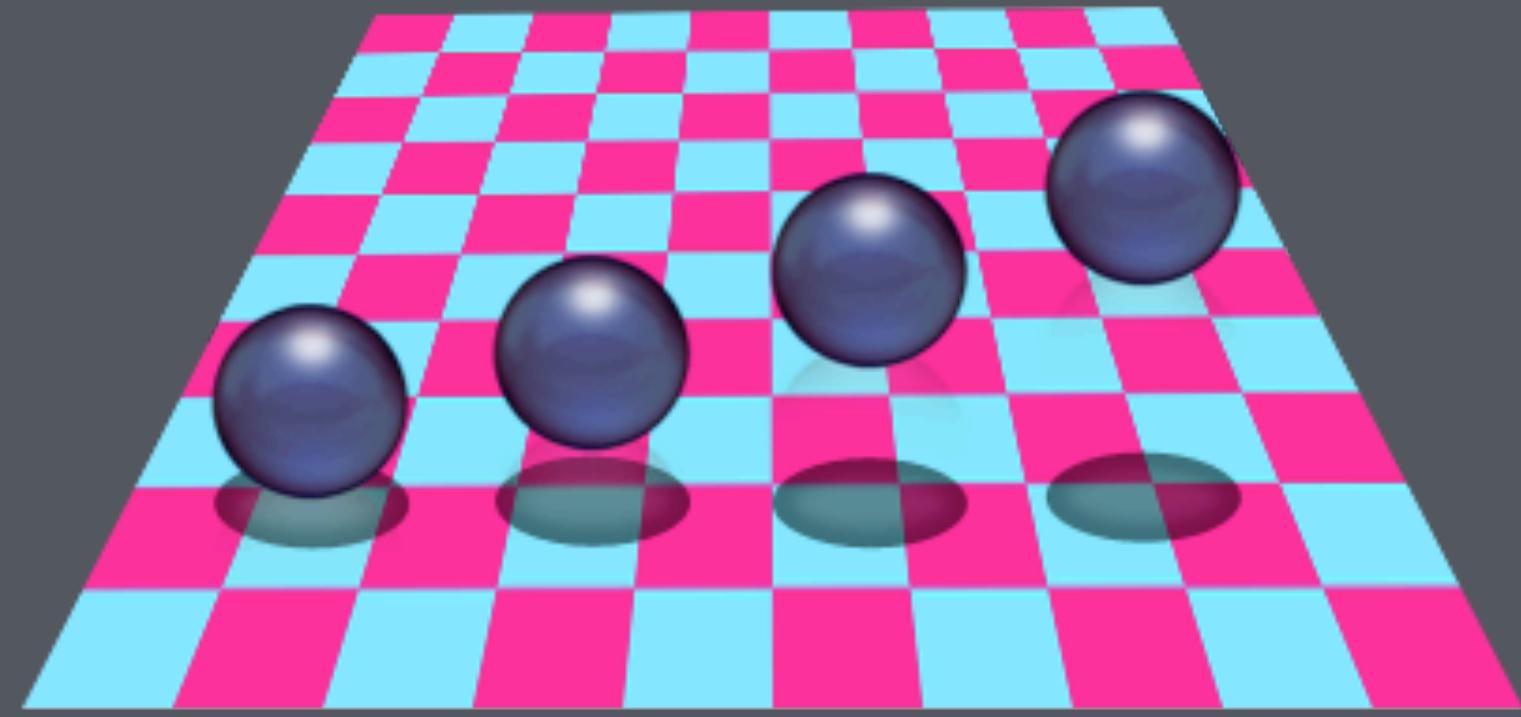
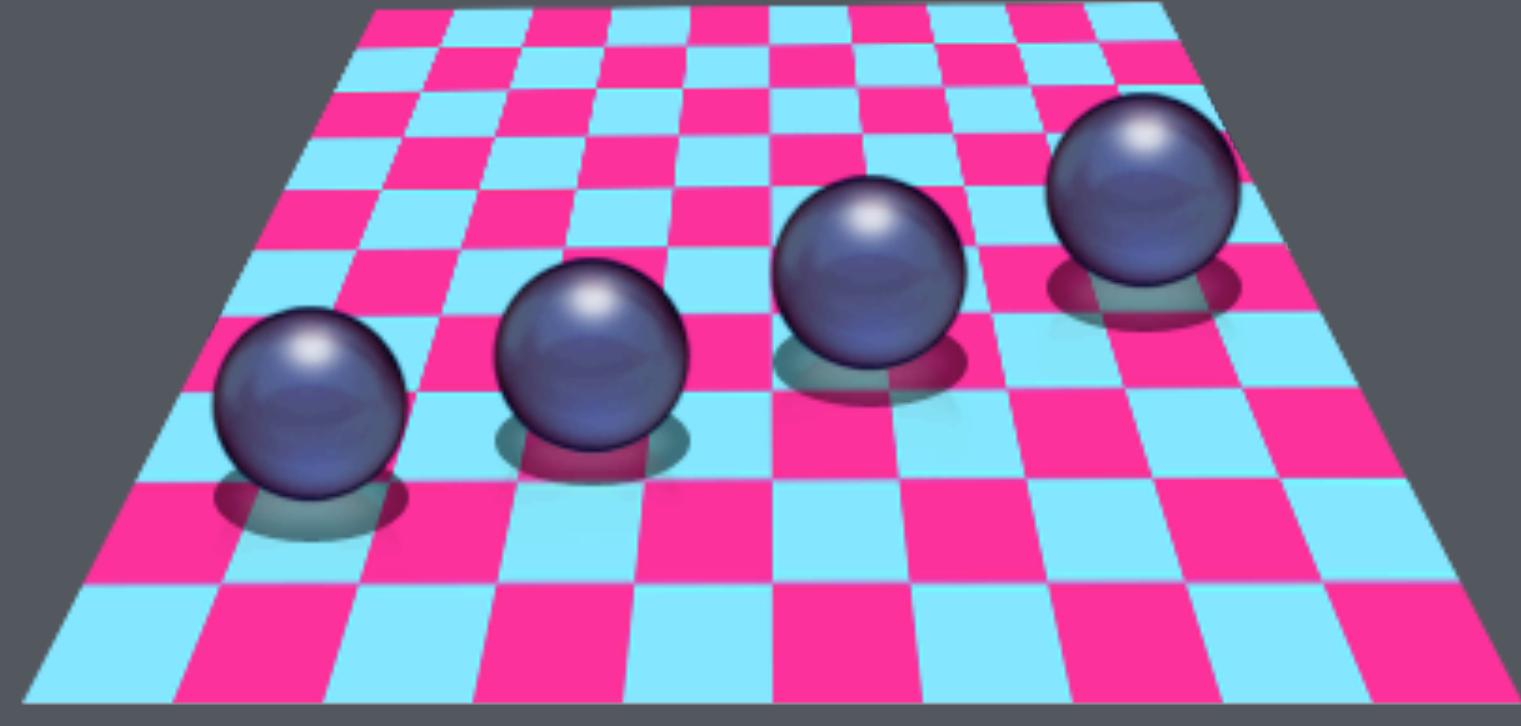


# 09 Shadow Mapping

Thanks to previous instructor Kavita Bala

Steve Marschner  
**CS5625** Spring 2019

# Shadows as depth cue



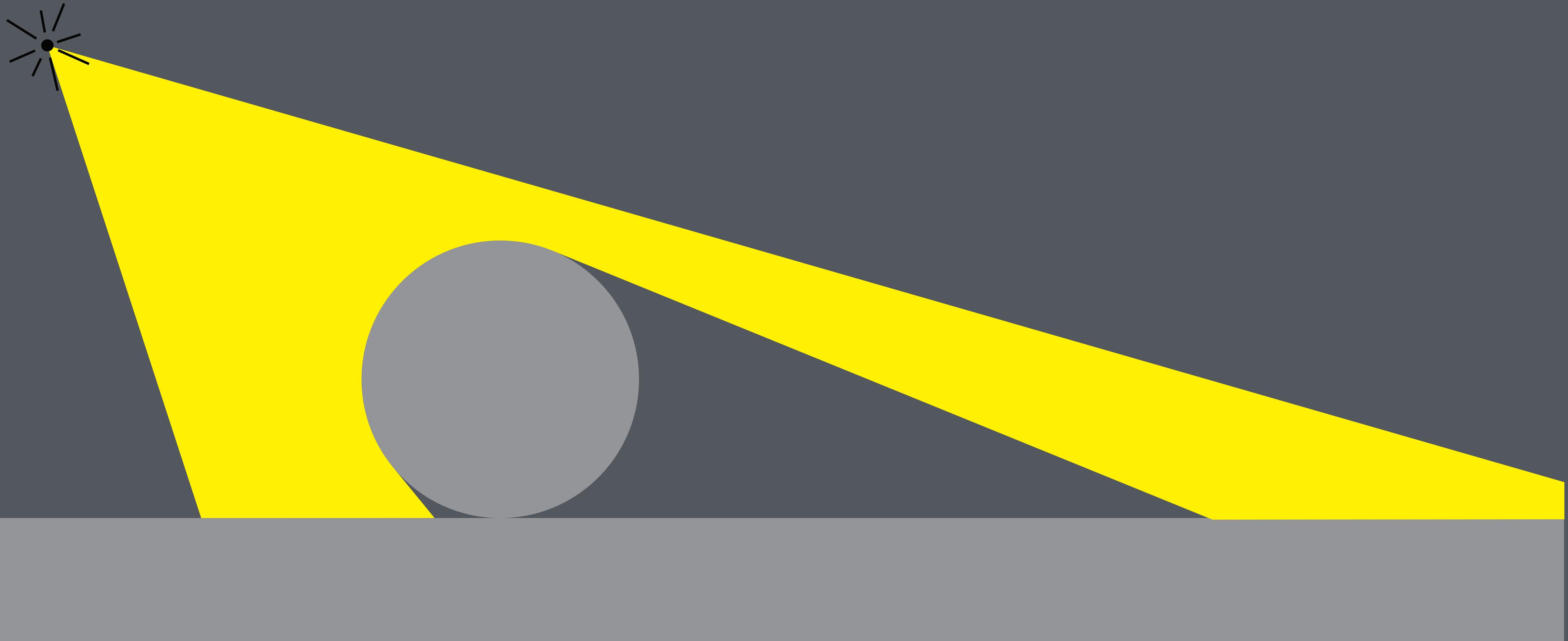
[tricks-and-illusions.com]

