Computer Graphics (CS 543)
Lecture 9b: Shadows and Shadow Maps

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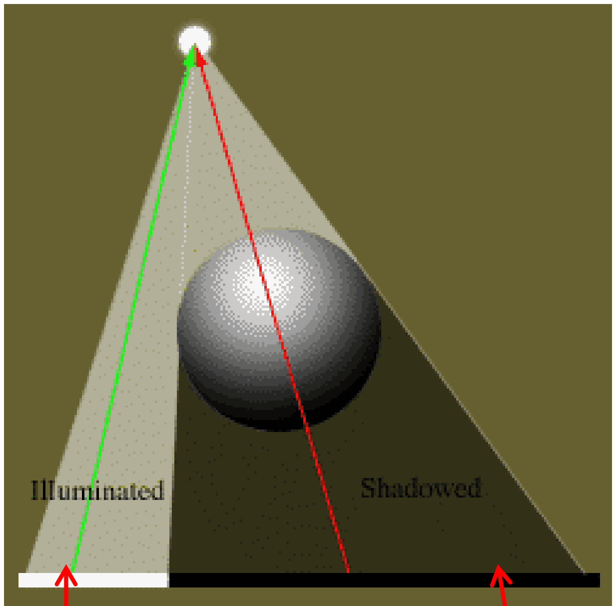
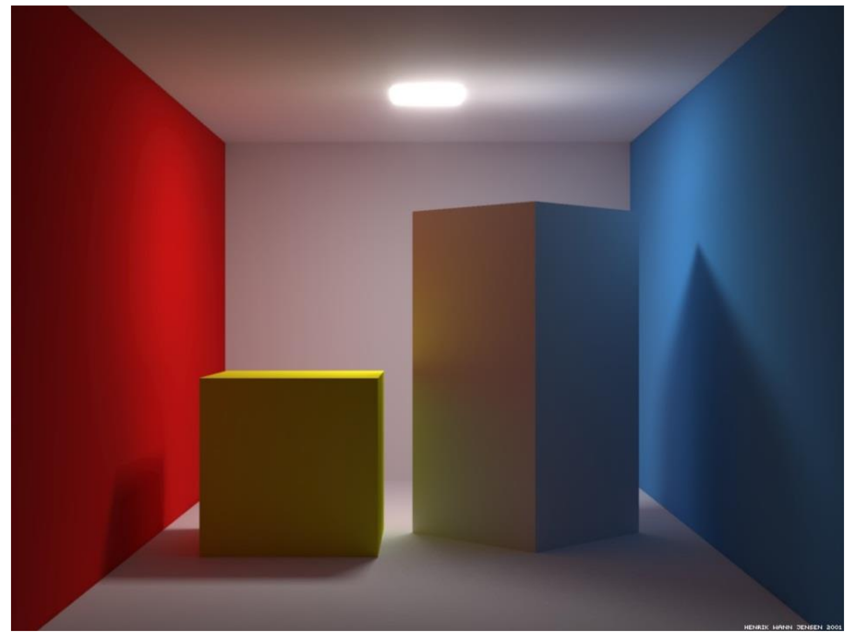
Introduction to Shadows

