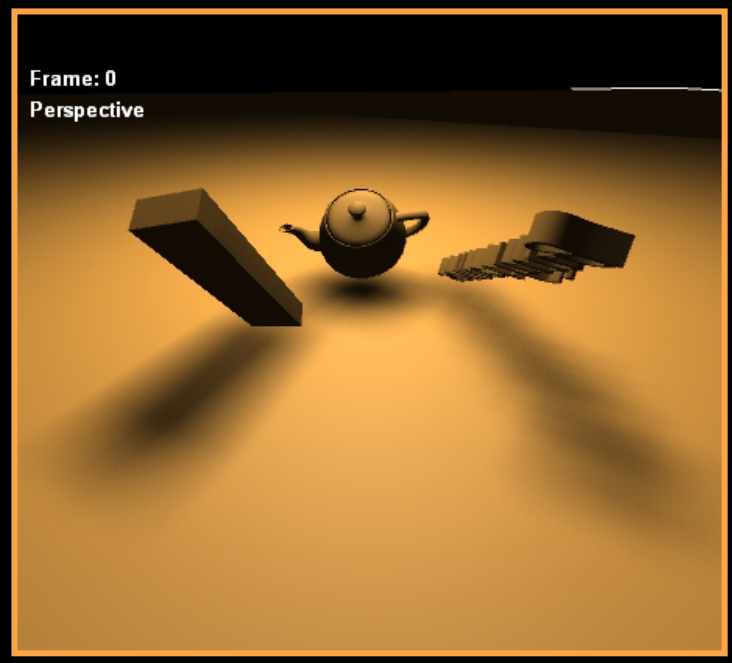
- Control shadow softness with PCF kernel width



Small Kernel
(Narrow Filter)

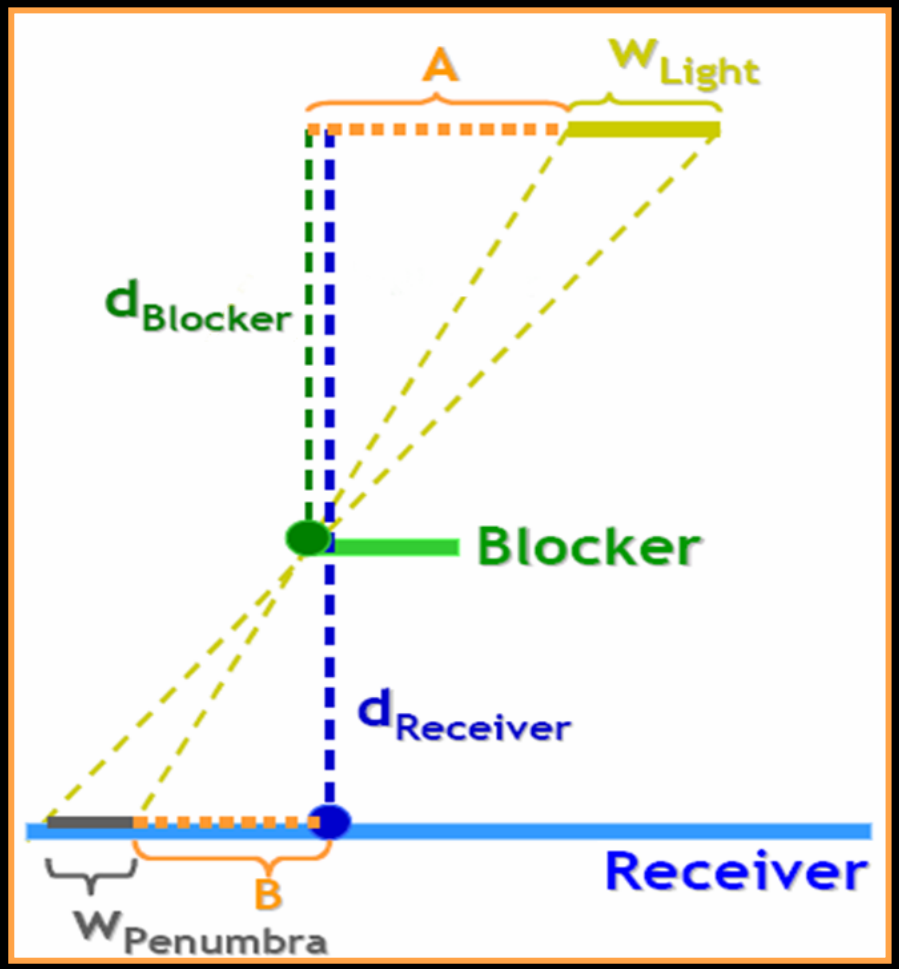


Large Kernel
(Wide Filter)

Penumbra Estimation

- Vary amount of softening
  - Based on penumbra size
- Penumbra size estimate based on:
  - Blocker depth
  - Receiver depth
  - Light size

Penumbra Size Estimation



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

- Equation comes from similar triangles
- 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 receiver to light source
    - ✓ Depth of the point we're shading
  - Light size
    - ✓ Uniform input to the shader
  - Distance from blocker to light source
    - × **Don't know this… yet.**