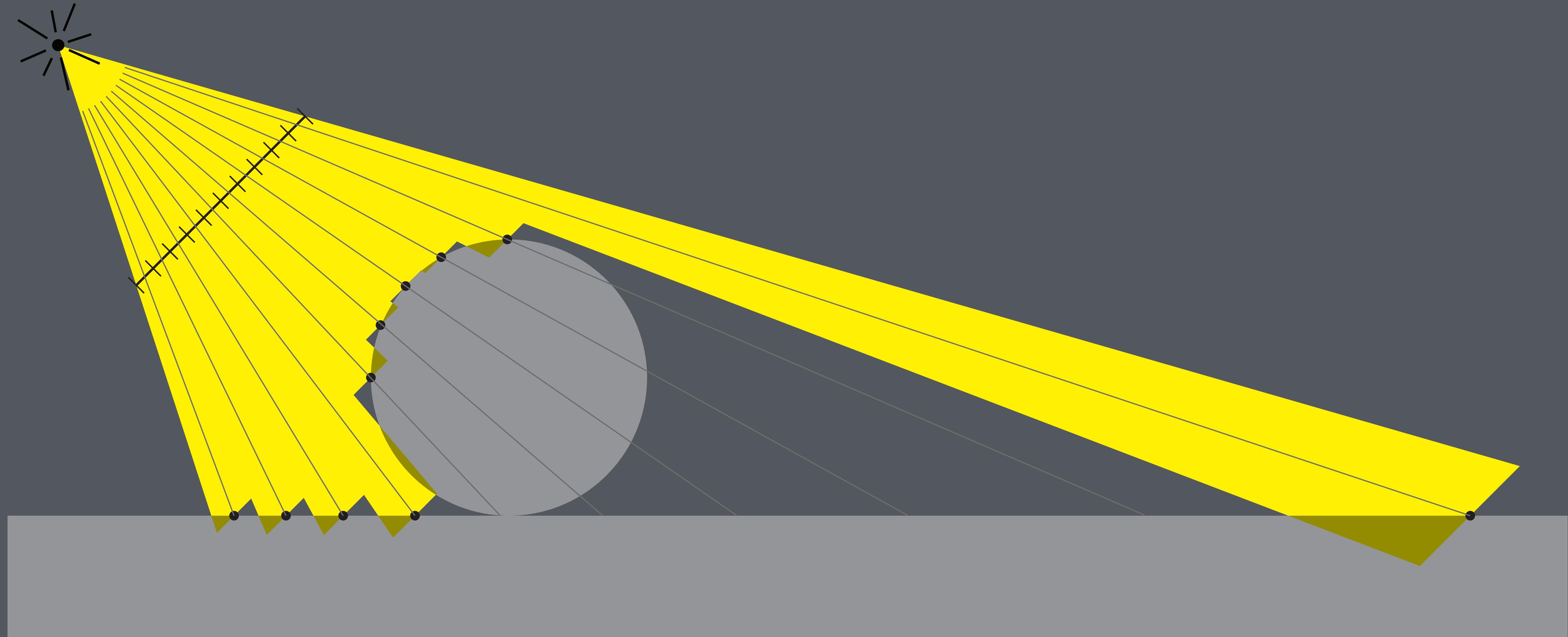
# Shadows as anchors

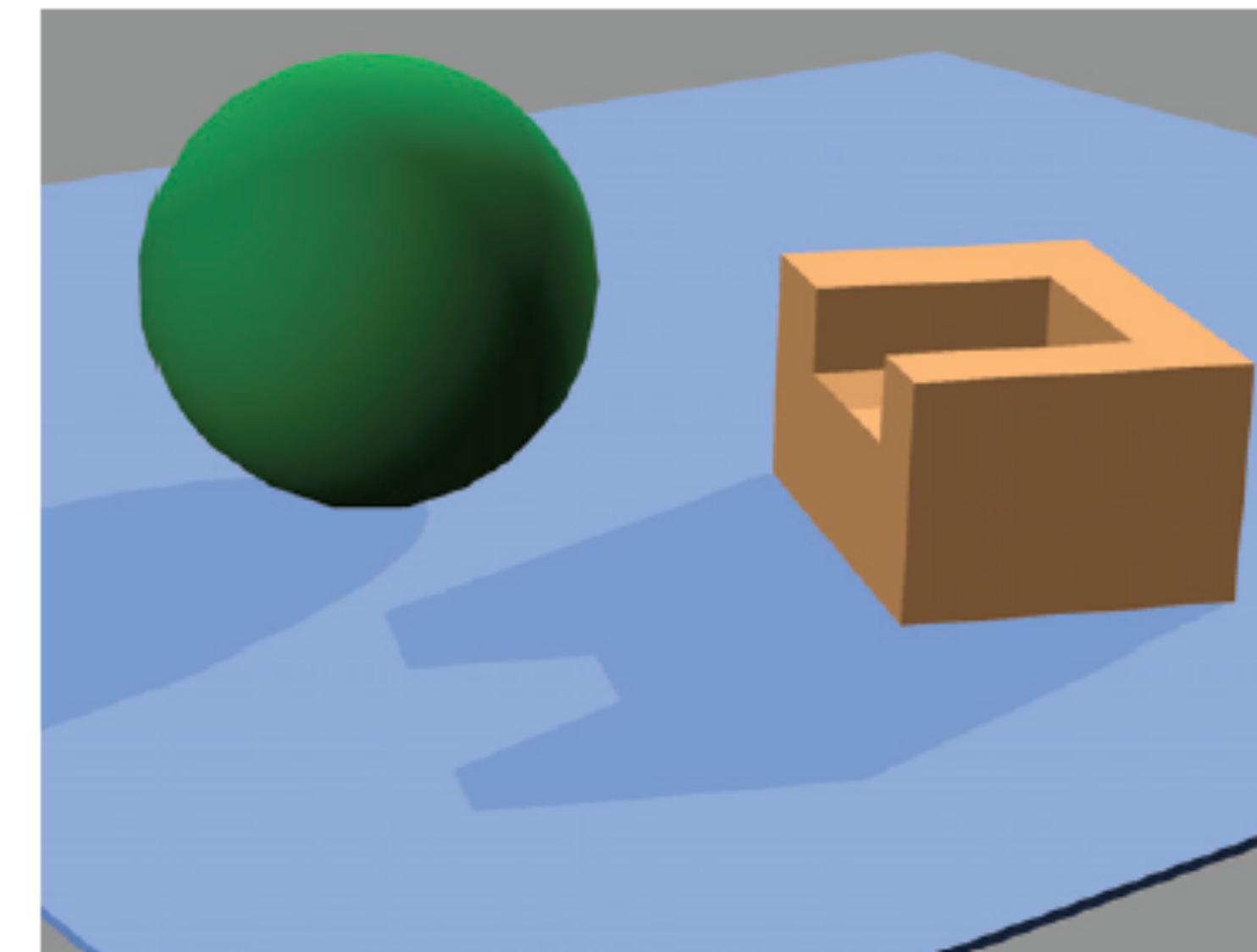
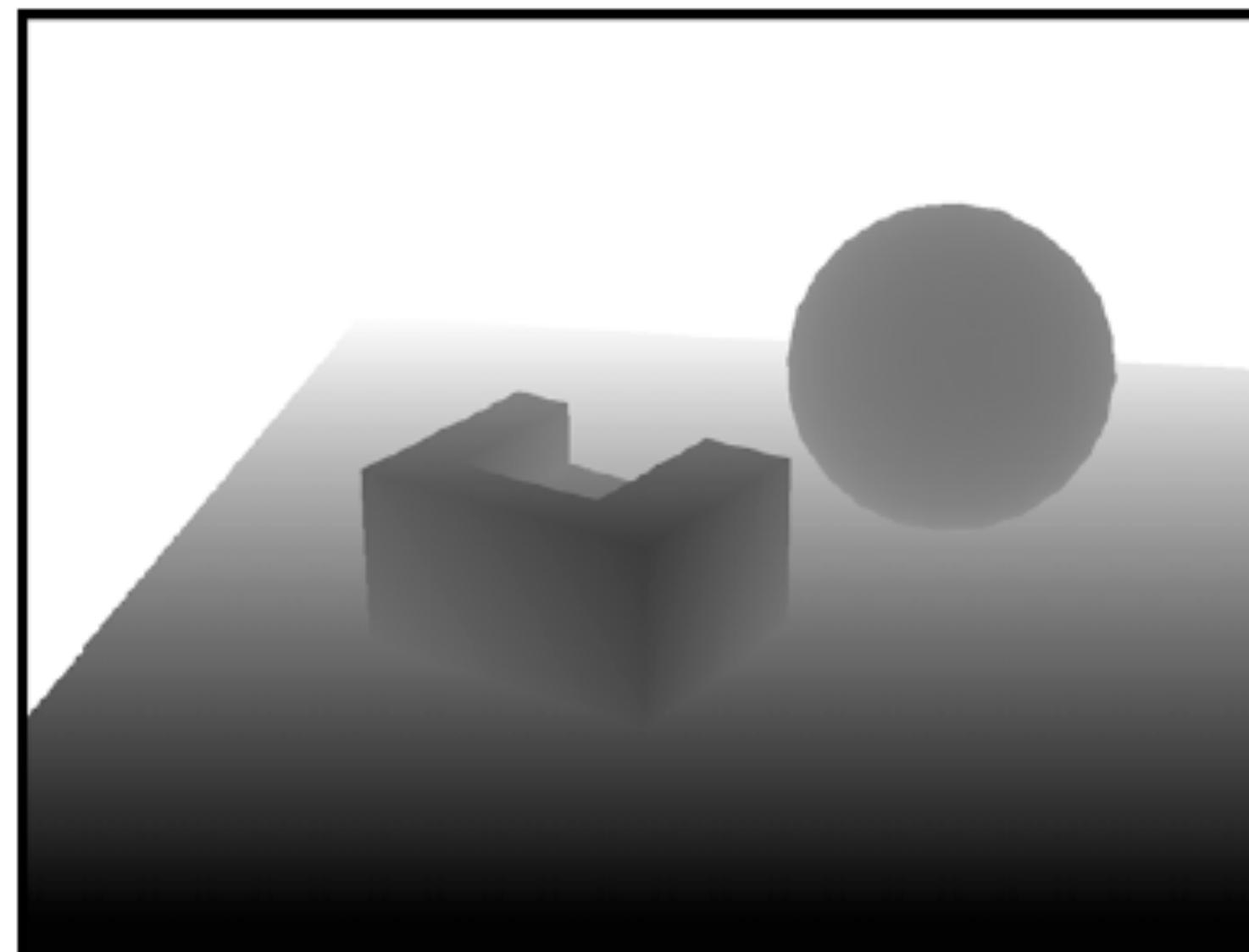
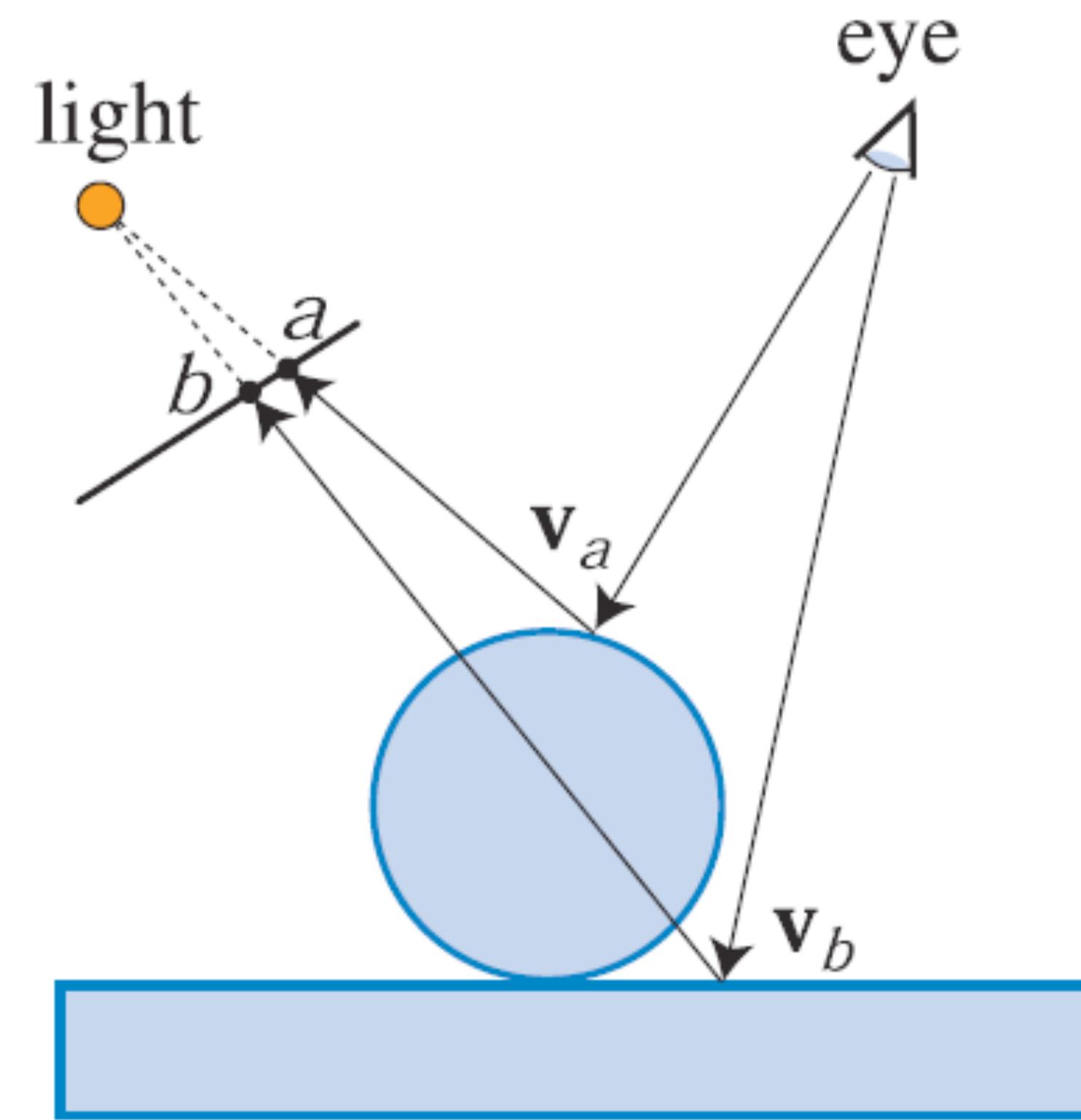
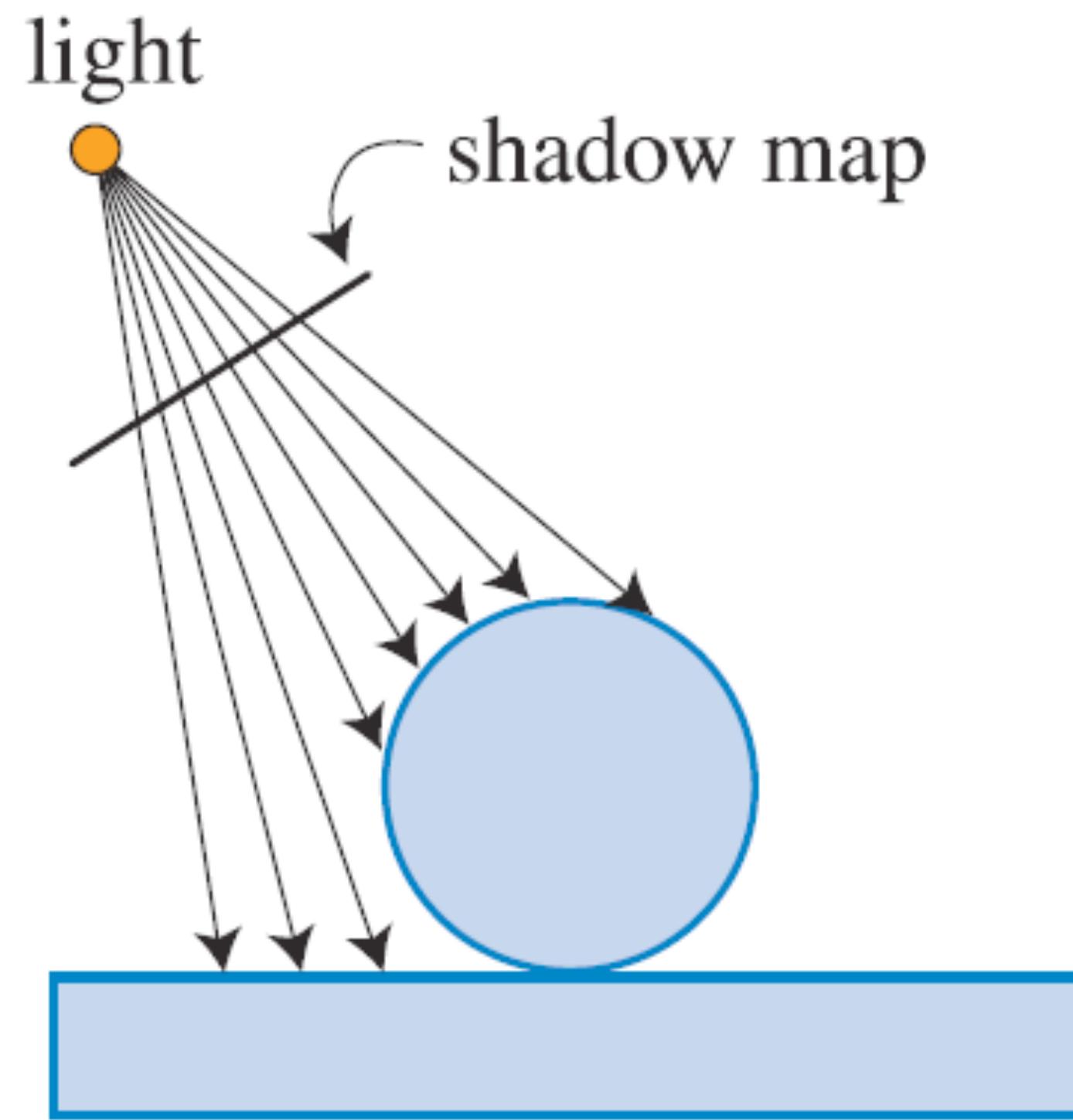


