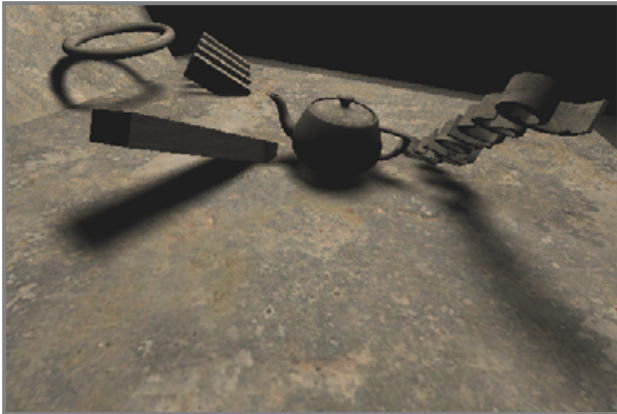


Percentage-Closer Soft Shadows

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1. Introduction

One of the fundamental problems in computer graphics is generating accurate soft shadows from area light sources. Soft shadows provide valuable cues about the relationships between objects, becoming sharper as objects contact each other and more blurry (softer) the further they are apart.



This sketch presents a new method, called Percentage-Closer Soft Shadows (PCSS), for generating perceptually accurate soft shadows. Based on shadow mapping [Williams 1978] and percentage-closer filtering (PCF) [Reeves et al. 1987], PCSS has these key characteristics:

- Generates perceptually accurate soft shadows
- Uses a single light source sample (one shadow map)
- Requires no pre-processing, post-processing, or additional geometry
- Seamlessly replaces a traditional shadow map query (embodies the same advantages as traditional shadow mapping— independent of scene complexity, works with alpha testing, displacement mapping, and so on)
- Runs in real-time on current consumer graphics hardware

This combination makes it uniquely suitable for a wide range of applications, from next-generation games to DCC/CAD applications. Because it uses just a single sample and requires no special processing steps, the technique easily replaces existing shadow mapping shader code in an application while producing much more compelling images. The only required change is to replace the typical shadow mapping pixel shader with a PCSS shader.

2. Previous Work

The history of shadow generation in computer graphics is vast and rich. A good survey of shadowing techniques can be found in [Hasenfratz 2003]. While many attempts to

generate soft shadows exist, none produce results as realistic as ours with the same features: ease of integration, robustness, and interactivity. Common failings include producing umbras that do not shrink as penumbras grow.

3. Percentage-Closer Soft Shadows

The PCSS technique builds on regular shadow mapping: when shading each pixel in the eye view, PCSS returns a floating-point value that indicates the amount of shadowing at each shaded point (replacing the traditional depth comparison of ordinary shadow mapping).

PCSS is based on the observation that as the size of the PCF kernel increases, the resulting shadows become softer. The challenge is to vary the filter size intelligently to achieve the correct degree of softness. To do this, the algorithm uses a three-step approach when shading each eye-view pixel:

Step 1: Blocker search. We search the shadow map and average the depths that are closer to the light source than to the point being shaded (the “receiver”). The size of the search region depends on the light size and the receiver’s distance from the light source.

Step 2: Penumbra estimation. Using a parallel planes approximation, we estimate the penumbra width based on the light size and blocker/receiver distances from the light:

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

Step 3: Filtering. Now we perform a typical PCF step on the shadow map using a kernel size proportional to the penumbra estimate from Step 2.

4. Results

A relatively unoptimized version of the technique runs in FX Composer at 21 fps on an NVIDIA GeForce Ultra at 640 x 480 with 64 samples used for the blocker search and for the PCF step. This gives excellent results, particularly for more realistic textured scenes, while maintaining a high degree of interactivity. The number of samples can be modified depending on the light size and desired quality.

5. References

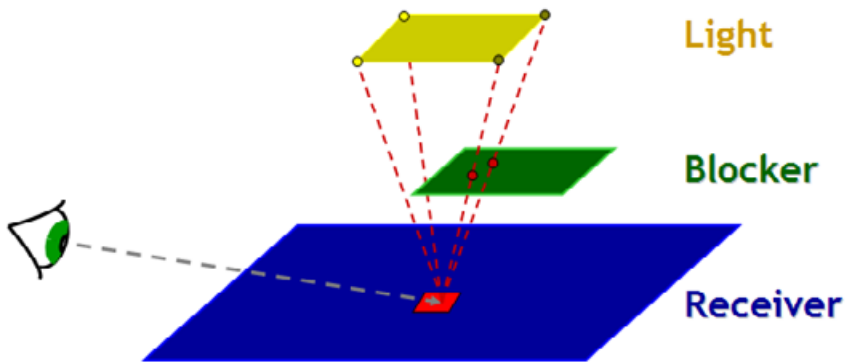
- HASENFRATZ, J., LAPIERRE, M., HOLZSCHUCH, N., AND SILLION, F. *A Survey of Real-Time Soft Shadow Algorithms*. Computer Graphics Forum, Vol. 22, No. 4 (December 2003)
- REEVES, W.T., SALESIN, D. H., AND COOK, R. I. *Rendering Antialiased Shadows with Depth Maps*. In Computer Graphics (SIGGRAPH 1987 Proceedings), pages 283-291, July 1987.
- WILLIAMS, L. *Casting Curved Shadows on Curved Surfaces*. In Computer Graphics (SIGGRAPH 1978 Proceedings), pages 270-274, August 1978.