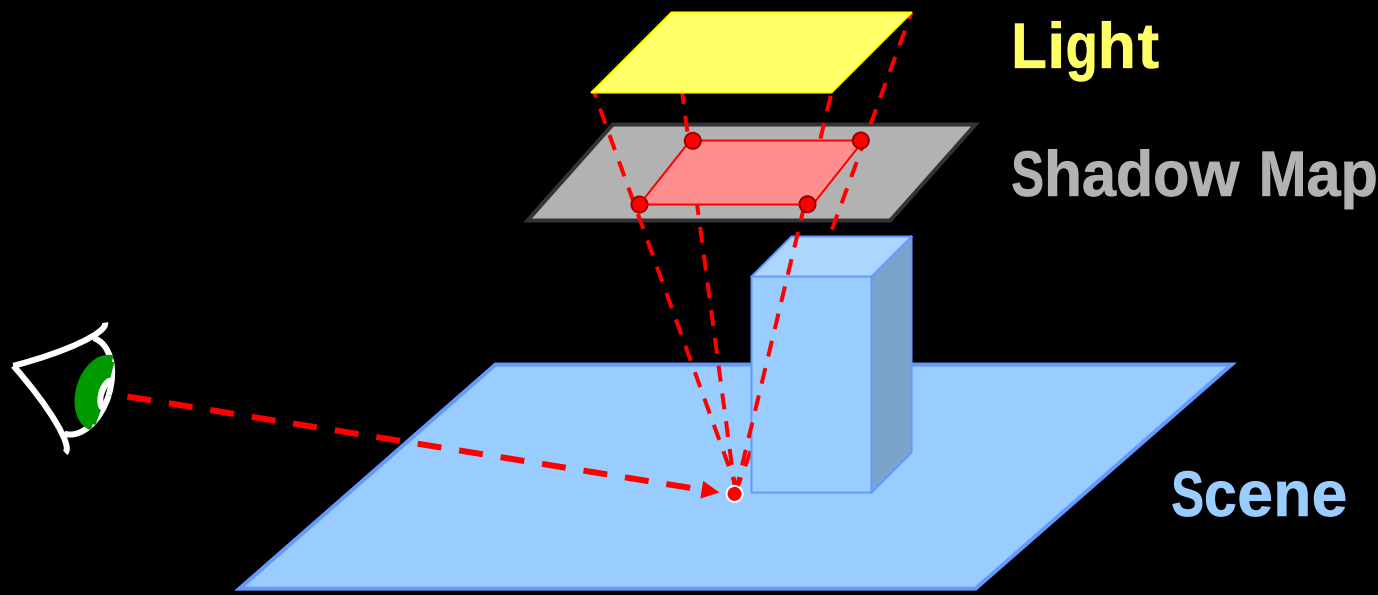
Main Algorithm

- Generate a shadow map from center of light source (as usual)

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

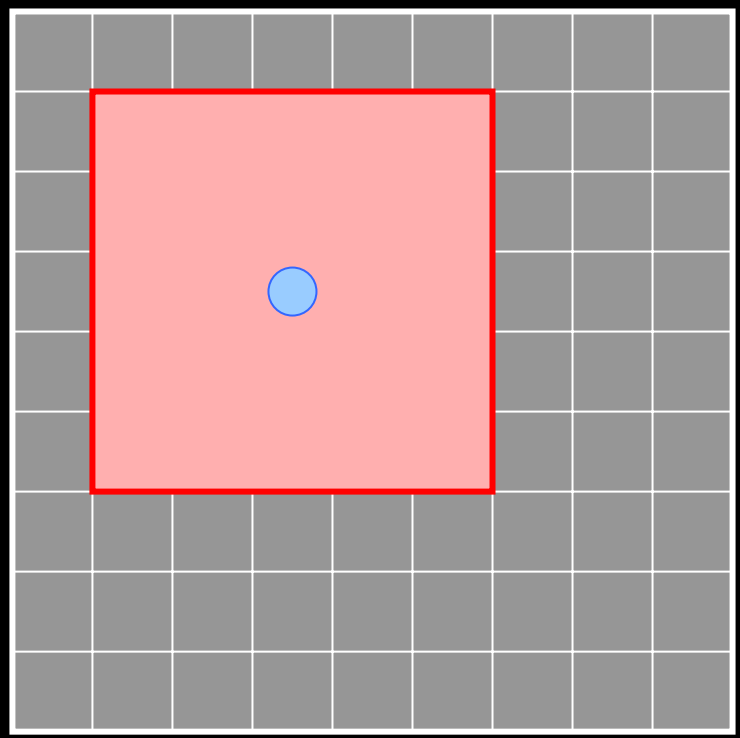
Blocker Search

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



Blocker Search

- Sample the texels in the **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

Penumbra Size Estimation

- We now have what we need:
  - Distance from receiver to light source
    - ✓ Depth of the point we're shading
  - Light size
    - ✓ Uniform input to the shader
  - Distance from blocker to light source
    - ✓ Result of blocker search
- Estimate penumbra per pixel:

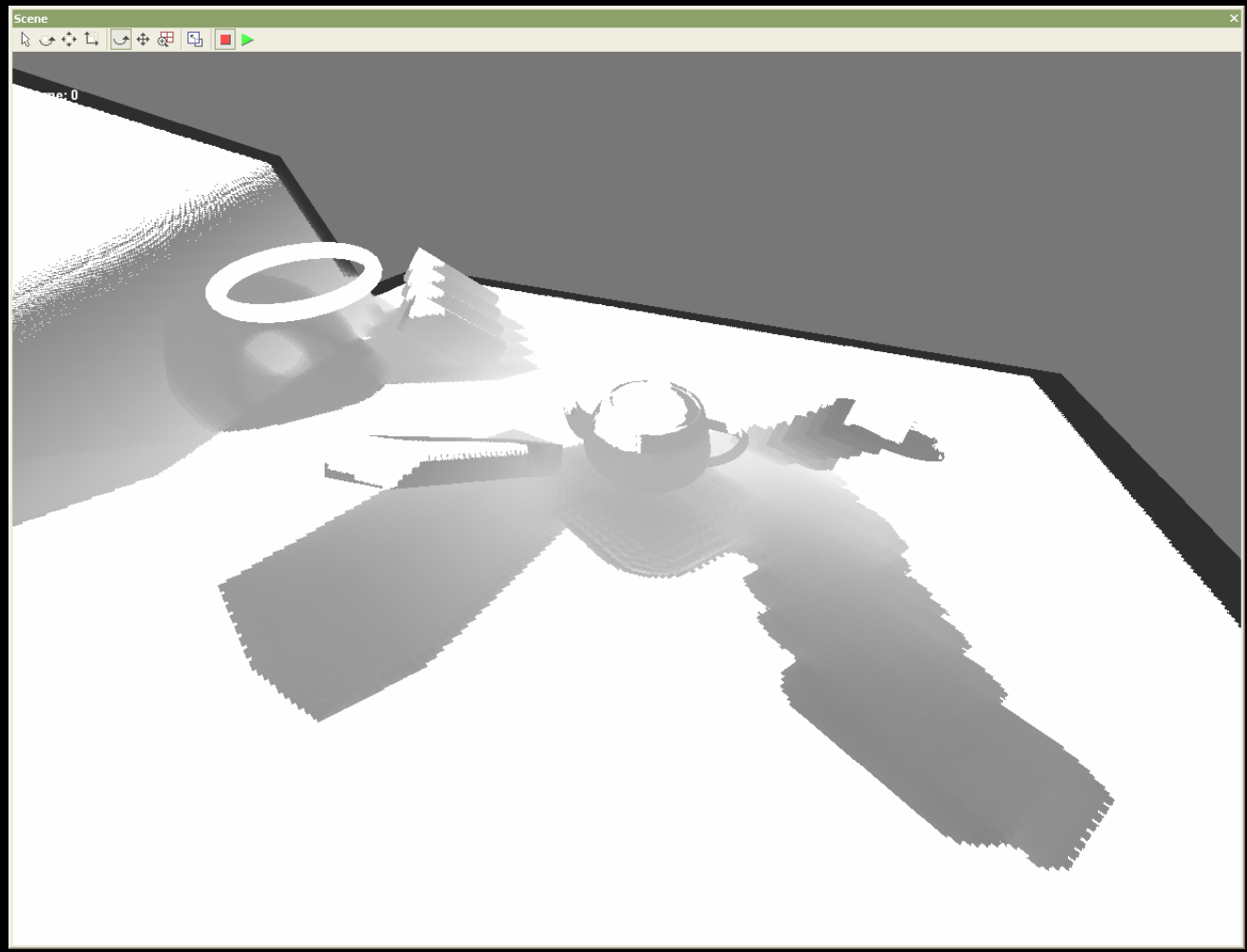
$$w_{Penumbra} = \frac{(d_{Receiver} - d_{Blocker}) \cdot w_{Light}}{d_{Blocker}}$$