# Shadows as anchors

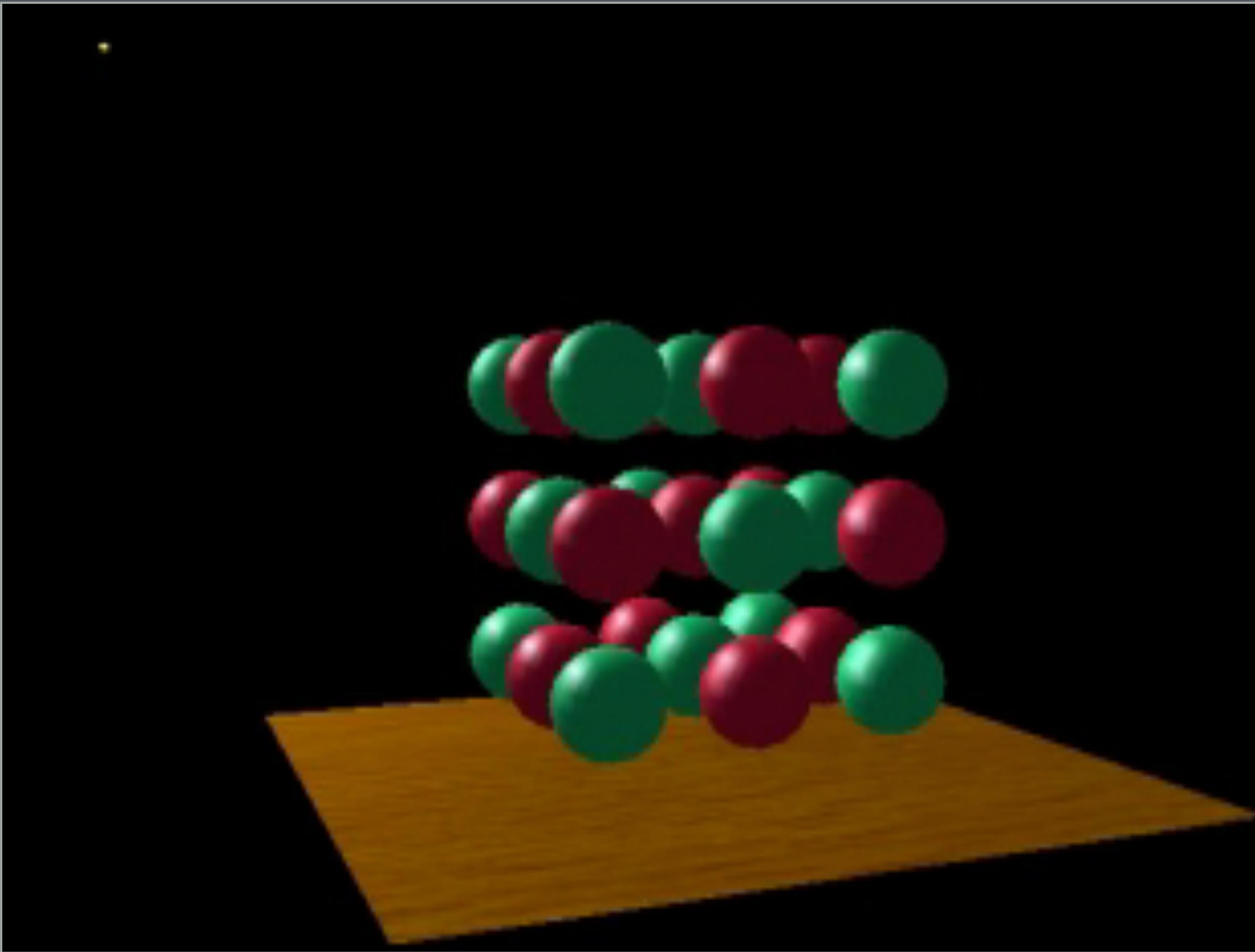




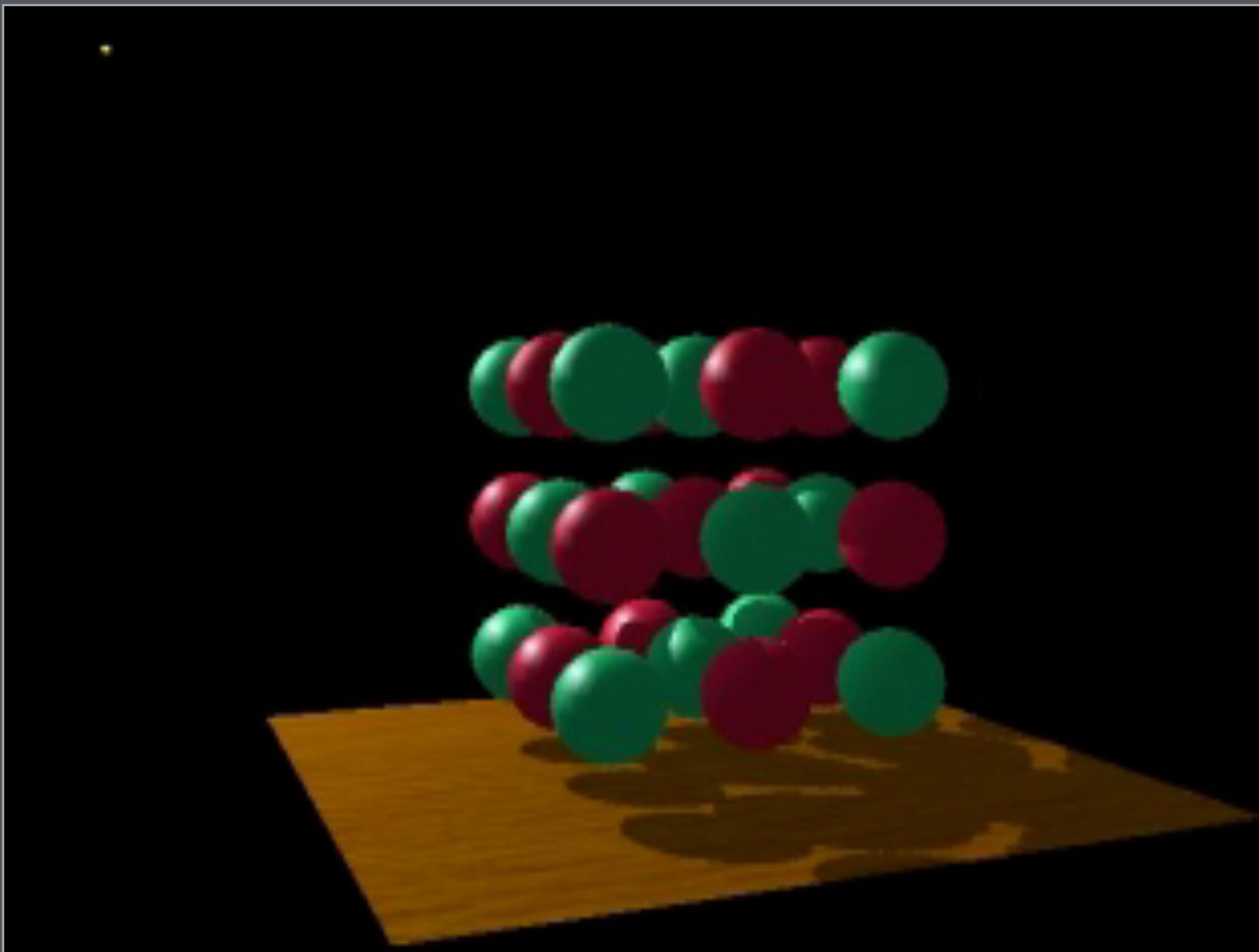




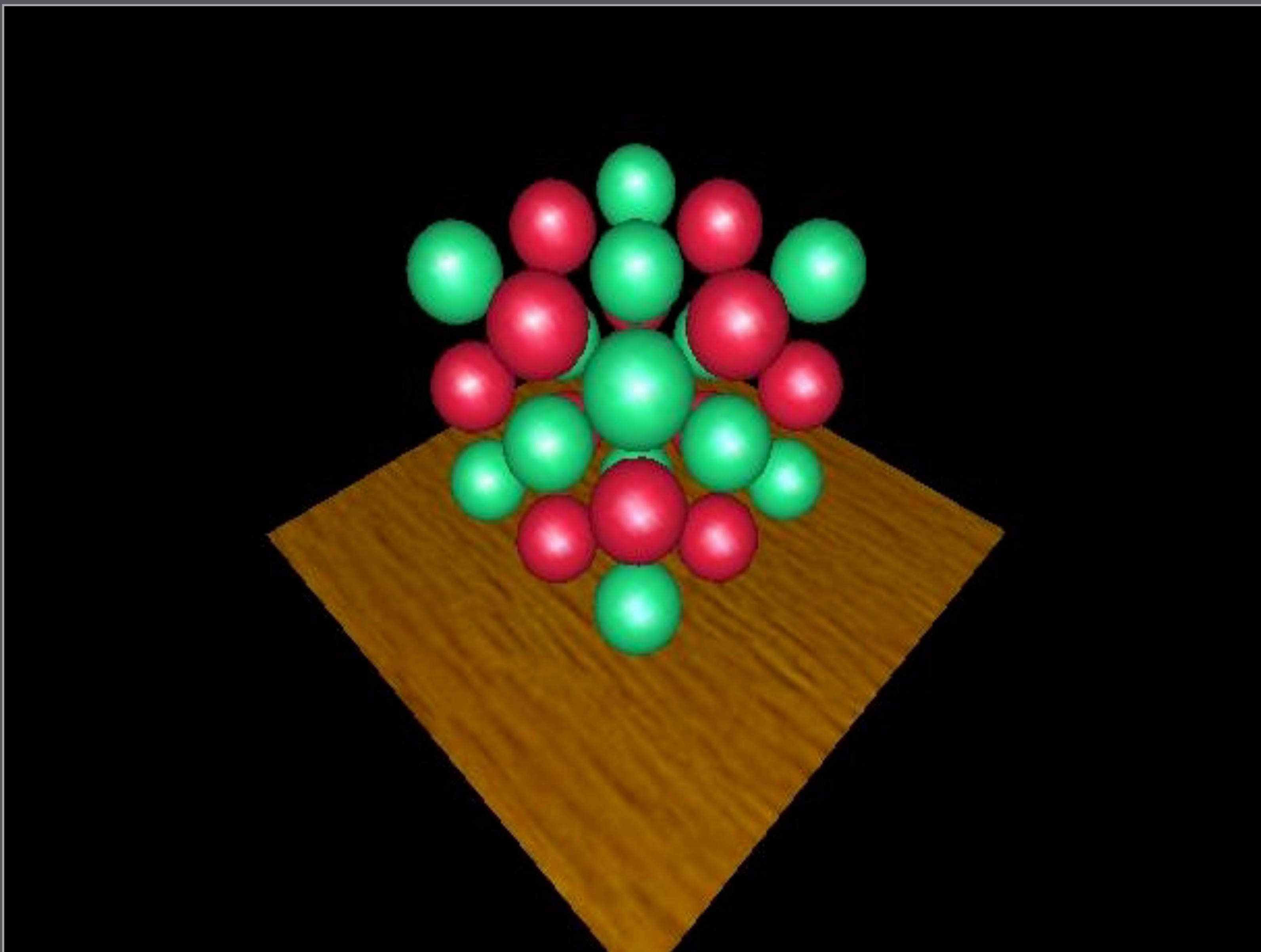
[Möller et al. *RTR*]