Percentage-Closer Soft Shadows (Supplementary Material)

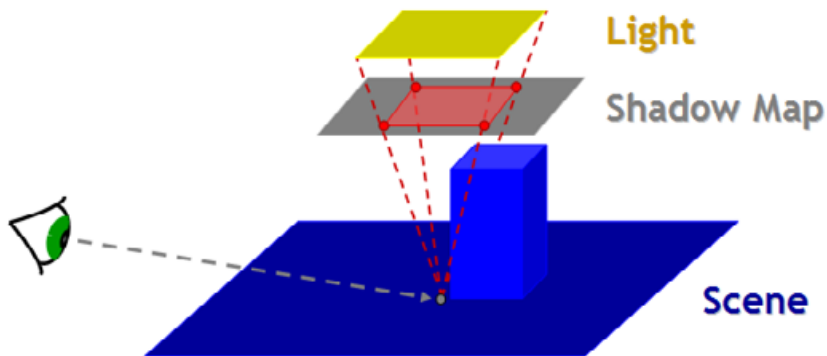
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Blocker Search Step

The following diagram illustrates the “blocker” and “receiver” terminology.

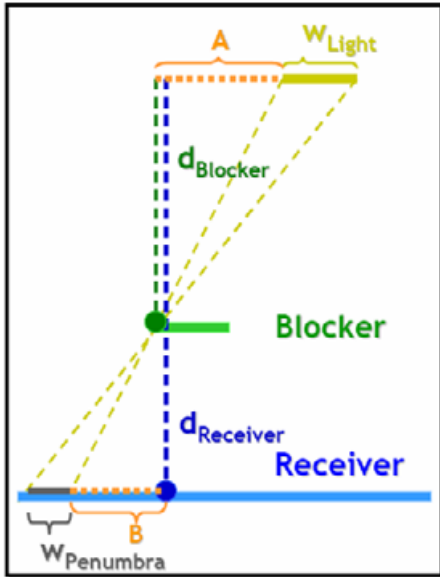


During the blocker search step, the PCSS algorithm searches a region of the shadow map (shown in red). During the search, it averages depth values that are closer to the light than the receiving point. This average depth value is used in the subsequent penumbra size estimation step.



Penumbra Size Estimation Step

The following diagram illustrates the geometry for estimating the penumbra size, assuming that the blocker, receiver, and light source are parallel. This assumption works very well in practice and could be relaxed as an improvement.

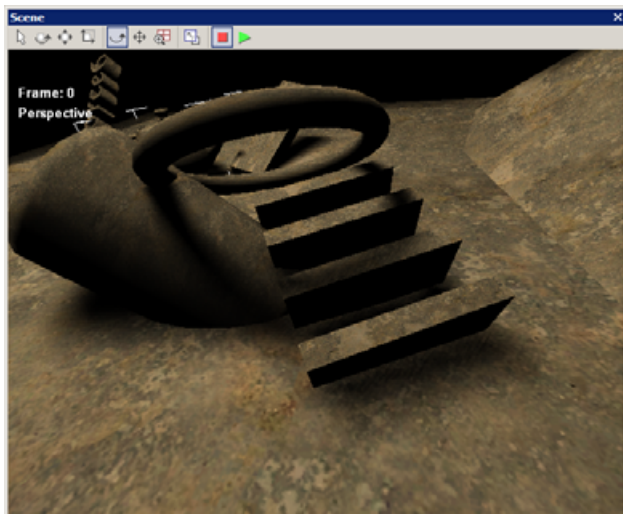


$$W_{Penumbra} = \frac{(d_{Receiver} - d_{Blocker}) \cdot W_{Light}}{d_{Blocker}}$$

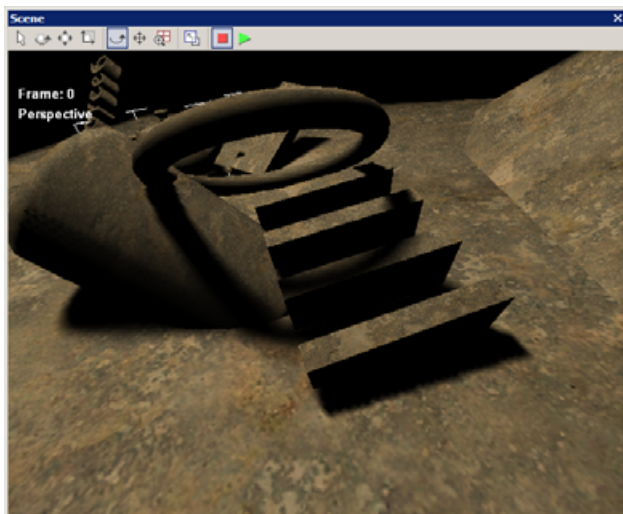
- Assumes that blocker, receiver, and light are parallel

Screenshots

A complex interaction between many objects (with a medium-sized light source):



Same scene with a smaller light source:



Same scene with a larger light source:

