ECE4893A/CS4803MPG: Multicore and GPU Programming for Video Games

Lecture 14: Projective Textures and Shadow Maps

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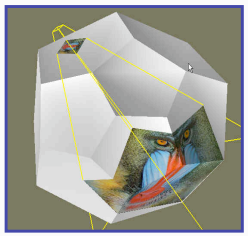
What is projective texturing?

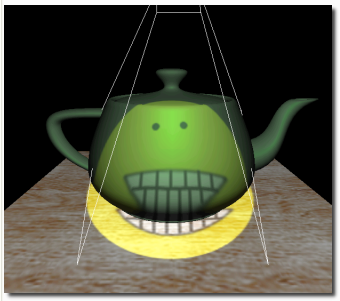
- An intuition for projective texturing
  - The slide projector analogy

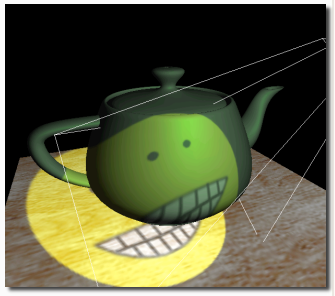


Source: Wolfgang Heidrich [99]

From Stanford CS448A: Real-Time Graphics Architectures lecture 11; see graphics.stanford.edu/courses/cs448a-01-fall

"Slide projector" in different locations





Images from C. Everitt, "Projective Texture Mapping," developer.nvidia.com/object/Projective_Texture_Mapping.html

Texture matrix

$$\begin{bmatrix} s \\ t \\ r \\ q \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & 0 & 0 & \frac{1}{2} \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 0 & \frac{1}{2} & \frac{1}{2} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \text{Light} \\ \text{Frustrum} \\ (\text{projection}) \\ \text{Matrix} \end{bmatrix} \begin{bmatrix} \text{Light} \\ \text{View} \\ (\text{lookat}) \\ \text{Matrix} \end{bmatrix} \begin{bmatrix} \text{Modeling} \\ \text{Matrix} \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ w_0 \end{bmatrix}$$

From "The Cg Tutorial," p. 252.

Projective texturing vertex shader

```
void C9E4v_projTexturing(float4 position    : POSITION,
                         float3 normal      : NORMAL,
                out float4 oPosition        : POSITION,
                out float4 texCoordProj     : TEXCOORD0,
                out float4 diffuseLighting  : TEXCOORD1,
 uniform float Kd, uniform float4x4 modelViewProj,
 uniform float3 lightPosition,
 uniform float4x4 textureMatrix)
{
  oPosition = mul(modelViewProj, position);
  // Compute texture coordinates for
  // querying the projective texture
  texCoordProj = mul(textureMatrix, position);

  // Compute diffuse lighting
  float3 N = normalize(normal);
  float3 L = normalize(lightPosition - position.xyz);
  diffuseLighting = Kd * max(dot(L, N), 0);
}
```

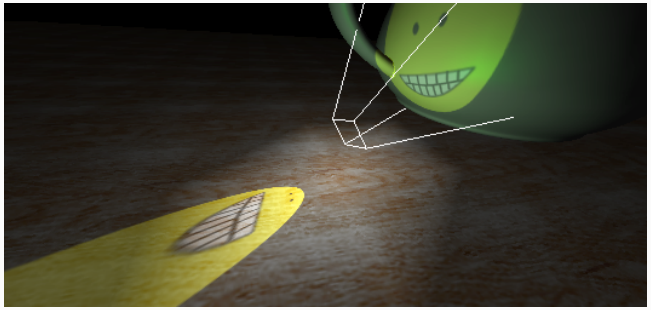
From "The Cg Tutorial"

Projective texturing pixel shader

```
void C9E5f_projTexturing
     (float4 texCoordProj     : TEXCOORD0,
      float4 diffuseLighting  : TEXCOORD1,
          out float4 color    : COLOR,
      uniform sampler2D projectiveMap)
{
  // Fetch color from the projective texture
  float4 projColor =
       tex2Dproj(projectiveMap, texCoordProj);
  color = projColor * diffuseLighting;
}
```

From "The Cg Tutorial"

Watch out for reverse projection!



Images from C. Everitt, "Projective Texture Mapping,"
developer.nvidia.com/object/Projective_Texture_Mapping.html

A dramatic shadow in 2K Games' BioShock

From www.wired.com/gaming/gamingreviews/multimedia/2007/08/pl_bioshock?slide=16&slideView=6

The shadow mapping concept (1)

- Depth testing from the light's point-of-view
  - Two pass algorithm
- First, render depth buffer from the light's point-of-view
  - the result is a "depth map" or "shadow map"
  - essentially a 2D function indicating the depth of the closest pixels to the light
  - This depth map is used in the second pass

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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The shadow mapping concept (2)