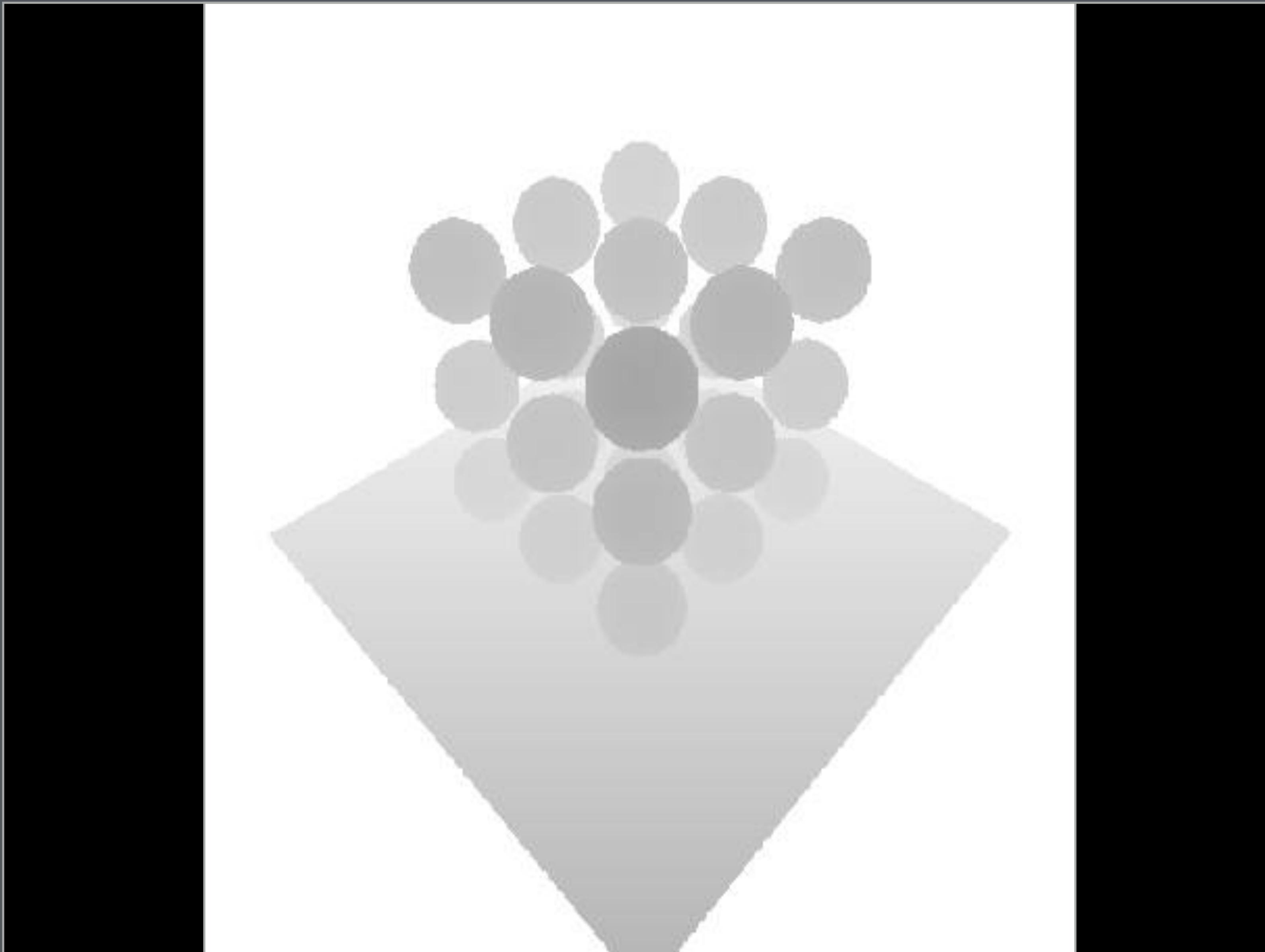
Mark Kilgard



Mark Kilgard



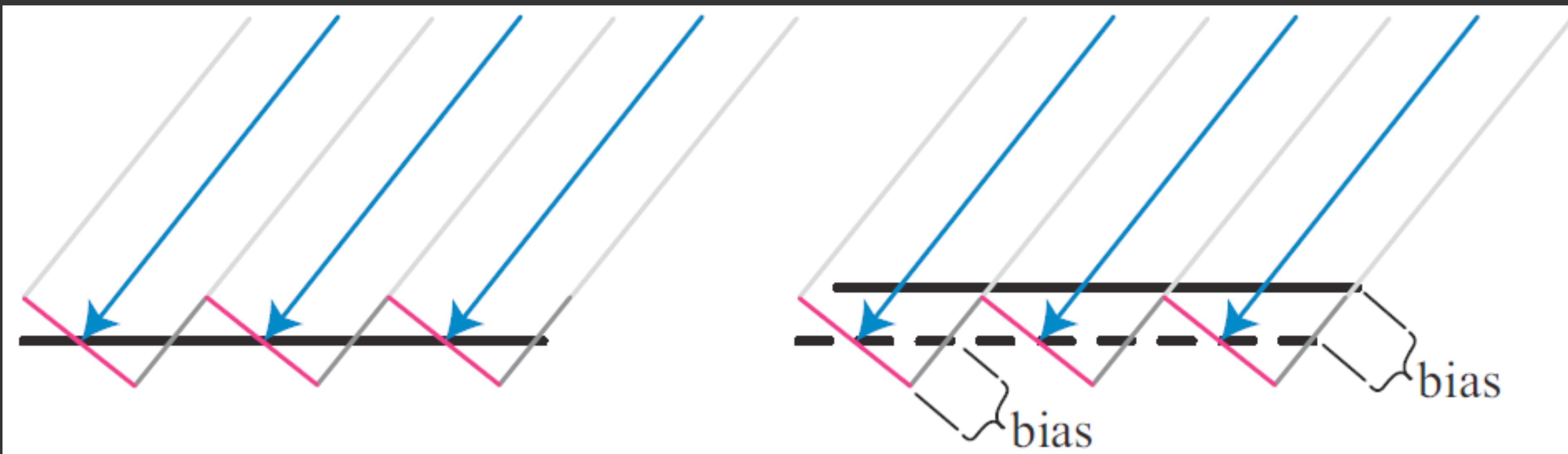
Mark Kilgard

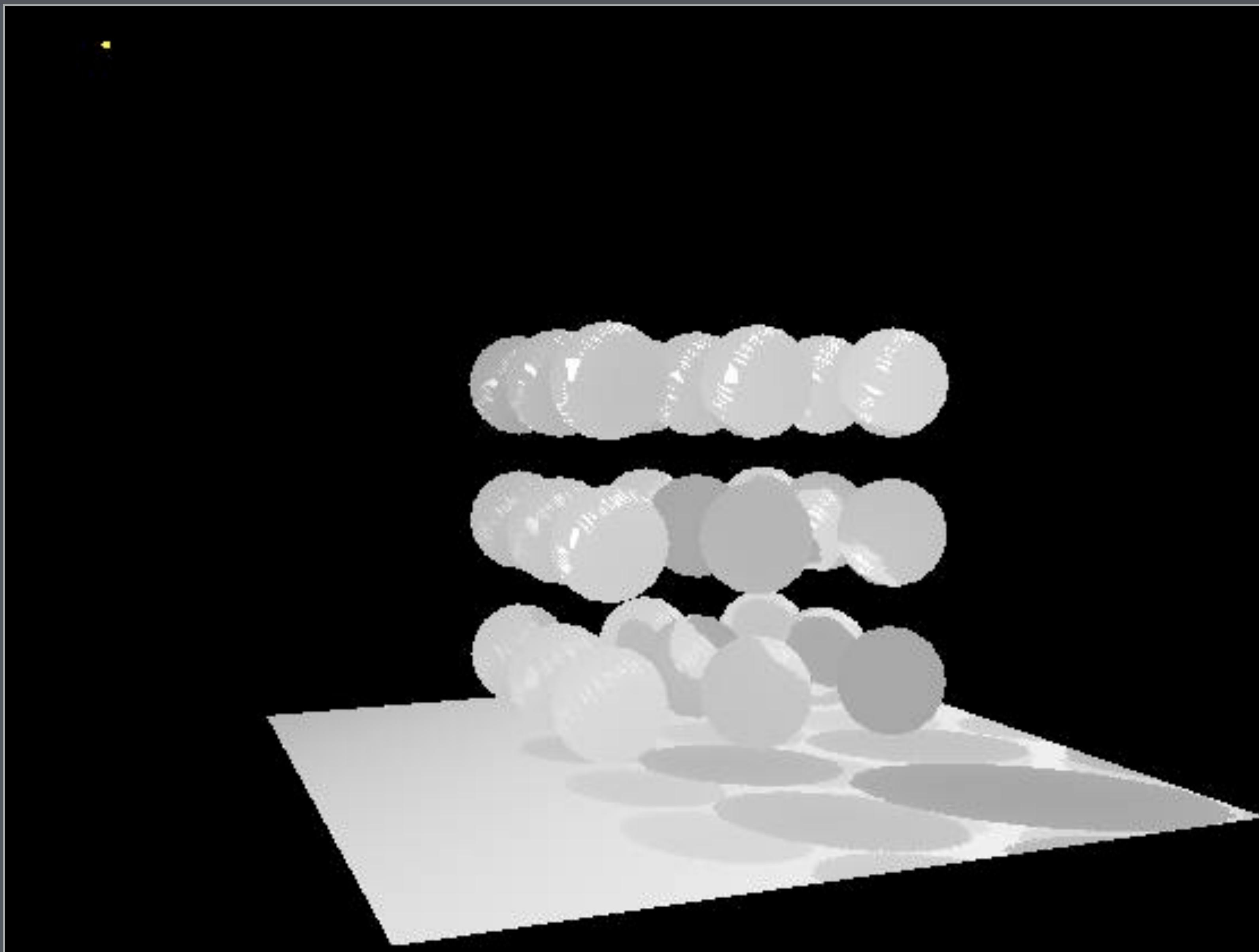


Mark Kilgard

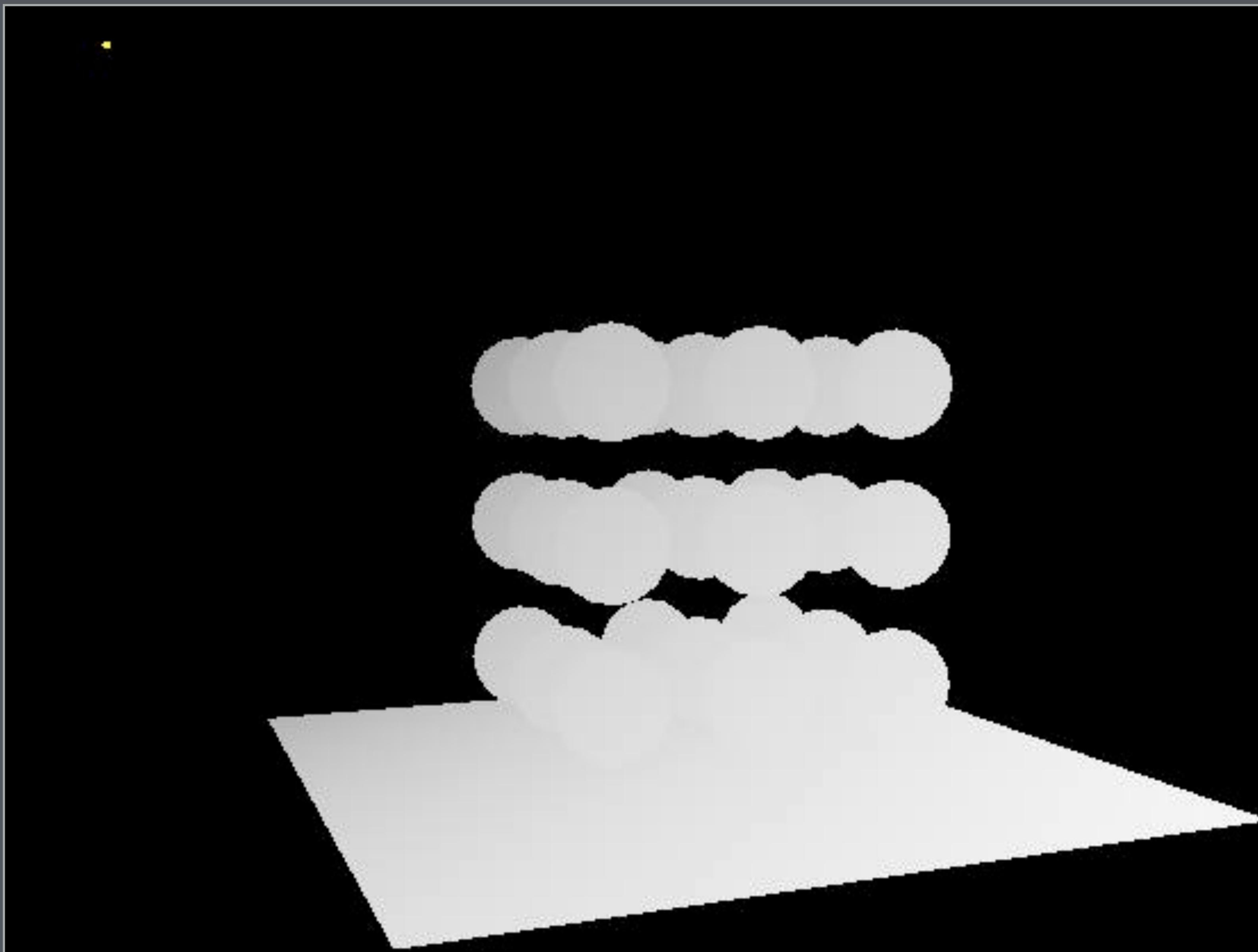
# Shadow Map Issues

- if A and B are approximately equal?
- Speckling

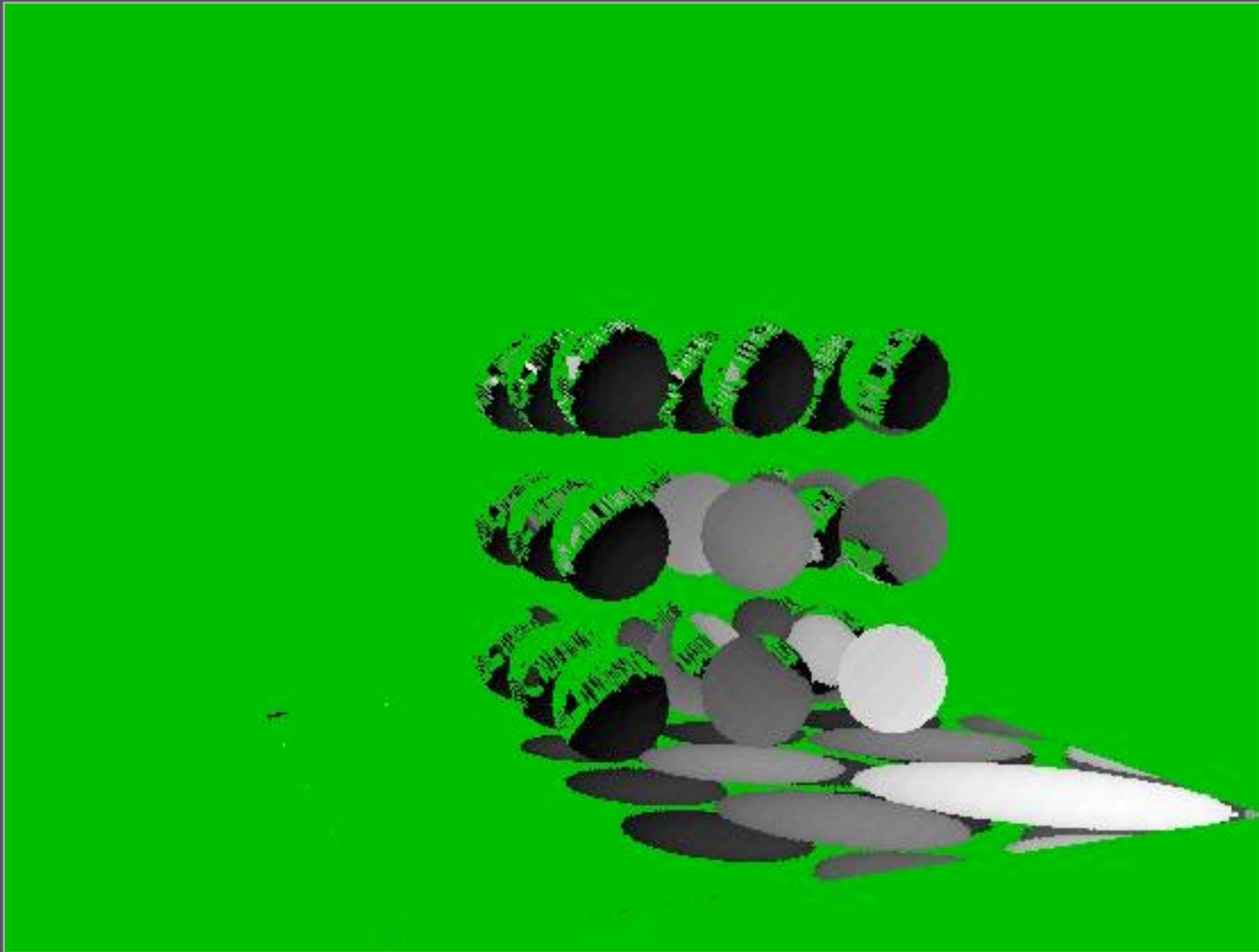




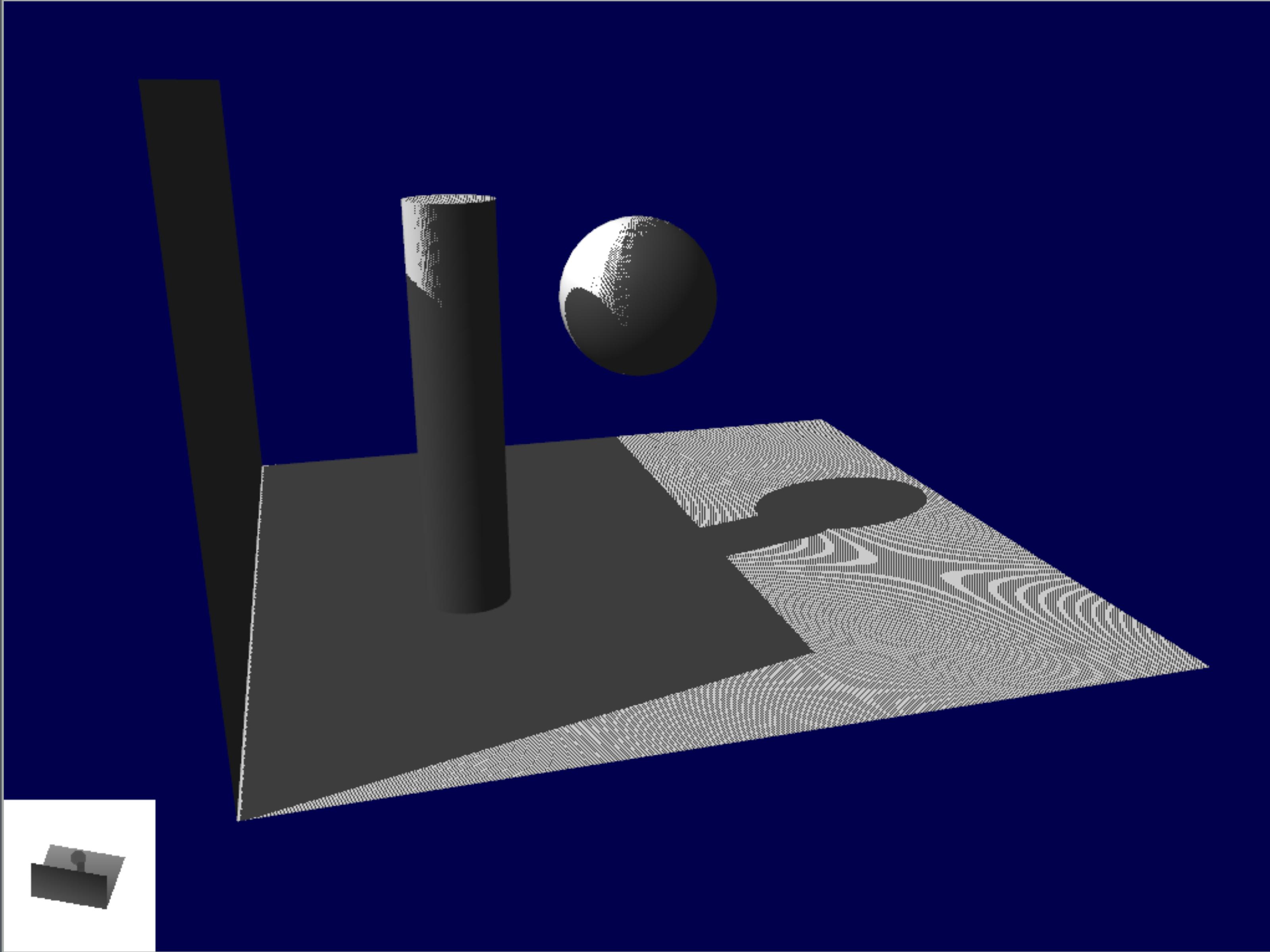
Mark Kilgard



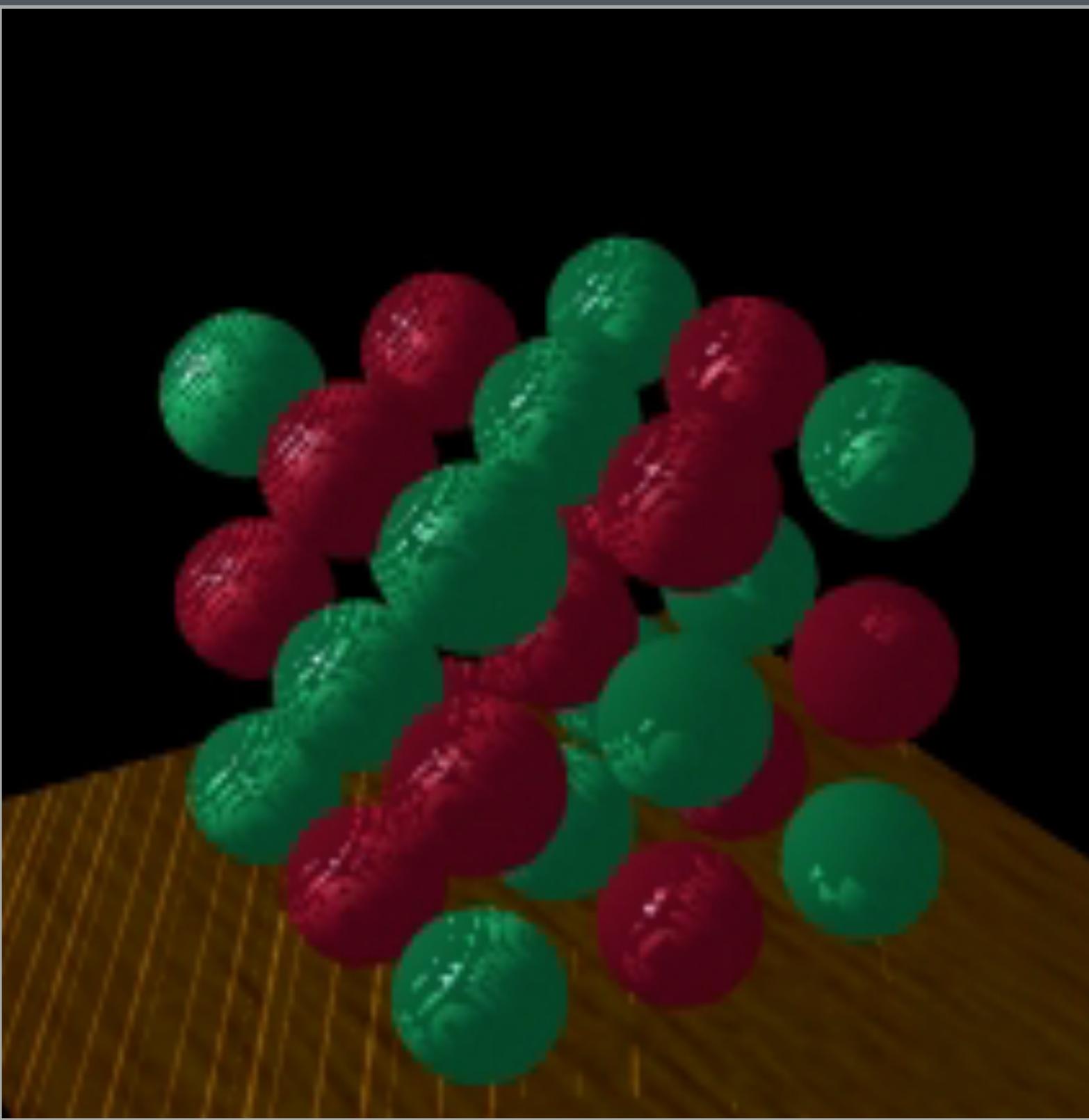
Mark Kilgard



