Computer Graphics 11 - Shadows

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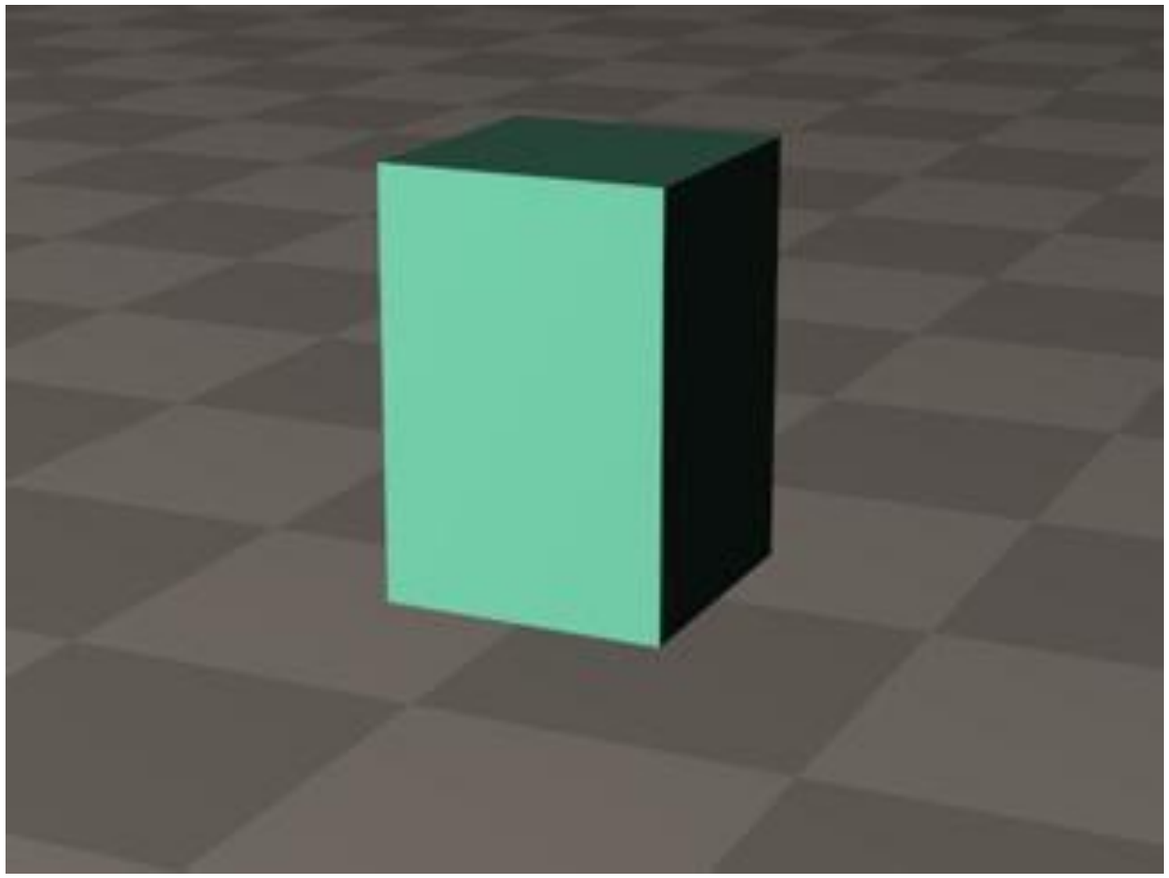
Slides courtesy of Taku Komura
www.inf.ed.ac.uk/teaching/courses/cg

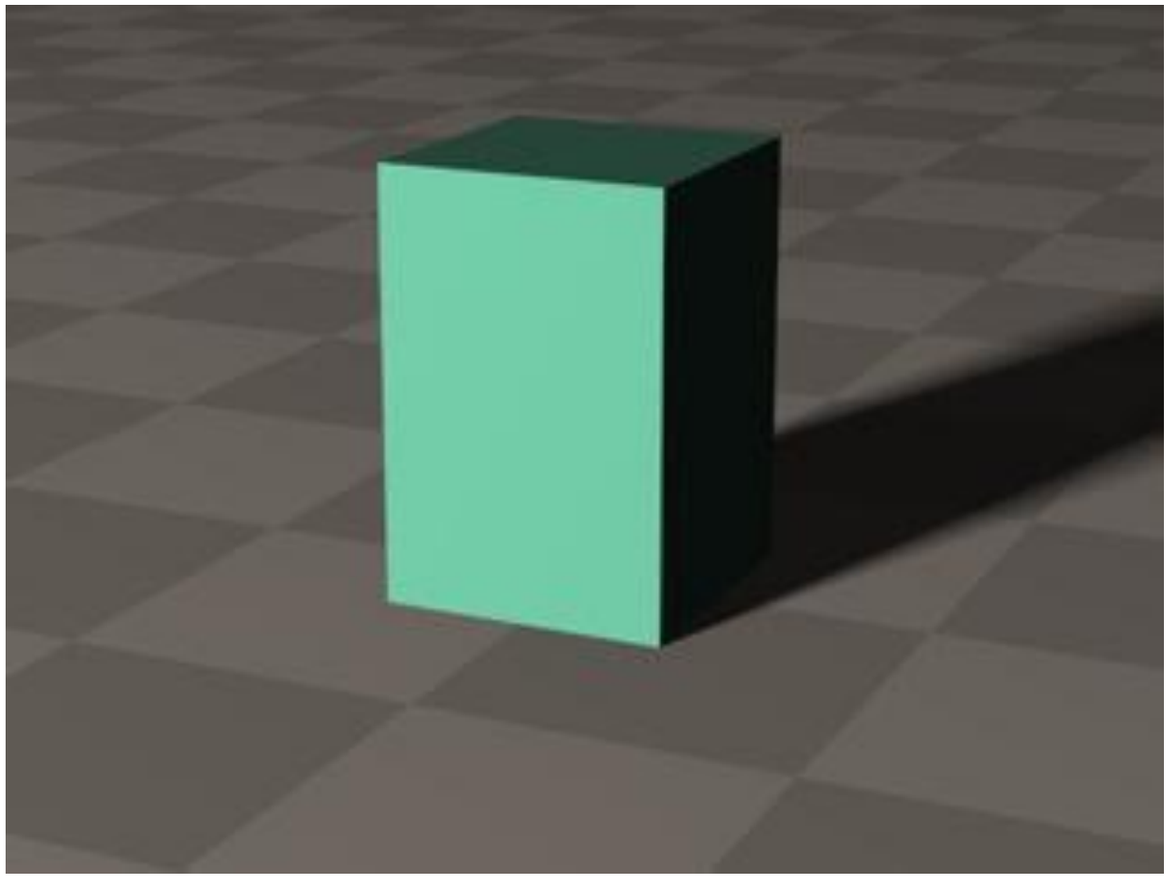
Overview

- Shadows
  - **Overview**
  - Projective shadows
    - Shadow textures
    - Shadow volume
    - Shadow map
    - Soft shadows

Why Shadows?

- Shadows tell us about relative locations and movements of objects

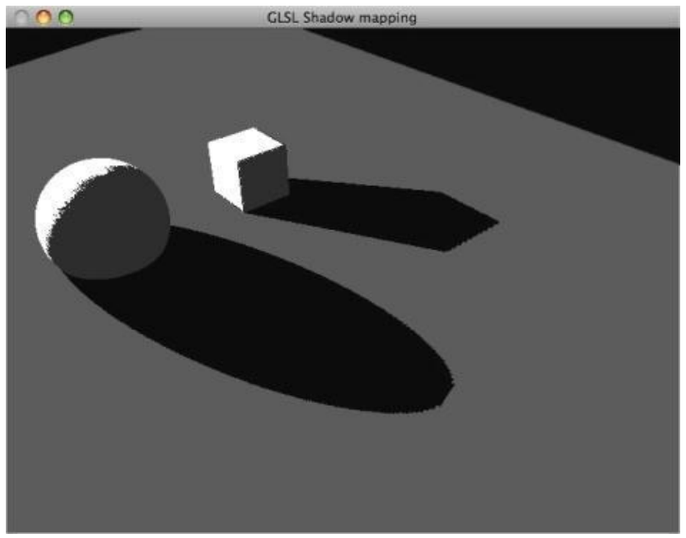




http://gandalf.psych.umn.edu/users/kersten/kersten-lab/images/ball-in-a-box.mov

What are shadows?

- Shadows can be considered as areas hidden from the light source

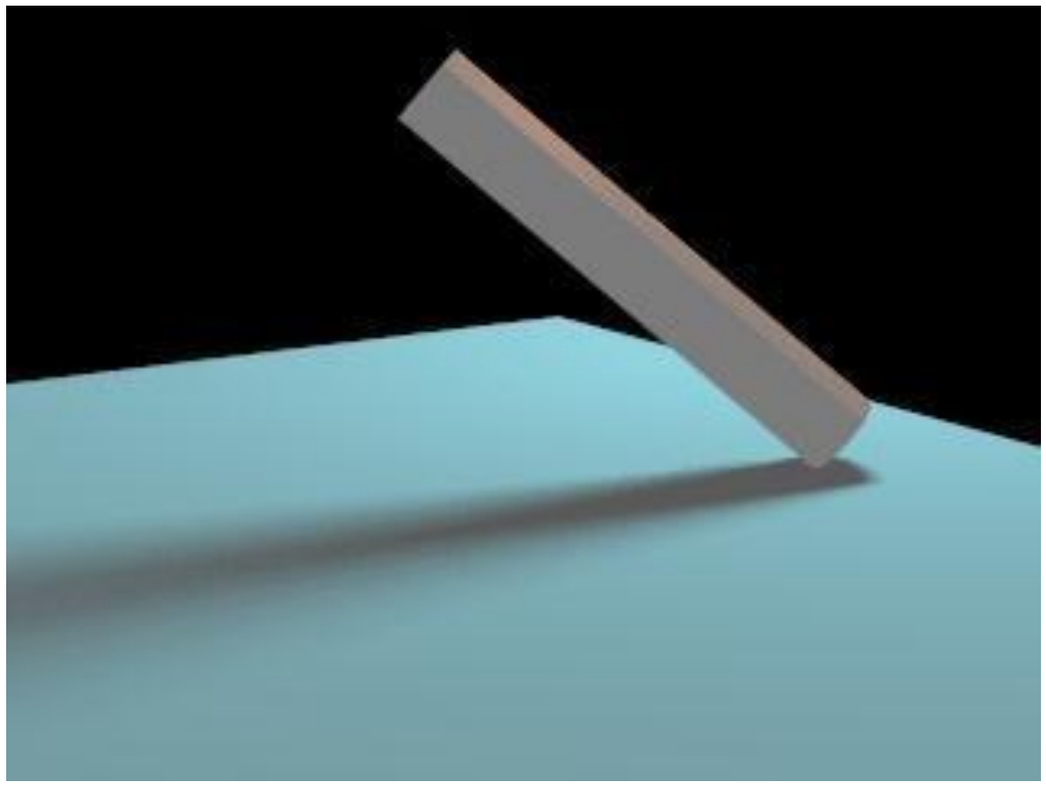


- We can find shadows on a surface A due to object B by projecting B onto A, with the light source as center of projection

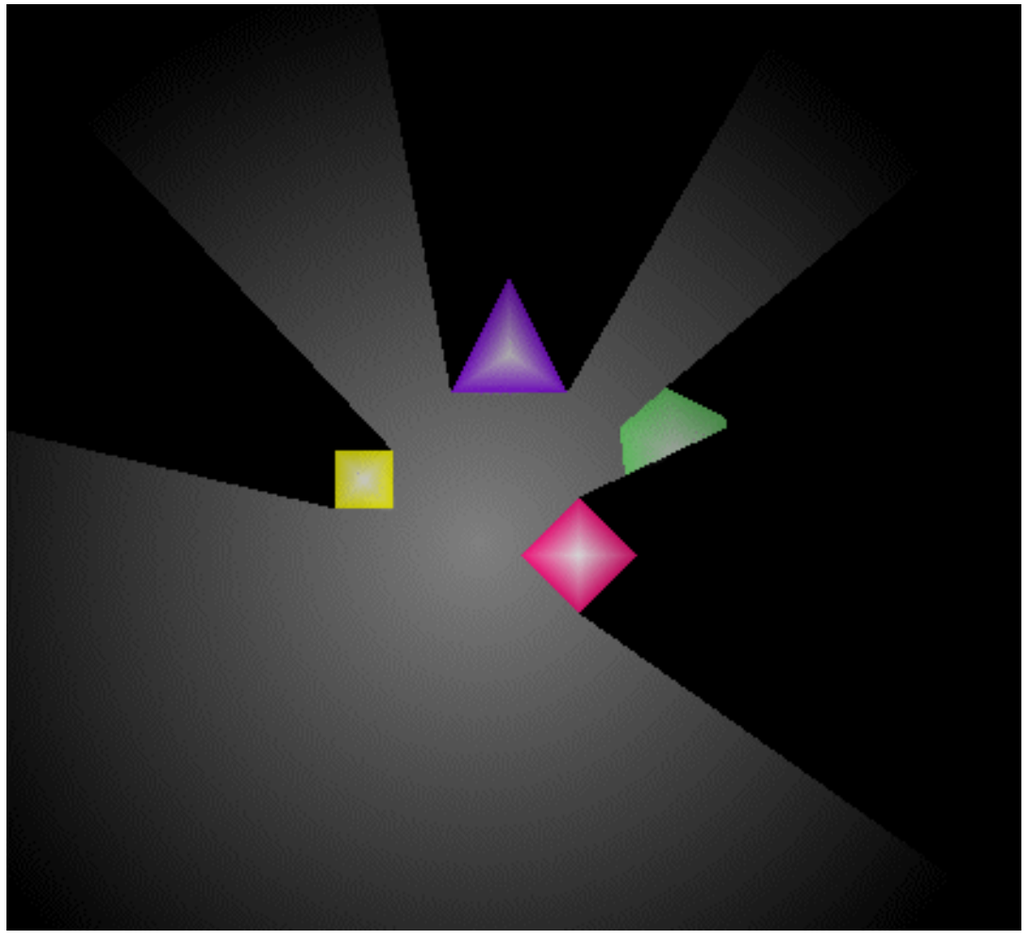
Soft and hard shadows

- Point light sources have hard edges, area lights have soft edges

Soft shadows

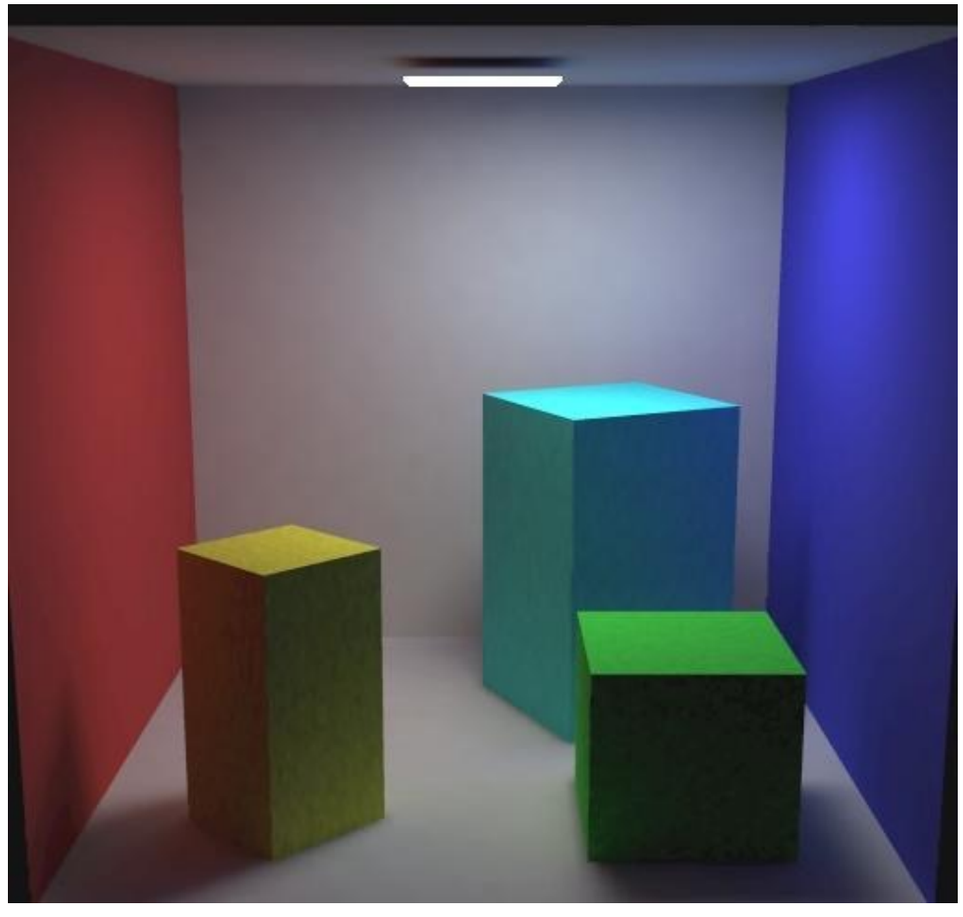


Hard shadows



Rendering shadows

- Rendering shadows is important, but not straightforward
- Precise rendering requires ray tracing or global illumination, which are computationally very expensive
- In order to avoid these techniques many approaches have been proposed for the rasterisation pipeline
  - Projective Shadows
  - Shadow textures
  - Shadow volumes
  - Shadow maps
  - Soft shadows