- Shadow determination with the depth map
  - Second, render scene from the eye's point-of-view
  - For each rasterized fragment
    - determine fragment's XYZ position relative to the light
    - this light position should be setup to match the frustum used to create the depth map
    - compare the depth value at light position XY in the depth map to fragment's light position Z

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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The shadow mapping concept (3)

- The Shadow Map Comparison
  - Two values
    - A = Z value from depth map at fragment's light XY position
    - B = Z value of fragment's XYZ light position
  - If B is greater than A, then there must be something closer to the light than the fragment
    - then the fragment is shadowed
  - If A and B are approximately equal, the fragment is lit

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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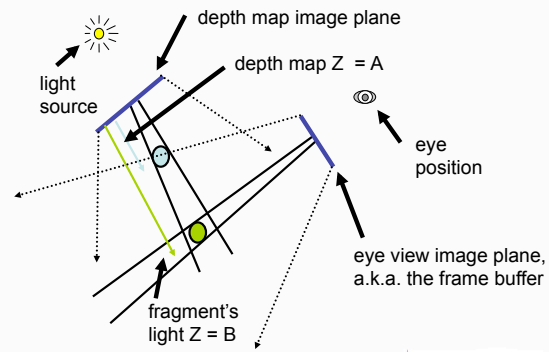
Shadow mapping with a picture in 2D (1)

The A < B shadowed fragment case



Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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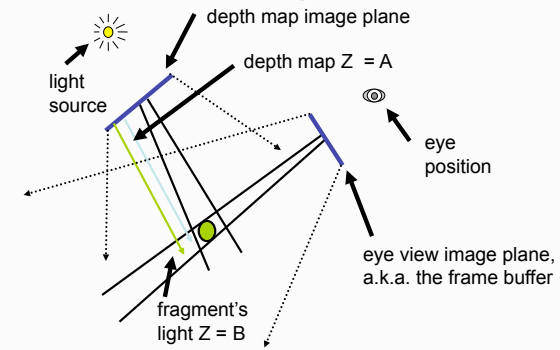
Shadow mapping with a picture in 2D (2)

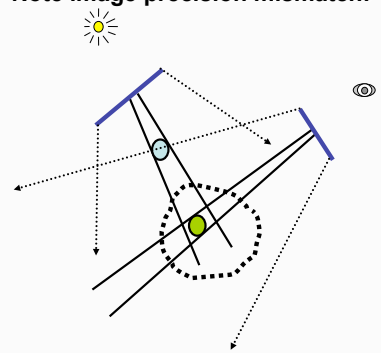
The A ≅ B unshadowed fragment case



Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Shadow mapping with a picture in 2D (3)

Note image precision mismatch!



The depth map could be at a different resolution from the framebuffer

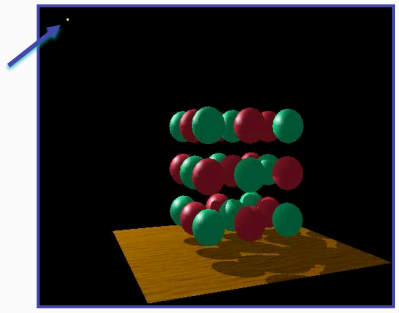
This mismatch can lead to artifacts

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Visualizing the shadow mapping technique (1)

- A fairly complex scene with shadows

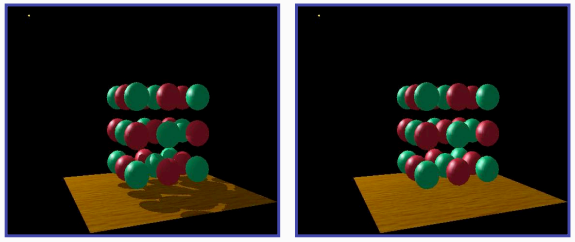
the point light source



Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Visualizing the shadow mapping technique (2)

- Compare with and without shadows

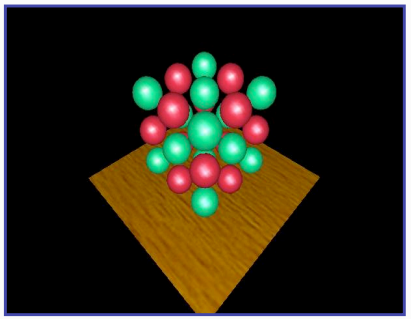


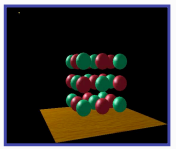
with shadows ***without shadows***

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Visualizing the shadow mapping technique (3)

- The scene from the light's point-of-view





FYI: from the eye's point-of-view again

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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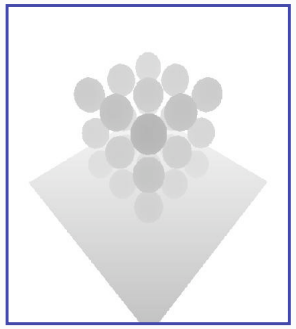
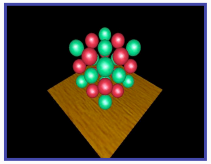
Visualizing the shadow mapping technique (4)

