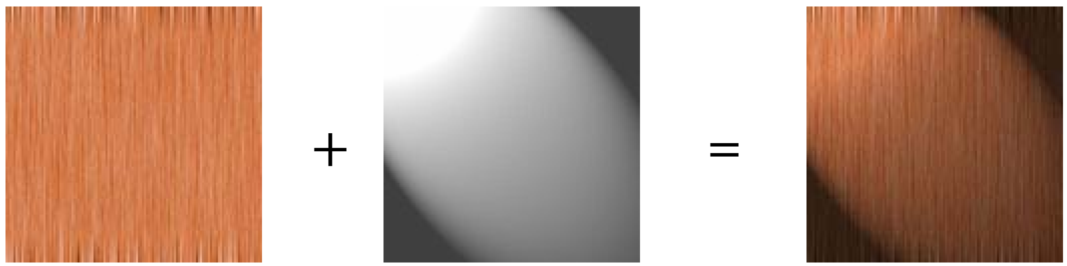
Texture Mapping II

- Light maps
- Environment Maps
- Projective Textures
- Bump Maps
- Displacement Maps
- Solid Textures
- Mipmaps
- Shadows

Light Maps

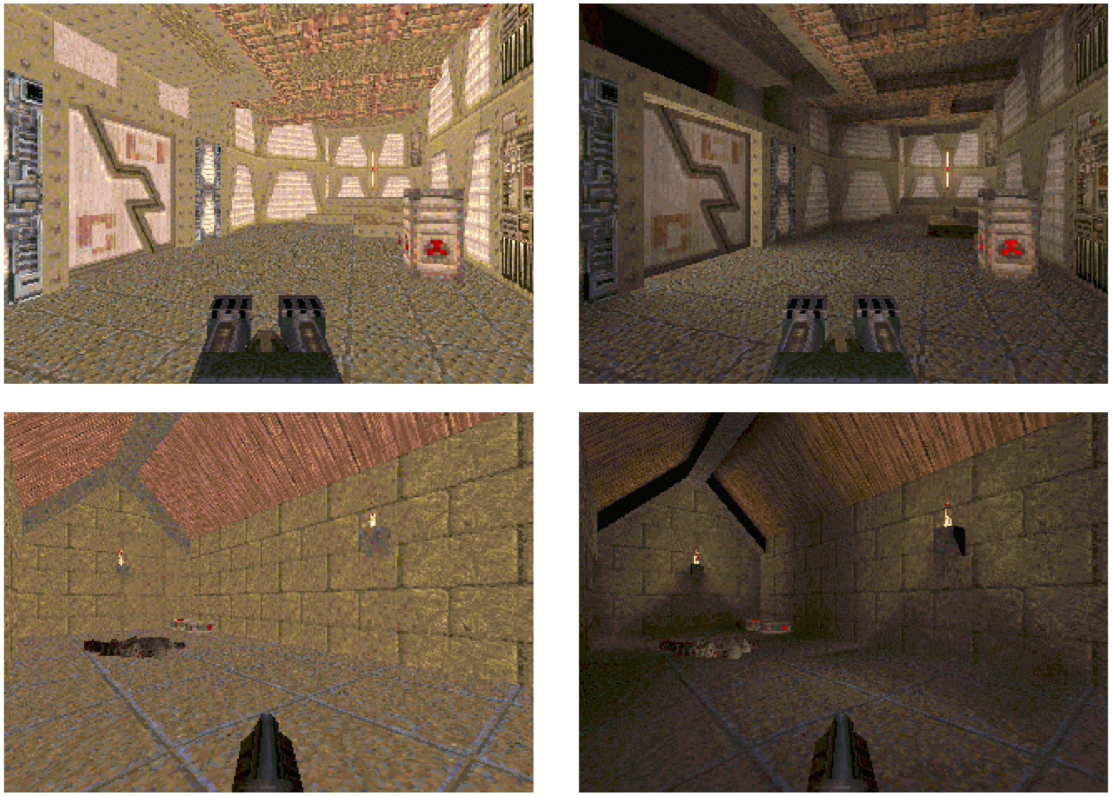
- Simulates the effect of a local light source



- Can be pre-computed and dynamically adapted

Light Maps

- Texture mapping in Quake

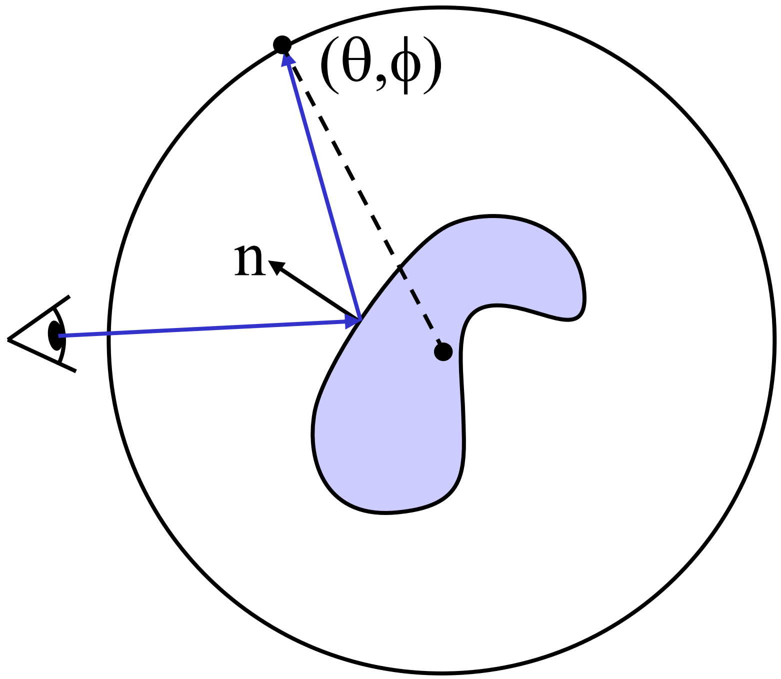


textures only　　　textures and light maps

Environment Map

Environment Map

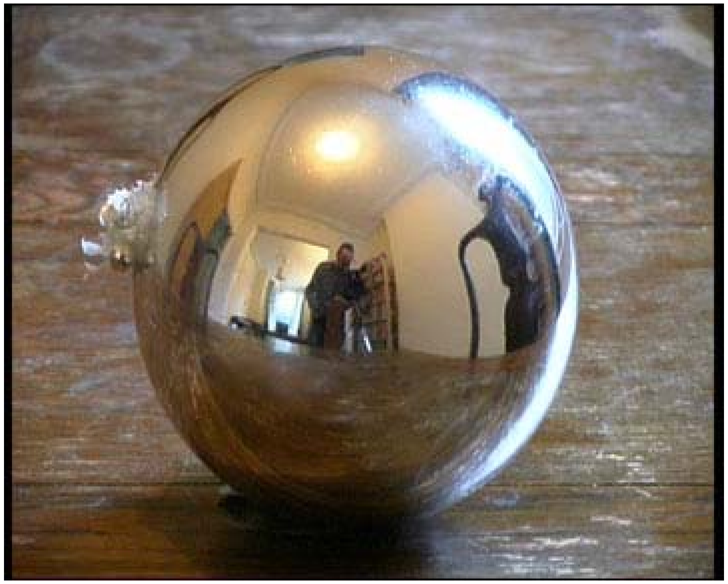
- Method to render reflective objects
- Compute intersection of reflected ray with surrounding sphere
- Take parameter values of intersection as texture coordinates



Examples – Environment Map

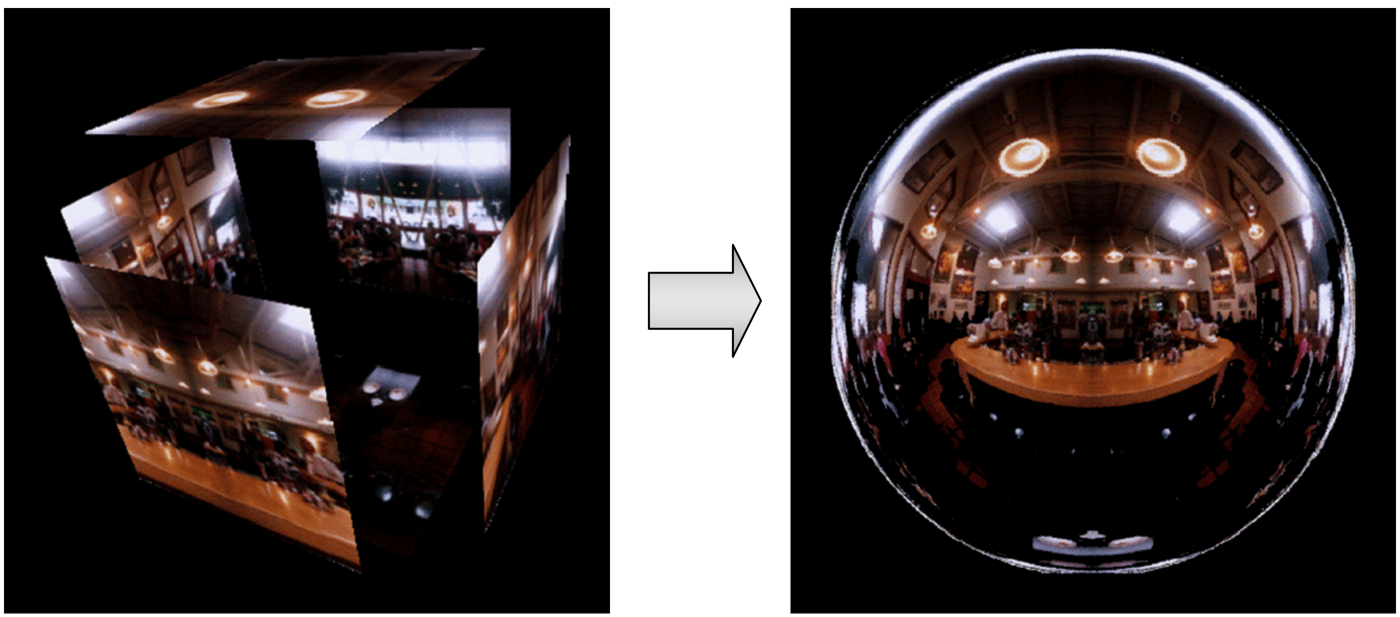
Environment Map

- How to get an environment map of a real environment?