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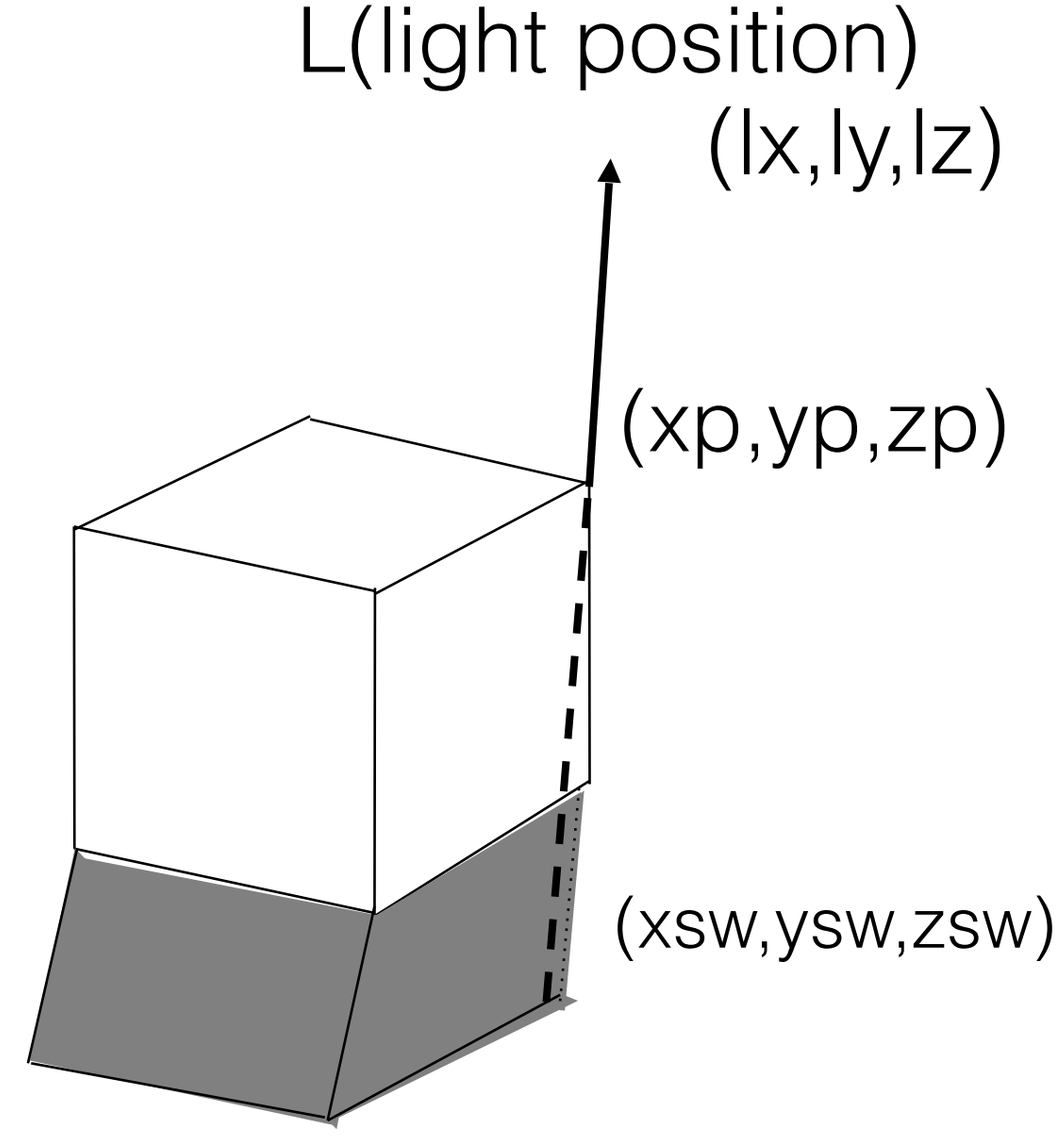
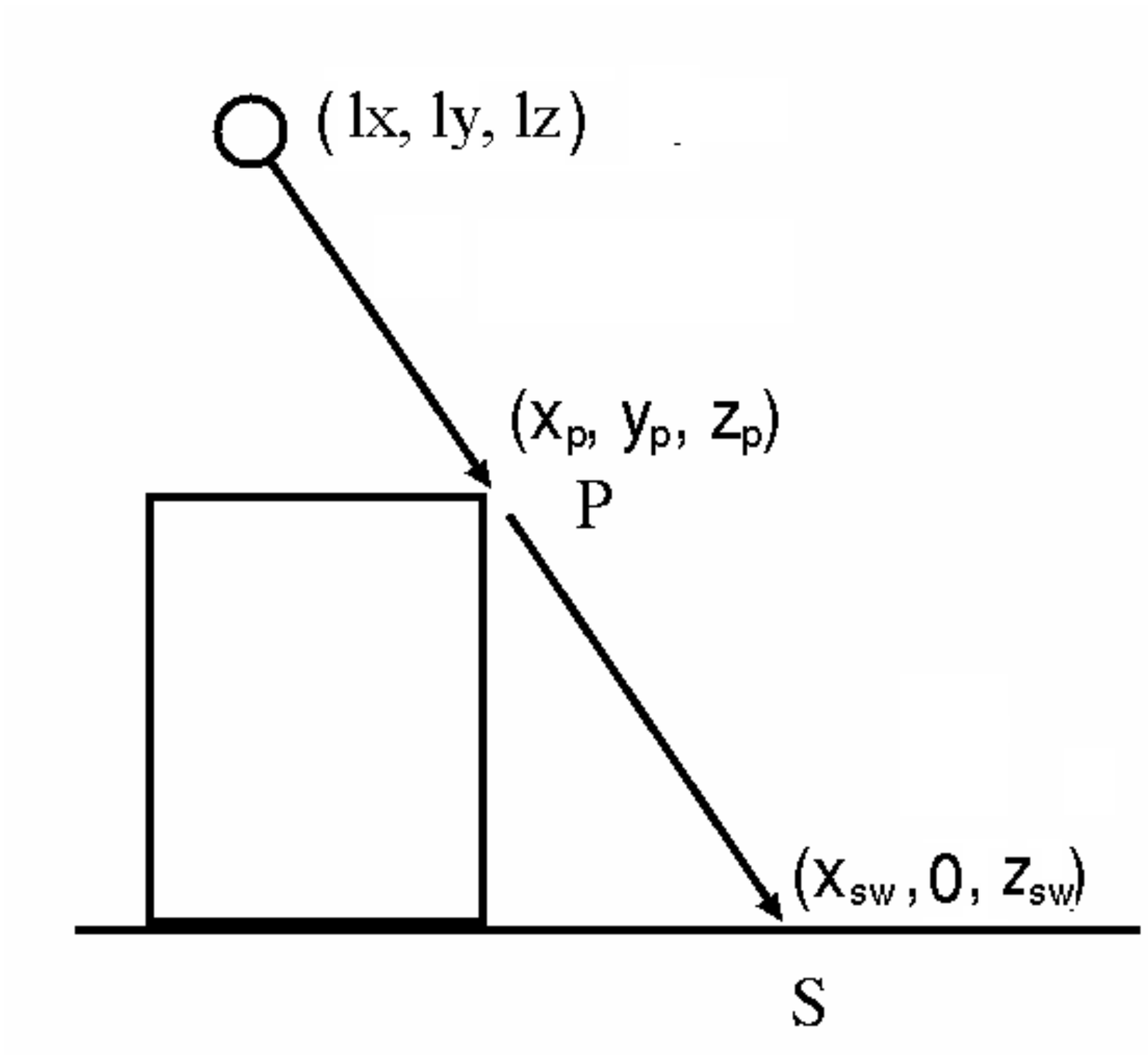
Projective shadows

- Shadows on planes from point light sources

- Relatively easy to compute



Point light shadows



Point light shadows

- Blinn '88 gives a matrix that works for local point light sources (based on projection)
- Takes advantage of perspective transformation (and homogeneous coordinates)

$$\begin{bmatrix} x_{sw} \\ 0 \\ z_{sw} \\ 1 \end{bmatrix} = \begin{bmatrix} l_y & -l_x & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -l_z & l_y & 0 \\ 0 & -1 & 0 & l_y \end{bmatrix} \begin{bmatrix} x_p \\ y_p \\ z_p \\ 1 \end{bmatrix}$$

Drawing shadows

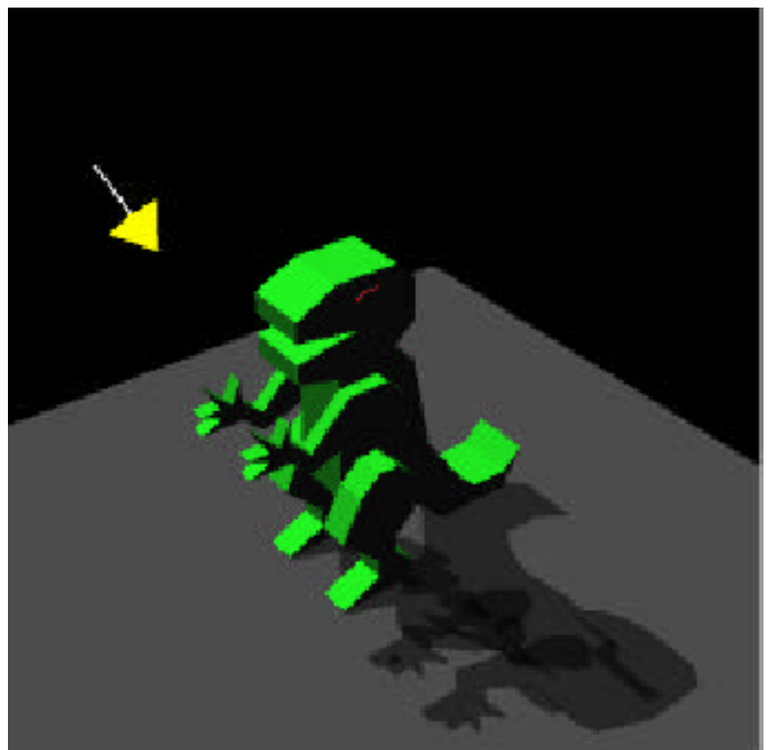
- We have a matrix that transforms an object into it's shadow
- Drawing the shadow:
  - Multiply the shadow matrix by the model transformation
  - Redraw the object translucently in grey