- The depth buffer from the light's point-of-view





FYI: from the light's point-of-view again

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

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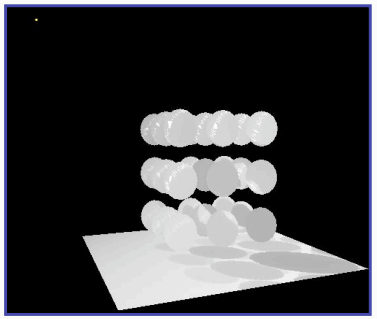
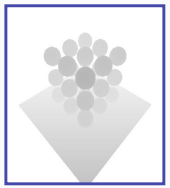
Visualizing the shadow mapping technique (5)

- Projecting the depth map onto the eye's view





FYI: depth map for light's point-of-view again

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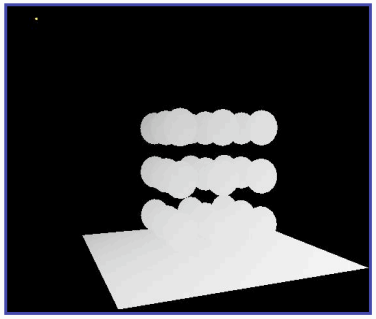
Visualizing the shadow mapping technique (6)

- Projecting light's planar distance onto eye's view



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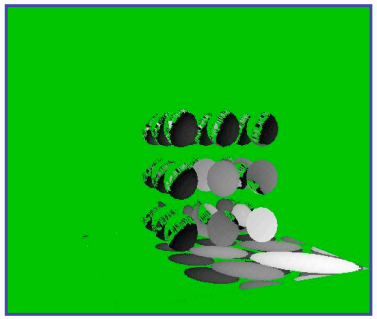
Visualizing the shadow mapping technique (7)

- Comparing light distance to light depth map

Green is where the light planar distance and the light depth map are approximately equal



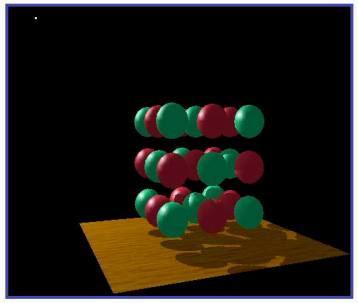
Non-green is where shadows should be

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Visualizing the shadow mapping technique (8)

- Scene with shadows

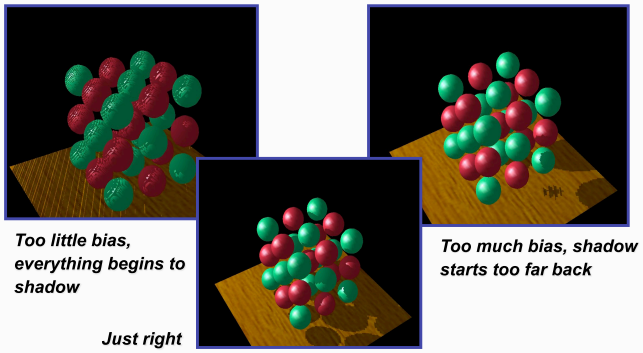
Notice how specular highlights never appear in shadows



Notice how curved surfaces cast shadows on each other

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Depth map bias issues



Too little bias, everything begins to shadow

Just right

Too much bias, shadow starts too far back

Slide from C. Everitt, "Shadow Mapping," Powerpoint presentation, developer.nvidia.com/attach/6392

Dedicated hardware shadow mapping support

- Performs the shadow test as a texture filtering operation
  - looks up texel at (s/q, t/q) in a 2D texture
  - compares lookup value to r/q
  - if texel is greater than or equal to r/q, then generate 1.0
  - if texel is less than r/q, then generate 0.0
- Modulate color with result
  - zero if fragment is shadowed or unchanged color if not

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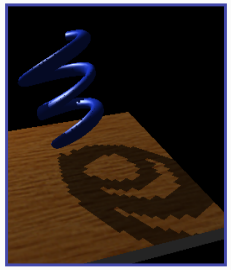
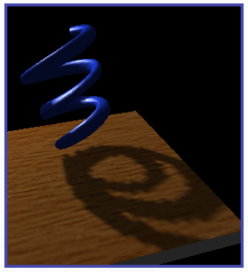
Hardware shadow map filtering example

GL_NEAREST: blocky ***GL_LINEAR: antialiased edges***





Low shadow map resolution used to heighten filtering artifacts

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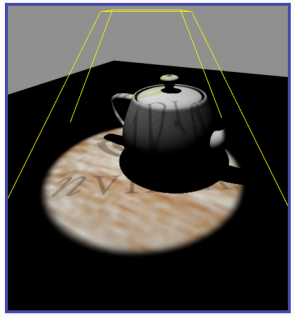
Combine with Projective Texturing for Spotlight Shadows

- Use a spotlight-style projected texture to give shadow maps a spotlight falloff



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