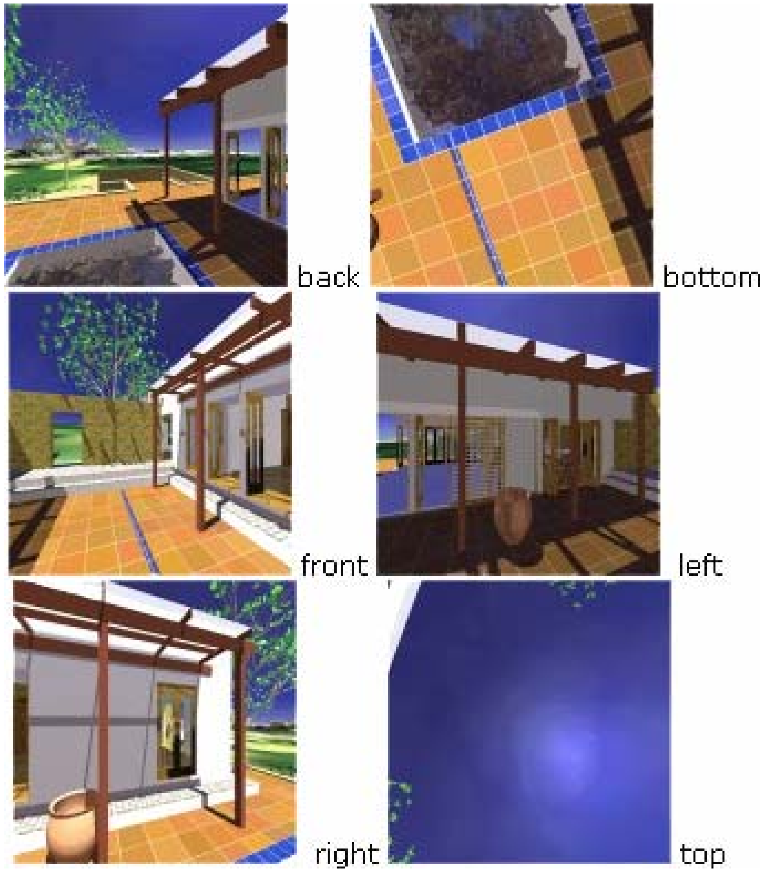


Cube Mapping

- Sphere can be replaced by cube
- Simplify computations



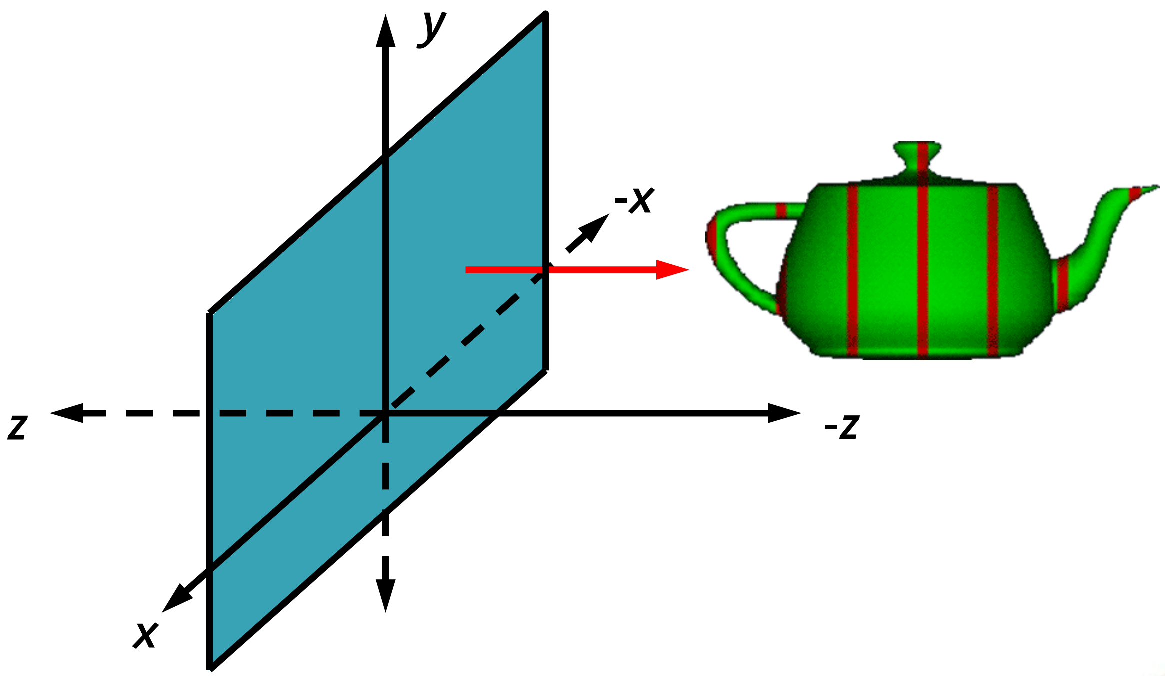
Cube Map Demo



http://developer.nvidia.com/object/cube_map_ogl_tutorial.html

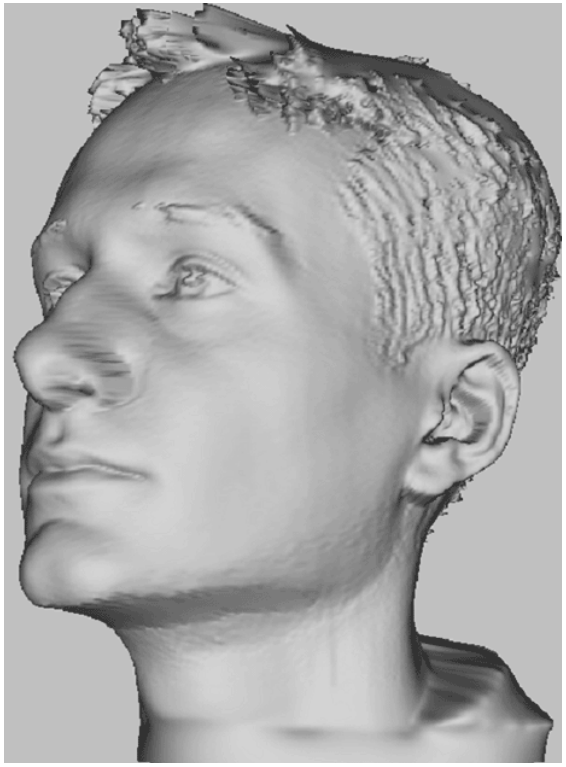
Linear Mapping

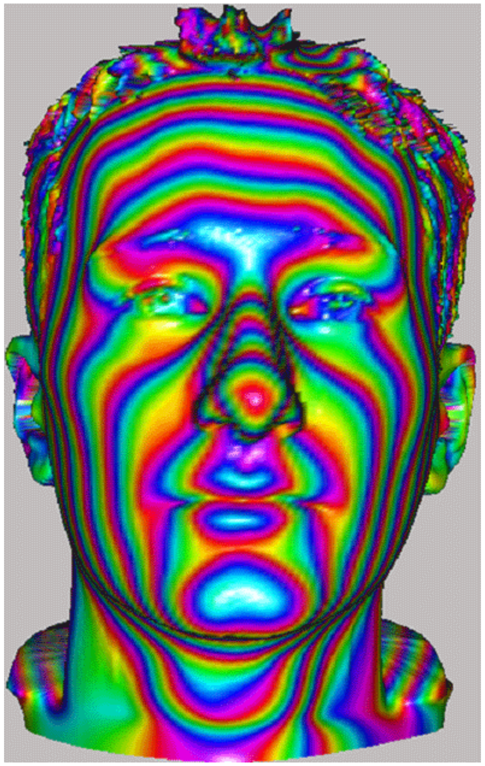
- Uses object or eye coordinates
- (In)dependent of transforms
- Can be used to visualize distance from objects



An Example

- Mapping of distances from laser range data

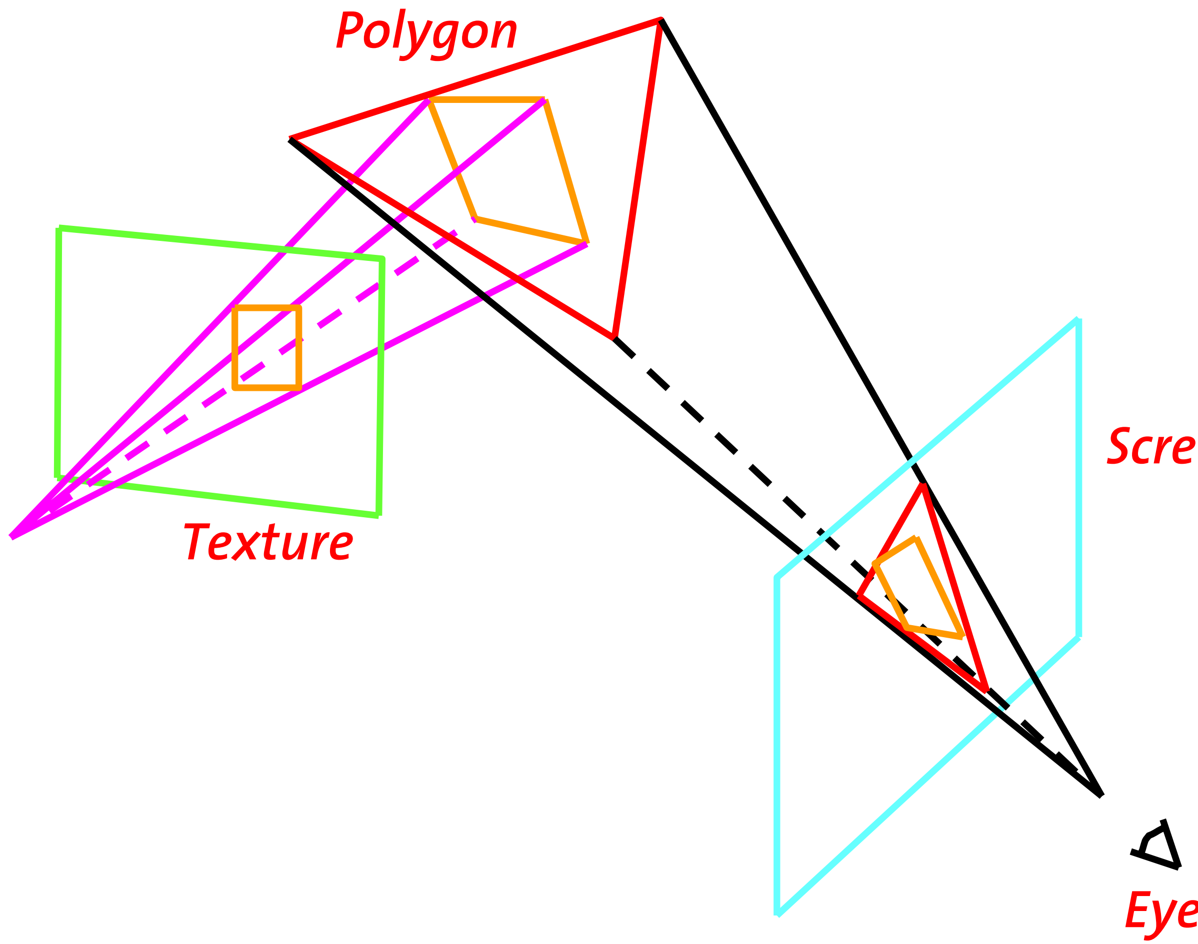




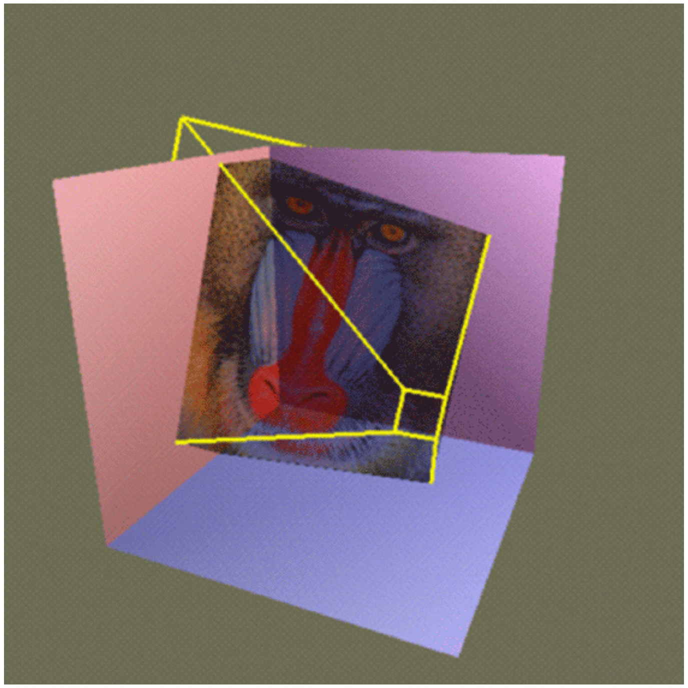
Projective Textures

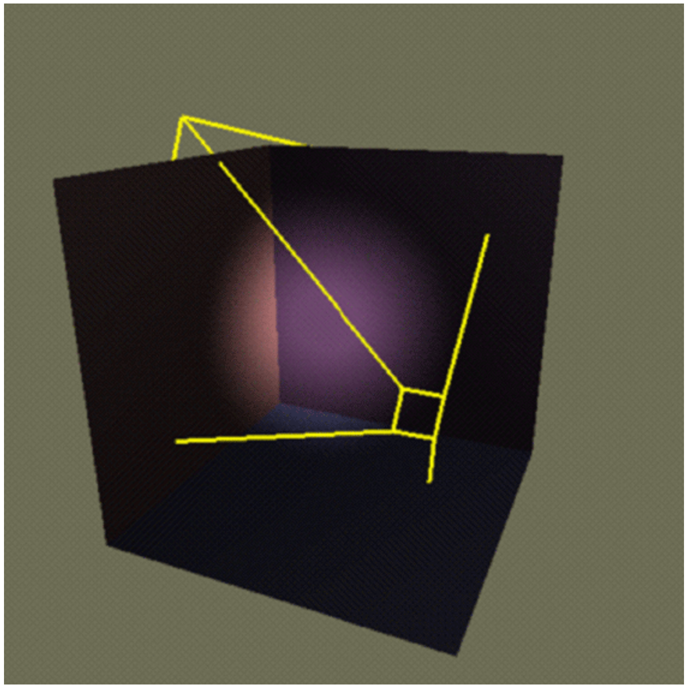
- Generalize texture coordinates to a 4D homogeneous vector (u, v, r, q)
- Texture matrix computes full 4x4 transform to (u^p, v^p) used for texture lookup
- Texture image can be projected independently of viewing projection
- Applications:
  - Slide projector
  - Spotlight simulation