$$v' = M_s M_{g \leftarrow l} v$$

shadow vertex

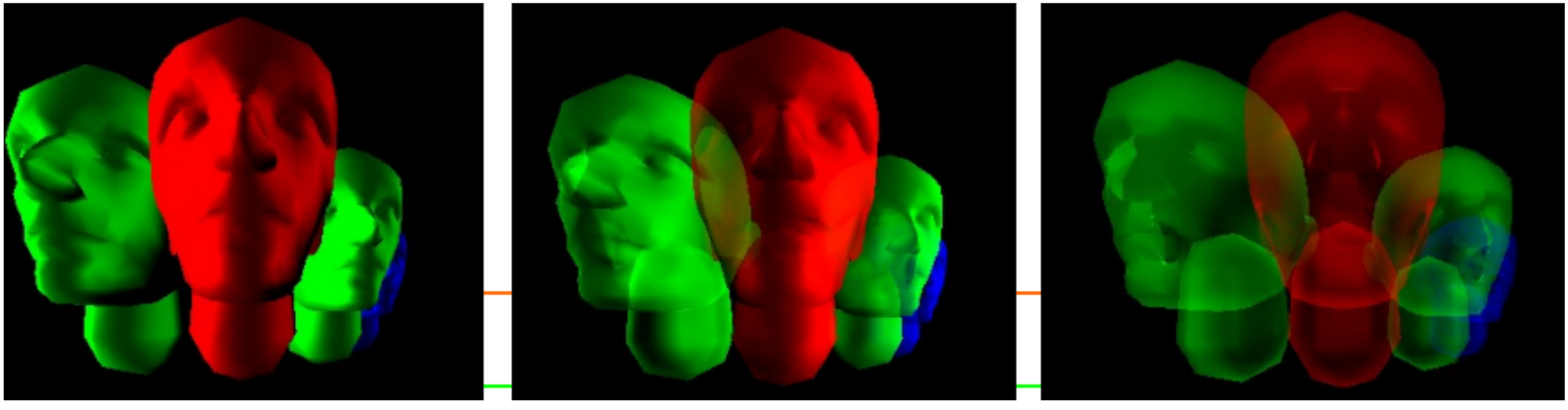
shadow matrix

point in local coordinates

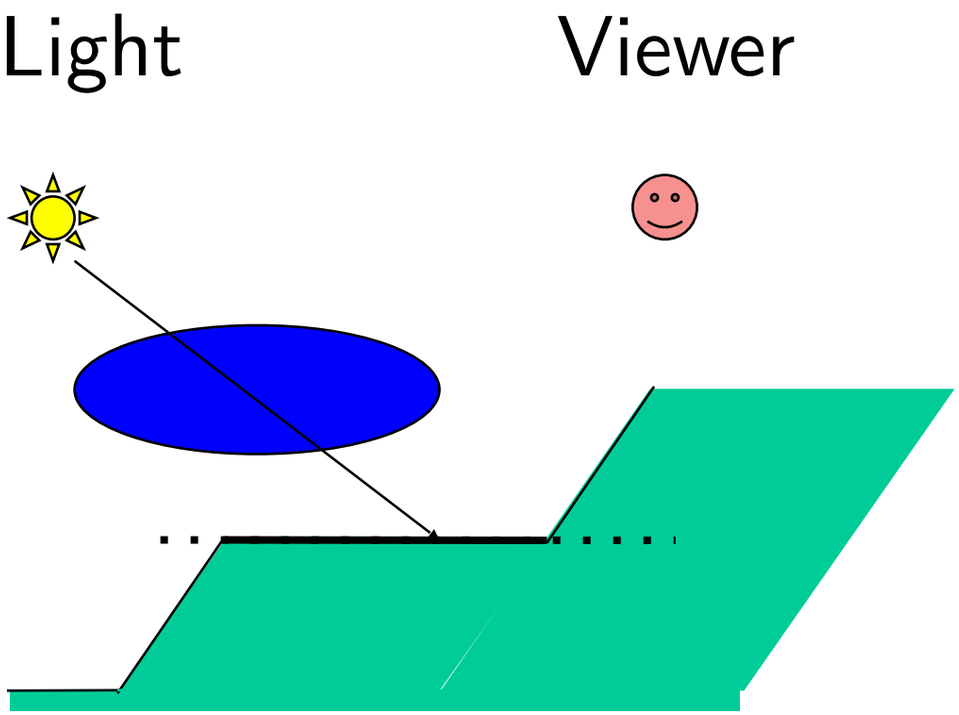


Alpha blending

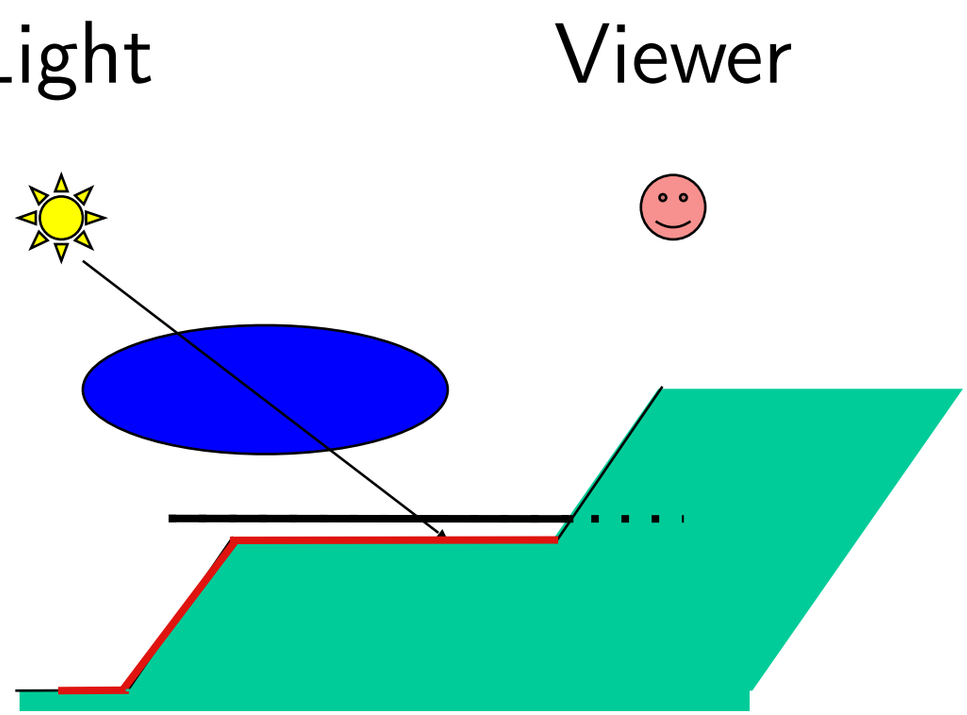
- A technique to render semi-transparent objects
- Will cover more in the following lecture



Lifting above the surface



Shadow on hit polygon

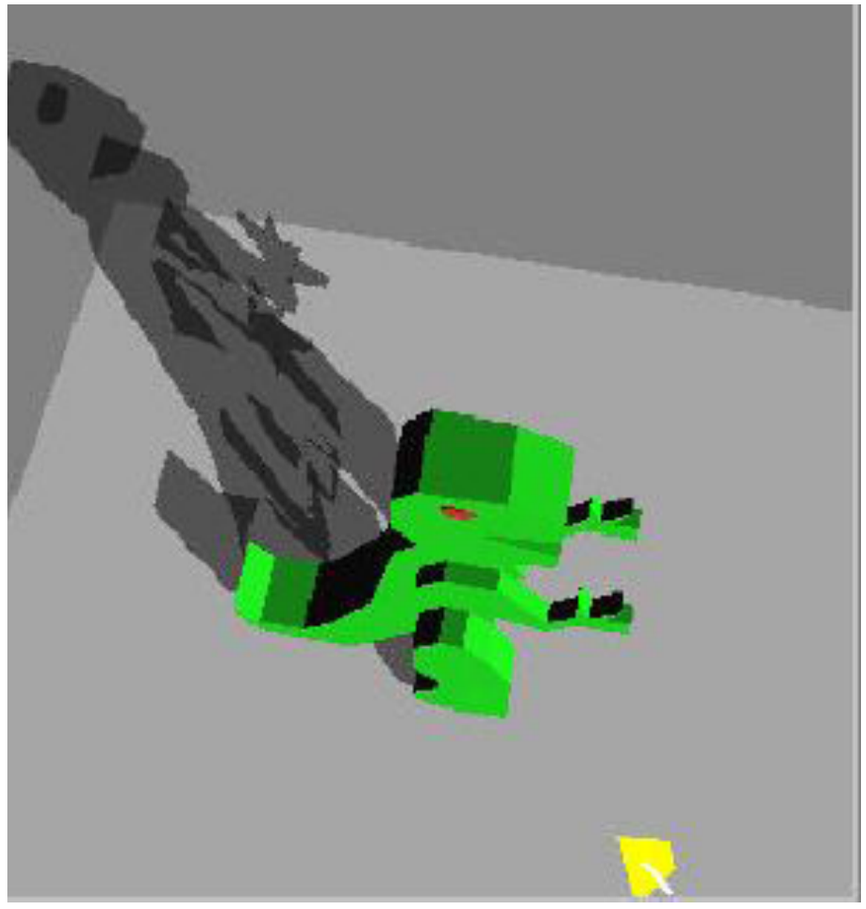


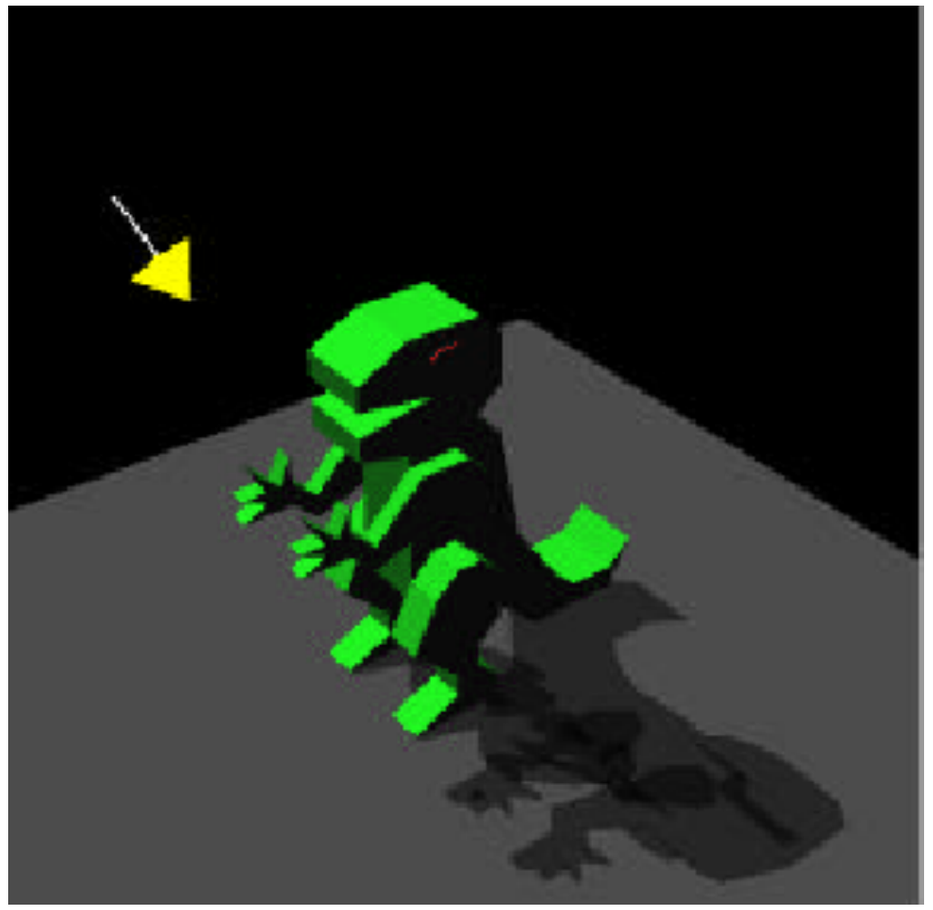
Shadow positioned above hit polygon

- Trick - lift the shadow off the plane to avoid Z-buffer quantisation errors

Point shadow problems

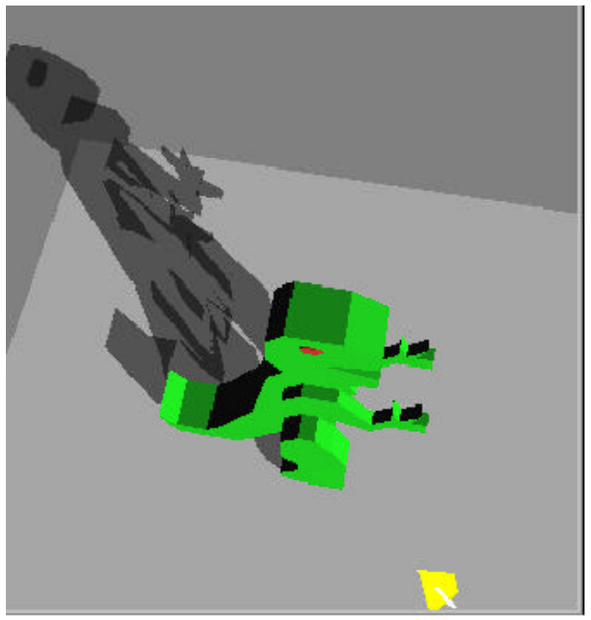
- Shadows can only be cast onto planes and not arbitrary objects
- The resulting shadows have hard edges
- If there is texturing on the plane, grey shadows look bad
- If we use blending, areas where multiple polygons overlapping look darker
- Shadows need to be re-rendered at every frame

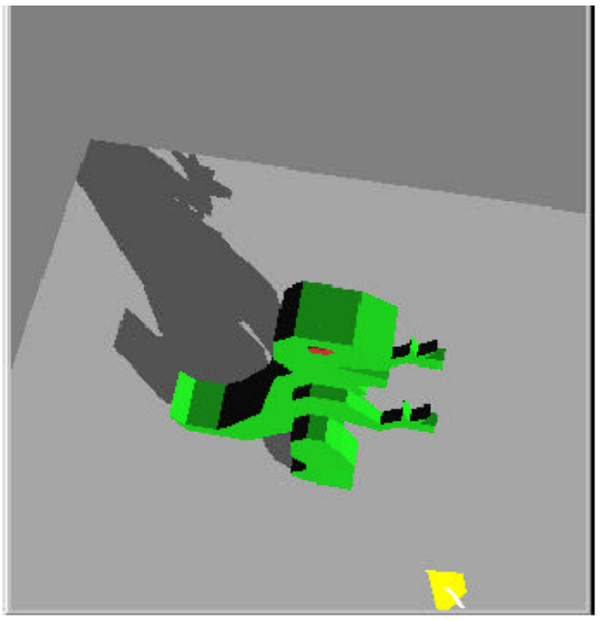




Improving projected shadows with a stencil

- Turn on the stencil for pixels on the plane
- Only render shadows on pixels with the stencil turned on
- After rendering the shadow, the stencil is set to zero
- No overdrawing with multiple polygons
- No need to lift shadows above the floor
- Shadows are not rendered outside the plane
- Still only works on planes...





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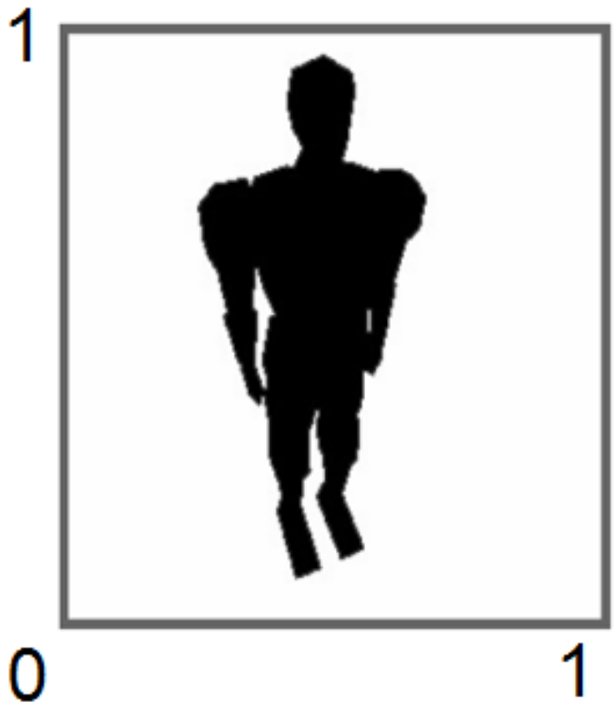
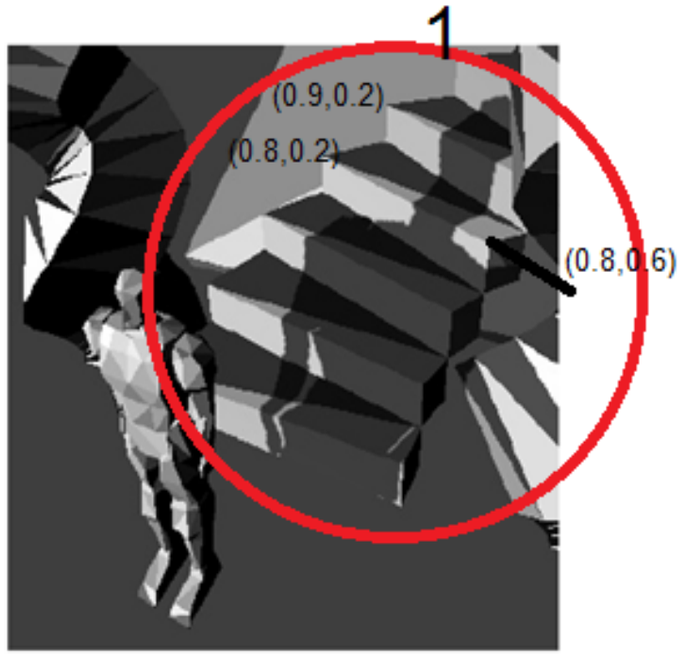
Shadow textures