- Shadows give information on relative positions of objects



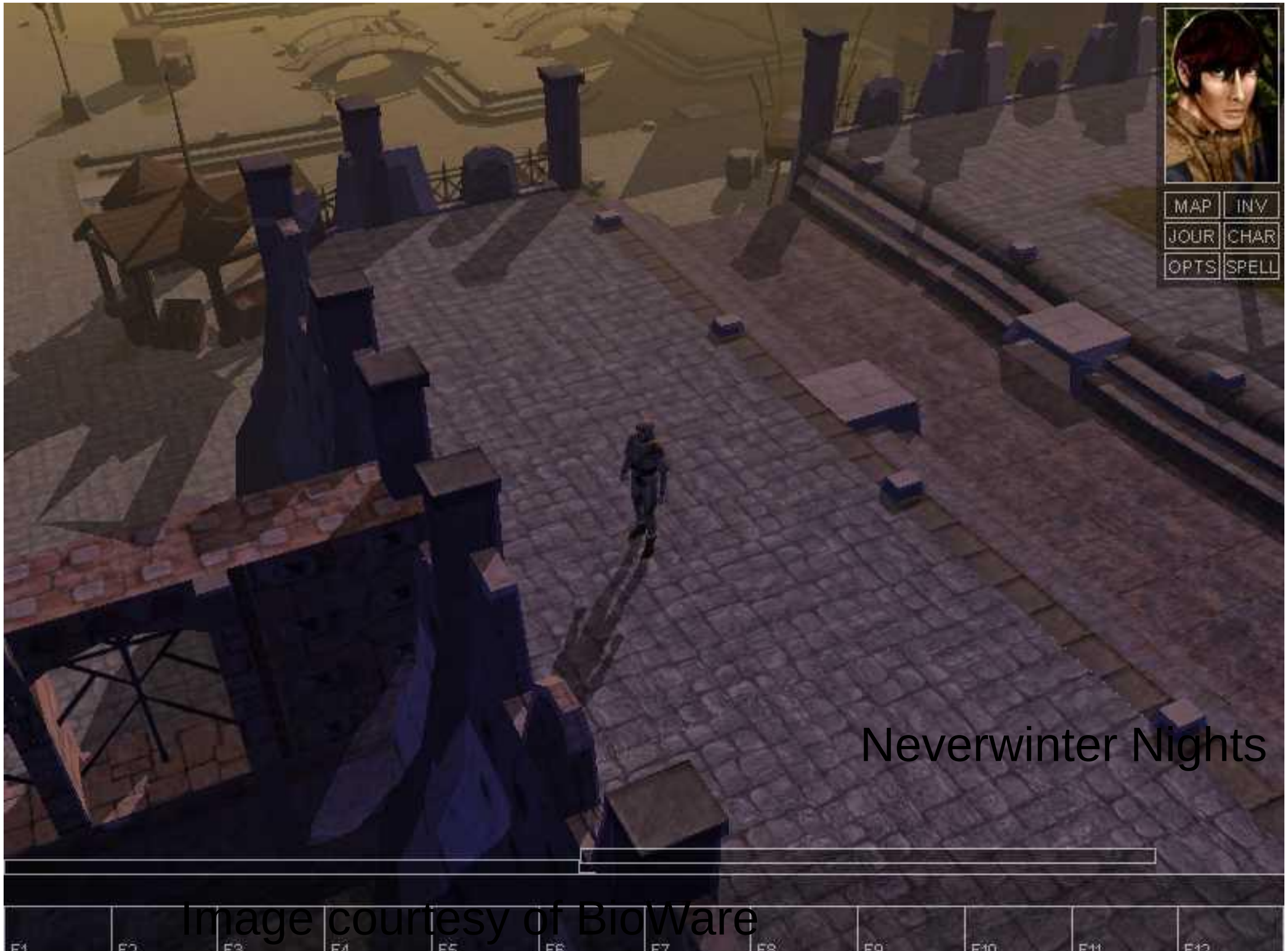
Use ambient + diffuse + specular components

Use just ambient component



Why shadows?

- More realism and atmosphere



Neverwinter Nights

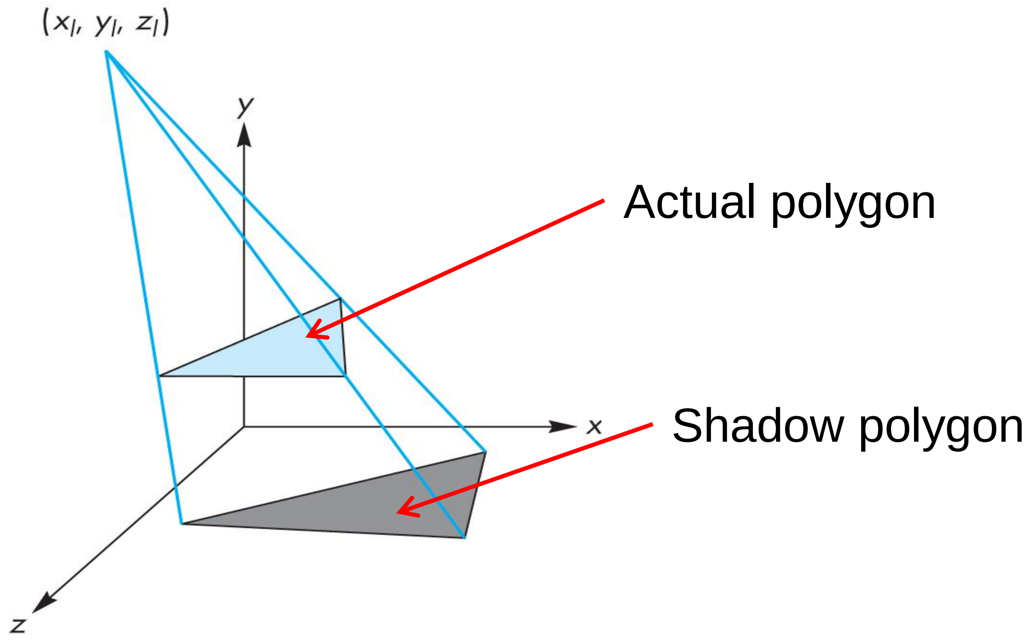
Image courtesy of BioWare

Types of Shadow Algorithms

- Project shadows as separate objects (like Peter Pan's shadow)
  - **Projective shadows**
- As volumes of space that are dark
  - **Shadow volumes** [Franklin Crow 77]
- As places not seen from a light source looking at the scene
  - **Shadow maps** [Lance Williams 78]
- Fourth method used in ray tracing