Projection

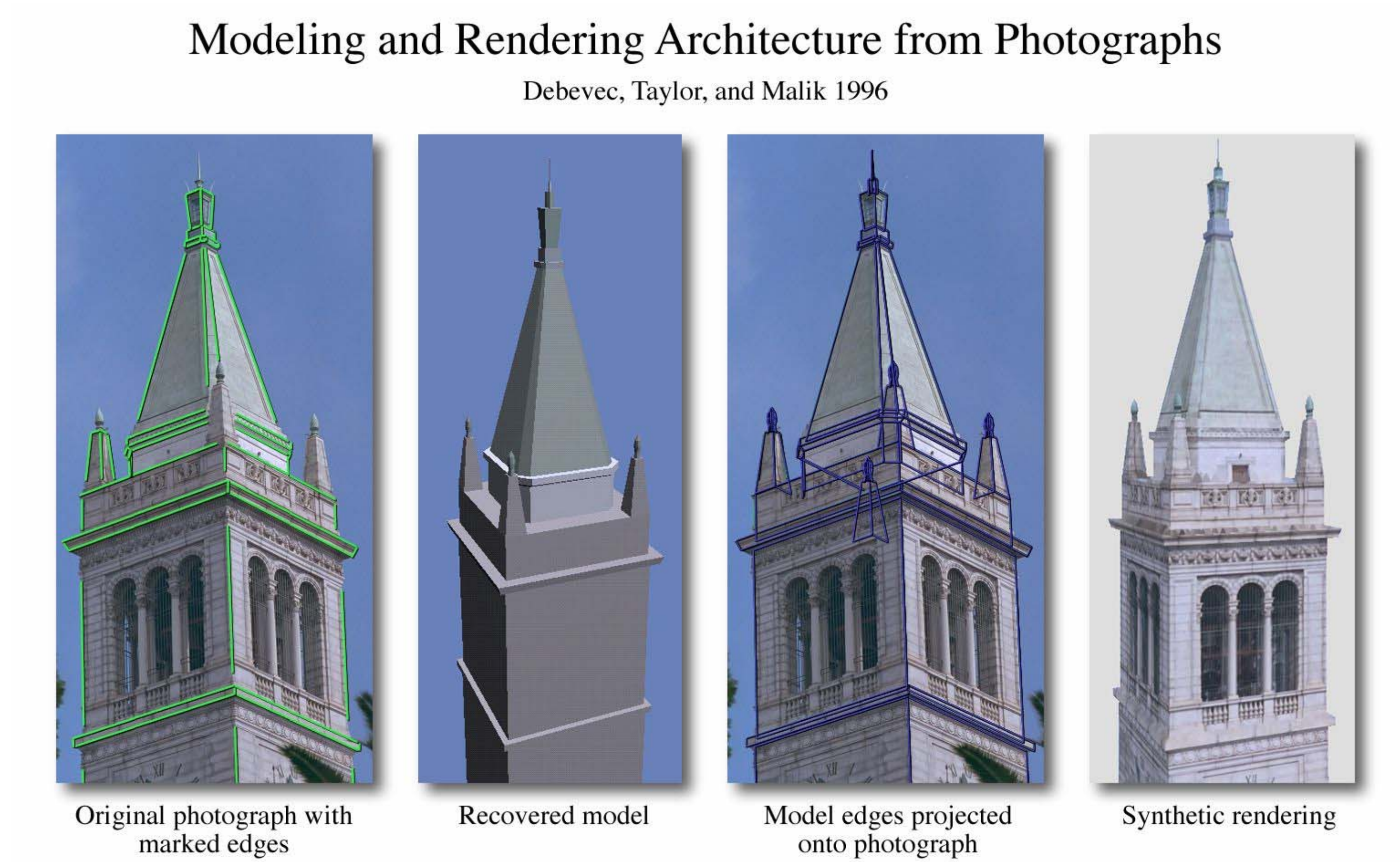


Examples





Examples



⇨ movie

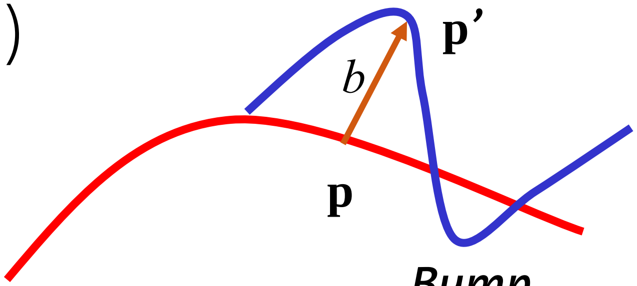
Bump Mapping

- Adding surface detail without adding geometry
- Perturbation of surface normal
- Details interact with light
- Bumps are small compared to geometry
- Bump pattern is taken from a (texture-) map
- Can also be procedural (fractals)

Bump Mapping

- Given a surface $\mathbf{p}(u,v)$ and a perturbation value b (*Jim Blinn*)

$$\mathbf{n} = \frac{\partial \mathbf{p}}{\partial u} \times \frac{\partial \mathbf{p}}{\partial v} = \mathbf{p}_u \times \mathbf{p}_v$$



- Point $\mathbf{p}'$ on the bumpy surface

$$\mathbf{p}' = \mathbf{p} + \frac{b\,\mathbf{n}}{|\mathbf{n}|}$$

- Compute normal at Point $\mathbf{p}'$

$$\mathbf{n}' = \frac{\partial \mathbf{p}'}{\partial u} \times \frac{\partial \mathbf{p}'}{\partial v}$$

Bump Mapping

- Partial derivatives at point **p'**

$$\frac{\partial \mathbf{p}'}{\partial u} = \frac{\partial \mathbf{p}}{\partial u} + \frac{\partial}{\partial u} \frac{(b\,\mathbf{n})}{|\mathbf{n}|}$$

- Perturbed normal approximated by (see Blinn)

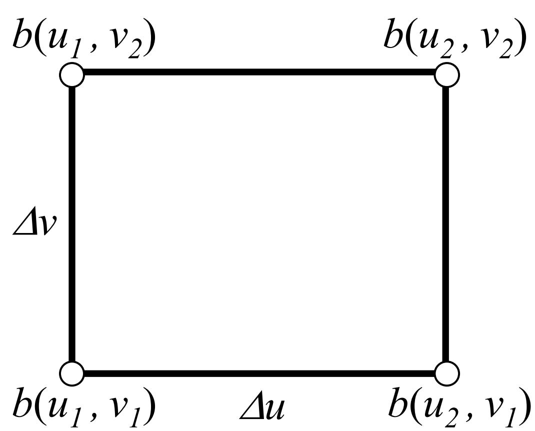
$$\mathbf{n}' = \mathbf{n} + b_u\,(\mathbf{n} \times \mathbf{p}_u) + b_v\,(\mathbf{n} \times \mathbf{p}_v)$$

Bump Mapping

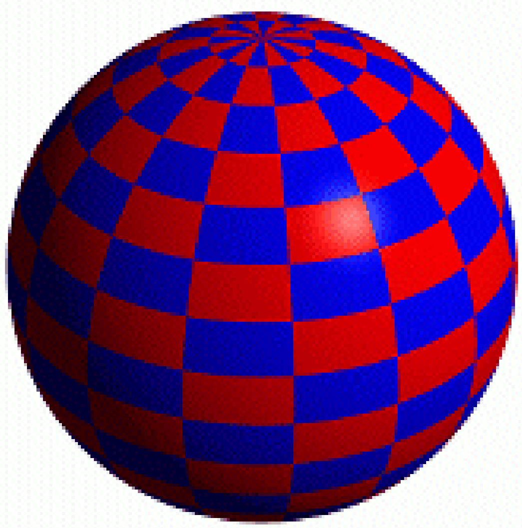
- Discretization using Finite Differences

$$b_u = \frac{b(u_2,v_1) - b(u_1,v_1) + b(u_2,v_2) - b(u_1,v_2)}{2\,\Delta u}$$

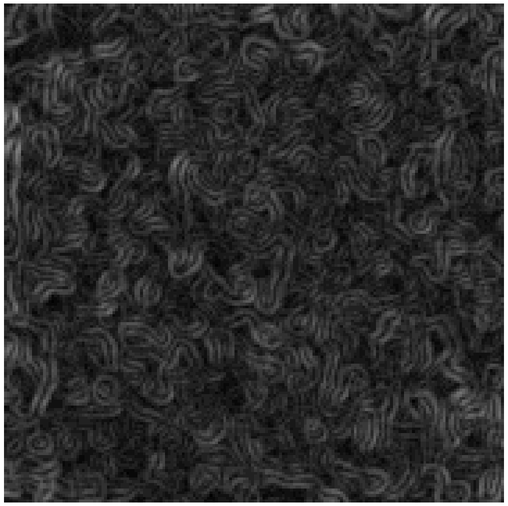
$$b_v = \frac{b(u_1,v_2) - b(u_1,v_1) + b(u_2,v_2) - b(u_2,v_1)}{2\,\Delta v}$$