- Use a shadow image as a projective texture
- Generate an image of the occluder from the light's point of view and colour it grey
- Produce a shadow by texture mapping this image onto the background object

Computing the uv coordinates

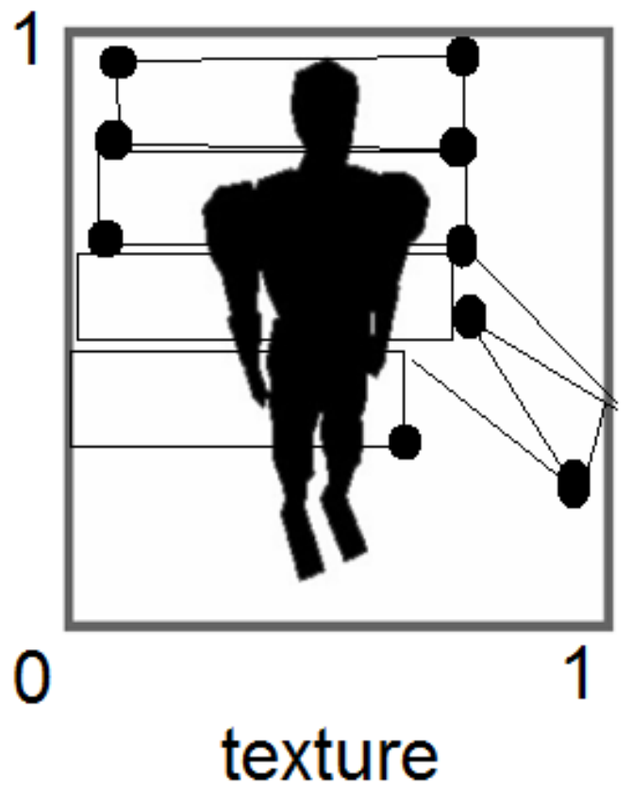
- To map the shadow texture, we need to know the uv coordinates of the texture at every vertex of the background mesh





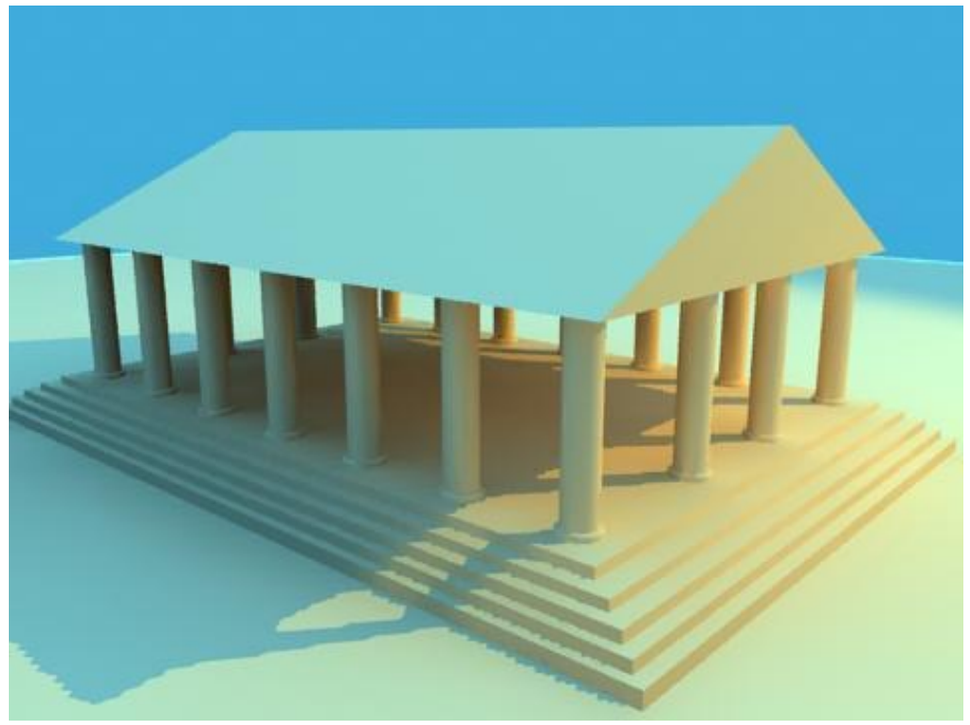
Computing the uv coordinates

- View the object from the light source
- Project the background object onto the projection plane used to produce the shadow texture
- Obtain the (x,y) coordinates and normalize
  - These become the uv coordinates

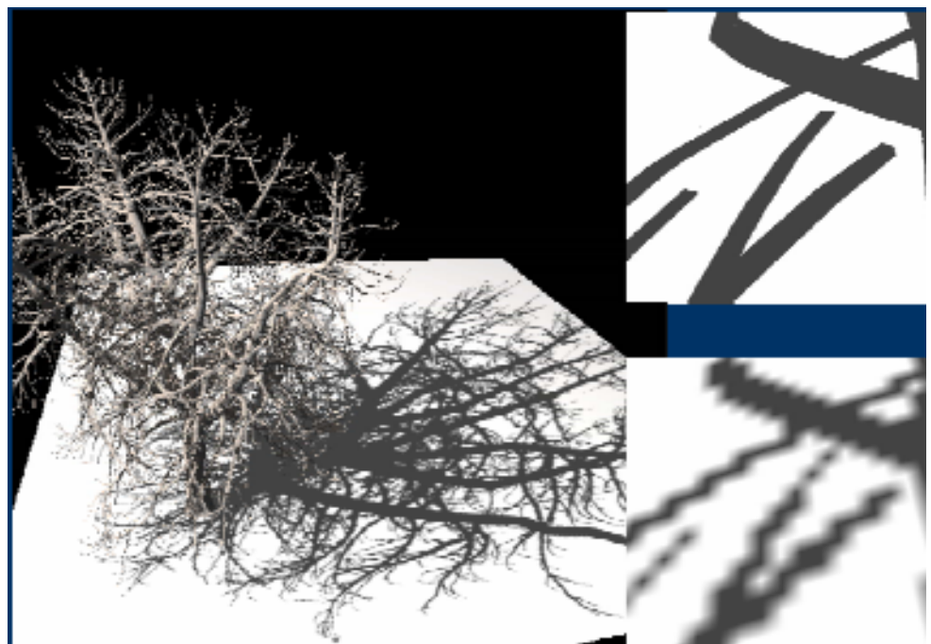


Shadow texture pros and cons

- Pros
  - The shadow does not need to be recomputed if the occluder does not move

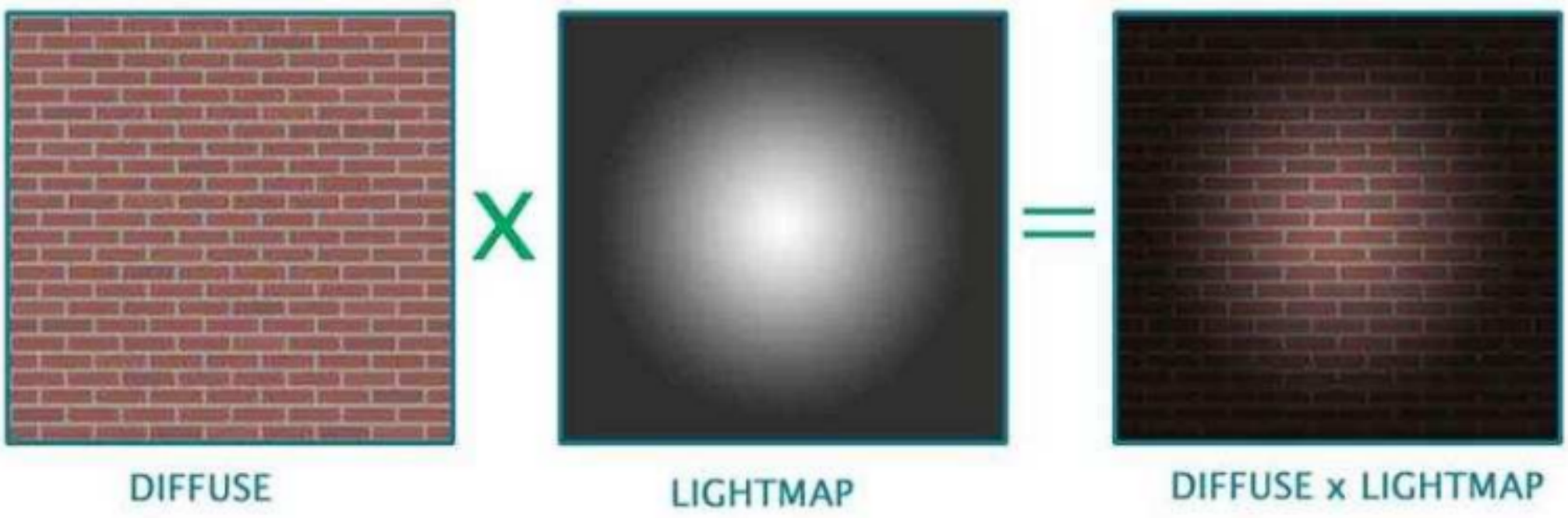


- Cons
  - ?



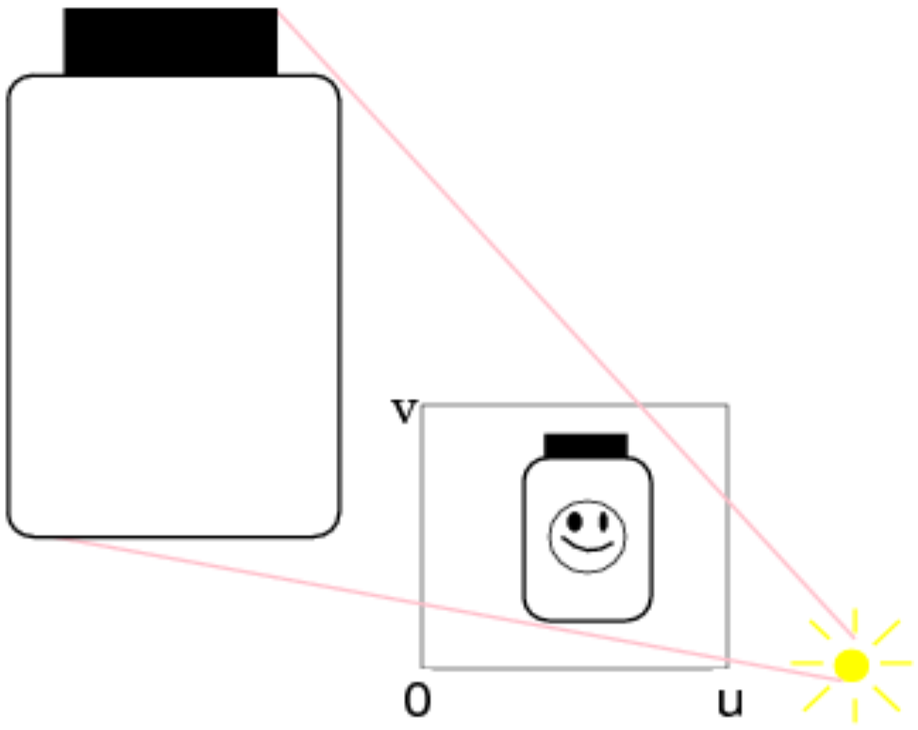
Light mapping

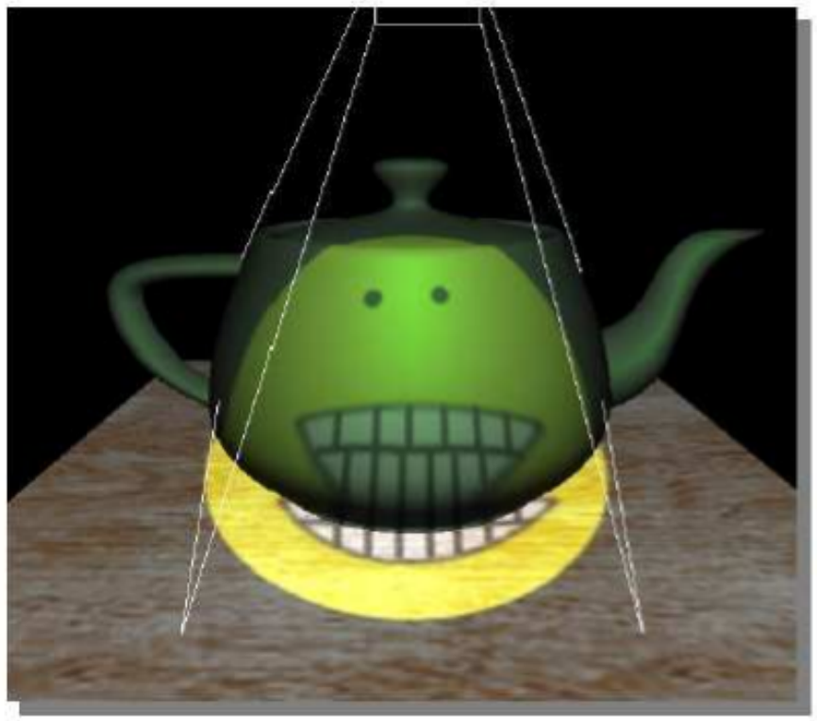
- Producing spotlight effects
- Difficult in traditional graphics pipeline
- Multiply light map by the original diffuse texture and map onto the surface

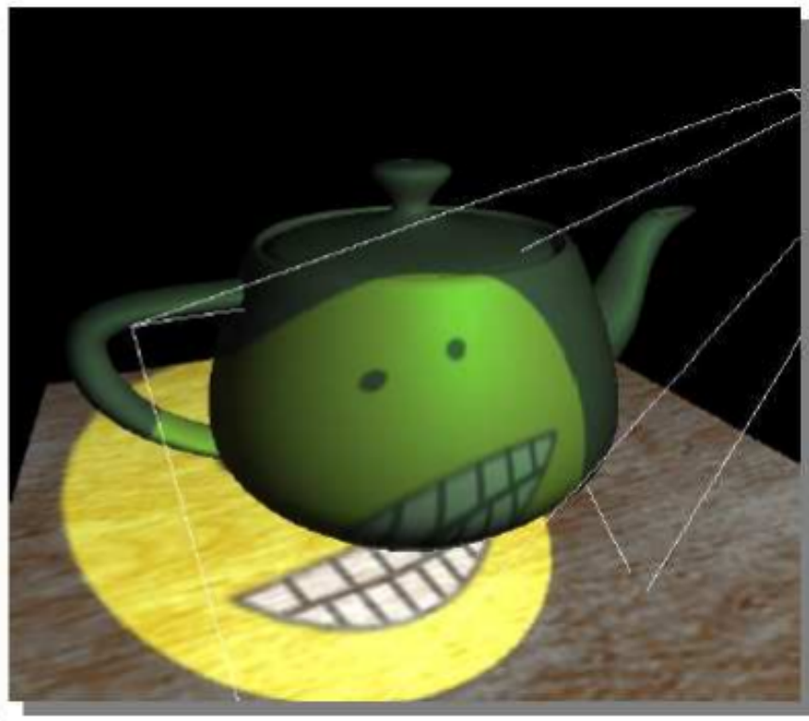


Light maps

- View the objects from the light source
- Compute the uv coordinates by projecting the object onto the screen space