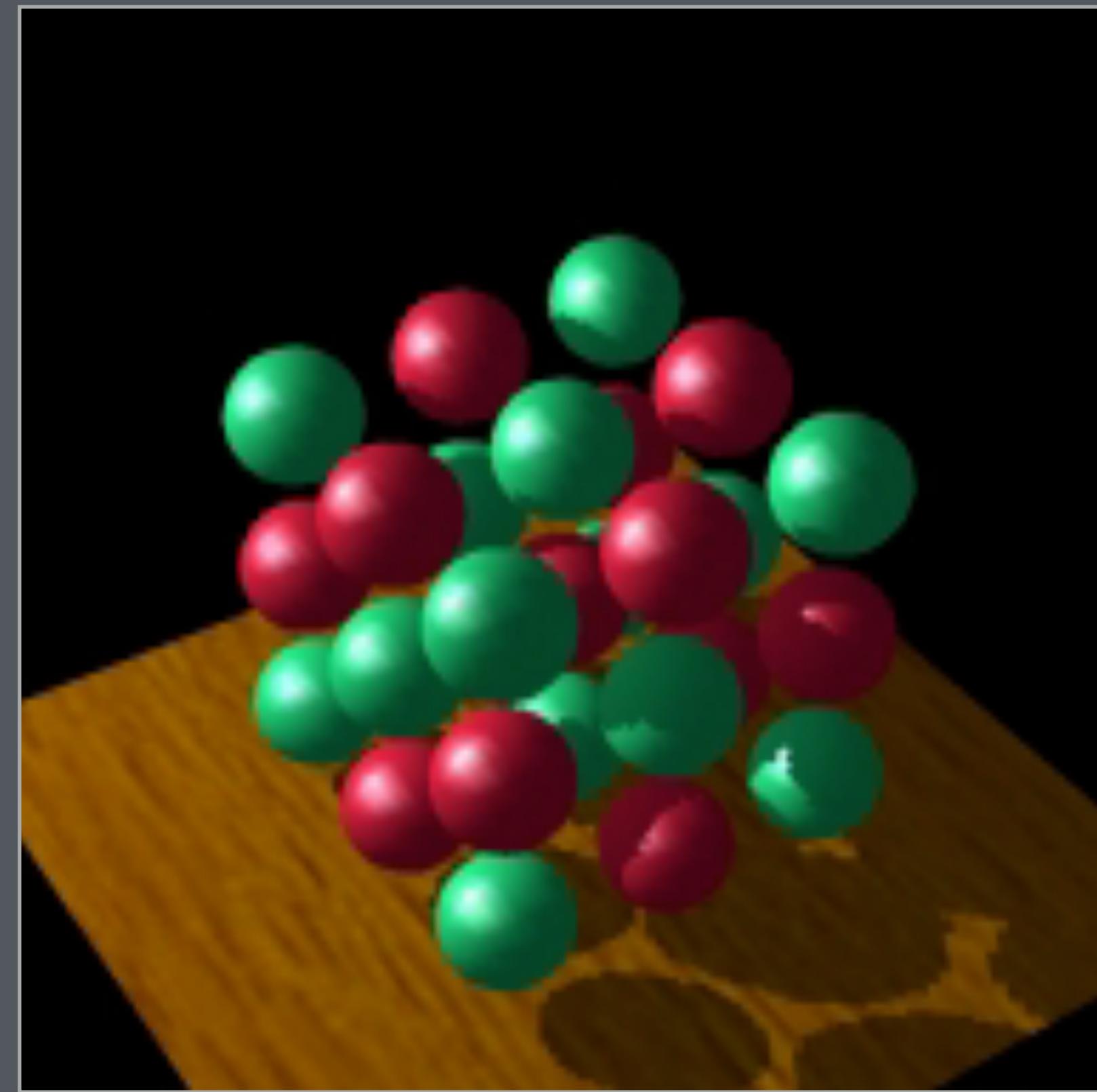
Mark Kilgard



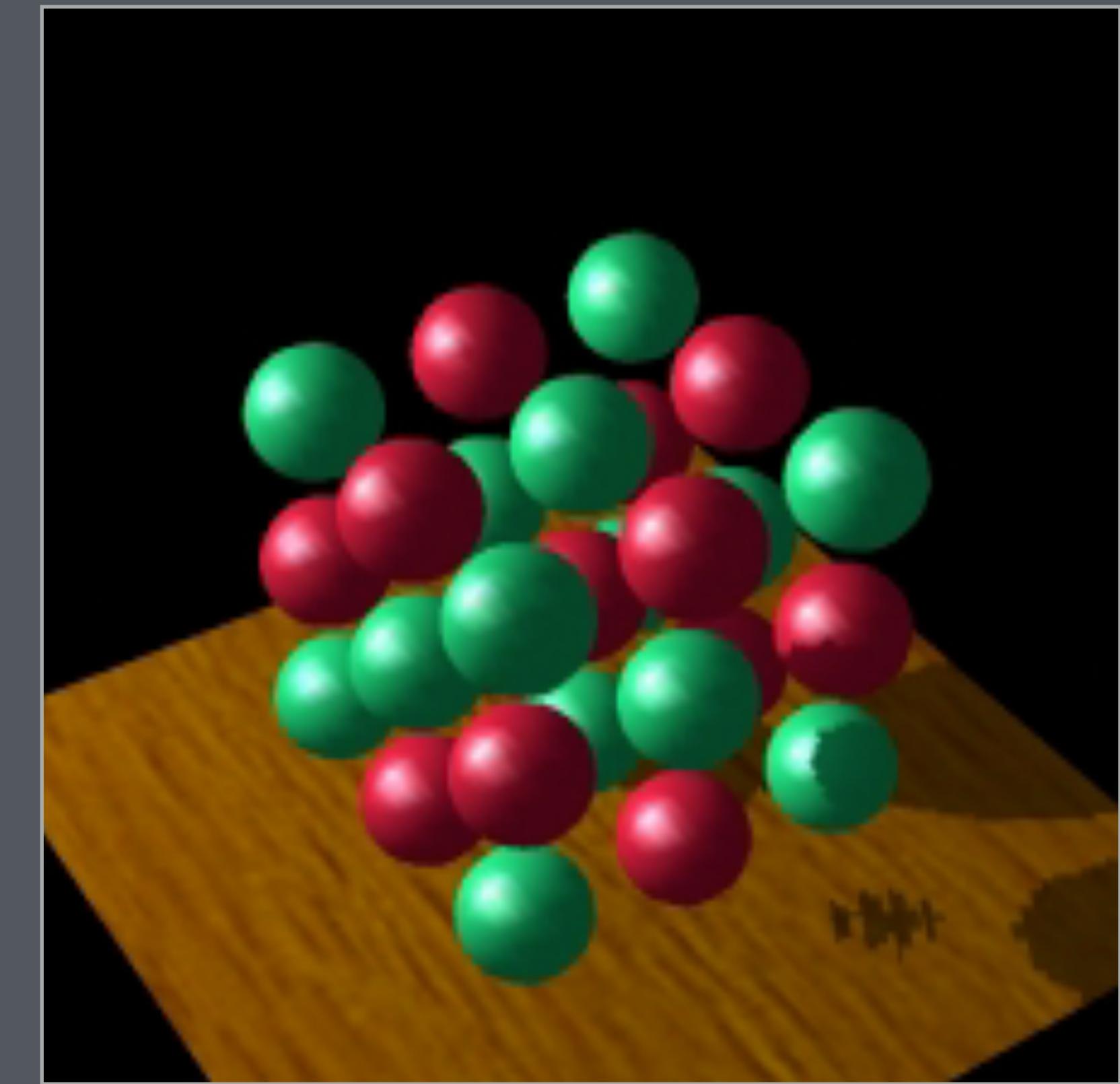
**first try at shadow mapping**



not enough shadow bias

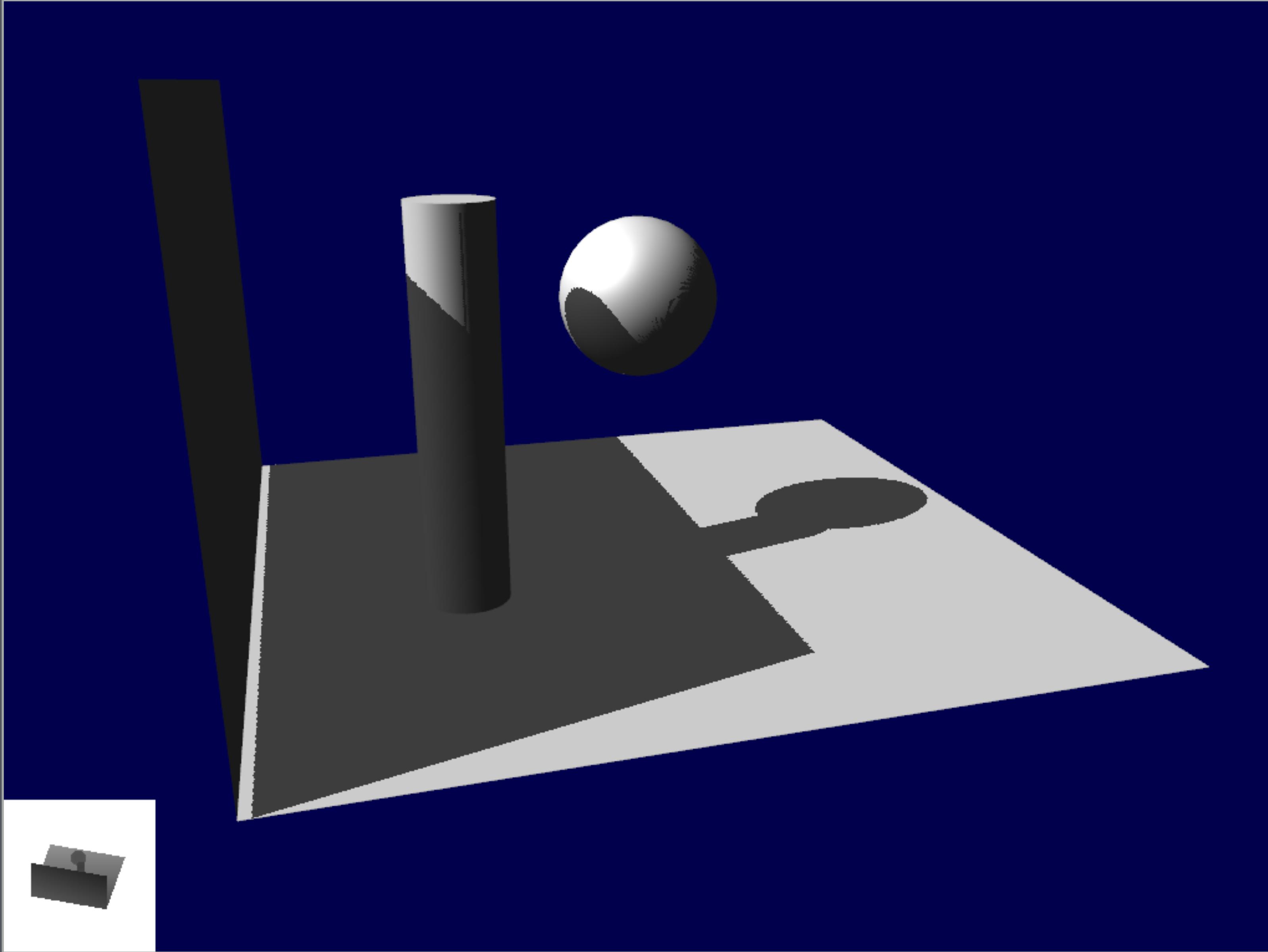


good shadow bias

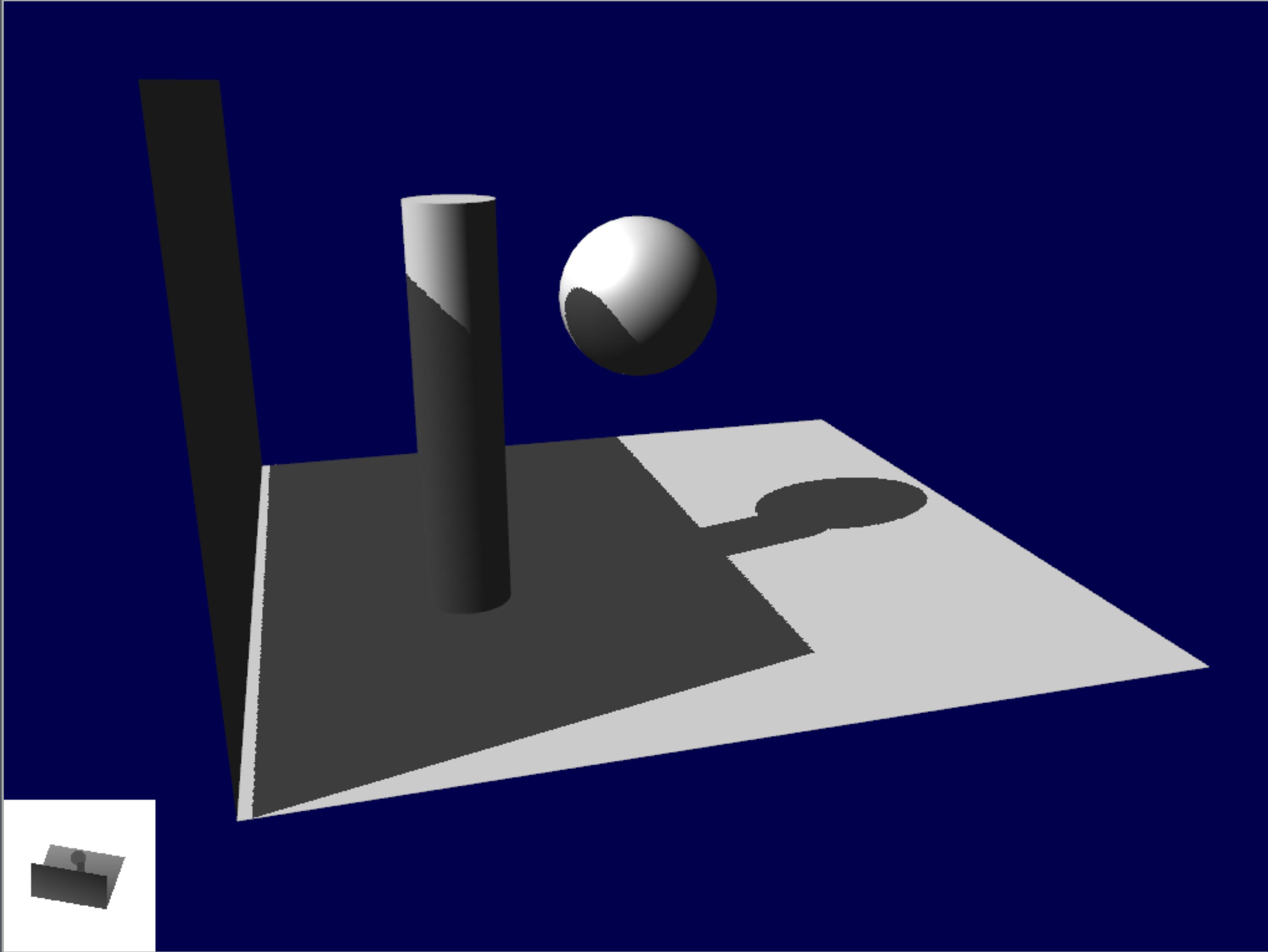


too much shadow bias

Mark Killgard

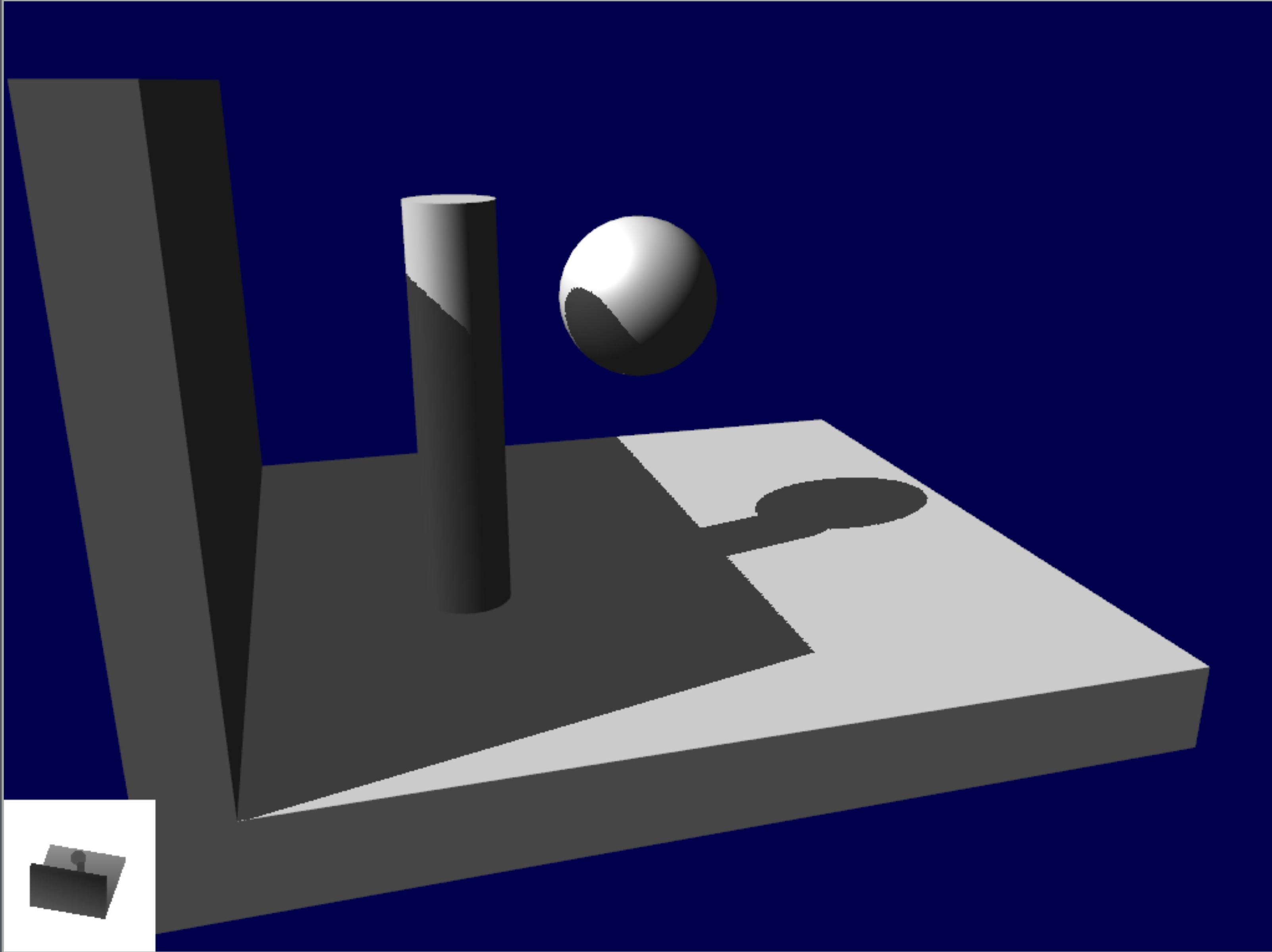


**shadow mapping with constant bias**

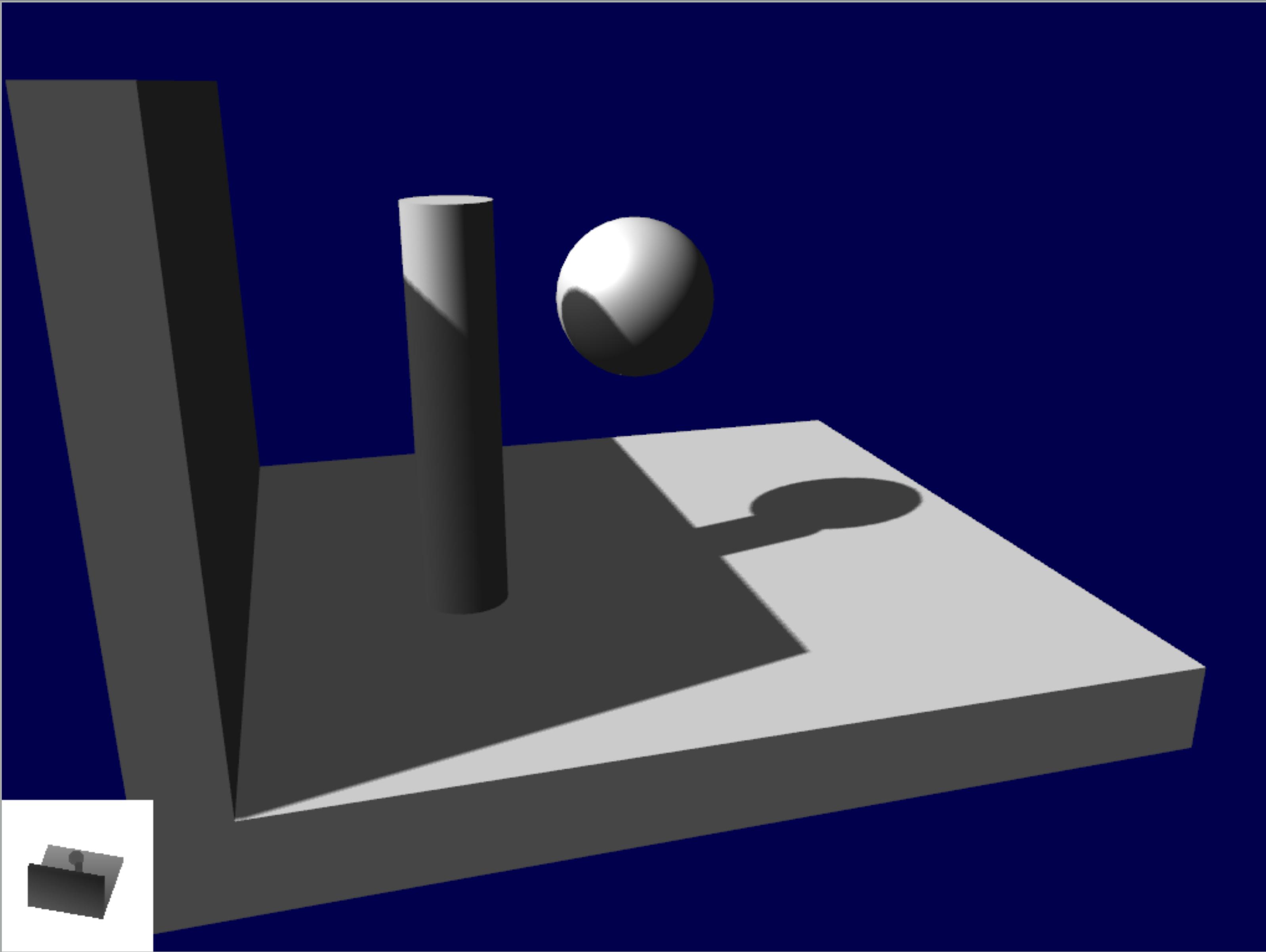


[opengl-tutorial.org](http://opengl-tutorial.org)