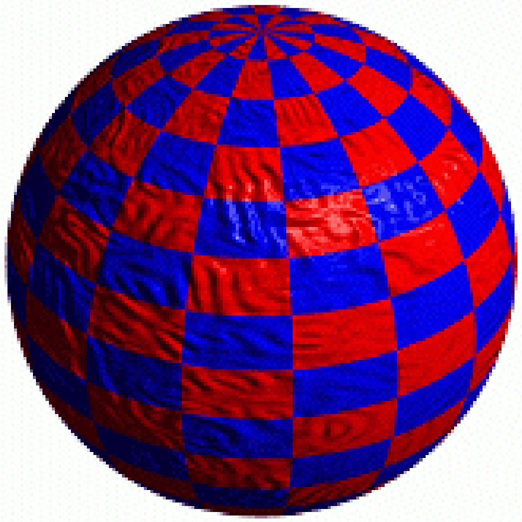
Examples



Sphere w/Diffuse Texture

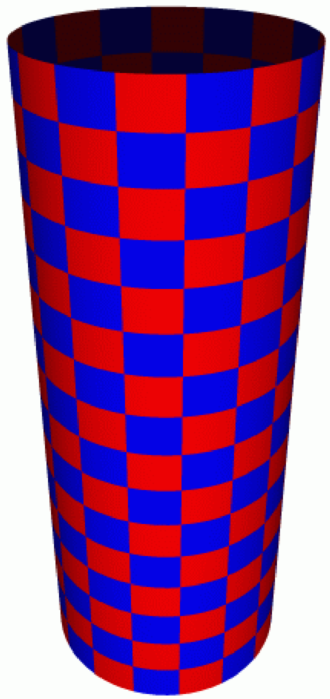


Swirly Bump Map

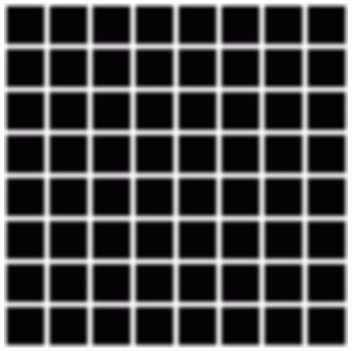


Sphere w/Diffuse Texture & Bump Map

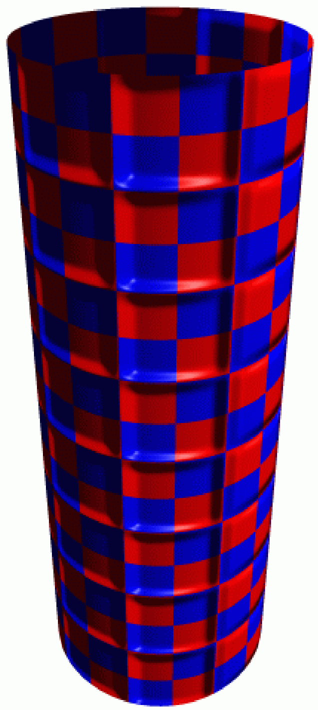
Examples



Cylinder w/Diffuse Texture Map



Bump Map

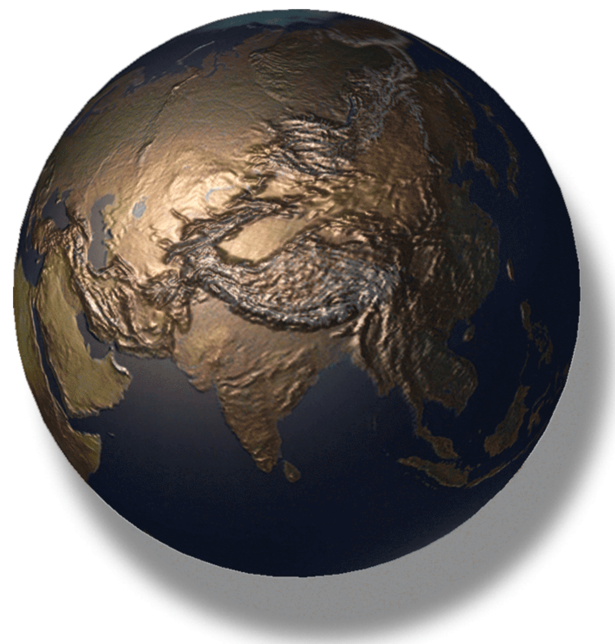


Cylinder w/Texture Map & Bump Map

⇨ **movie**

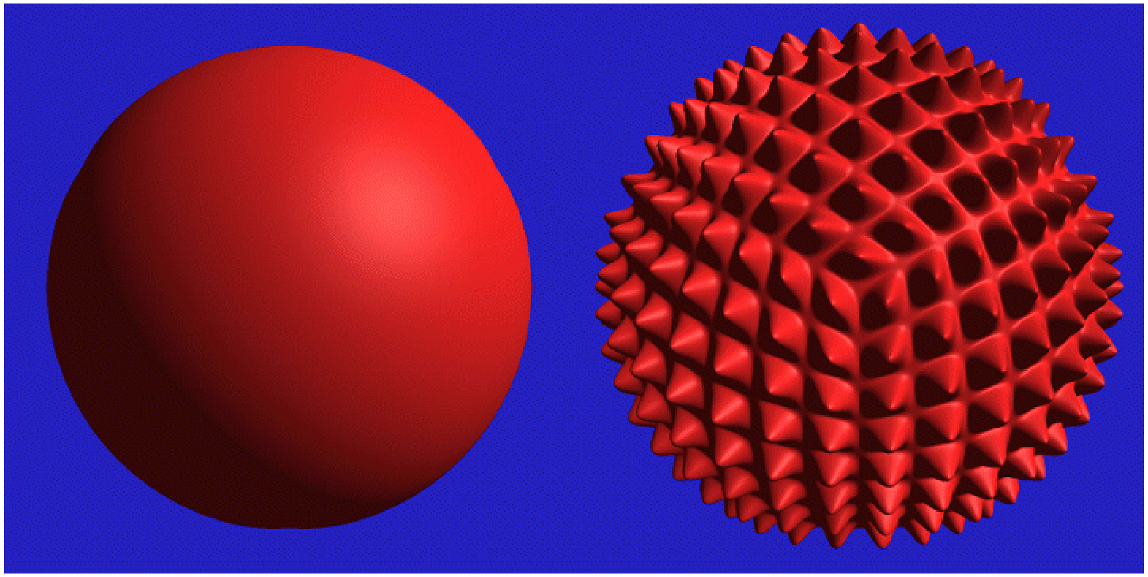
Bump Mapping

- What's missing?
  - Bumps on silhouette
  - Self-occlusion
  - Self-shadowing



Displacement Mapping

- Use the texture map to displace the geometry



Displacement Mapping

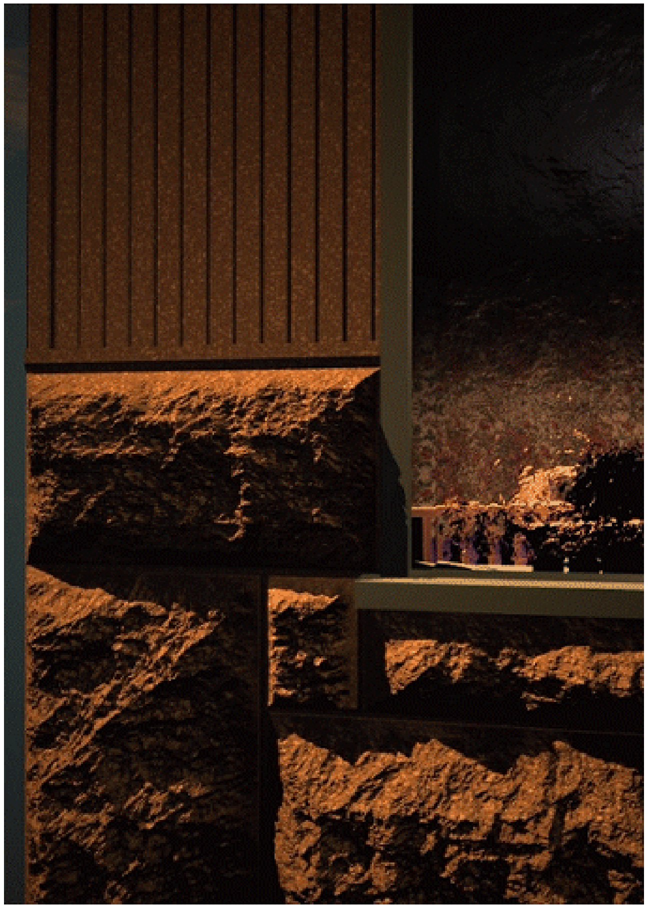


Image from:

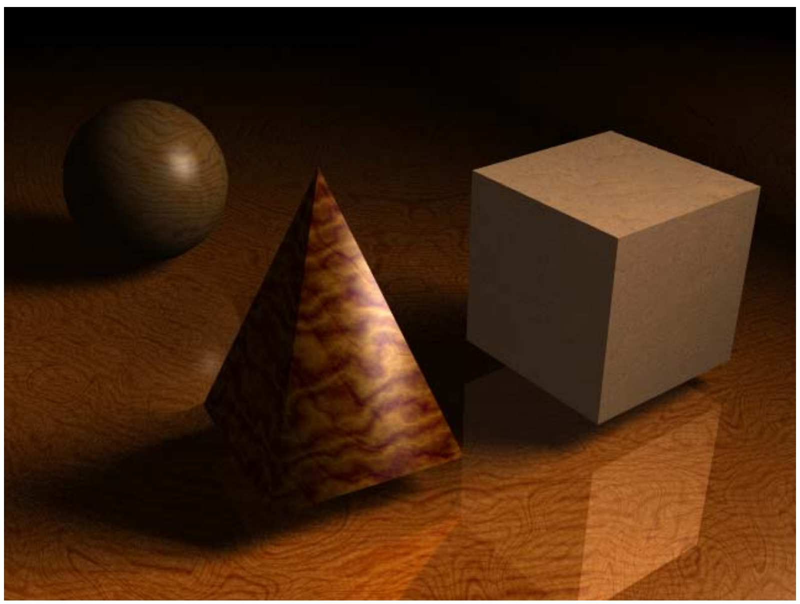
Geometry Caching for Ray-Tracing Displacement Maps

by Matt Pharr and Pat Hanrahan.

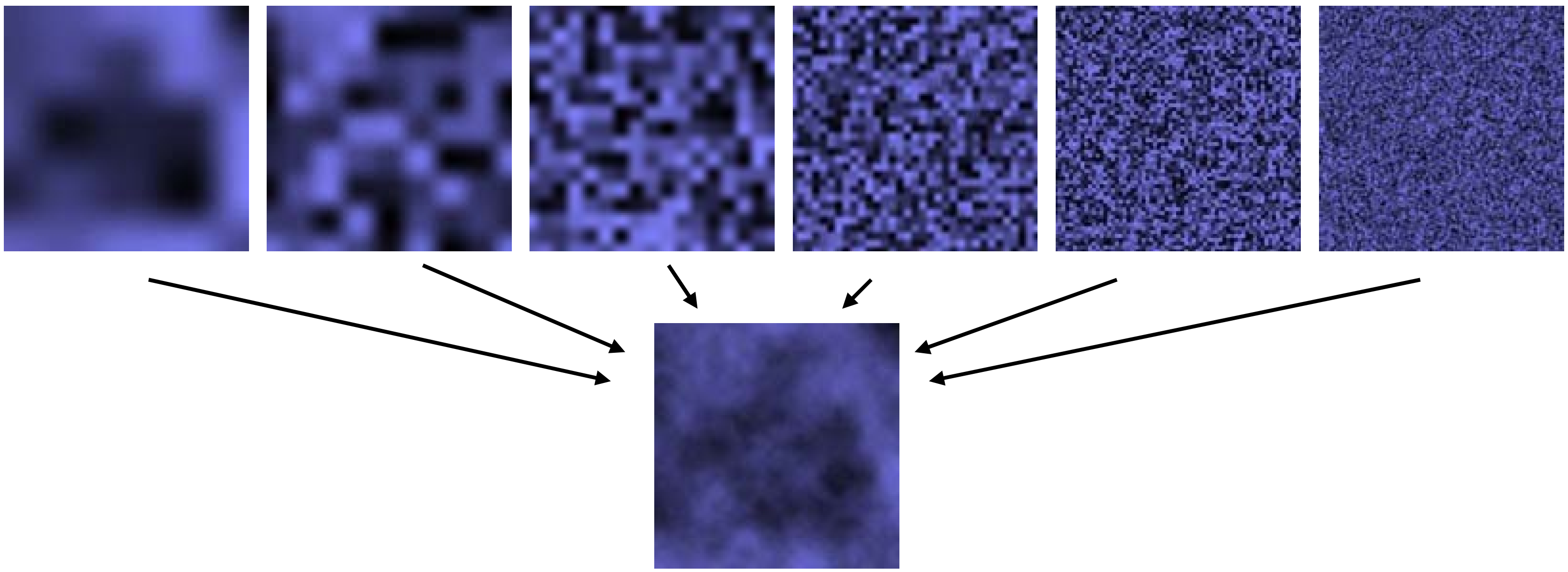
note the detailed shadows cast by the stones

Solid Textures

- 3D bitmaps
- Procedural textures

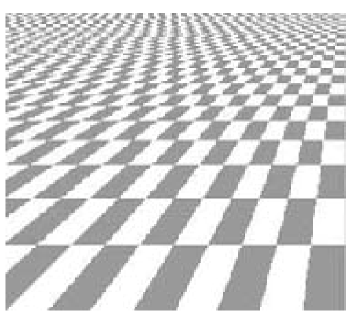


Perlin Noise

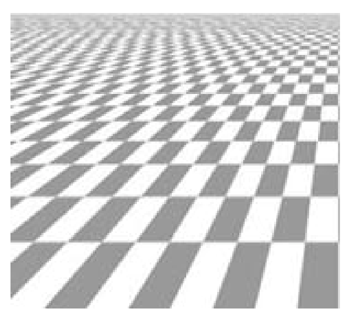


Mip-Mapping

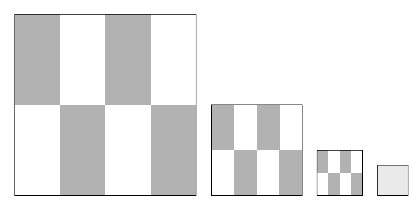
- Minimized textures produce aliasing effects
- Store texture at multiple levels-of-detail
- Use smaller versions when far from camera
- *MIP* comes from the Latin *multum in parvo*, meaning a multitude in a small space.



without mipmap



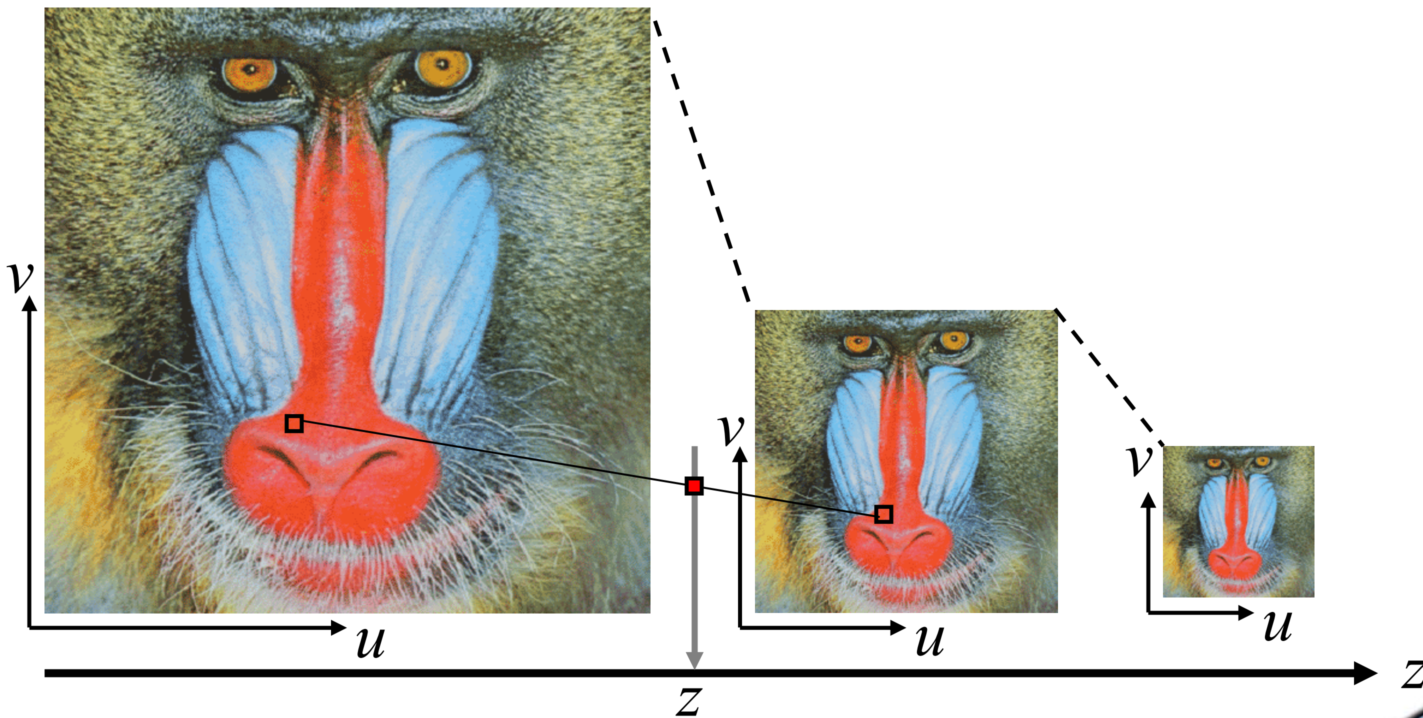
with mipmap



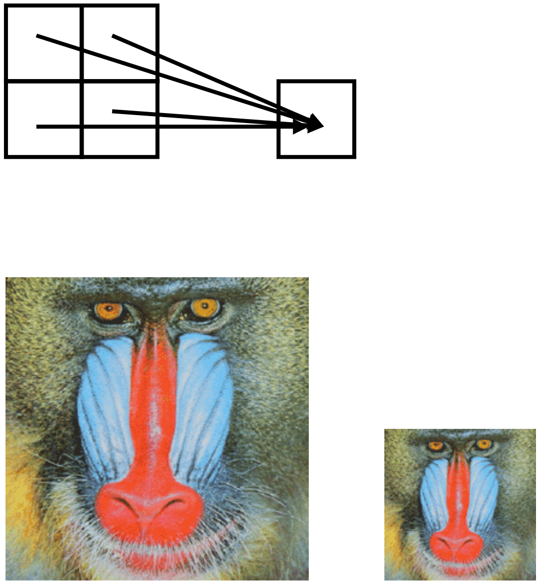
mipmap

Texture Interpolation

- Compute texture value *(R,G,B)* as function of *(u,v,z)*
- Tri-linear interpolation



Computation of the Mip Map

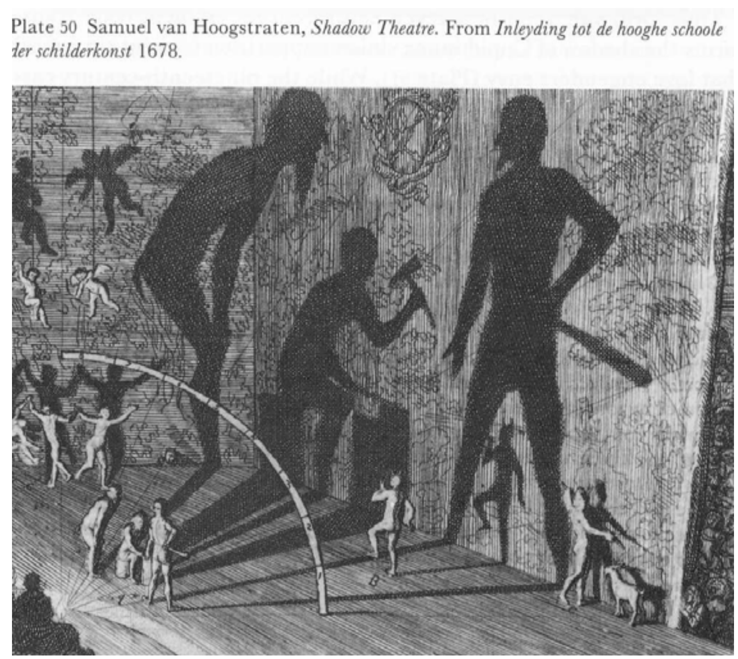


- Color = weighted average of nearby pixels (filter)
- See **`gluBuild2DMipMaps()`**