Overview

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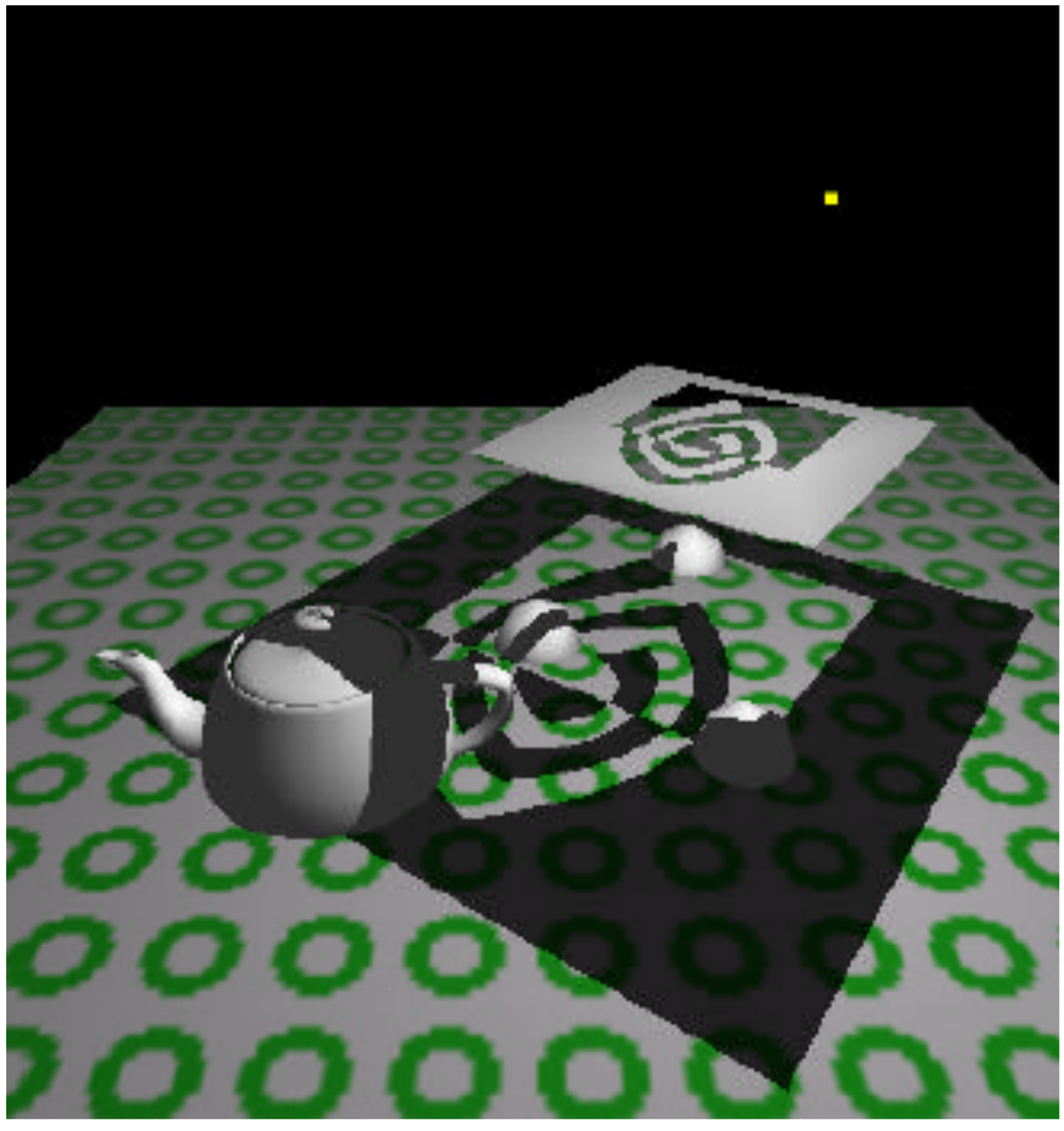
Shadow volumes

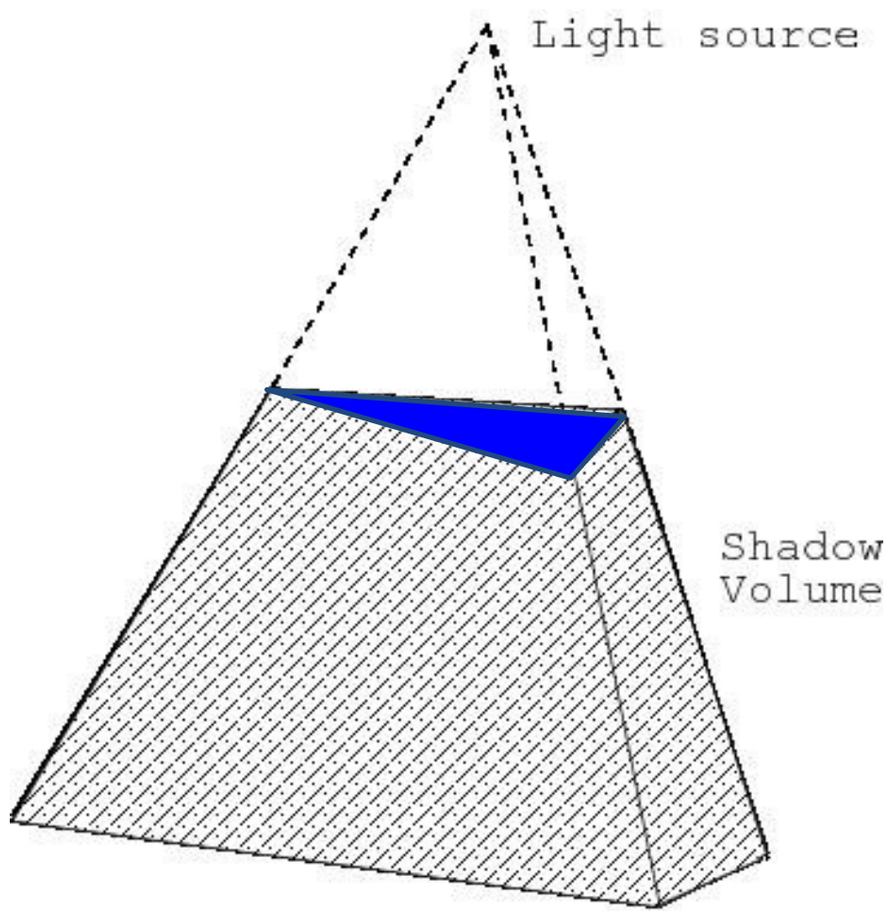
- In reality the shadow of an object is a volume rather than a two dimensional area on a plane

- Shadow volumes models shadow regions as volumes



Using shadow volumes

- Two stages:
  - Compute the shadow volume formed by a light source and the shadowing objects
  - Each triangle produces a shadow volume



Using shadow volumes

- Two stages:
  - Compute the shadow volume formed by a light source and the shadowing objects
  - Each triangle produces a shadow volume
- Check whether a point is inside/outside the shadow volume
- Inside -> shadowed
- Outside -> illuminated

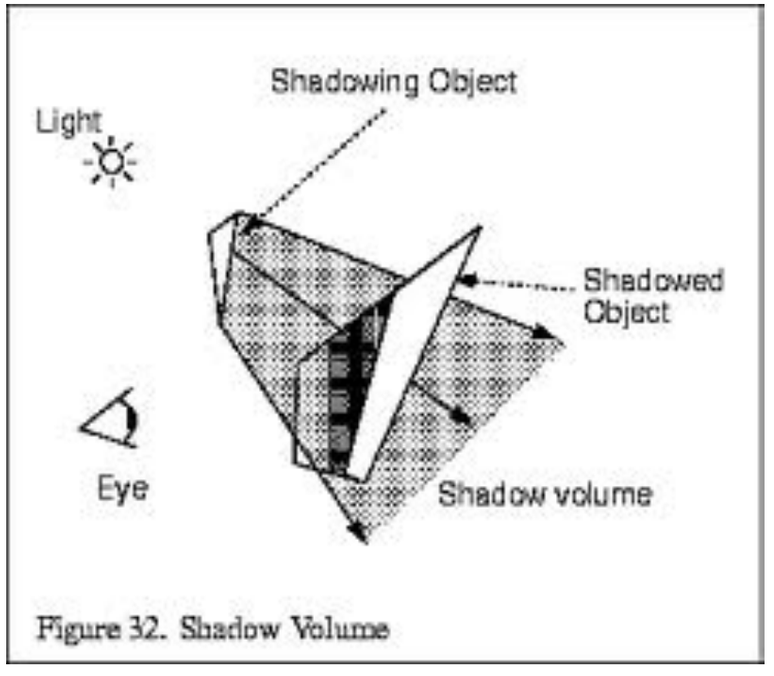
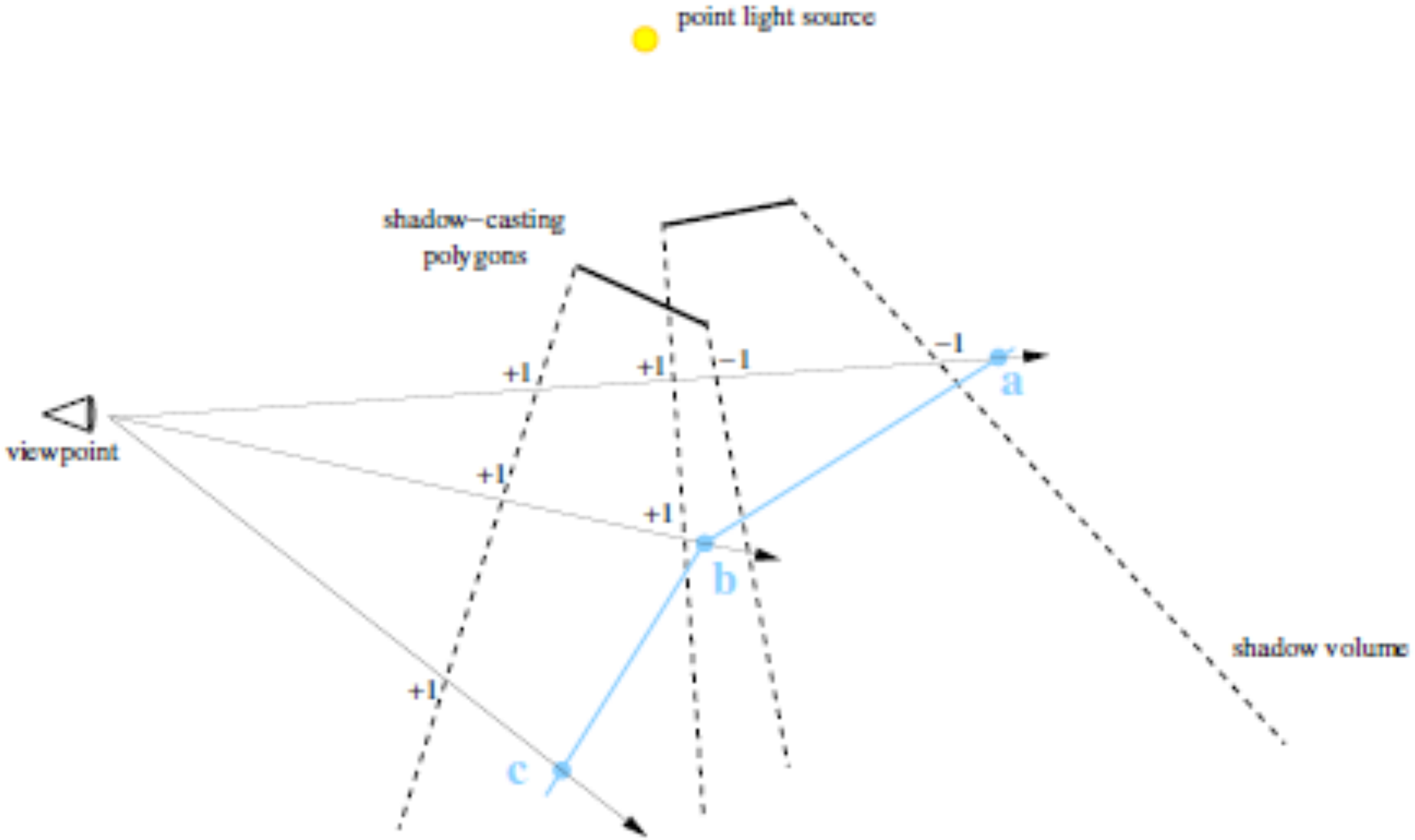
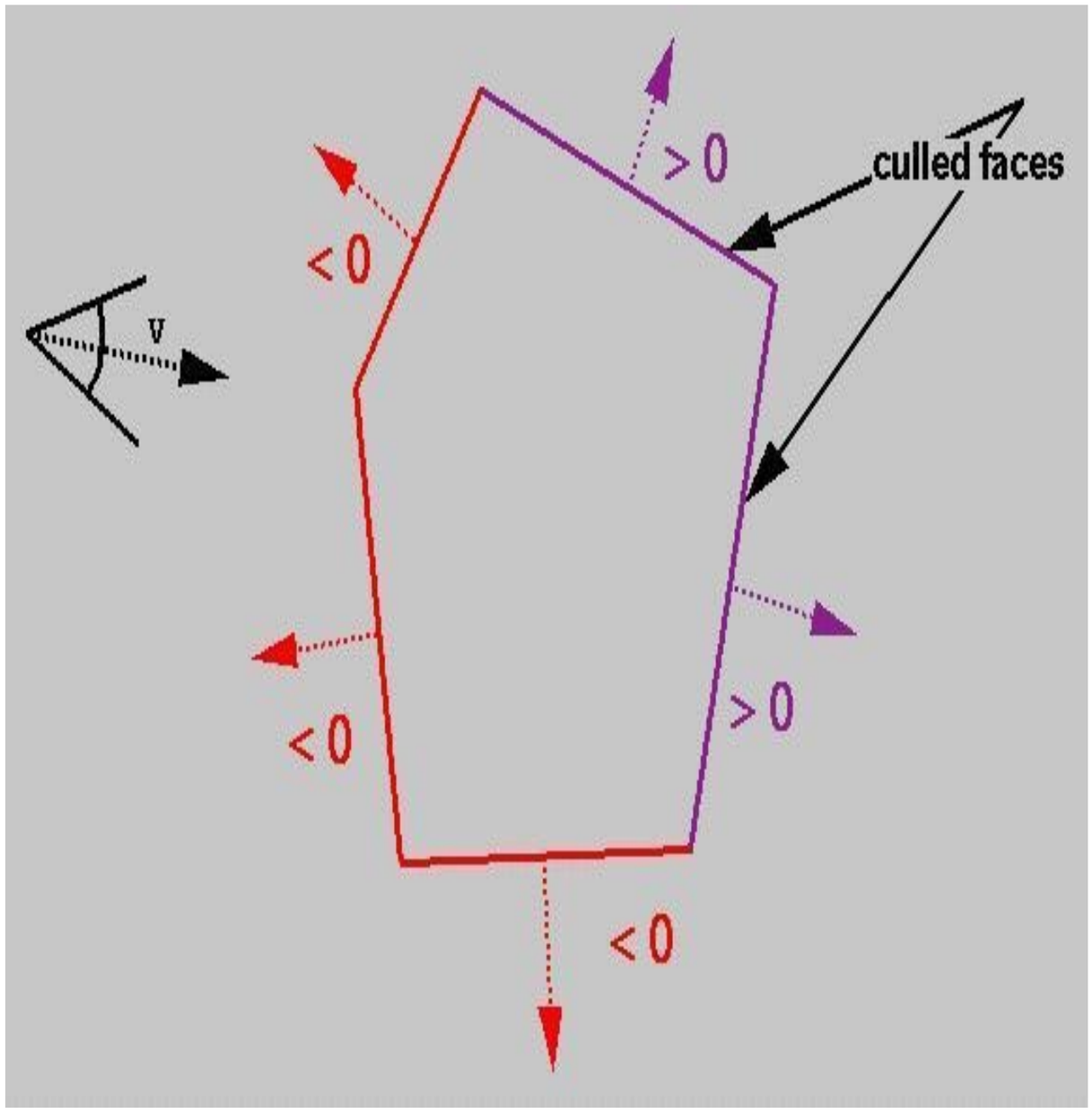