**shadow mapping with slope-dependent bias**



**closed surfaces and slope-dependent bias**



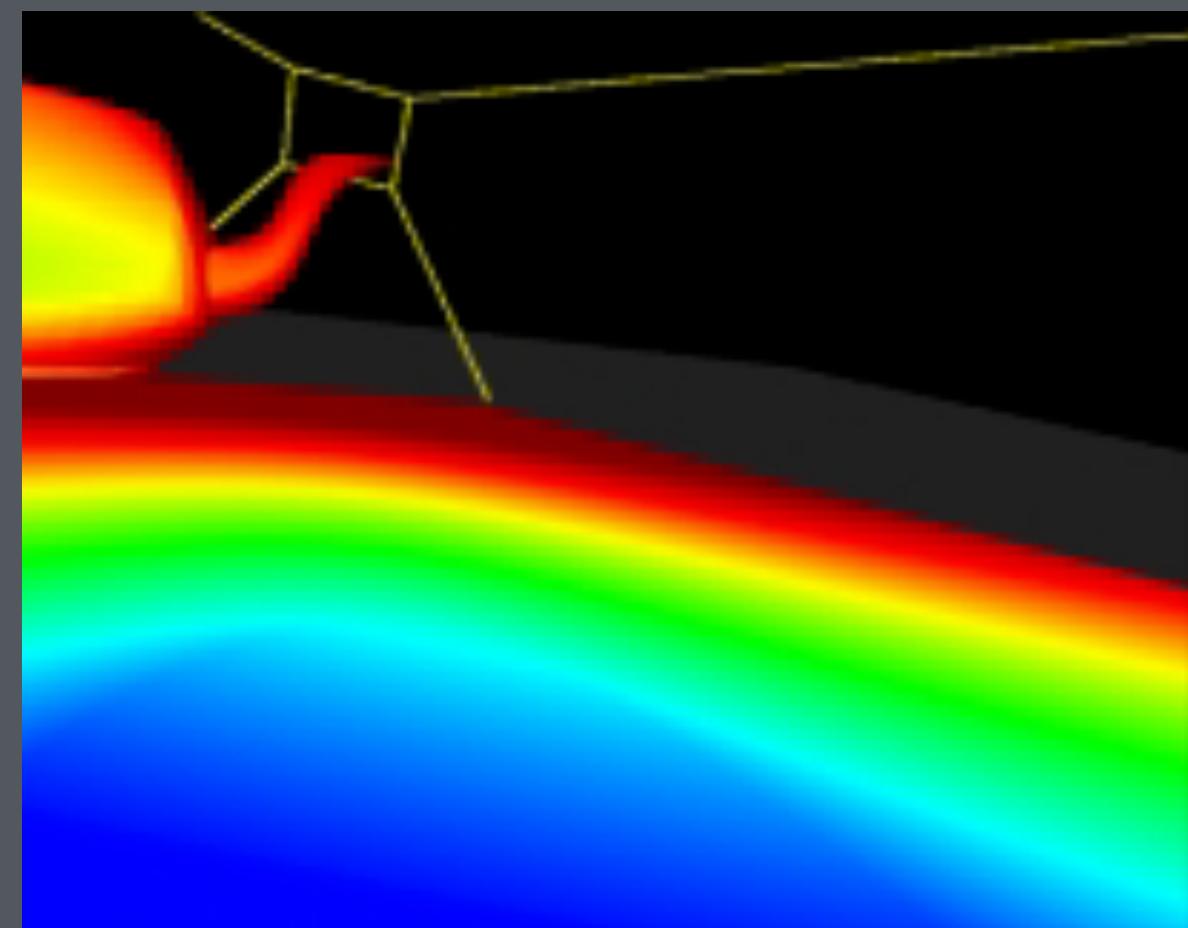
adding percentage-closer filtering

# Shadow map sample rate—bad case

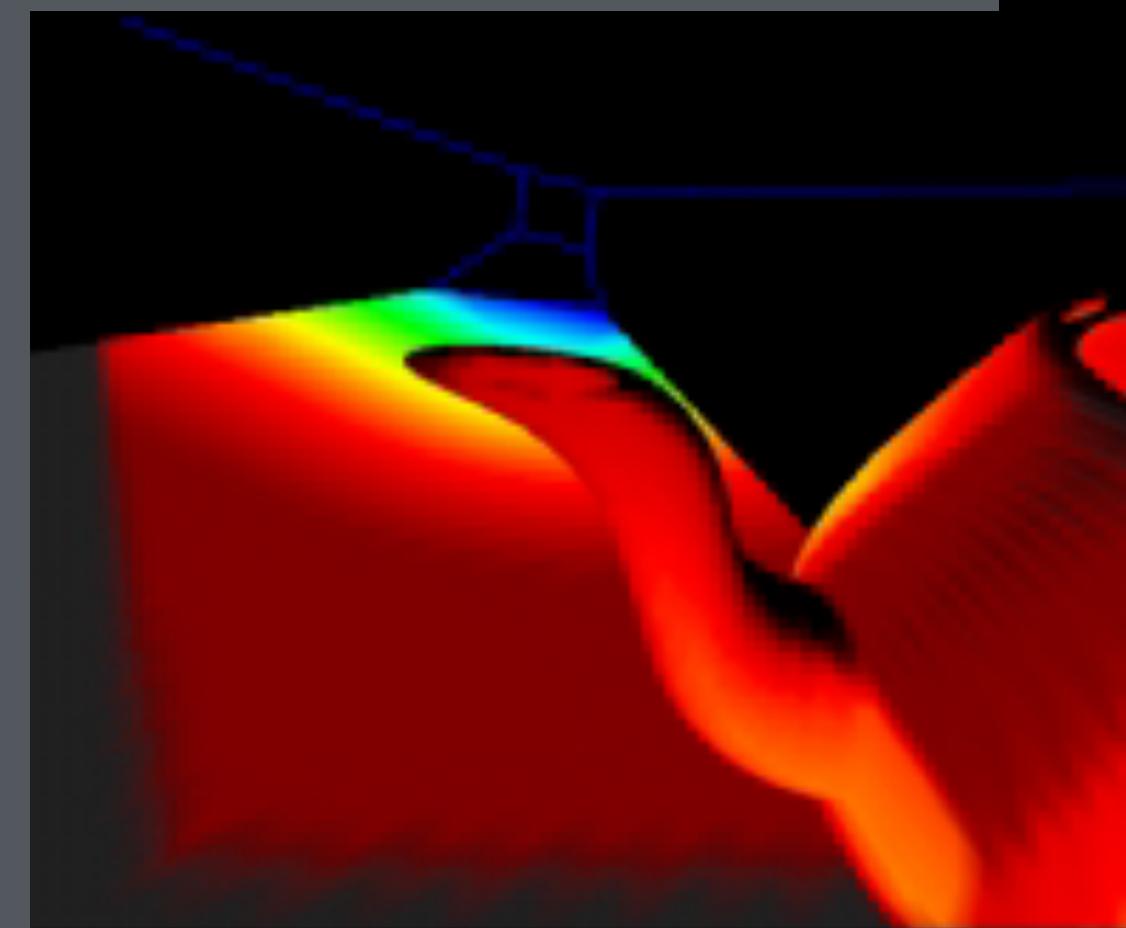
**Light behind object**

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

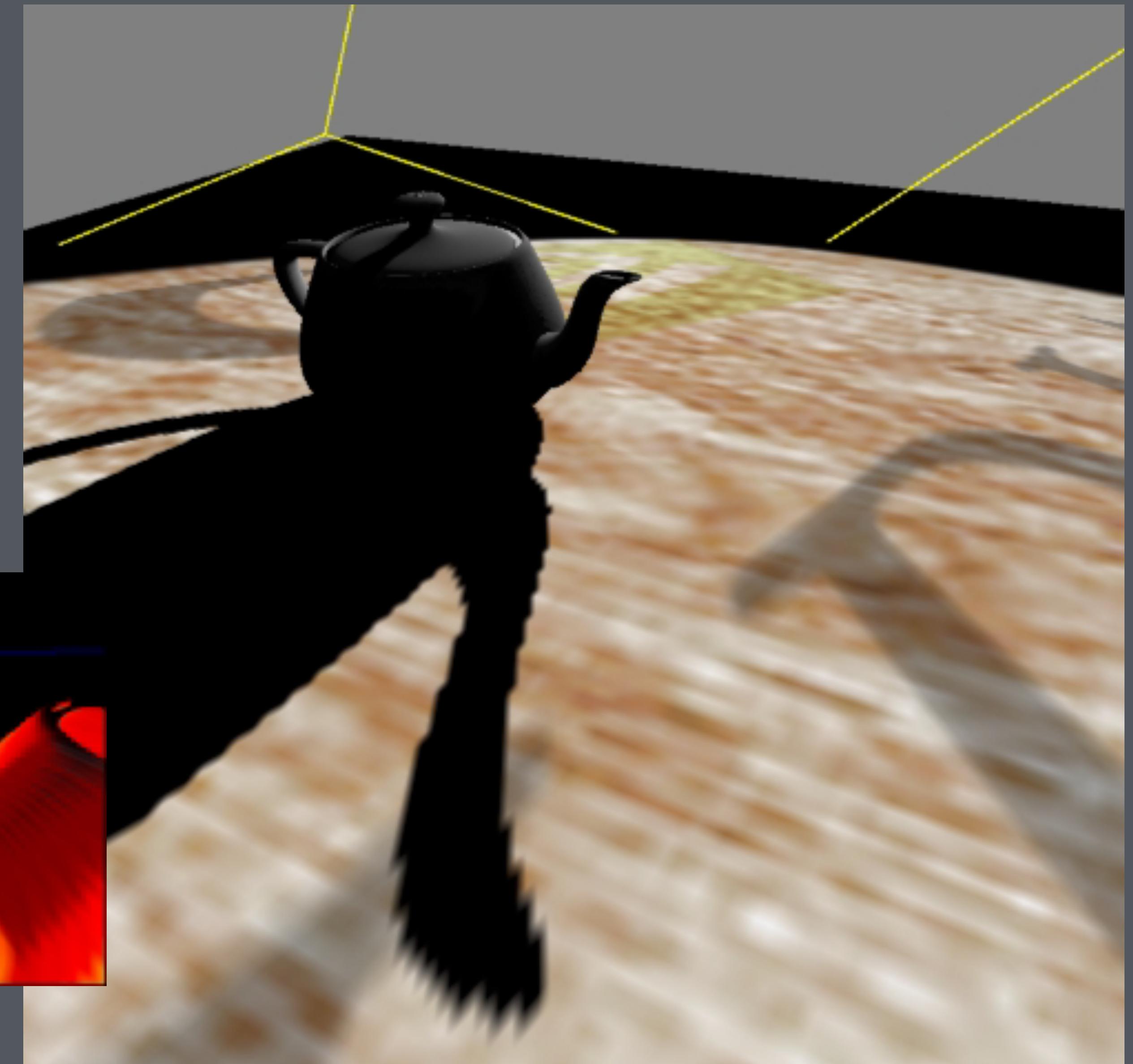
**“Dueling frusta”**



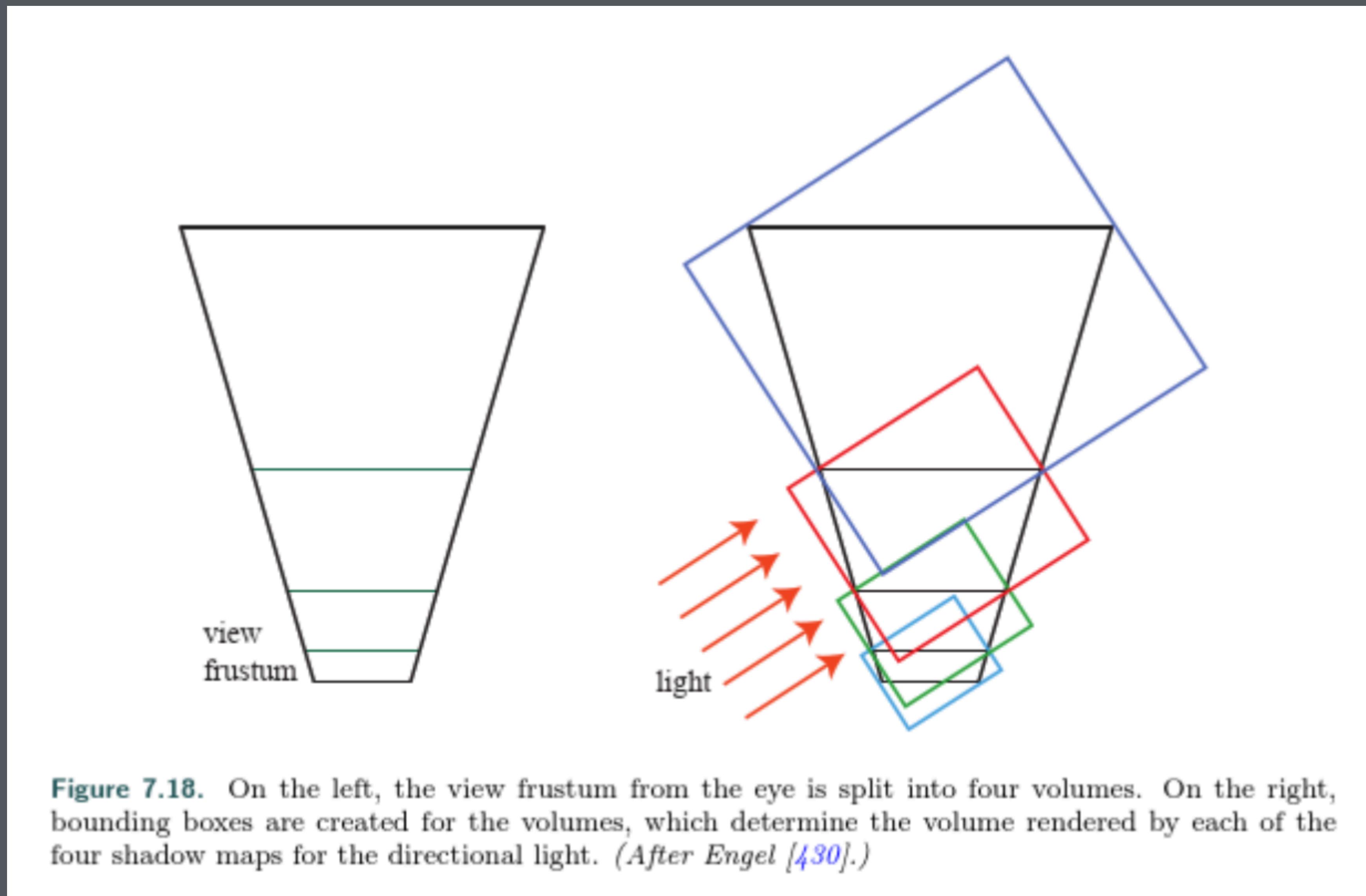
eye view



light view

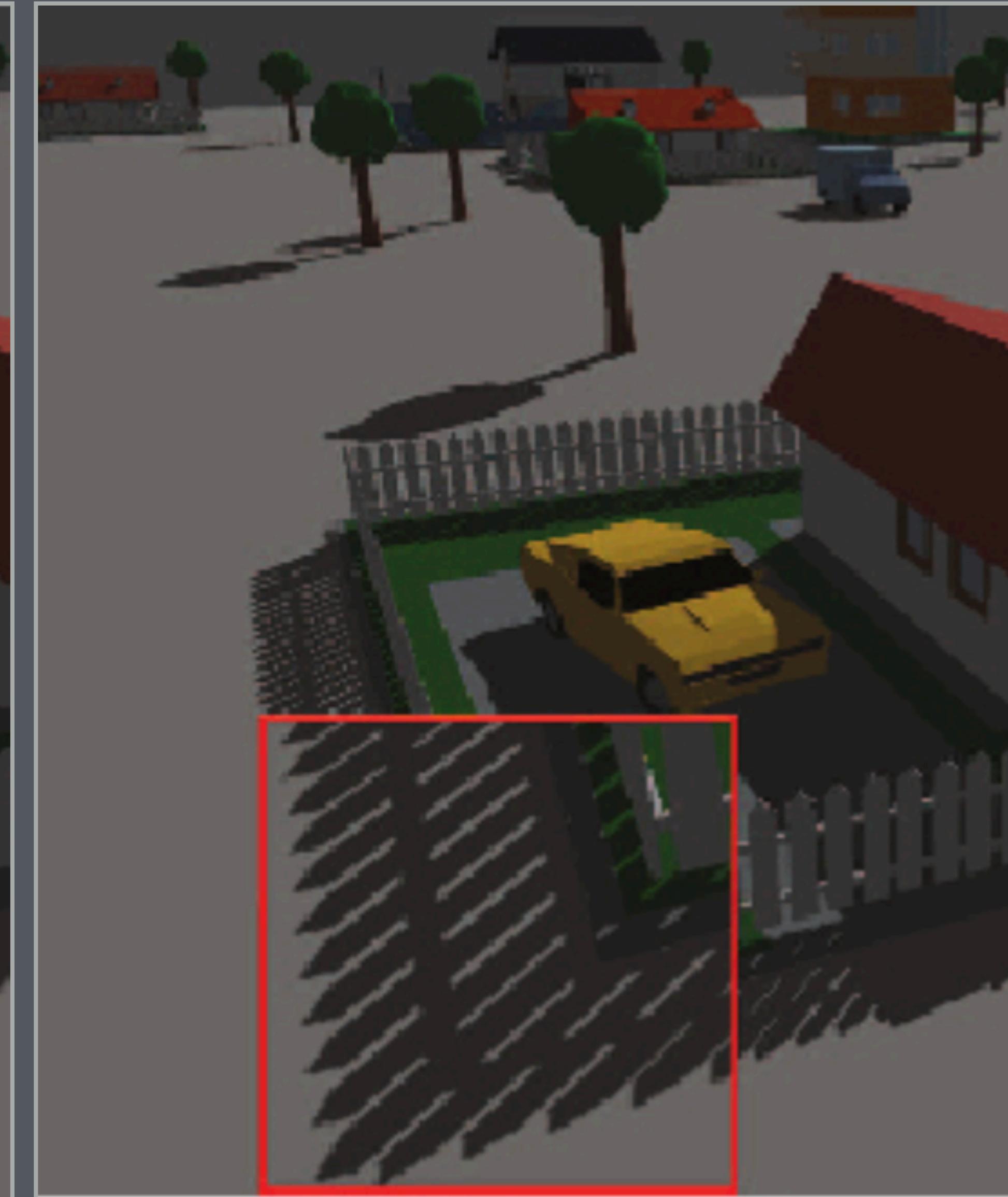


# Cascaded shadow maps (aka. parallel-split SM)





Single shadow map, 2048x2048



Four 1024x1024 shadow maps (equal memory)

Fan Zhang, Chinese U. Hong Kong

# Filtering shadow maps

**Shadow map lookups cause aliasing, need filtering**

**As with normal maps, pixel is a nonlinear function of the shadow depth**

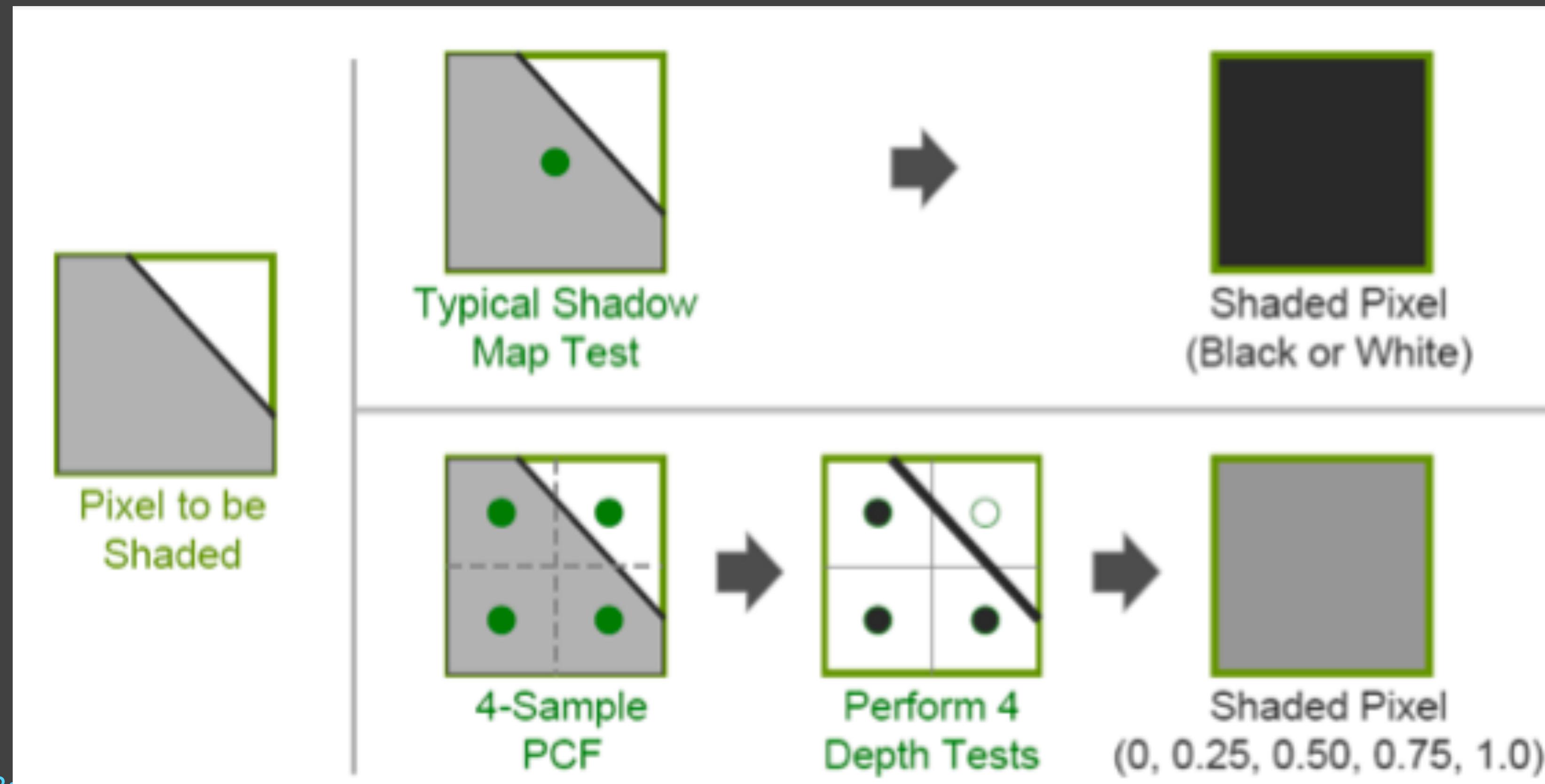
- this means applying a linear filter to the depth is wrong

**We want to filter the output, not the input, of the shadow test**

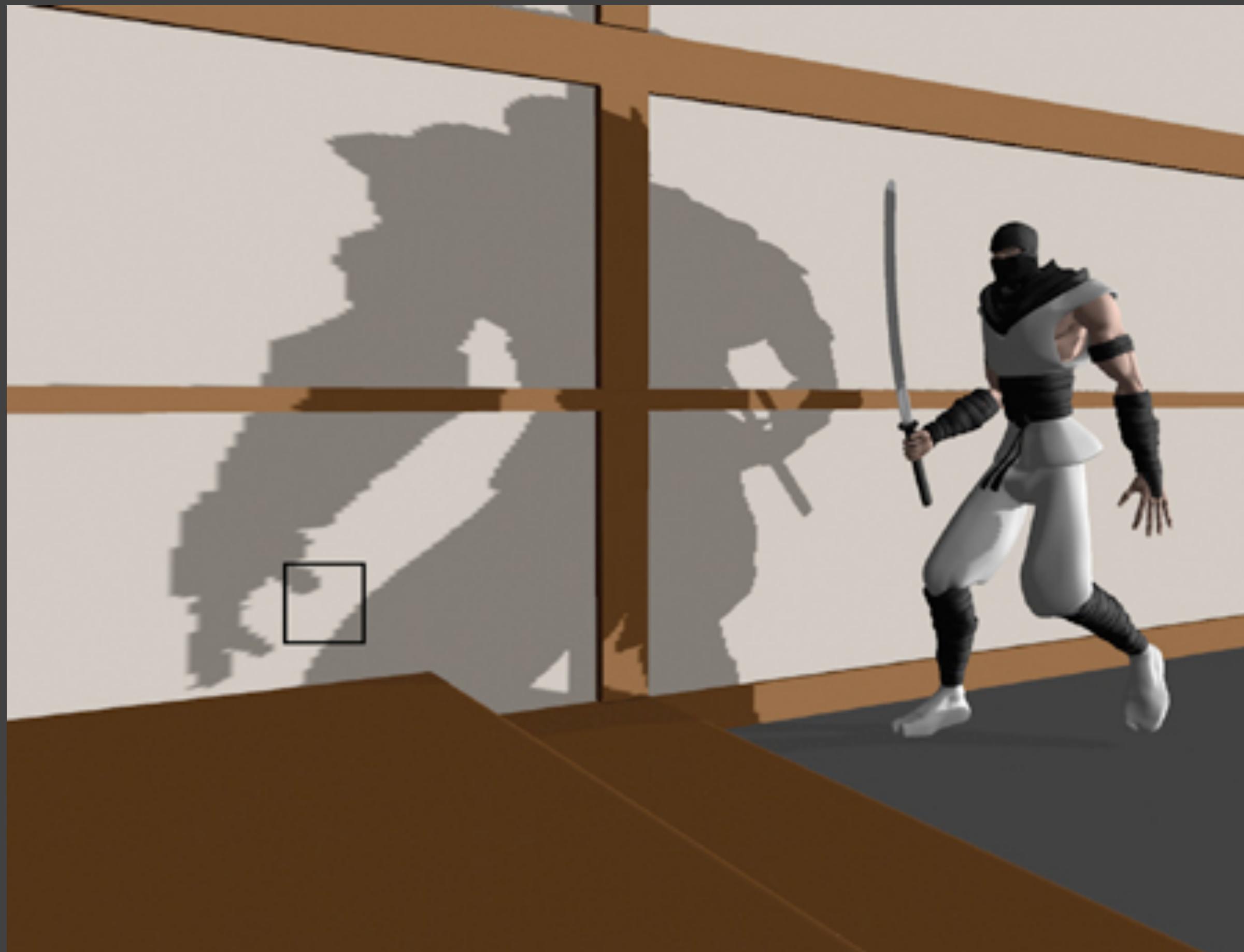
- what fraction of samples pass the test
- samples pass the test if they are closer than the shadow map depth
- therefore “percentage closer filtering” or PCF

# Percentage Closer Filtering

- Soften the shadow to decrease aliasing
  - Reeves, Salesin, Cook 87
  - GPU Gems, Chapter 11



# 1 sample SM

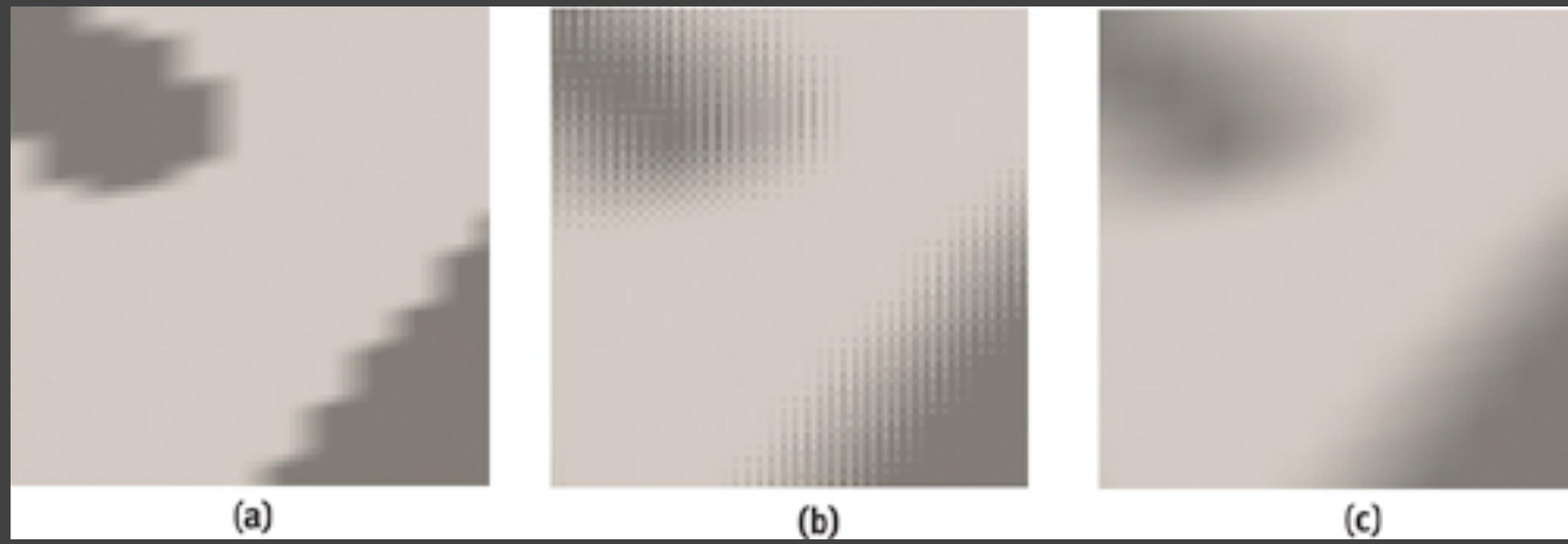


# 4 sample PCF



# 16 sample PCF





# Soft shadows from small sources

## **Main effect is to blur shadow boundaries**

- PCF can do this
- ...but how wide to make the filter?

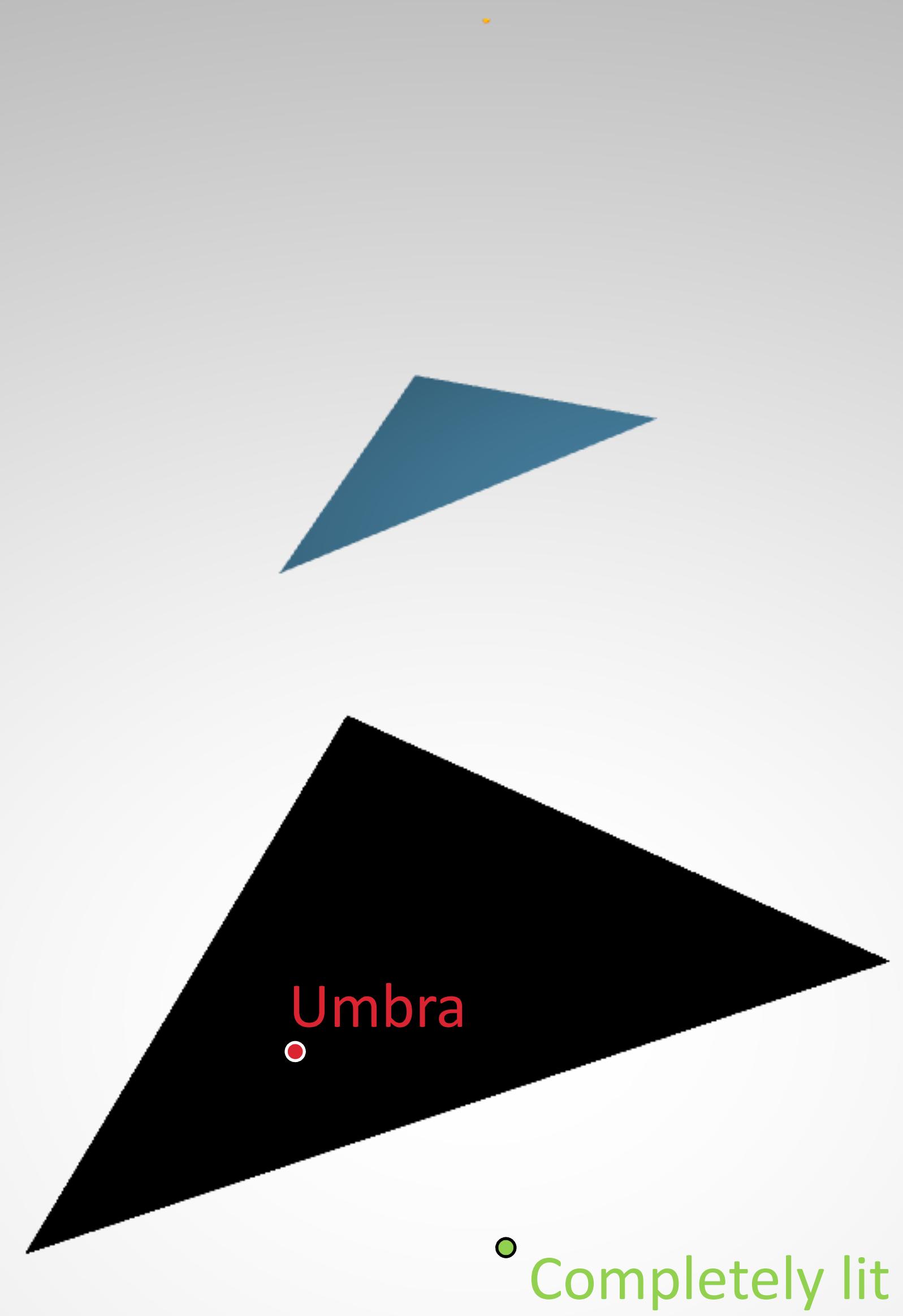
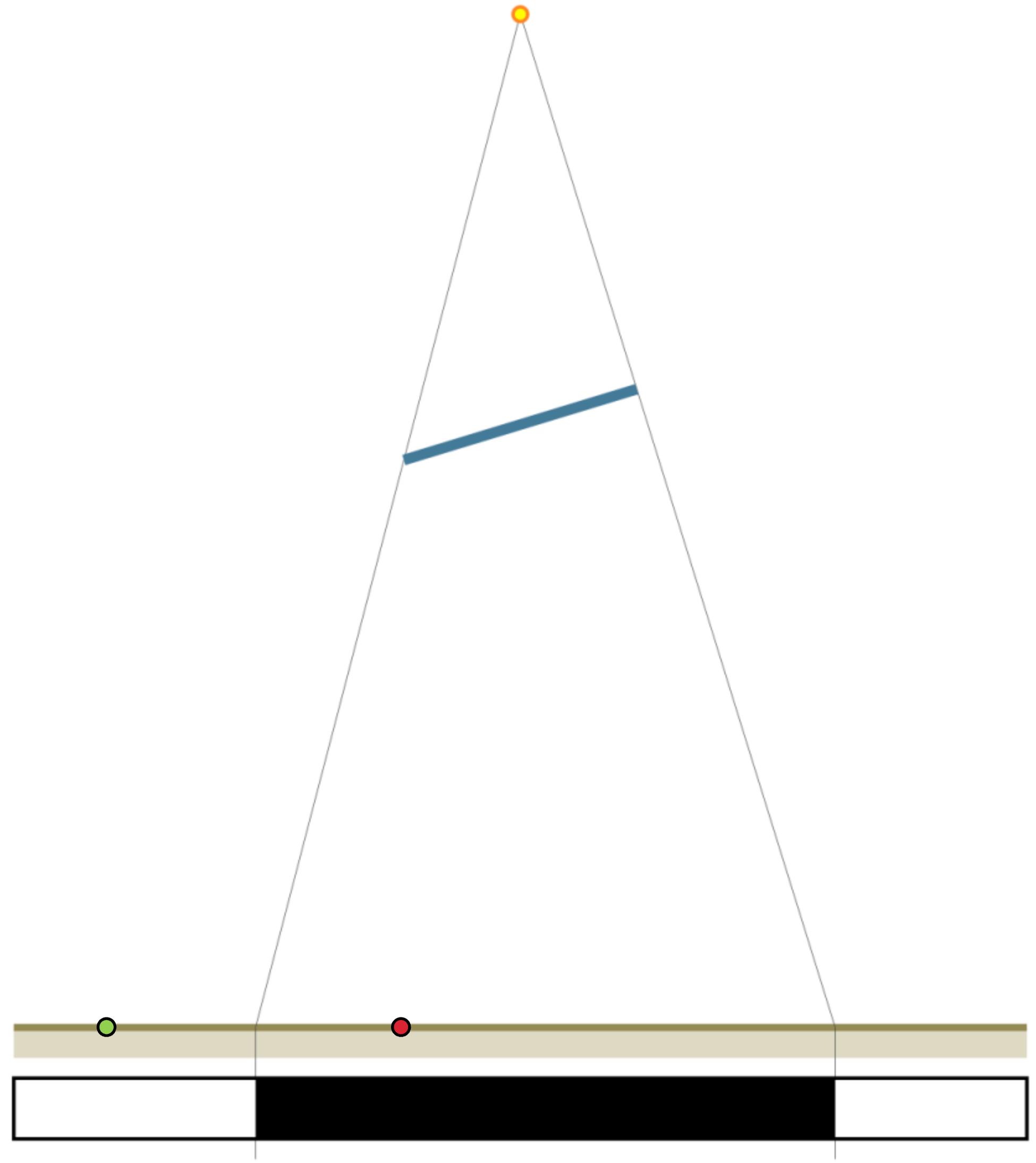
## **Real shadows depend on area of light visible from surface**