⇨ demo

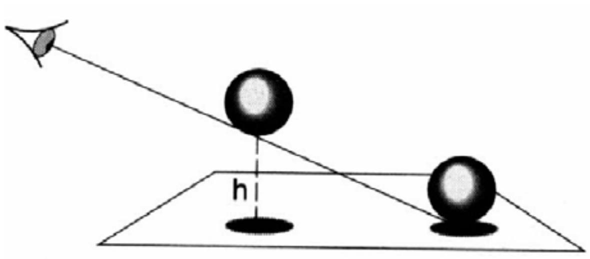
Shadows

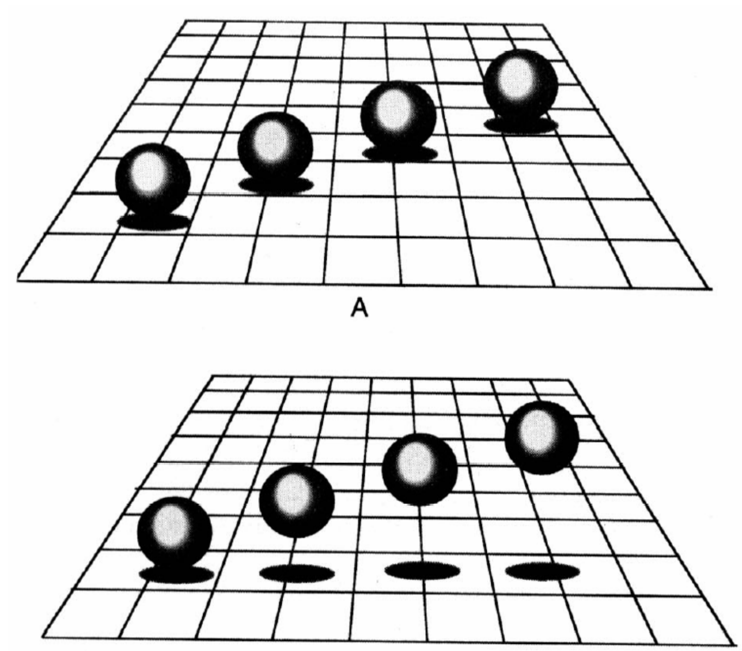
- Why are shadows important?
  - Depth cue
  - Scene lighting
  - Realism
  - Contact points



from Fredo Durand's graphics class...

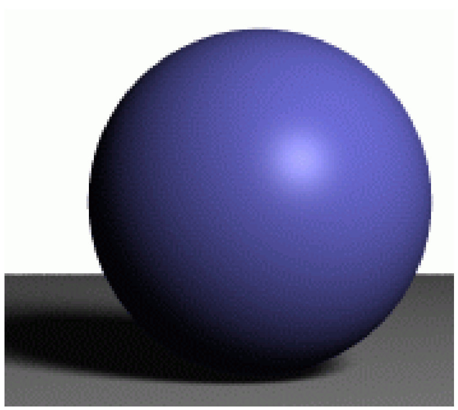
Shadows as a Depth Cue

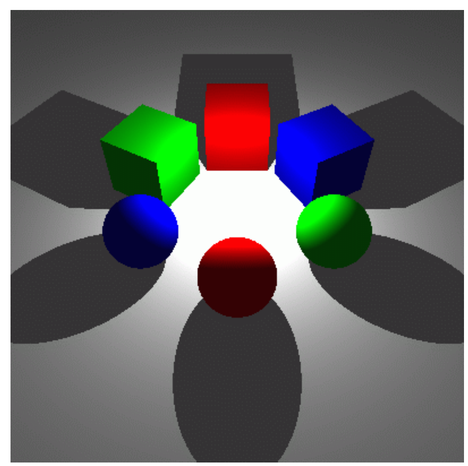




For Intuition about Scene Lighting

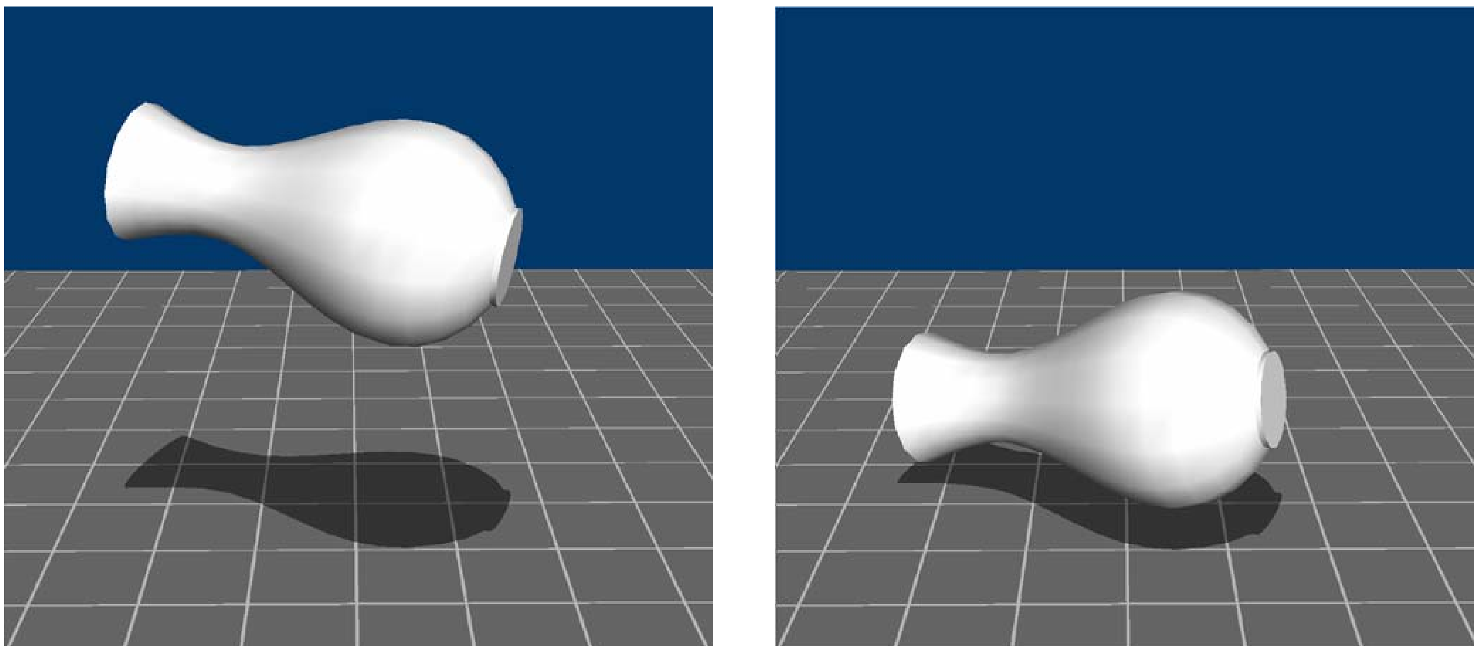
- Position of the light (e.g. sundial)
- Hard shadows vs. soft shadows
- Directional light vs. point light





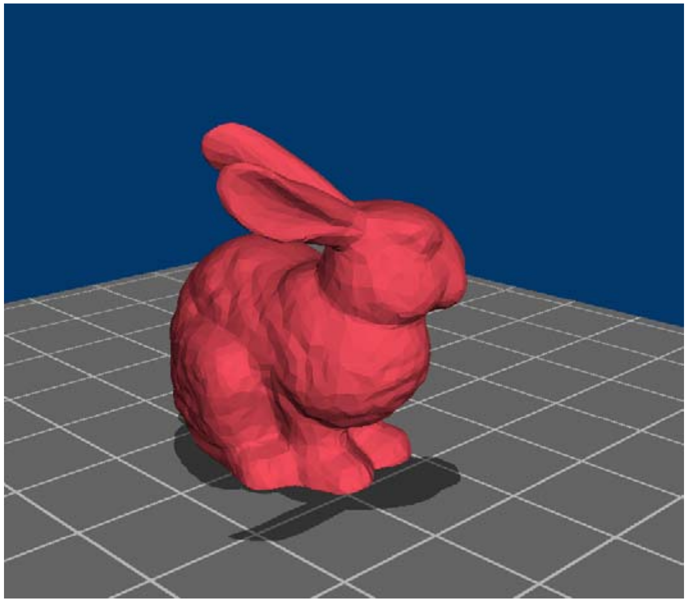
Cast Shadows on Planar Surfaces

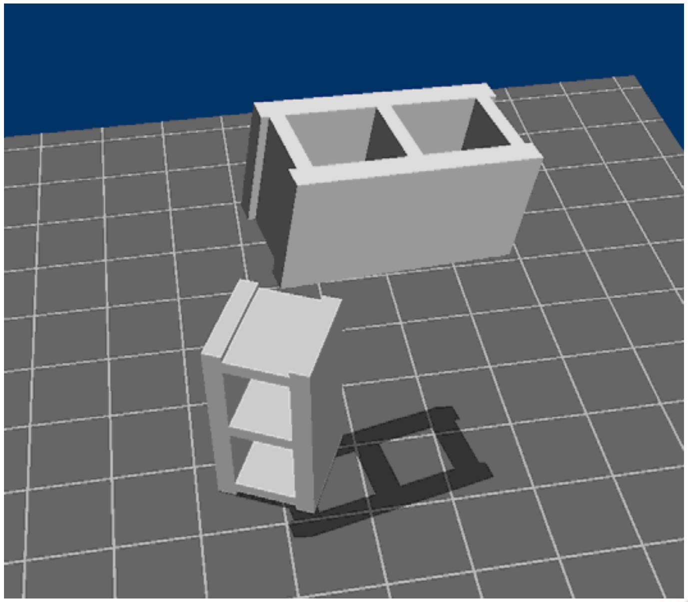
- Draw the object primitives a second time, projected to the ground plane



Limitations of Planar Shadows

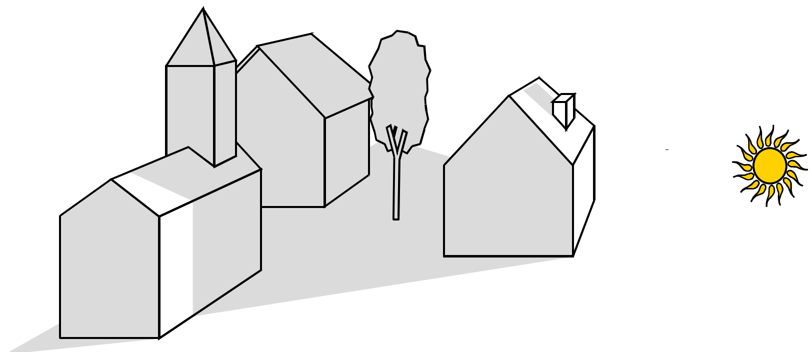
- Does not produce self-shadows, shadows cast on other objects, shadows on curved surfaces, etc.