Figure 32. Shadow Volume


point light source
shadow–casting
polygons
viewpoint
+1
+1
−1
−1
+1
+1
+1
a
b
c
shadow volume

Back face culling

- We do not draw polygons facing the other direction
- Test z component of surface normals, if it is negative then cull
- If N.V>0 we are viewing the back face

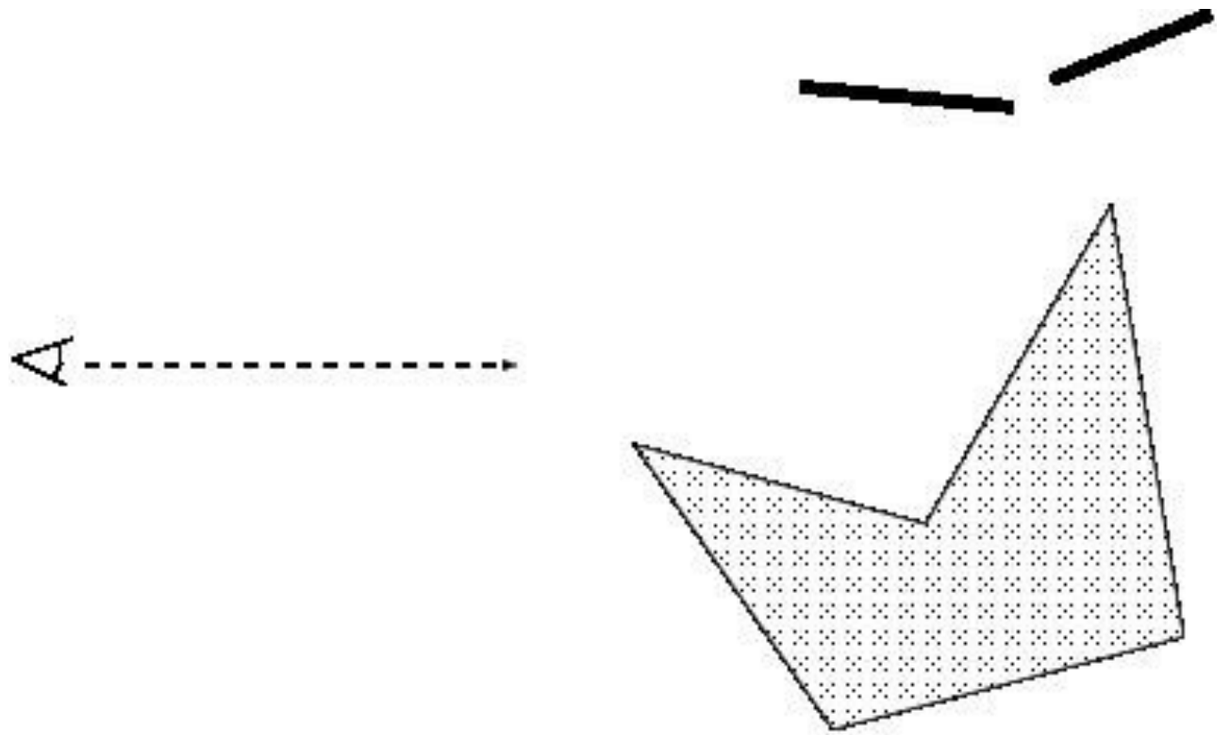


Shadow volumes with stencil buffers

- Render the scene with ambient light
- Clear the stencil buffer, and render the shadow volume with the colour buffer off and back face culling on
- Whenever a rendered fragment of the shadow volume is closer than the depth of the other objects, increment the stencil value for that pixel
- Turn on the front face culling and turn off the back face culling
- Whenever a rendered fragment of the shadow volume is closer than the depth of the other objects, decrease the stencil value for that pixel
- Render the scene using diffuse and specular reflection for the area where the stencil value is 0

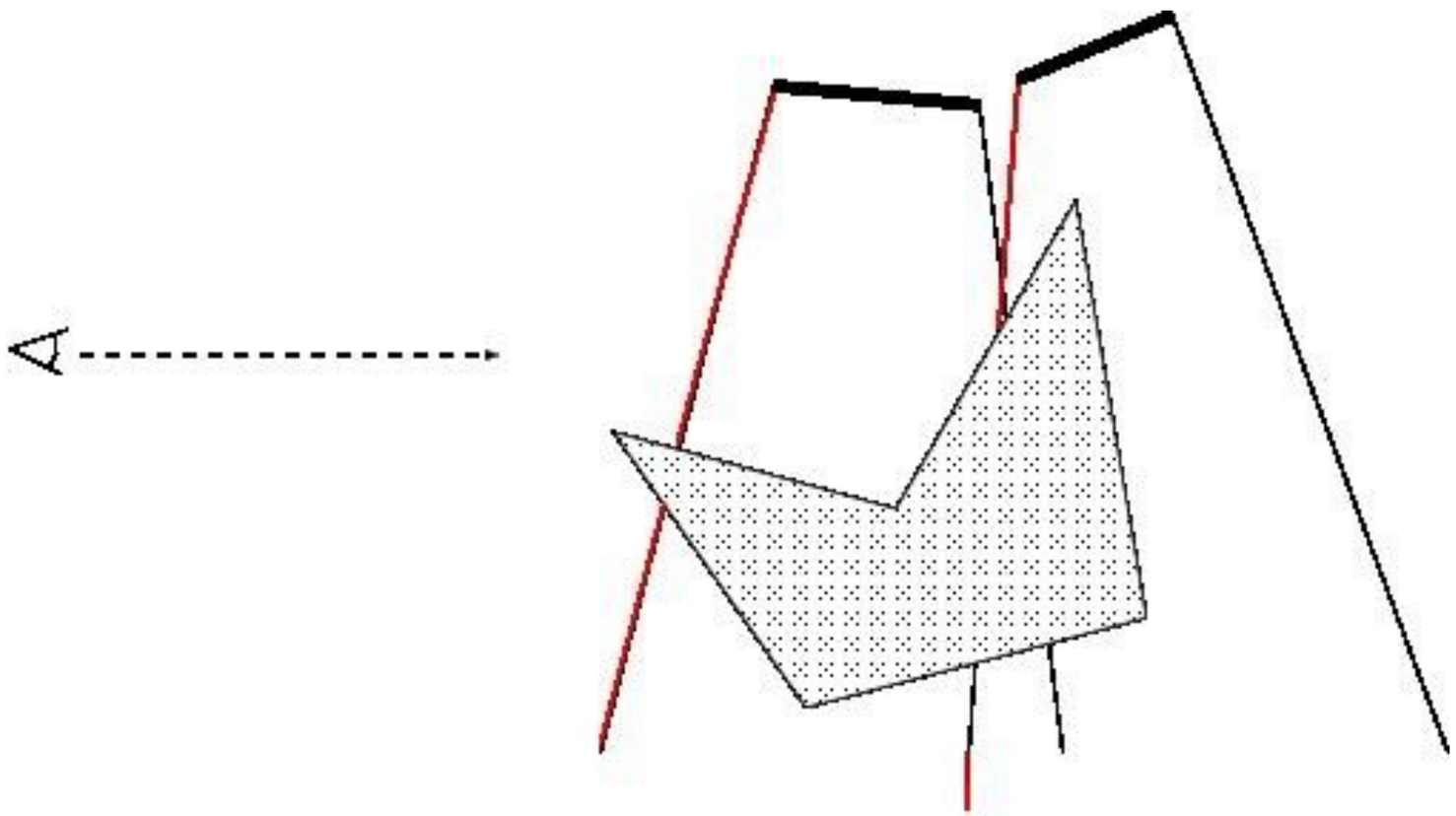
Stencil buffer

- **Render the scene with ambient light**

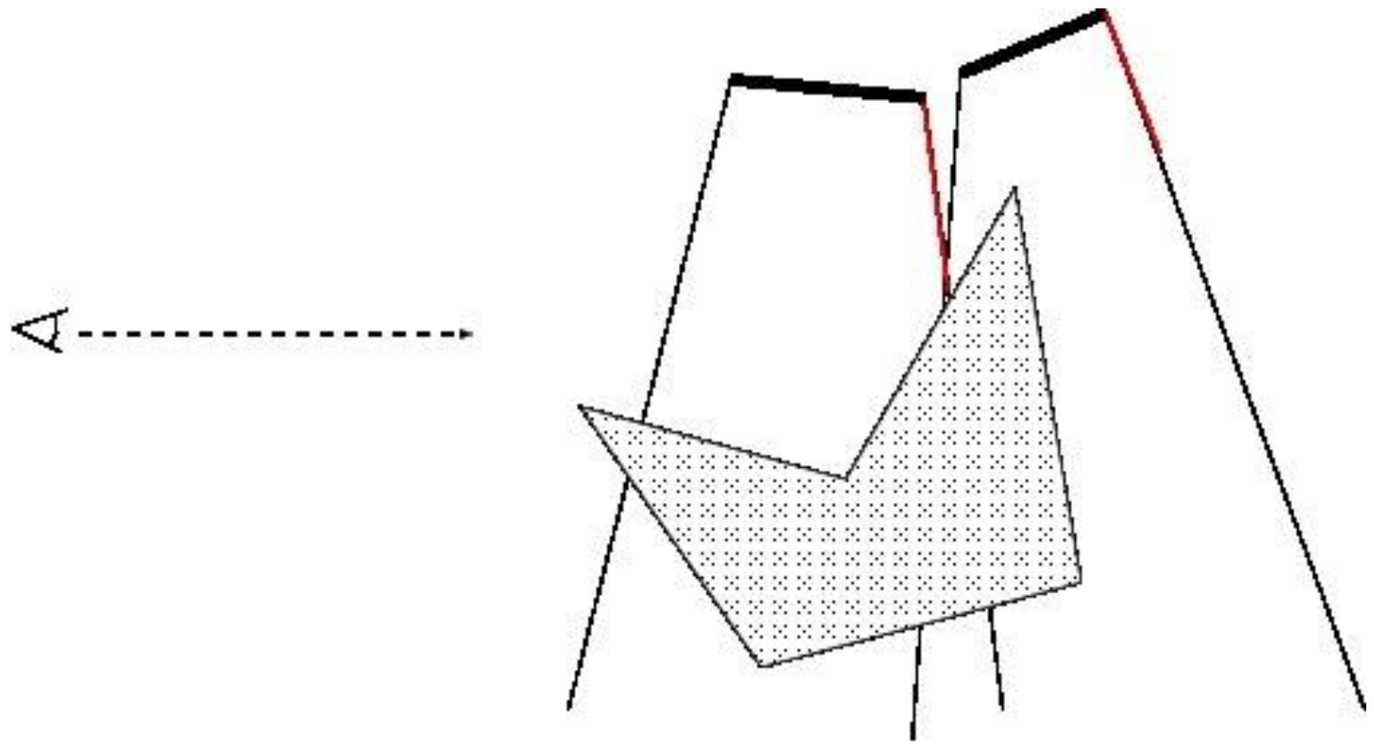


Stencil buffer

- Render the scene with ambient light
- **Clear the stencil buffer, and render the shadow volume with the colour buffer off and back face culling on**
- **Whenever a rendered fragment of the shadow volume is closer than the depth of the other objects, increment the stencil value for that pixel**



Stencil buffer



- **Turn on the front face culling and turn off the back face culling**
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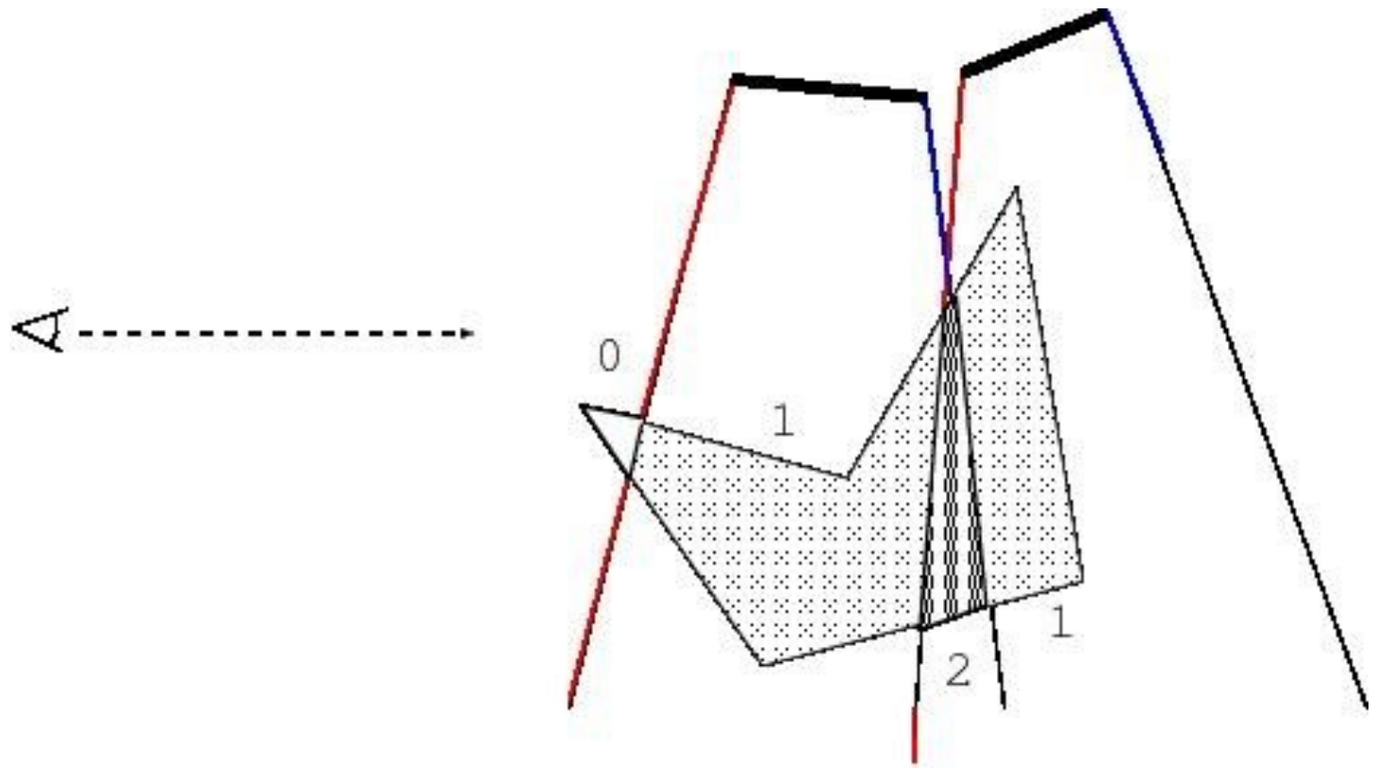
Stencil buffer



- **Render the scene using diffuse and specular reflection for the area where the stencil value is 0**

Shadow volume pros and cons

- Pros
  - Do not need to manually specify the shadowed objects
  - The occluder can shadow itself
  - High precision
- Cons
  - Bottleneck at the rasteriser
  - Many shadow volumes covering many pixels

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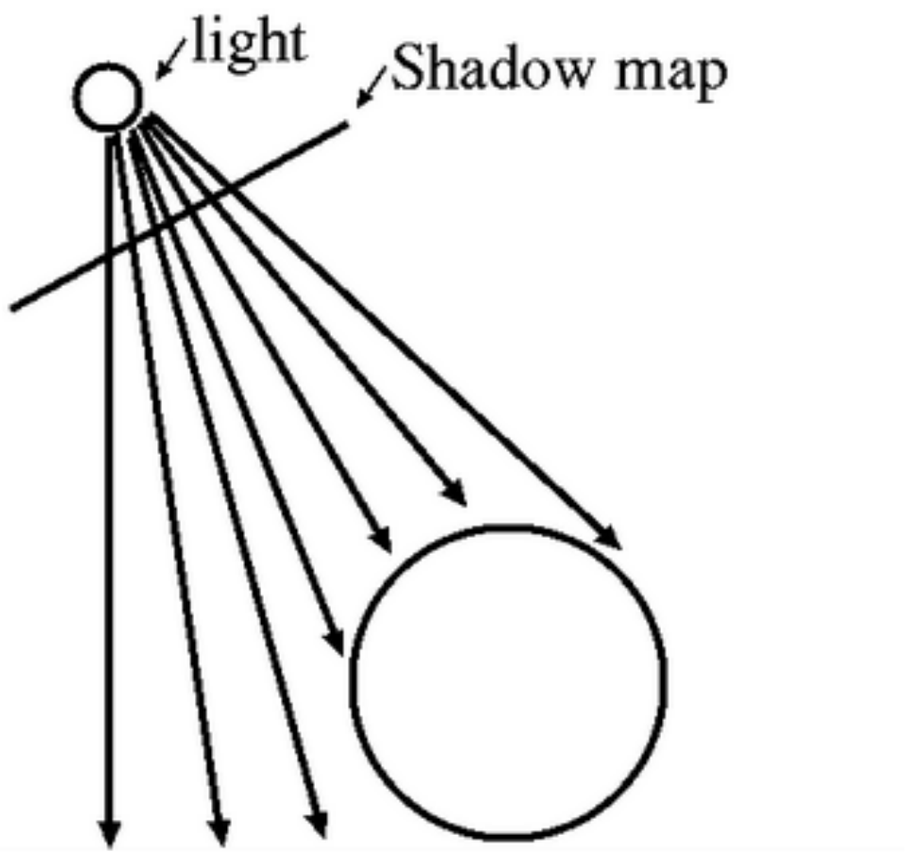
Shadow mapping

- Another method that can handle shadows of multiple objects cast onto arbitrary shaped objects

- Uses the z-buffer

Shadow map

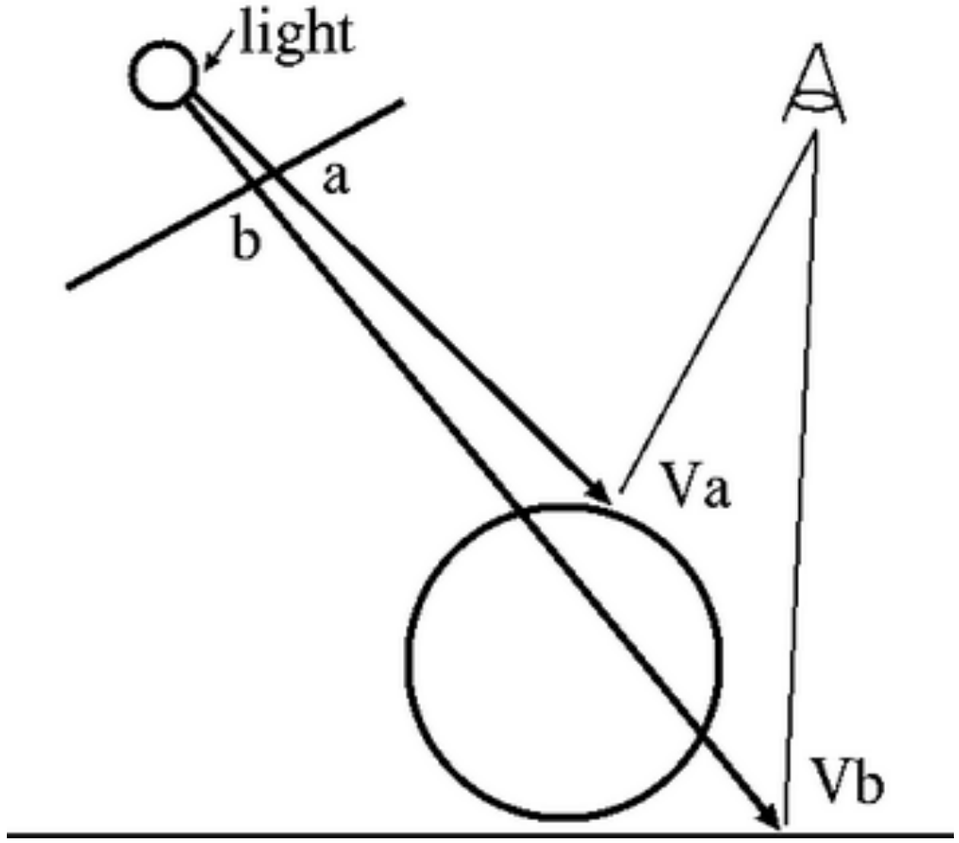
- Preparation
  - Prepare a depth buffer for each light
  - Render the scene from the light position
  - Save the depth information in the depth buffer



Shadow map

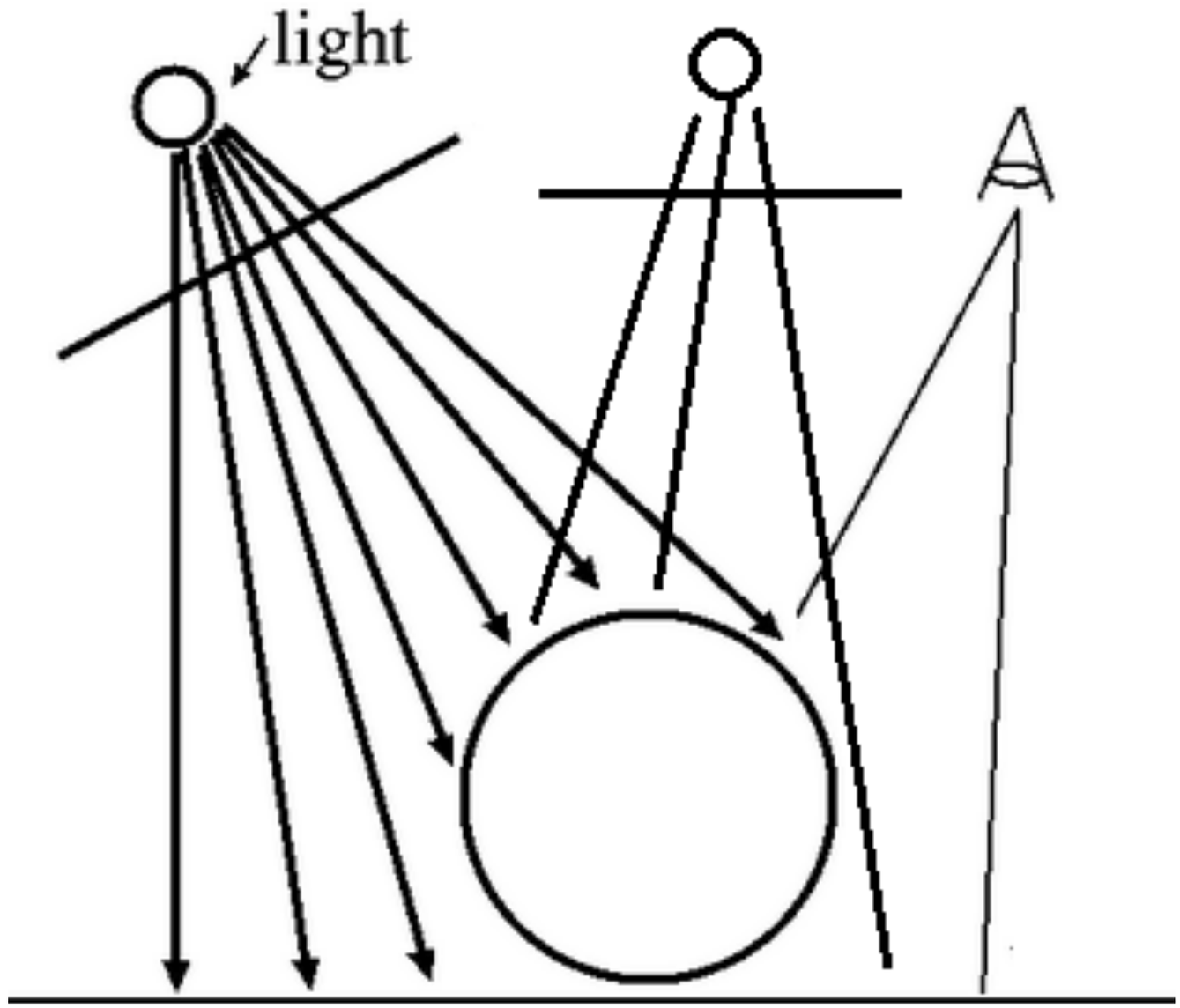
Rendering the scene

1. Render the objects; whenever rendering an object, check if it is shadowed or not by transforming its coordinate into the light space
2. After the transformation, if the depth value is larger than that in the light's depth buffer it should be shadowed



Shadow map

- Works with multiple light sources

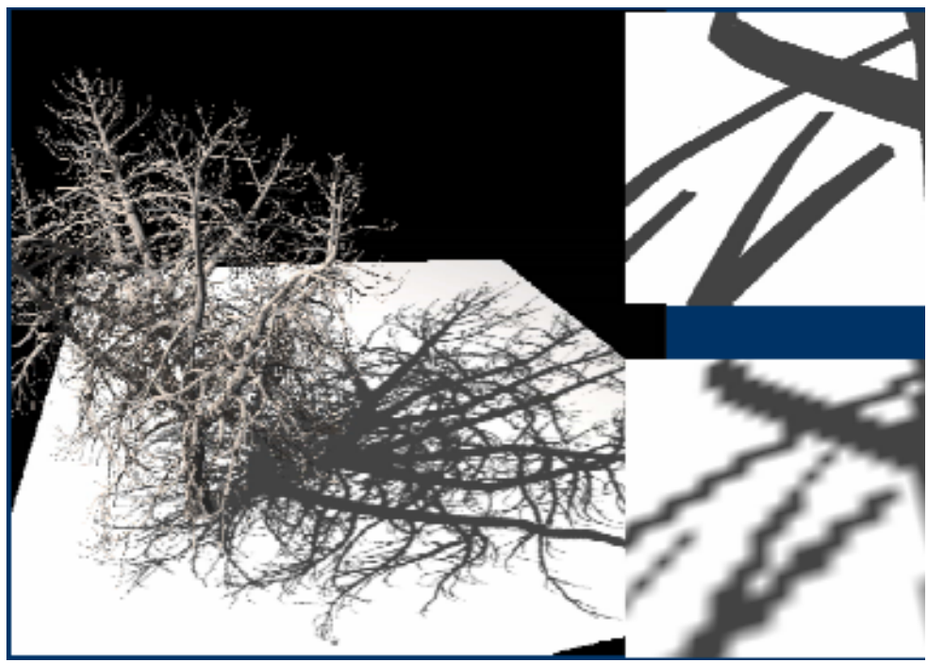


Shadow map - comparison

- Self shadows?
- Need to specify the occluder/occludee?

Shadow map comparison

- When there are many shadows this is faster compared to a shadow volume
- Precision is low compared to a shadow volume



Adaptive shadow mapping

- If the resolution of the map is lower than the rendered image, we have many artifacts
- Need a higher resolution shadow map
- Change resolution of maps according to the viewport
- Adaptive Shadow Maps, Fernando et al. SIGGRAPH 2001

Figure 2: A conventional 2,048×2,048 pixel shadow map (left) compared to a 16 MB ASM (right). EFFECTIVE SHADOW MAP SIZE: 65,536×65,536 PIXELS.

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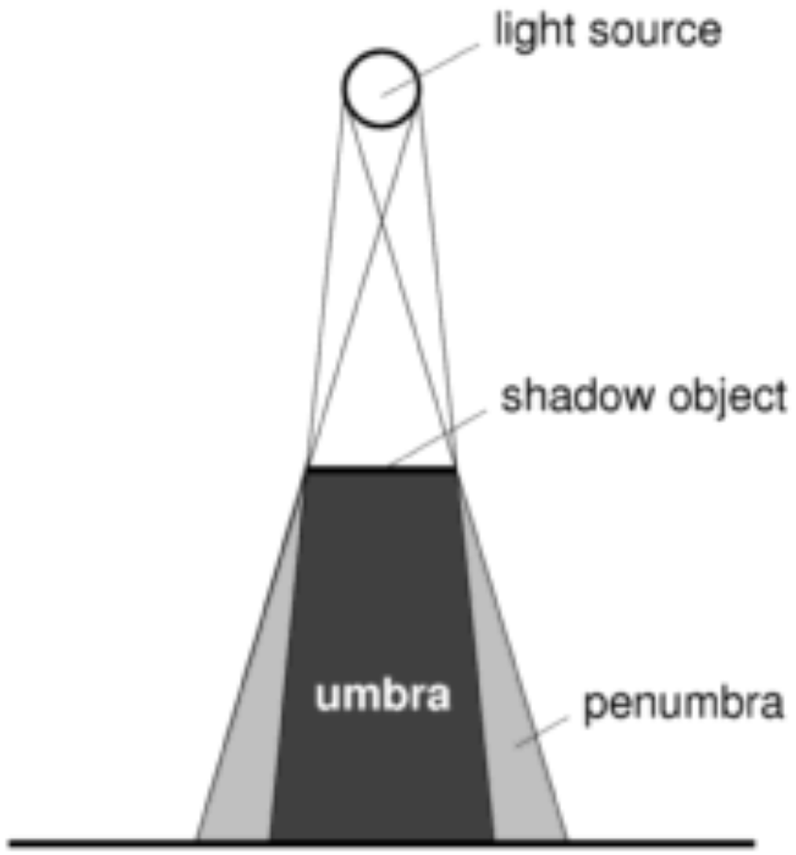
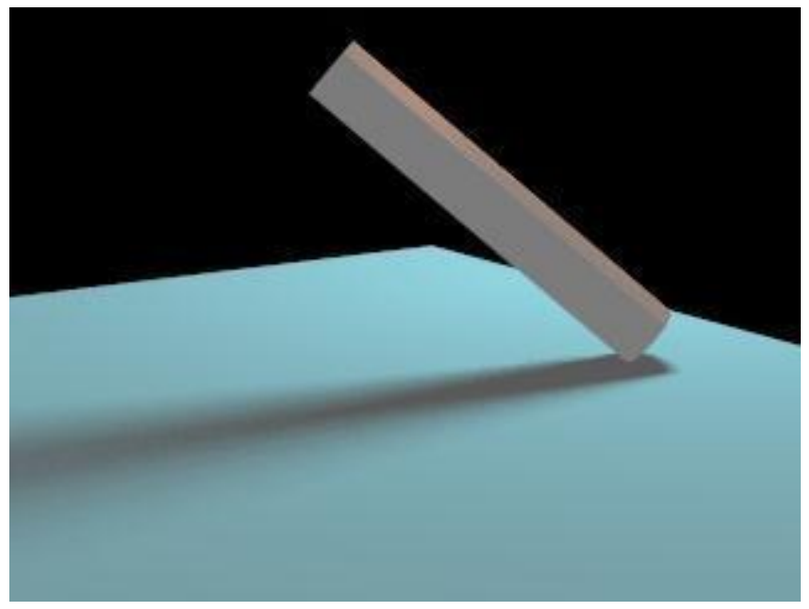
Soft shadows