- this can vary in complex ways
- example: sun viewed through leafy trees

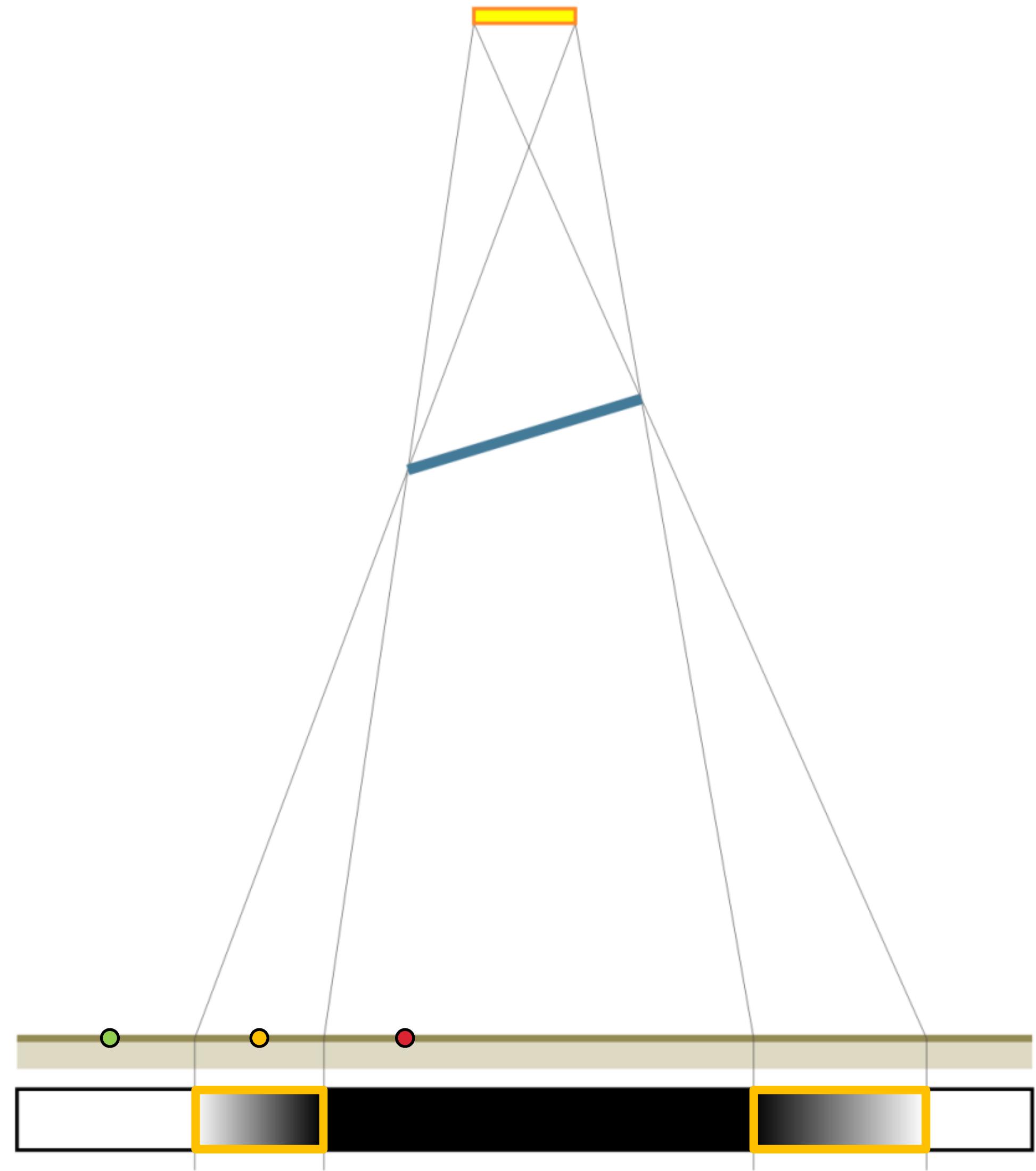
## **Useful approximation: convolution**

- shadows are convolutions when the blocker and source are parallel and planar
- occluder fusion: approximating some occluding geometry as a planar blocker

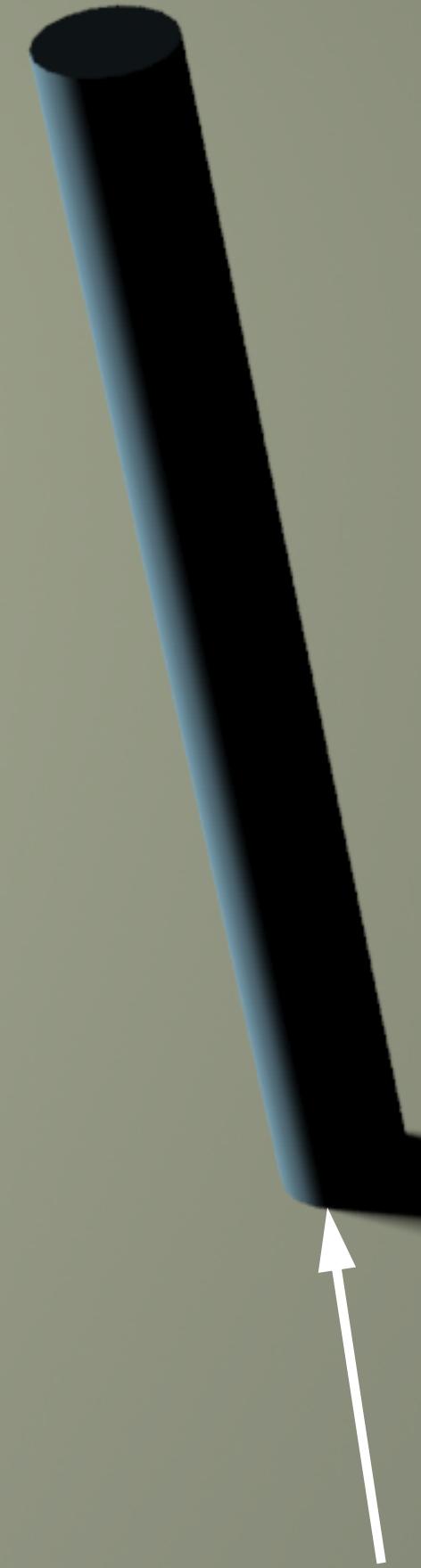
# Hard Shadows



# Soft Shadows

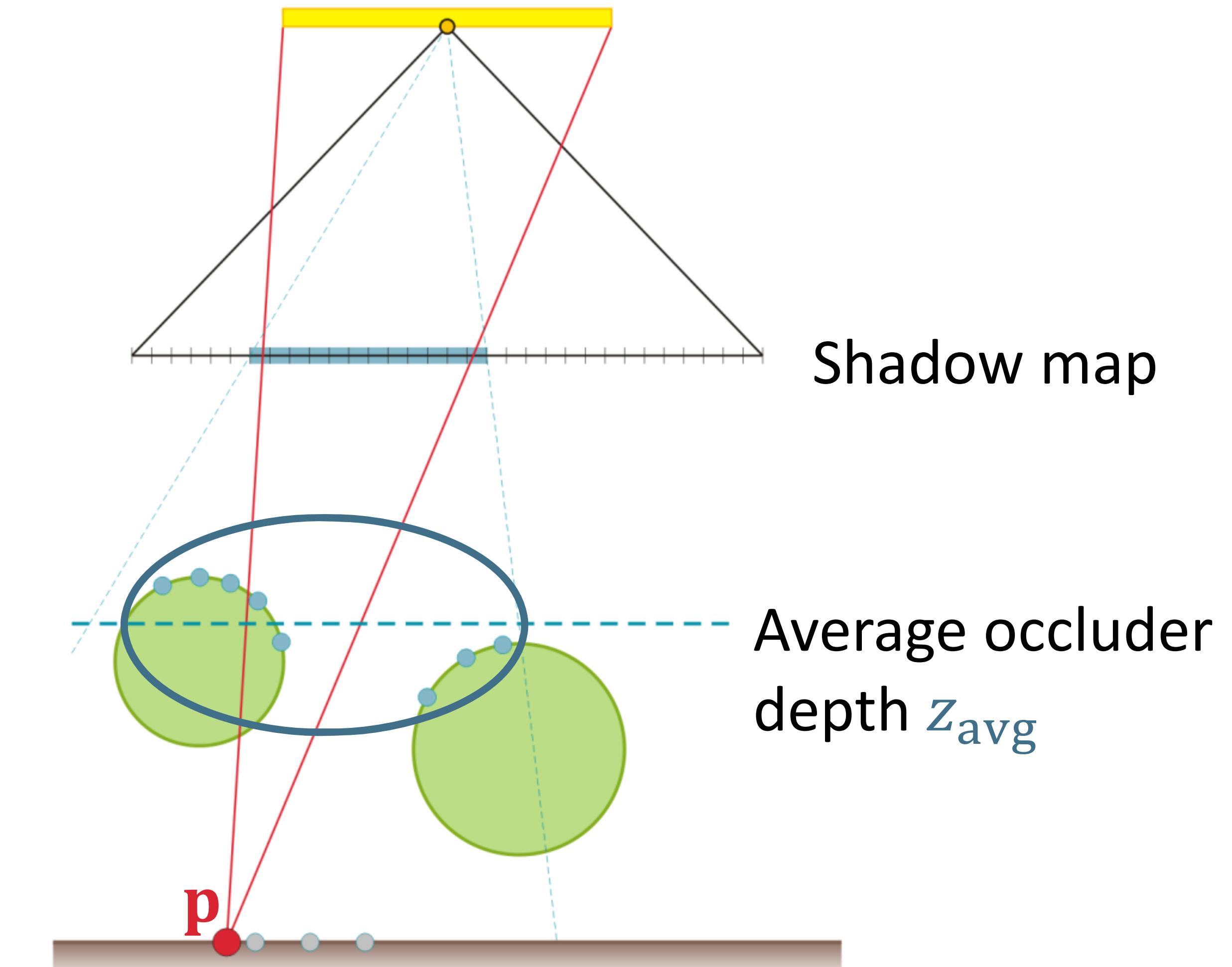


# Shadow Hardening on Contact



# Percentage-Closer Soft Shadows

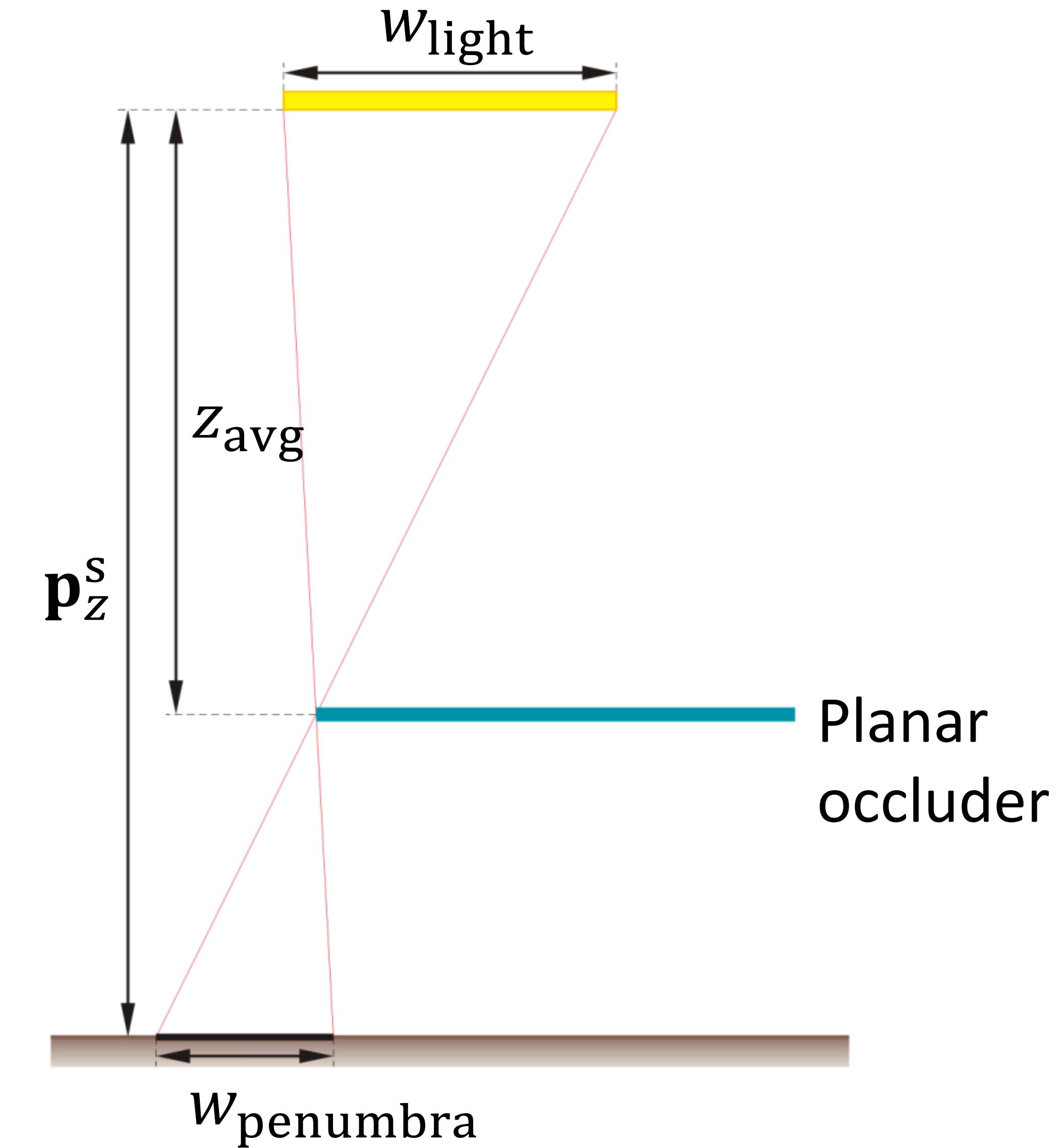
## 1. Blocker search



# Percentage-Closer Soft Shadows

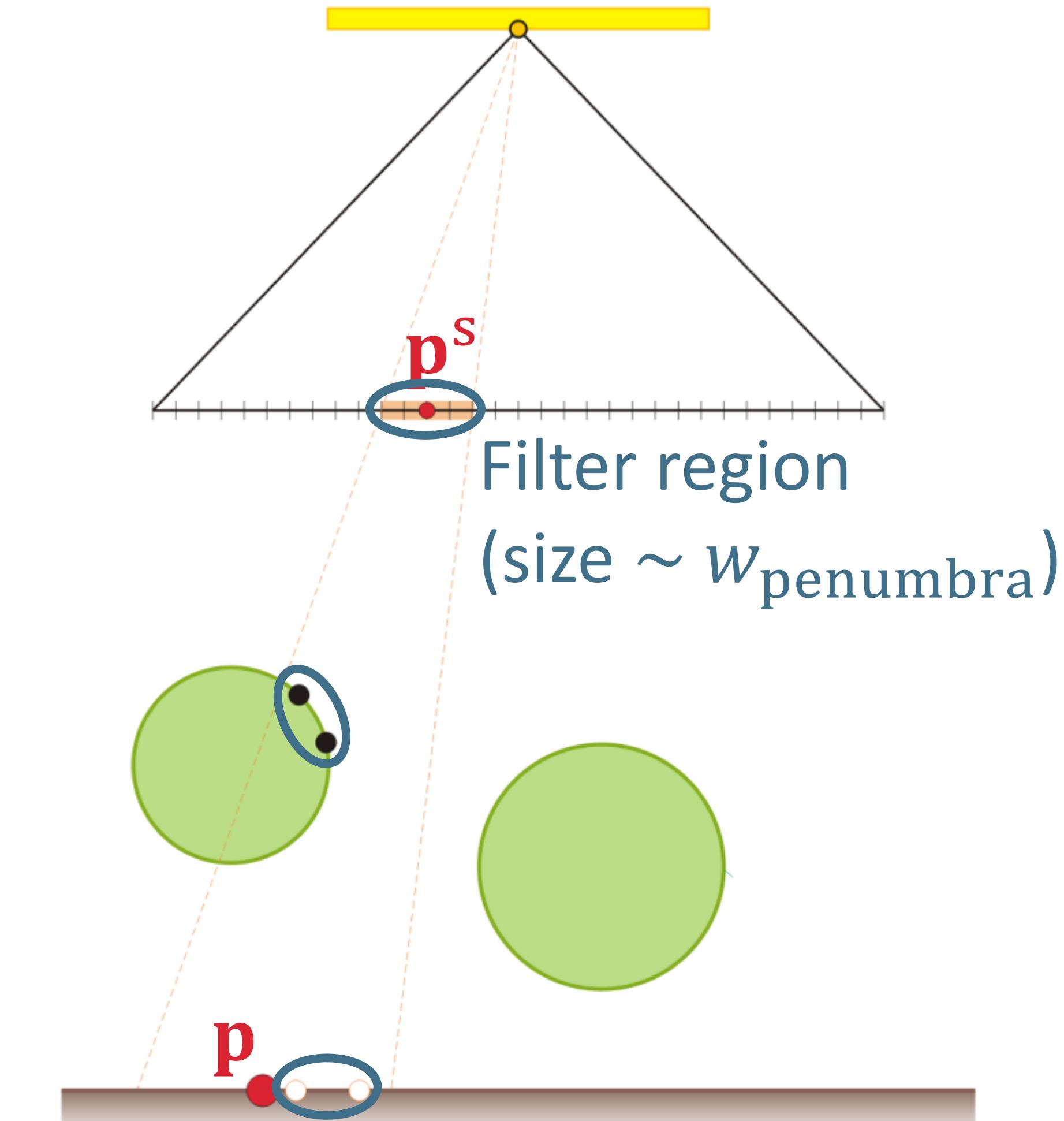
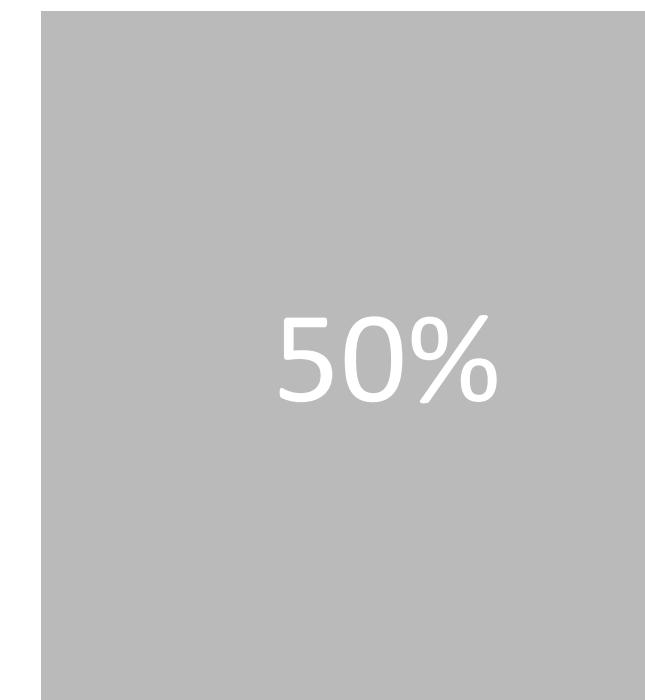
1. Blocker search
2. Penumbra width estimation

$$w_{\text{penumbra}} = \frac{p_z^s - z_{\text{avg}}}{z_{\text{avg}}} w_{\text{light}}$$



# Percentage-Closer Soft Shadows

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



# Percentage-closer soft shadows



Fernando, NVidia whitepaper ~2005