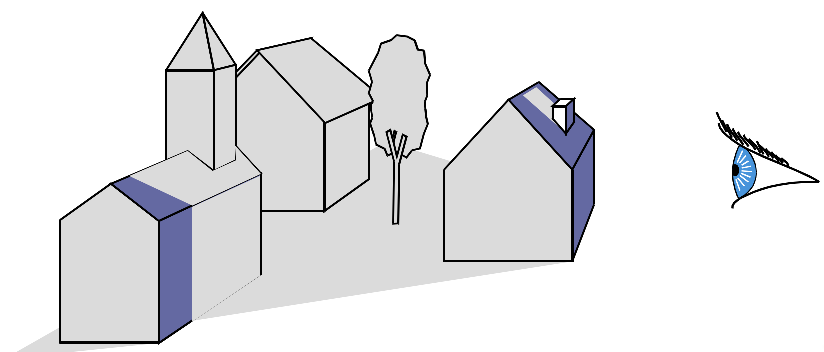


Shadow/View Duality

- A point is lit if it is visible from the light source



- Shadow computation similar to view computation



Fake Shadows using Projective Textures

- Separate obstacle and receiver
- Compute b/w image of obstacle from light
- Use image as projective texture for each receiver

Image from light source BW image of obstacle Final image

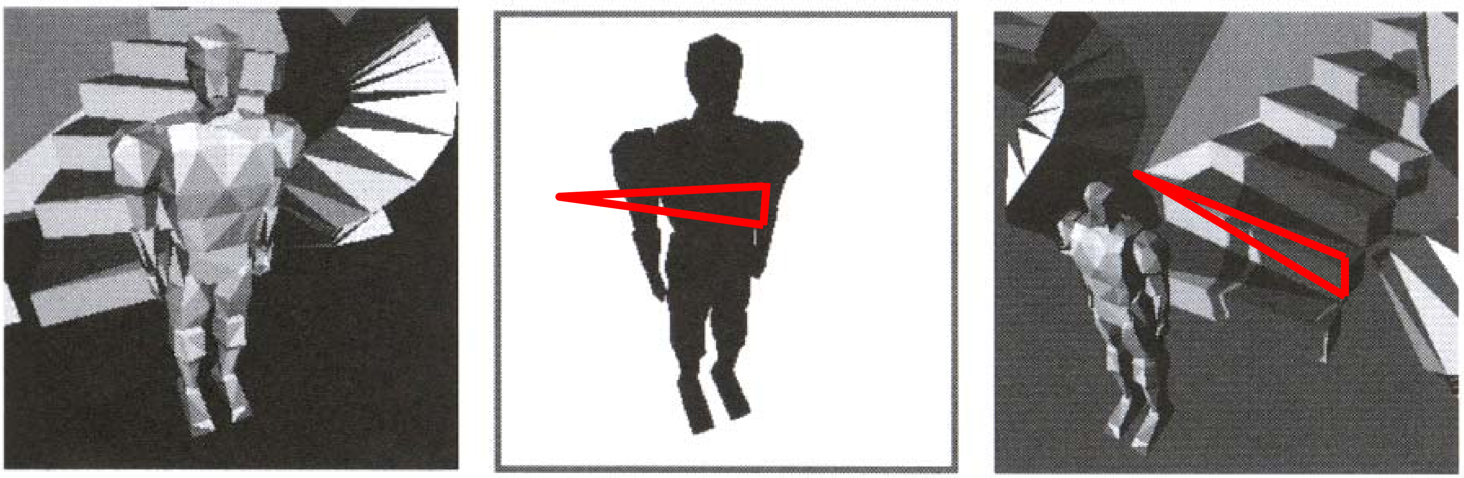


Figure from Moller & Haines “Real Time Rendering”

Projective Texture Shadow Limitations

- Must specify occluder & receiver
- No self-shadows
- Resolution

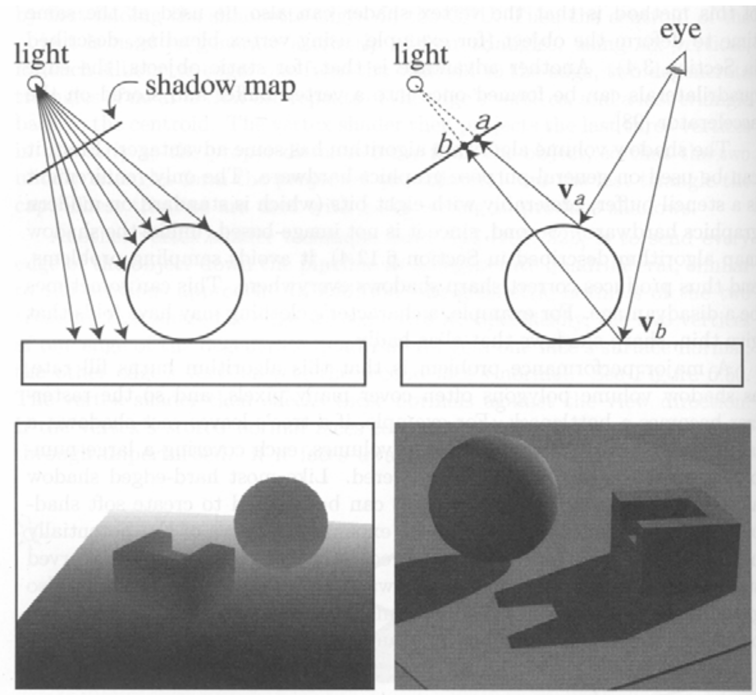
Figure from Moller & Haines “Real Time Rendering”

Shadow Maps

- In Renderman (High-end production software)
- In Games (GPUs)

Shadow Mapping

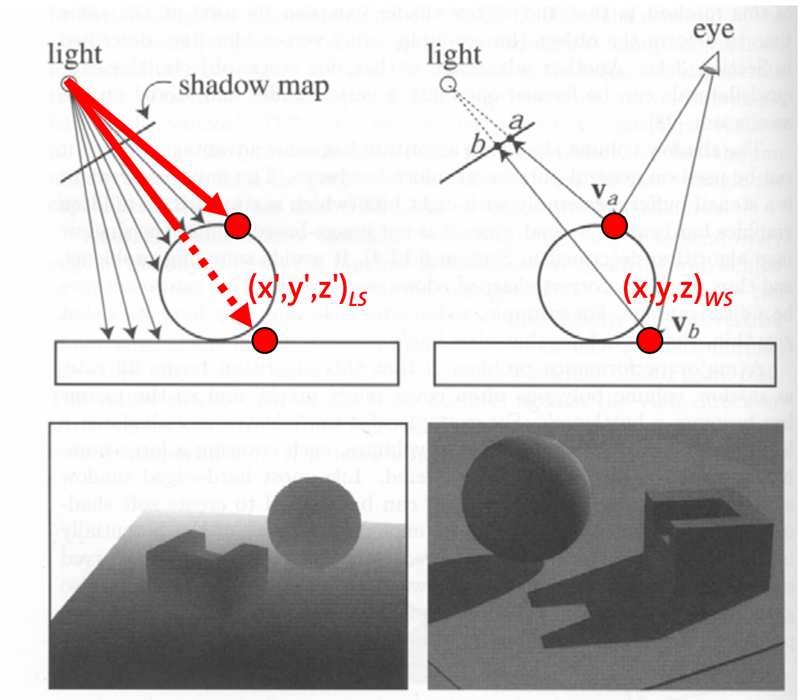
- Texture mapping with depth information
- Requires 2 passes through the pipeline:
  - Compute shadow map (depth from light source)
  - Render final image, *check shadow map to see if points are in shadow*



Foley et al. "Computer Graphics Principles and Practice"

Shadow Map Look Up

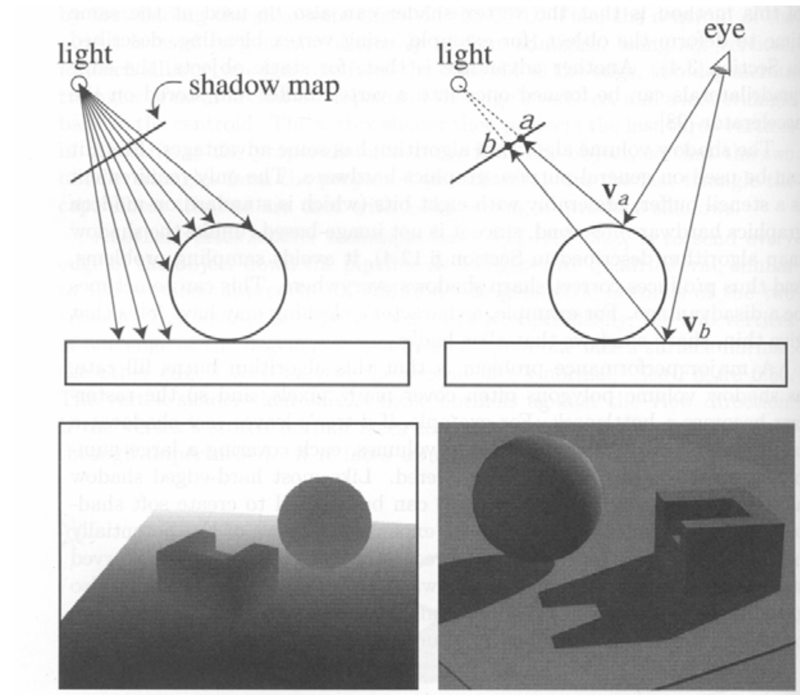
- We have a 3D point $(x,y,z)_{WS}$
- How do we look up the depth from the shadow map?
- Use the 4x4 perspective projection matrix from the light source to get $(x',y',z')_{LS}$
- ShadowMap(x',y') < z'?



Foley et al. "Computer Graphics Principles and Practice"

Limitations of Shadow Maps

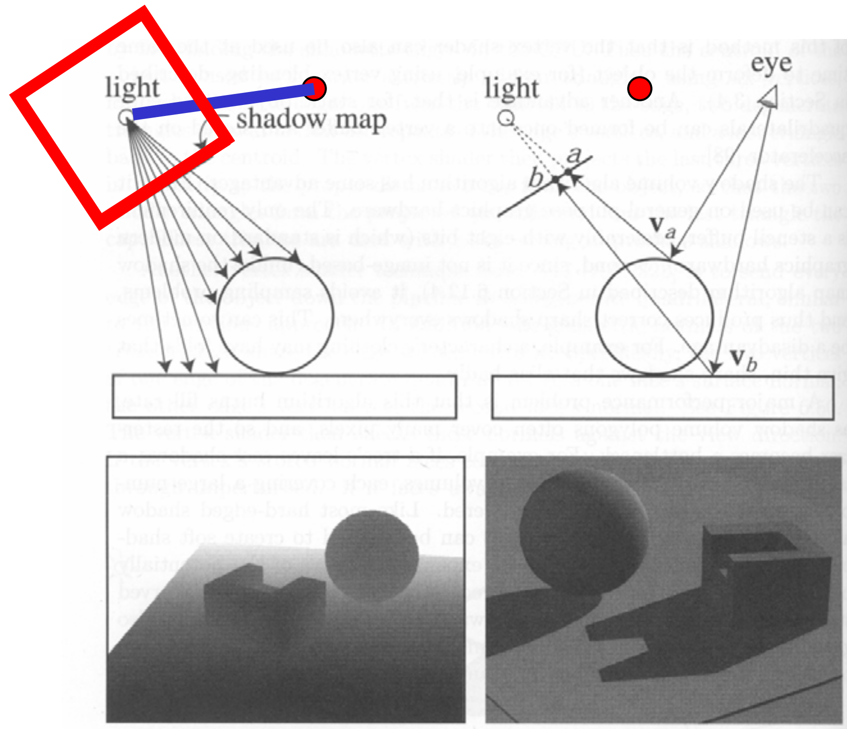
1. Field of View
2. Bias (Epsilon)
3. Aliasing



Foley et al. "Computer Graphics Principles and Practice"

1. Field of View Problem

- What if point to shadow is outside field of view of shadow map?
  - Use cubical shadow map
  - Use only spot lights!



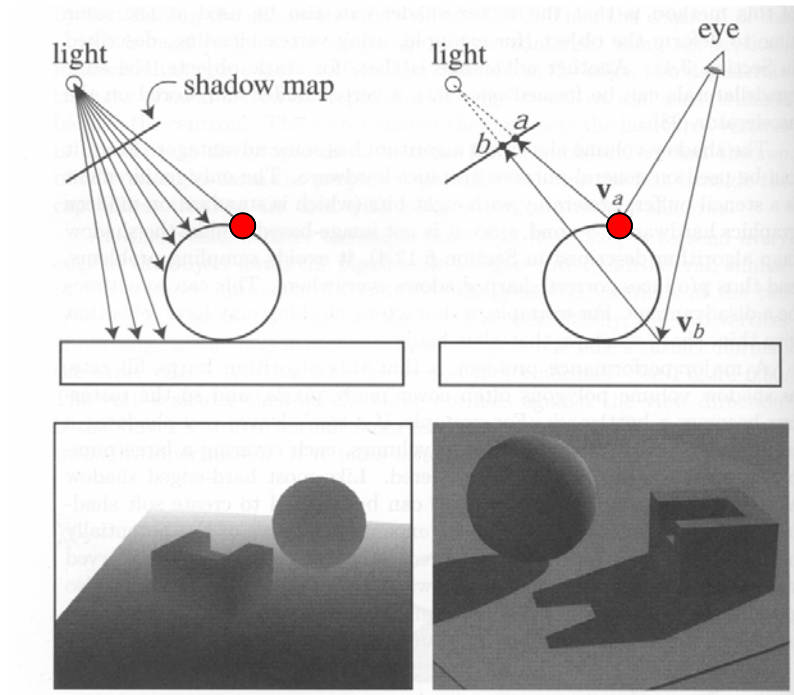
Foley et al. "Computer Graphics Principles and Practice"

2. The Bias (Epsilon) Nightmare

- For a point visible from the light source

  ShadowMap(x’,y’) ≈ z’

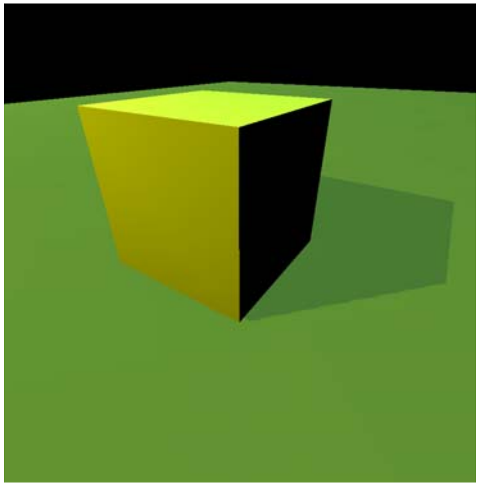
- How can we avoid erroneous self-shadowing?
  – Add bias (epsilon)