- Change PCF kernel based on the result

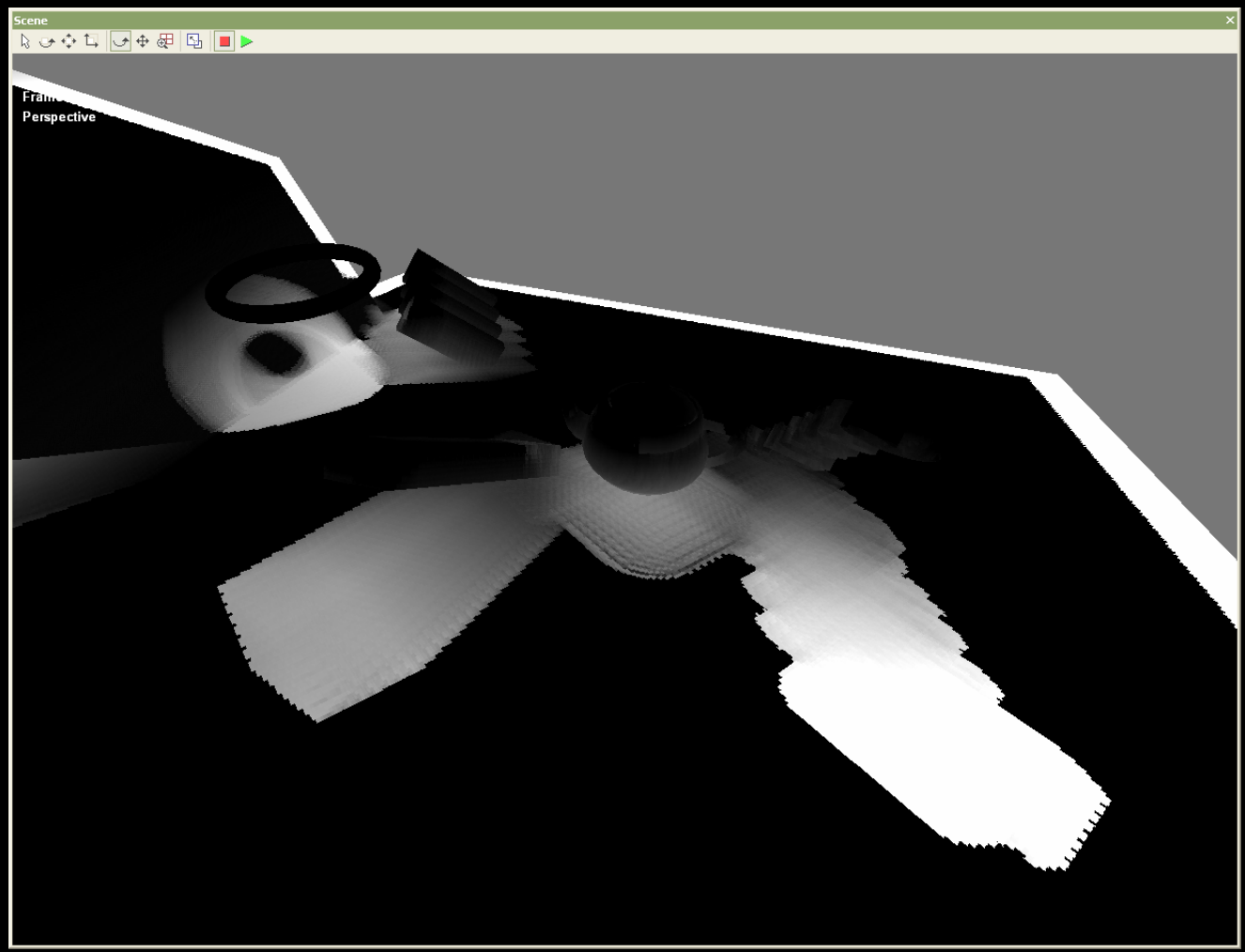
Variable PCF

- 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)

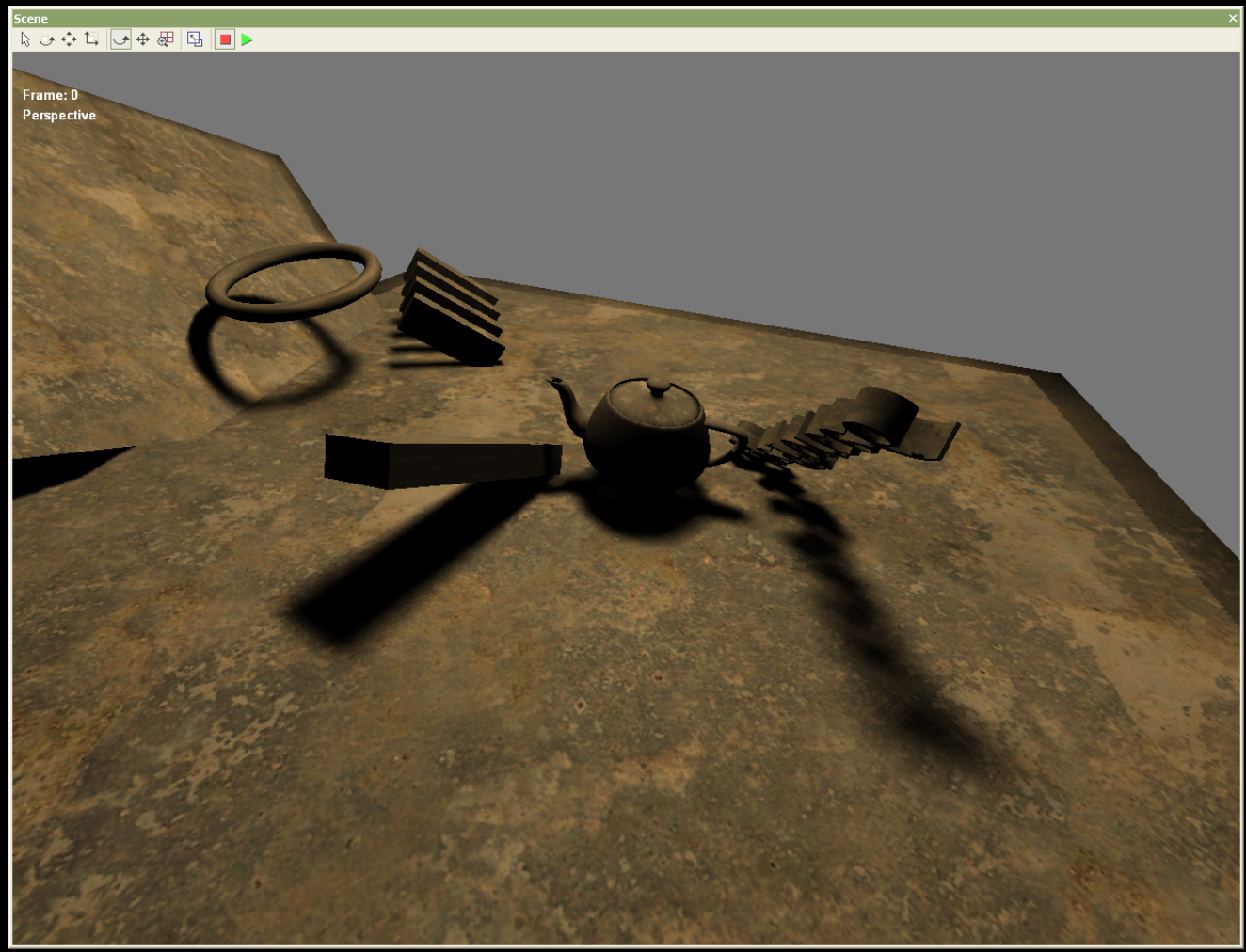
Blocker Search Results



Penumbra Estimates



After Percentage-Closer Filtering



Performance

- Up to **191 fps @ 640 x 480** in a standalone application
- **<10%** hit to add 4xAA, 8xAF on GeForce 7800 GTX