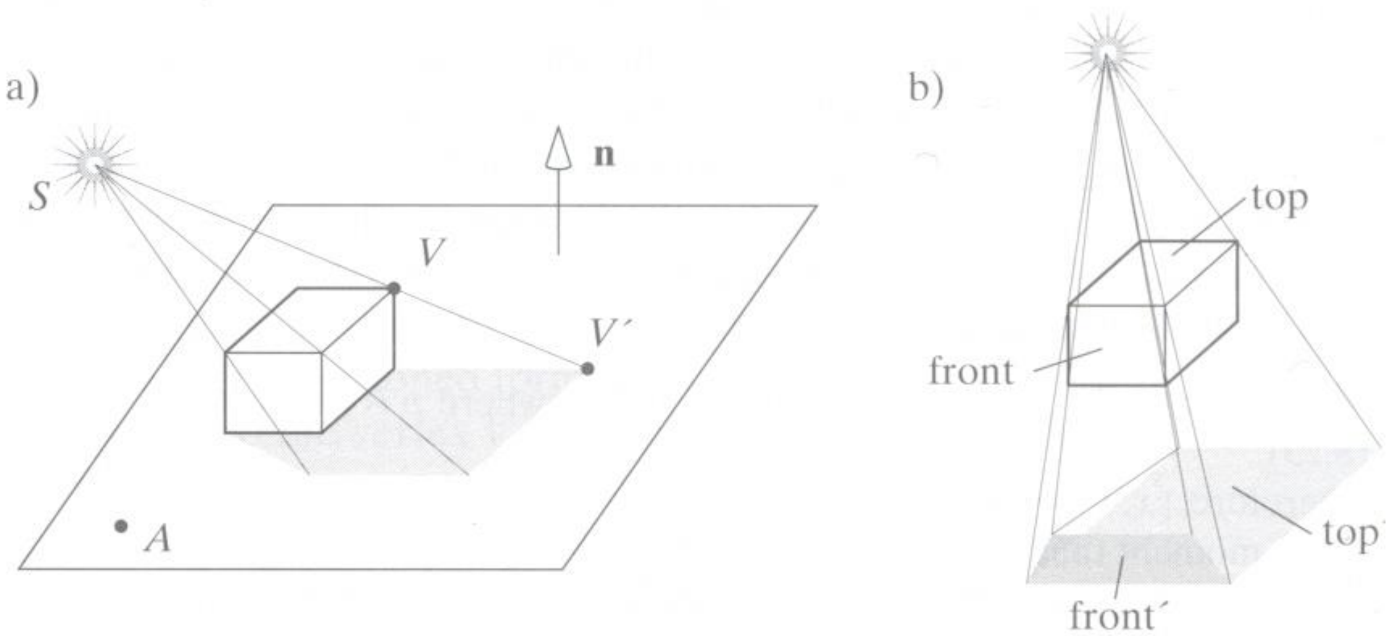
Projective Shadows

- Oldest method: Used in early flight simulators
- Projection of polygon is polygon called **shadow polygon**



Projective Shadows

- Works for flat surfaces illuminated by point light
- For each face, project vertices **V** to find **V'** of shadow polygon
- Object shadow = union of projections of faces