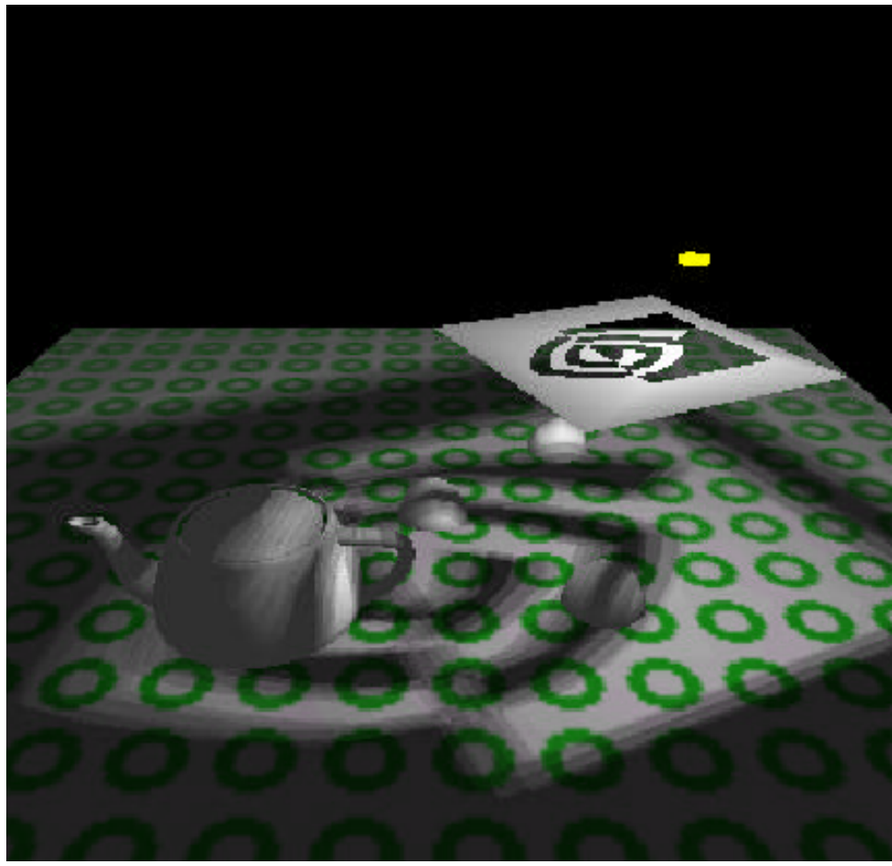
- Produced by area lights
- Umbra - totally blocked
- Penumbra partially blocked from the light source
- Can model with a collection of point light sources





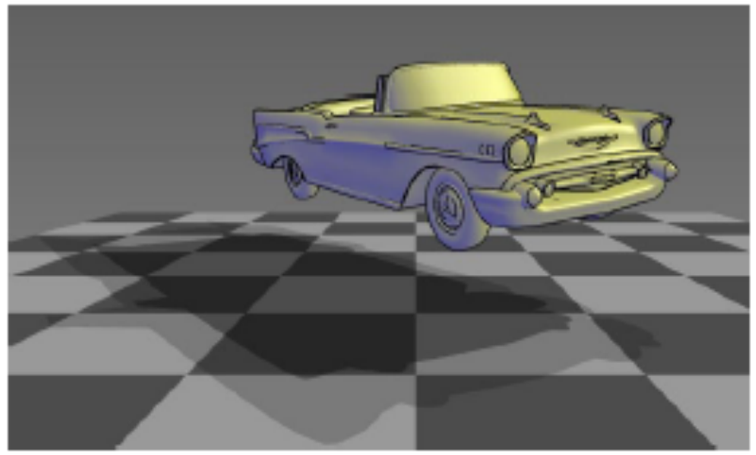
Soft shadowing by multiple point light sources

- Additive blending is used to accumulate the contribution of each light
- Can apply both planar projected shadows approach or shadow volume approach
- Then apply convolution
- The softness of the shadow depends on an adequate number of samples.
- The time to render the scene increases linearly with the number of samples used to approximate an area light source.
- Artifacts are introduced if not enough samples are used
- Drawback: slow

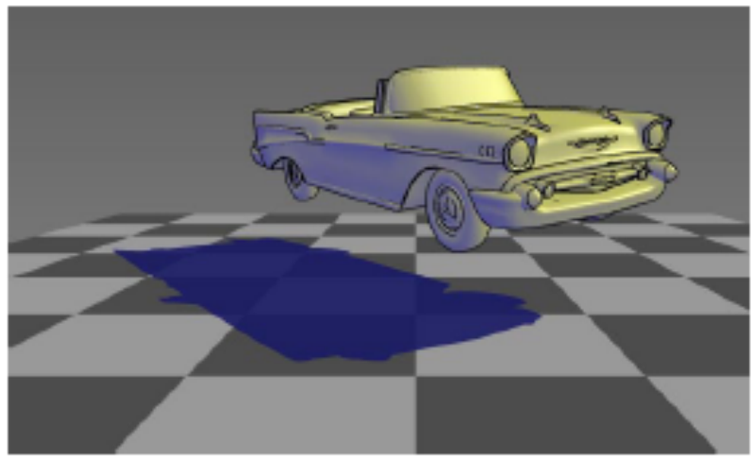


Other techniques: Gooch et al.

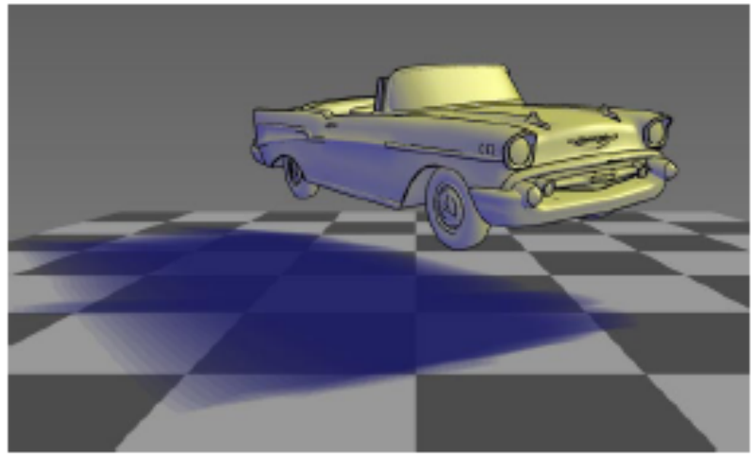
- Moving the projected plane up and down instead of moving the light source
- The projections cast upon it are averaged
- Can use projective shadows:
  - Applying the same texture multiple times to planes of different heights and overlapping them
- "Interactive technical illustration", Gooch et al. I3D 1998



(a) Hard penumbra and hard umbra.



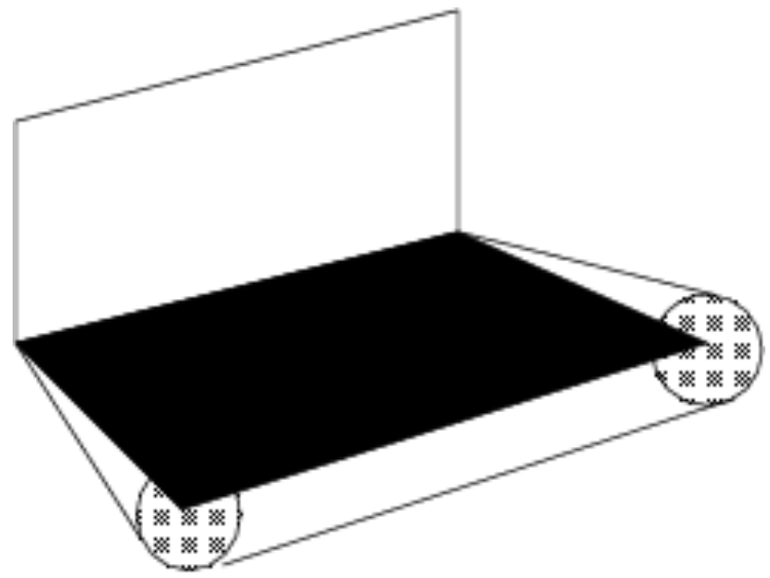
(b) Single hard, colored shadow.



(c) Colored soft shadow.

Other techniques: Haines 2001

- First create a hard shadow and then paint the silhouette edges with gradients that go from dark in the center to white on the edge.
- The gradient areas have a width proportional to the height of the silhouette edge casting the shadow



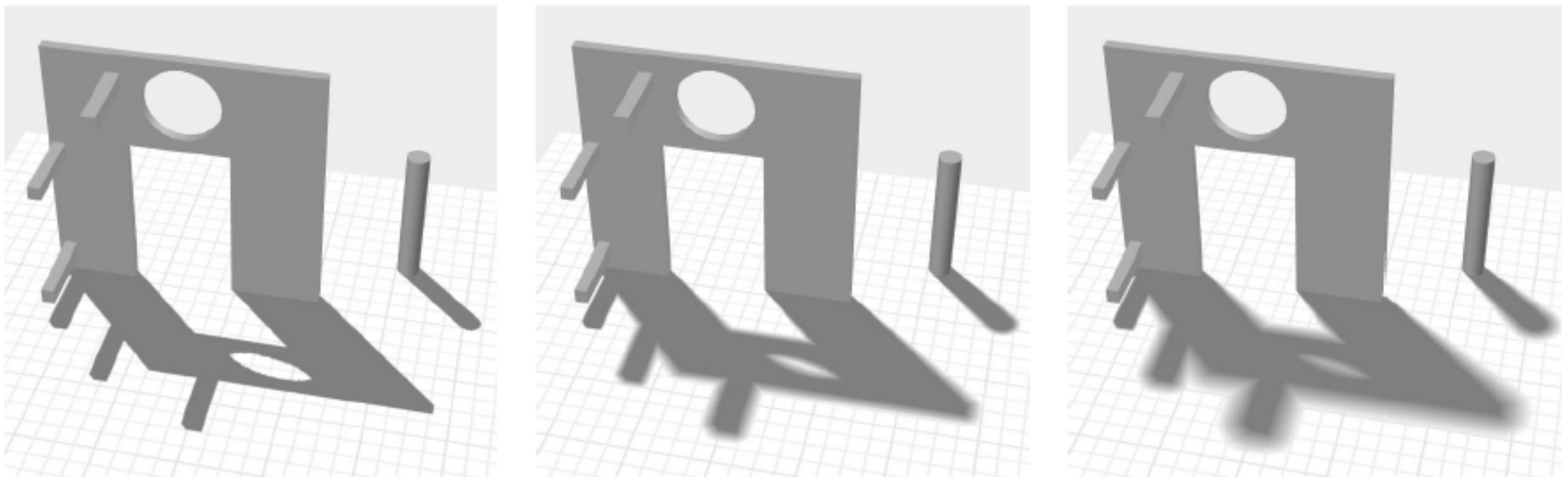
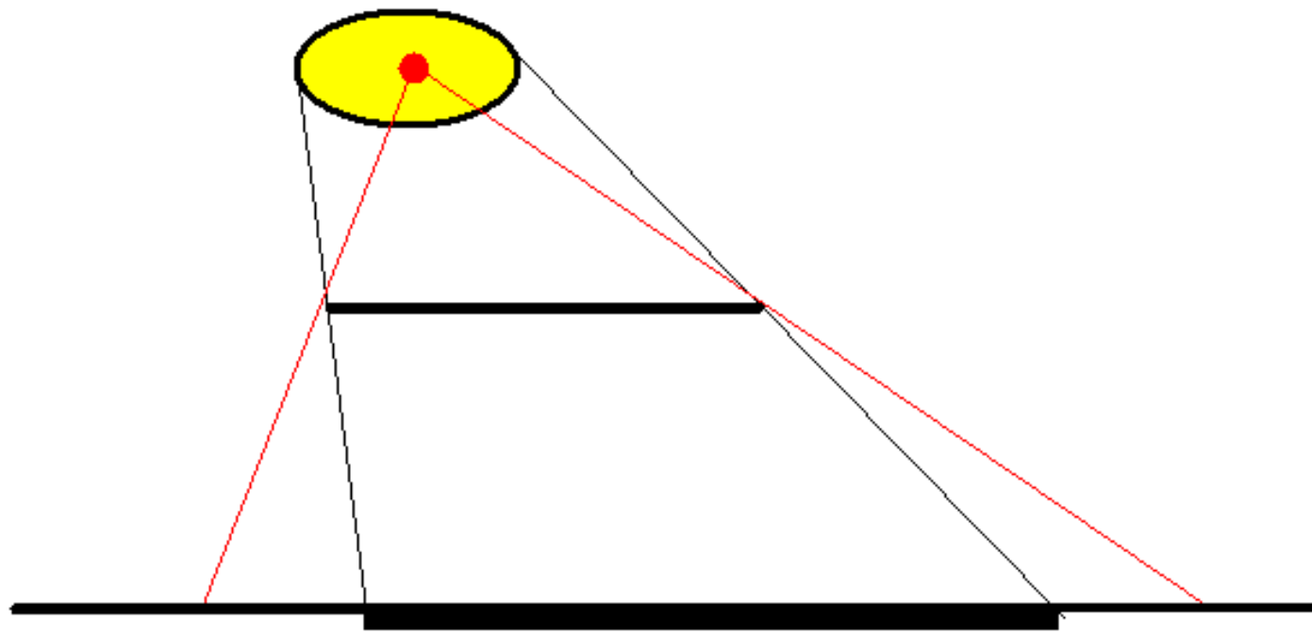


Figure 3: On the left is a hard shadow, the middle shows the effect of a small area light source, the right a larger light source.

Problems

- The umbra is too large as it is produced by a point light source
- Actual area light sources have a smaller umbra



References

- Akenine-Möller, Chapter 9.1 (Shadows)
- Real-Time Shadows , Eric Haines, Tomas Möller, GDC 2001, CMP, 335-352
- Foley, Chapter 16.4