# SAMPLES						FPS	6800	7800 GTX	7800 GTX SLI
Search		PCF		Total			12 pipes	24 pipes	48 pipes
36	+	36	=	72			49	104	191
36	+	64	=	100			35	75	141
36	+	256	=	292			13	31	60

- **292 texture fetches/pixel = ~900 cycles/pixel = 60 fps!**

Performance Characteristics

- Scales very well with number of pipes
- Each blocker search sample is ~30% more expensive than each PCF sample
- 36 search samples works well for most scenes
- 64 PCF samples works great with a reasonably complex texture

Performance Improvements

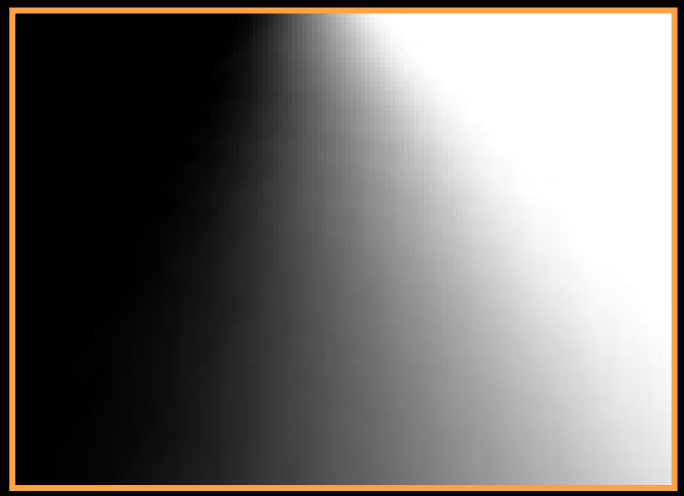
- Mask out umbras and fully-lit regions
  - Pass 1: Estimate penumbras
  - Pass 2: Perform PCF only where penumbra exists
- Vectorize
  - Much of the code is very scalar
  - Can try to work on 4 texels simultaneously
- Profiling/tuning

Quality Improvements

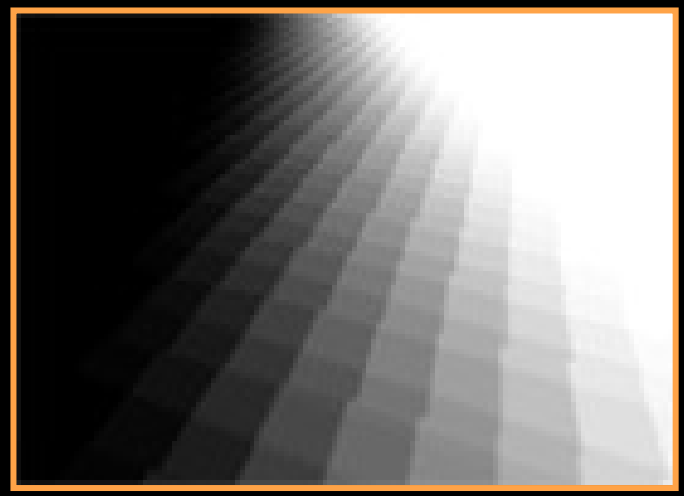
- Better blocker search heuristics
  - 5 shadow maps (4 corners + center of light)
  - Estimate penumbra using all five
  - Filter using center shadow map only
- Better filtering to remove banding in large penumbras
  - Add offset jitter for samples
  - Screen-space blur to save on PCF work
  - Combine filtering from several resolutions of shadow maps?

Quality Improvements

- Take advantage of NVIDIA's hardware PCF
  - 32-bit floating-point shadow map for analysis
  - 24-bit integer shadow map for filtering
  - Small performance hit for large quality improvement



With HW Filtering



Without HW Filtering

Parting Thoughts

- Algorithm is completely encapsulated in one shader file for easy integration
- Try it out – please let me know what you find
- Tweak "**Near Plane Distance**" (in world units) and "**Shadow Map Bias**" to match your scene
- Applications: DCC/CAD applications, pre-visualization, future games