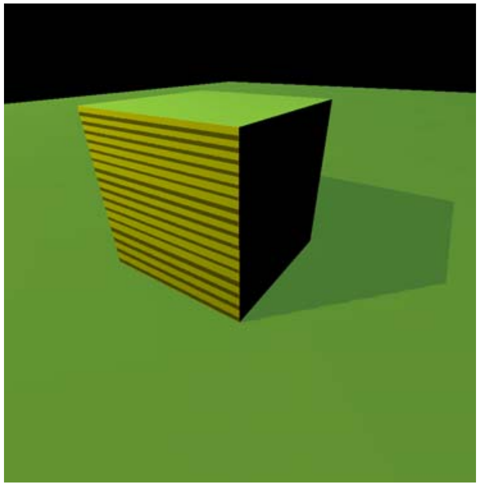
Foley et al. “Computer Graphics Principles and Practice”

2. Bias (Epsilon) for Shadow Maps

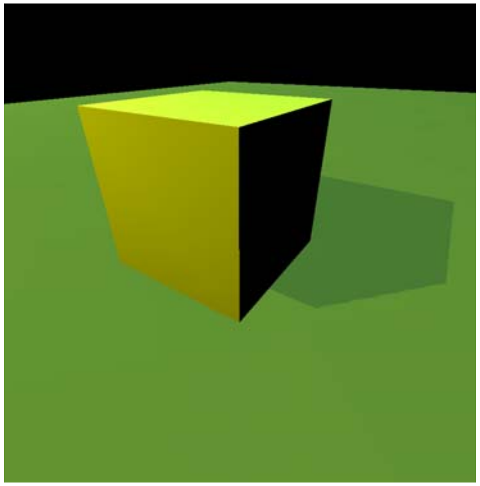
- ShadowMap(x',y') + bias < z'
- Choosing a good bias value can be very tricky



Correct image



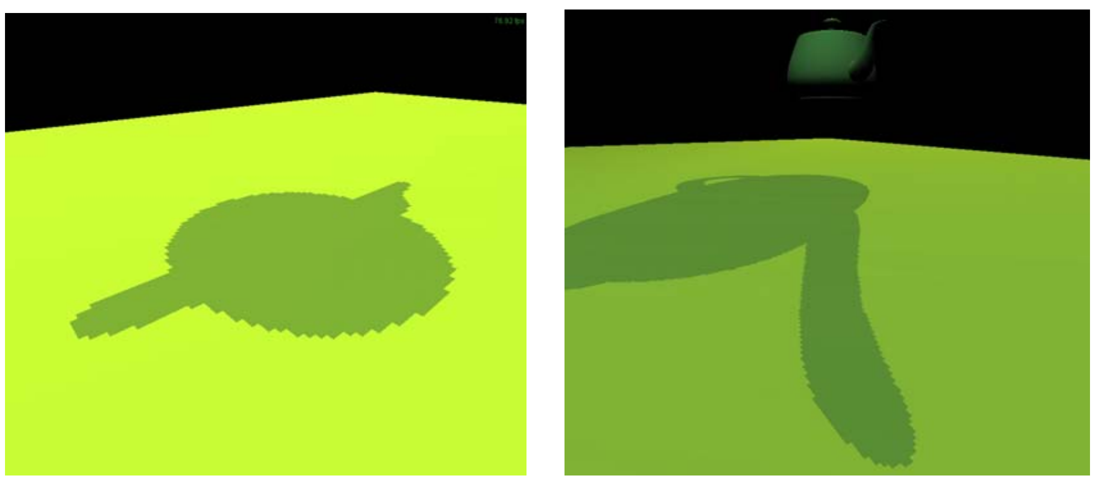
Not enough bias



Way too much bias

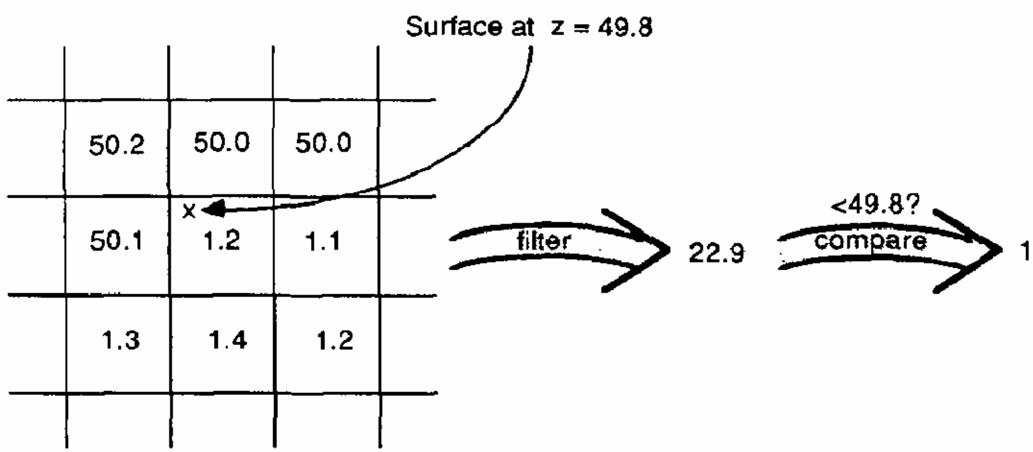
3. Shadow Map Aliasing

- Under-sampling of the shadow map
- Reprojection aliasing – especially bad when the camera & light are opposite each other



3. Shadow Map Filtering

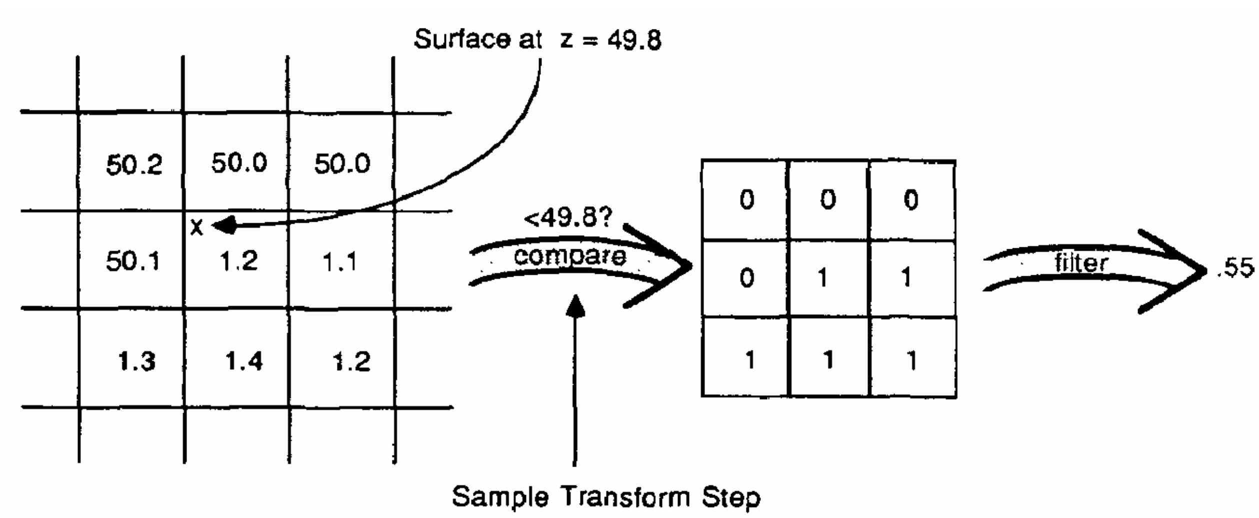
- Should we filter the depth?
(weighted average of neighboring depth values)
- No… filtering depth is not meaningful



a) Ordinary texture map filtering. Does not work for depth maps.

3. Percentage Closer Filtering

- Instead filter the result of the test (weighted average of comparison results)
- But makes the bias issue more tricky

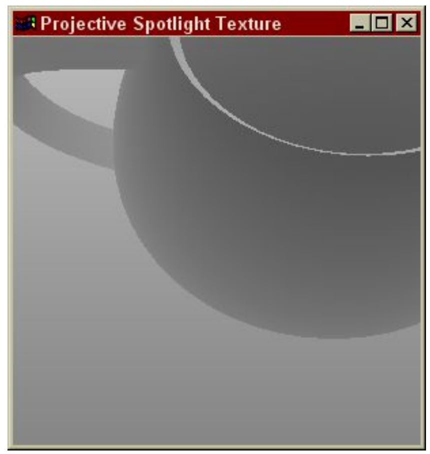


3. Percentage Closer Filtering

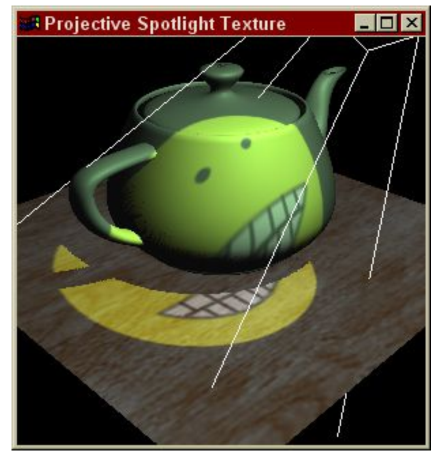
- 5x5 samples
- Nice antialiased shadow
- Using a bigger filter produces fake soft shadows
- Setting bias is tricky

Projective Texturing + Shadow Map

Light's View



Depth/Shadow Map



Eye's View

Images from Cass Everitt et al.,
"Hardware Shadow Mapping"
NVIDIA SDK White Paper

Shadows in Production

- Often use shadow maps
- Ray casting as fallback in case of robustness issues

Figure 12. Frame from *Luxo Jr.*

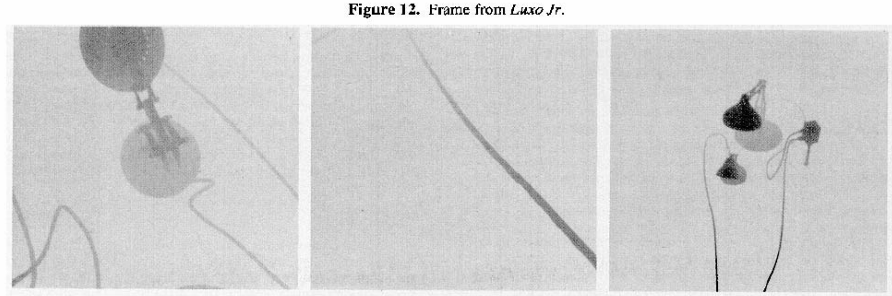
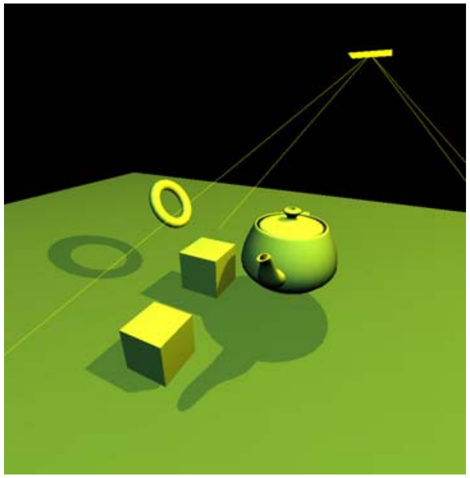
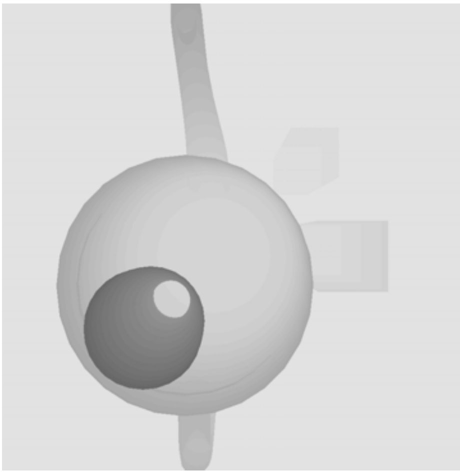


Figure 13. Shadow maps from *Luxo Jr.*

Hardware Shadow Maps

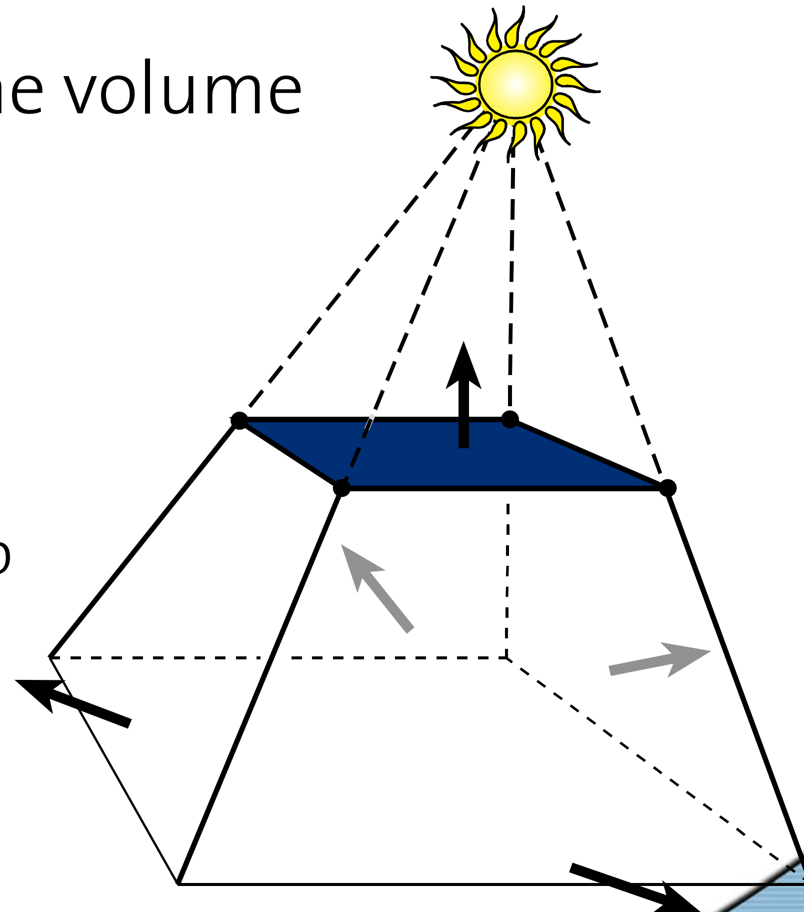
- Can be done with hardware texture mapping
  - Texture coordinates u,v,w generated using 4x4 matrix
  - Modern hardware permits tests on texture values