Thanks to…

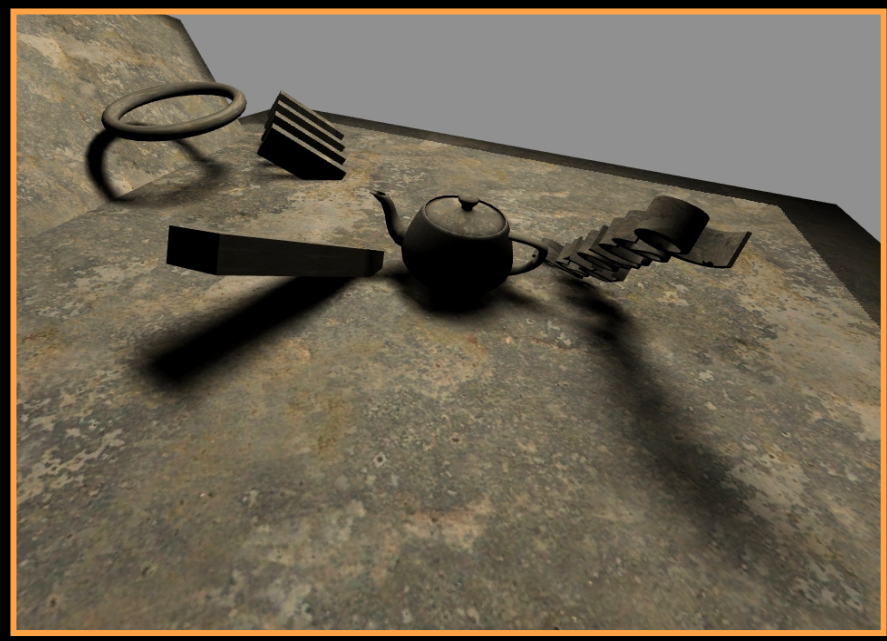
- Kevin Bjorke, whose basic PCF shader I started with
- Chris Maughan and the FX Composer team for making shader development so easy
- Various folks at NVIDIA, and especially Matthias Wloka, for comments and suggestions

Suggestions/Questions Welcome

- Slides, short whitepaper, code, and video for this FX Composer effect are in the NVIDIA SDK: http://download.developer.nvidia.com/developer/SDK/Individual_Samples/featured_effects.html#PCSS

- A standalone code sample is coming soon

- E-mail: RFernando@nvidia.com



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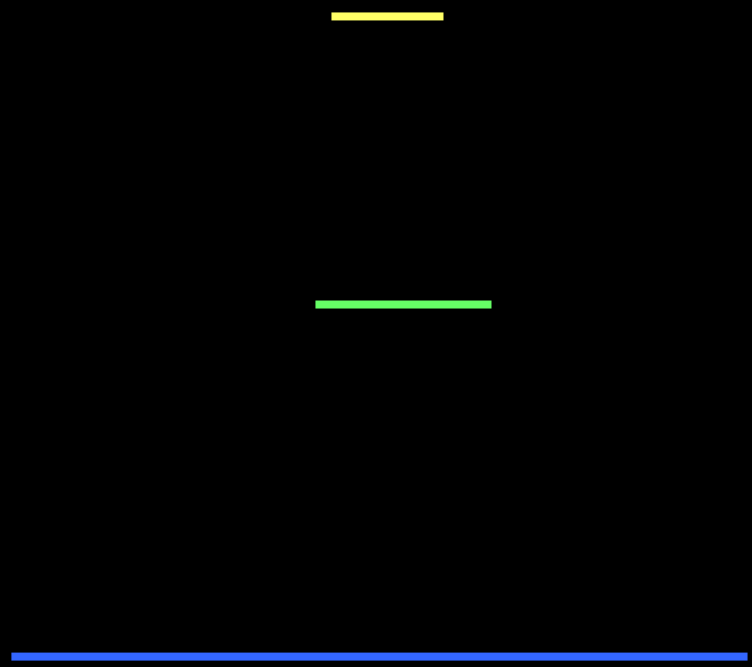
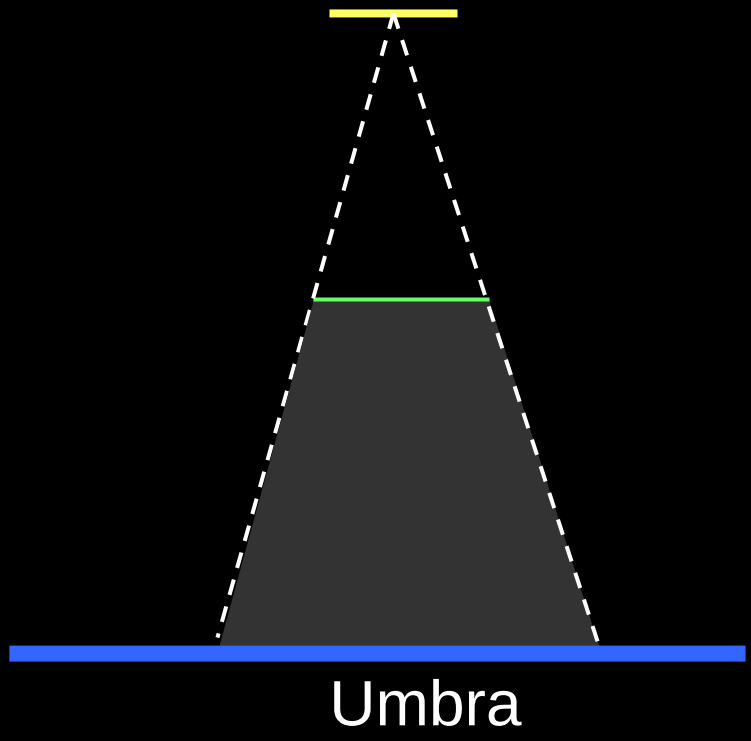
Extras