Shadow Volumes

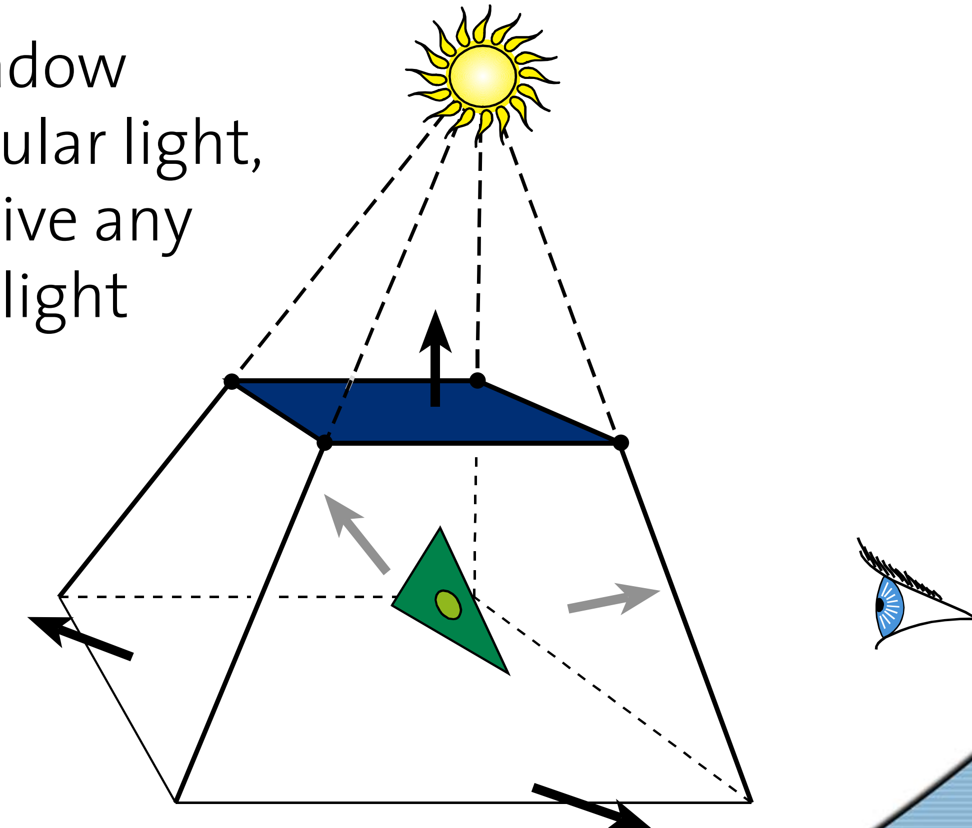
- Explicitly represent the volume of space in shadow
- For each polygon
  - Pyramid with point light as apex
  - Include polygon to cap
- Shadow test similar to clipping



Shadow Volumes

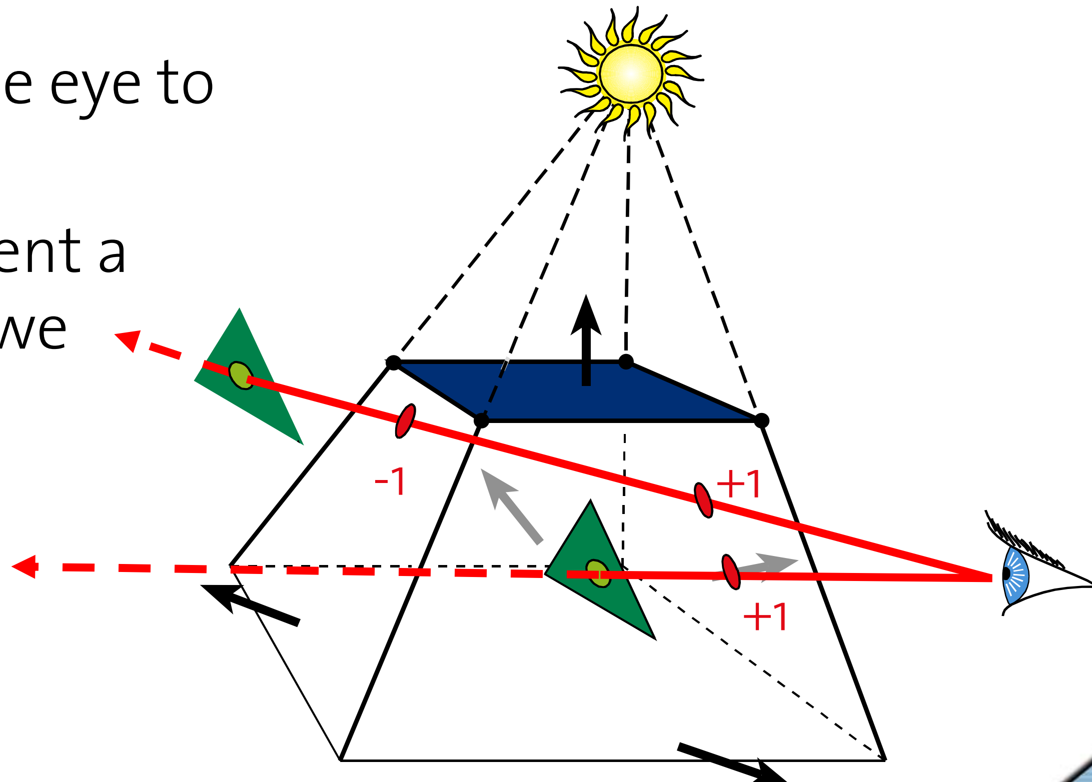
- If a point is inside a shadow volume cast by a particular light, the point does not receive any illumination from that light

- Cost of naive implementation:
  #polygons * #lights



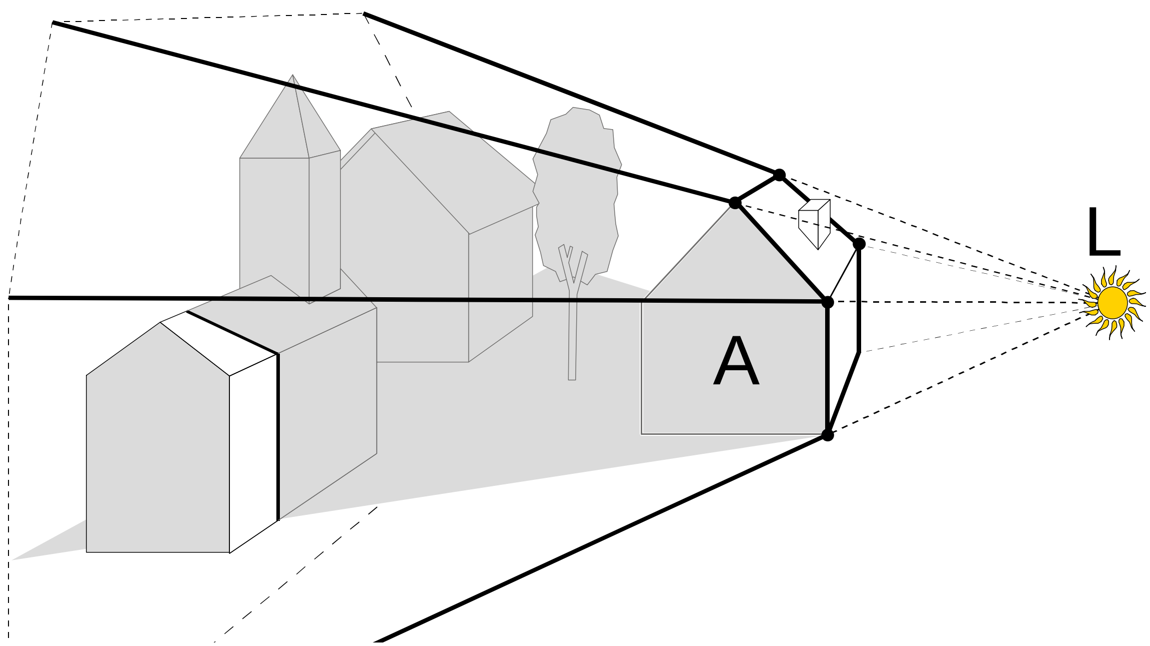
Shadow Volumes

- Shoot a ray from the eye to the visible point
- Increment/decrement a counter each time we intersect a shadow volume polygon
- If the counter $\neq 0$, the point is in shadow



Optimizing Shadow Volumes

- Use silhouette edges only (edge where a back-facing & front-facing polygon meet)

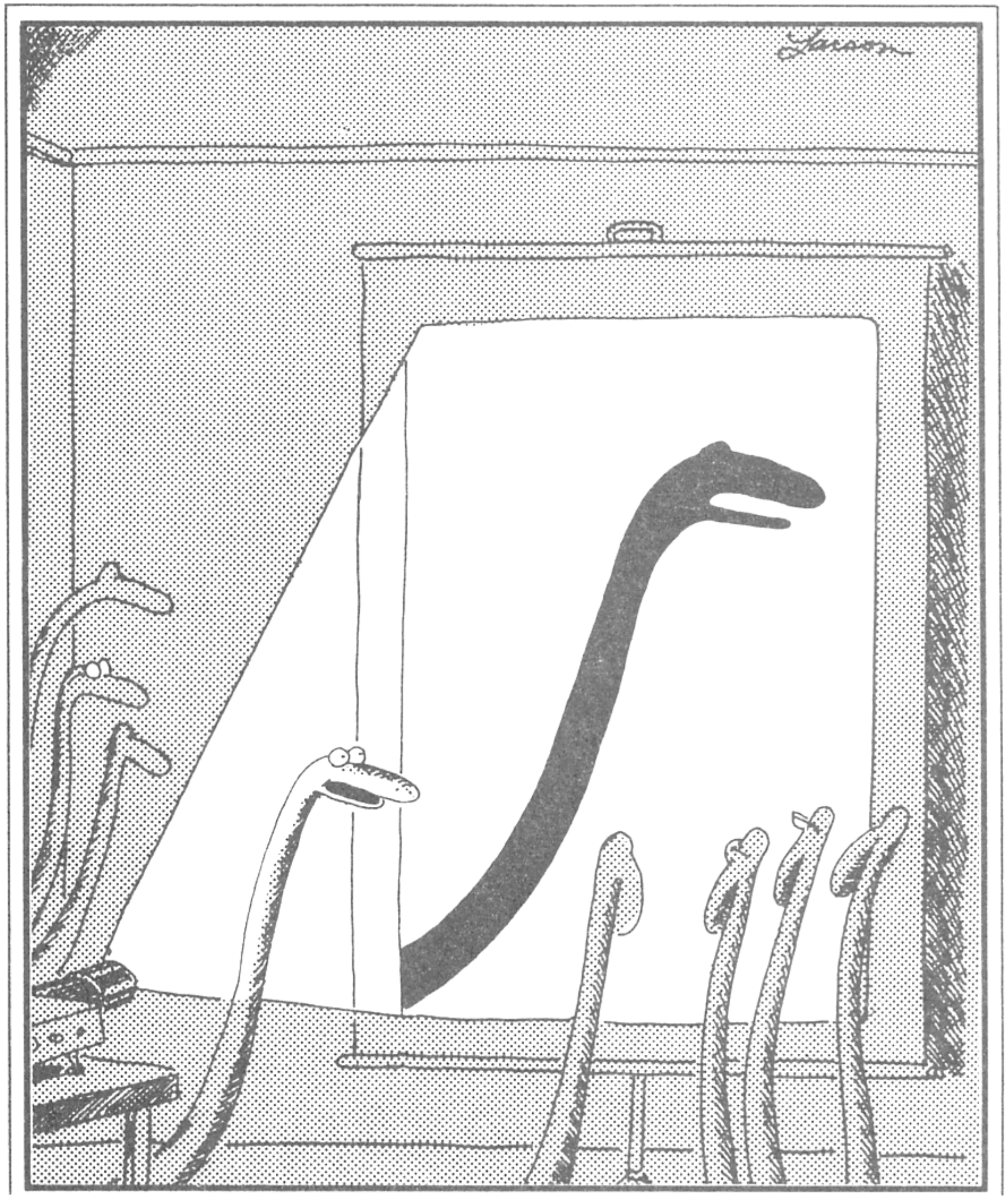


Limitations of Shadow Volumes

- Introduces a lot of new geometry
- Expensive to rasterize long skinny triangles
- Objects must be watertight to use silhouette trick
- Rasterization of polygons sharing an edge must not overlap & must not have gap

Homework

Features / Limitations	Planar Fake Shadows	Projective Texture Shadows	Shadow Maps	Shadow Volumes
Allows objects to cast shadows on themselves (self shadowing)				
Permits shadows on arbitrary surfaces (i.e. curved)				
Renders geometry from the viewpoint of the light				
Generates extra geometric primitives				
Limited resolution of intermediate representation can result in jaggie shadow artifacts				



"Now this is…this is…well, I guess it's another snake."