SIGGRAPH2005

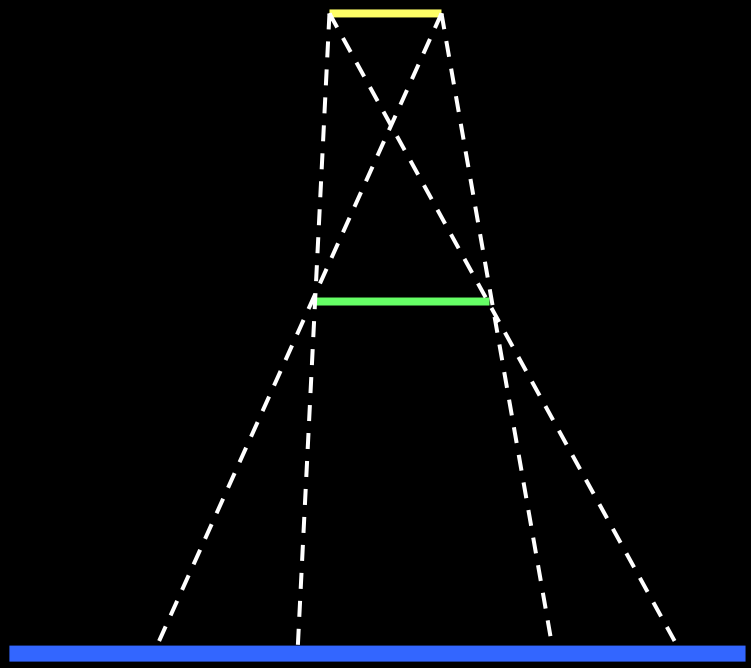
A Simple Scene



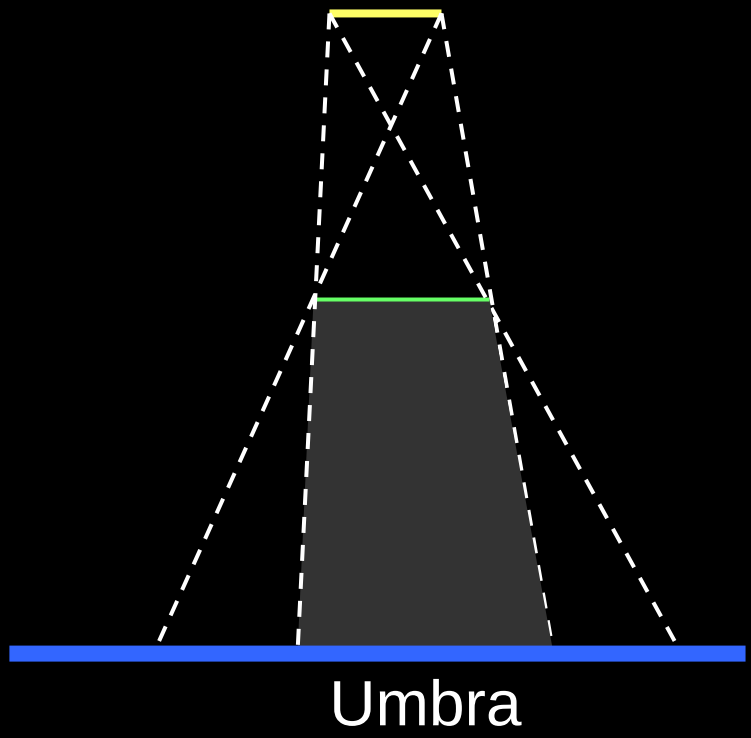
Shadows from a Point Light



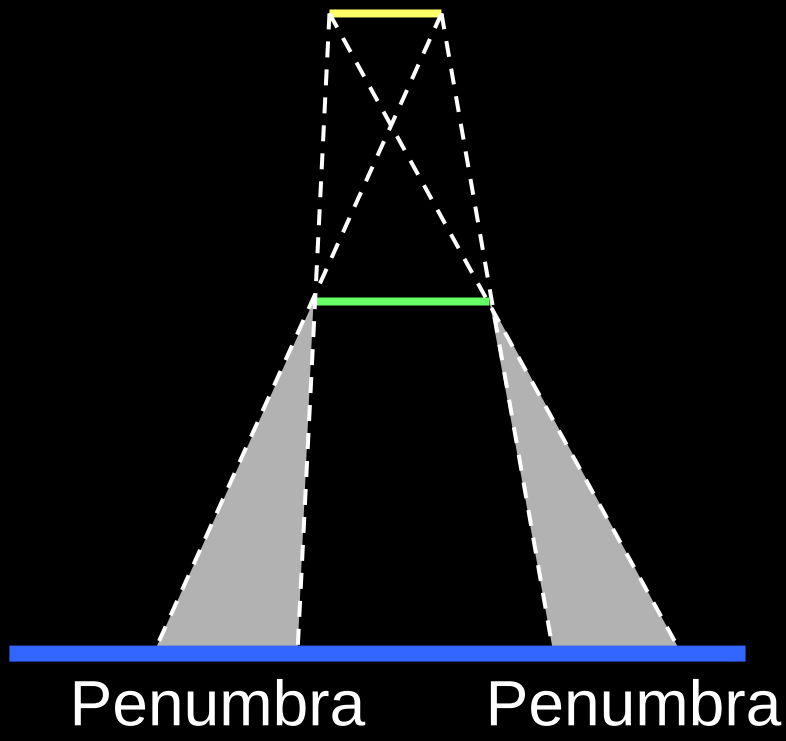
Shadows from an Area Light



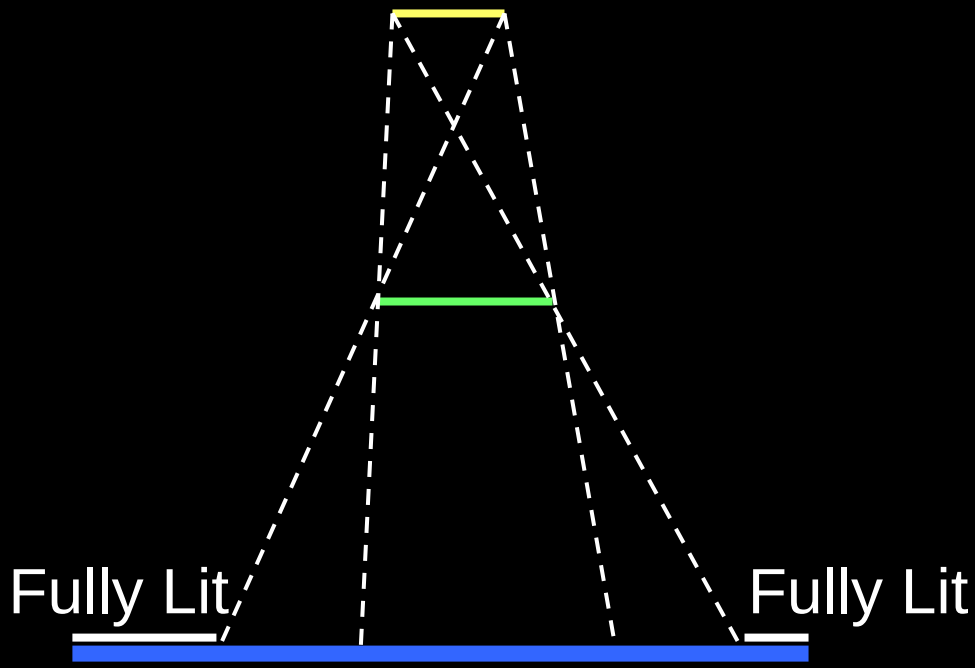
Shadows from an Area Light



Shadows from an Area Light



Shadows from an Area Light



Point Light vs. Area Light

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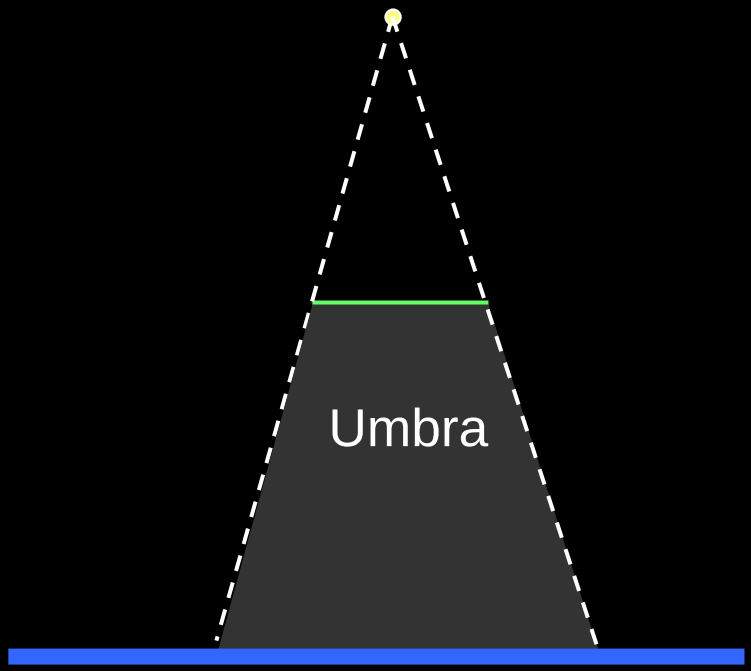
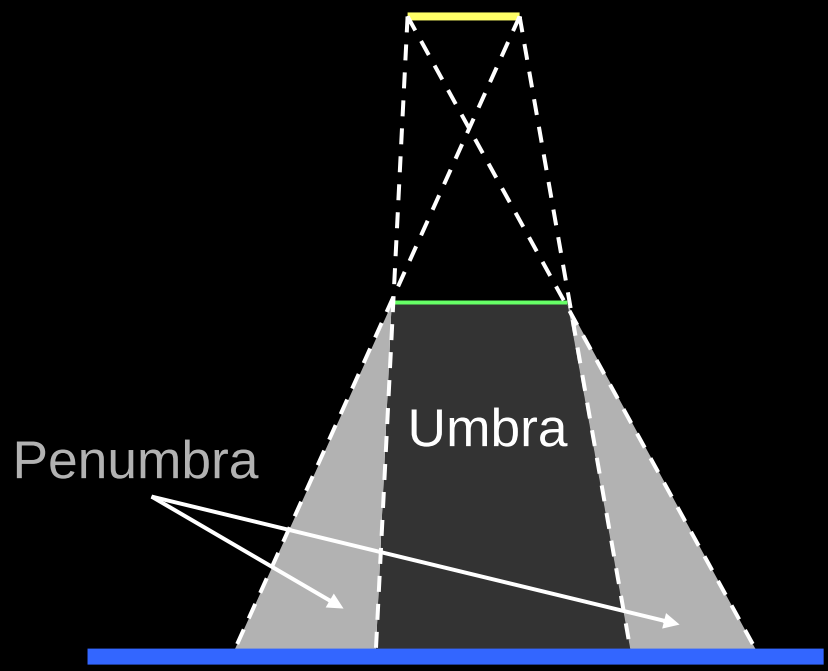


Point Light



Area Light