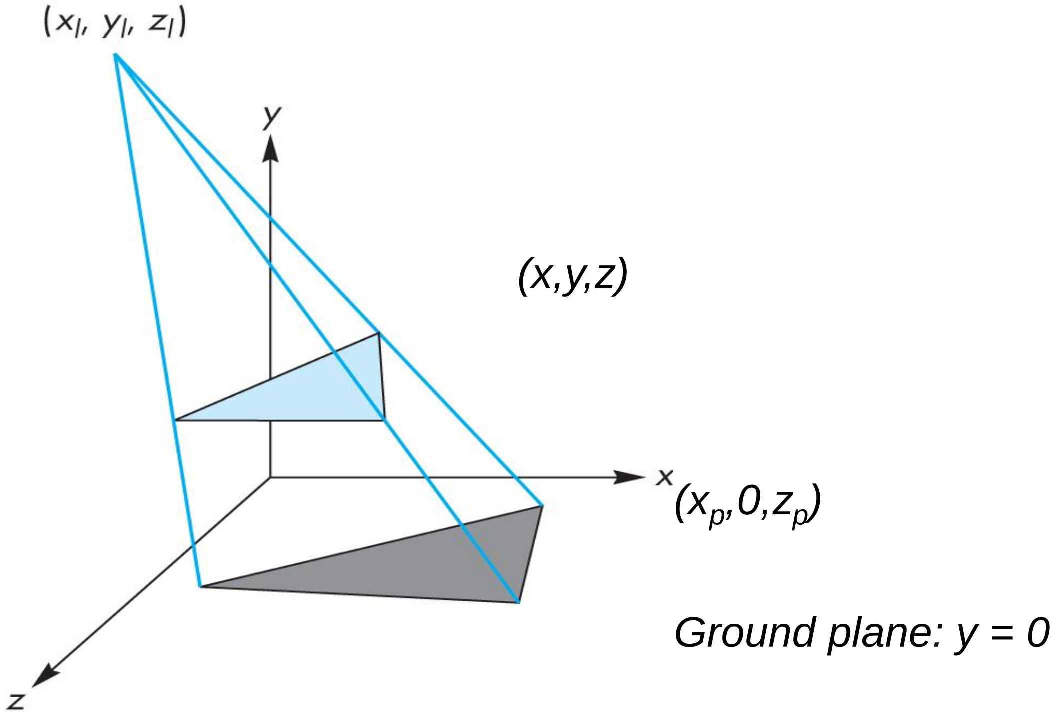


Projective Shadow Algorithm

- Project light-object edges onto plane
- Algorithm:
  - First, draw ground plane/scene using specular+diffuse+ambient components
  - Then, draw shadow projections (face by face) using only ambient component

Projective Shadows for Polygon

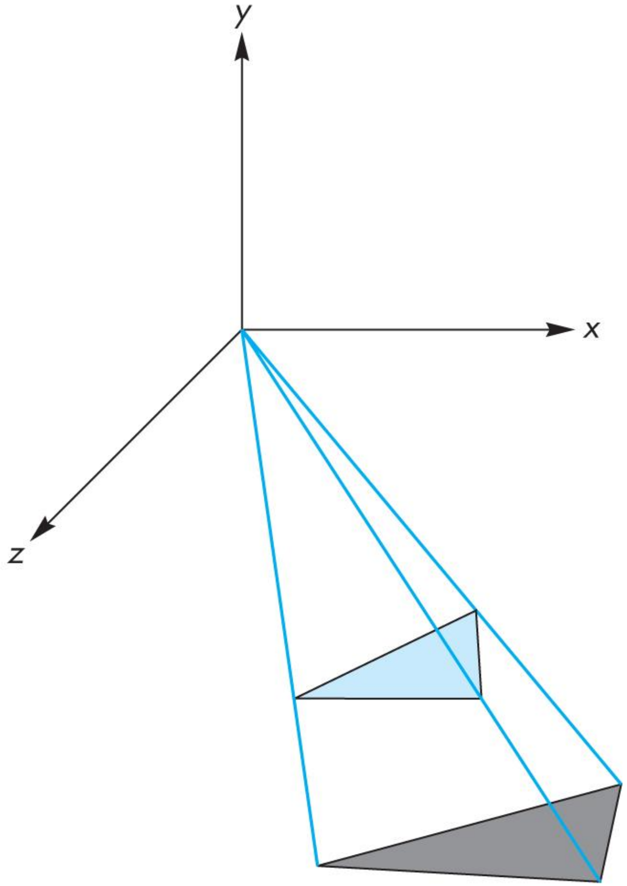
1. If light is at (x_l, y_l, z_l)
2. Vertex at (x, y, z)
3. Would like to calculate shadow polygon vertex V projected onto ground at $(x_p, 0, z_p)$



Projective Shadows for Polygon

- If we move original polygon so that light source is at origin
- Matrix *M* projects a vertex V to give its projection V' in shadow polygon

$$m = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & \frac{1}{-y_l} & 0 & 0 \end{bmatrix}$$



Building Shadow Projection Matrix

1. Translate source to origin with $T(-x_l, -y_l, -z_l)$
2. Perspective projection
3. Translate back by $T(x_l, y_l, z_l)$

$$M = \begin{bmatrix} 1 & 0 & 0 & x_l \\ 0 & 1 & 0 & y_l \\ 0 & 0 & 1 & z_l \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & \frac{1}{-y_l} & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -x_l \\ 0 & 1 & 0 & -y_l \\ 0 & 0 & 1 & -z_l \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Final matrix that projects
Vertex V onto V' in shadow polygon

Code snippets?

- Set up projection matrix in OpenGL application

```
float light[3];  // location of light
mat4 m;    // shadow projection matrix initially identity

M[3][1] = -1.0/light[1];
```

$$M = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & \frac{1}{-y_l} & 0 & 0 \end{bmatrix}$$

Projective Shadow Code

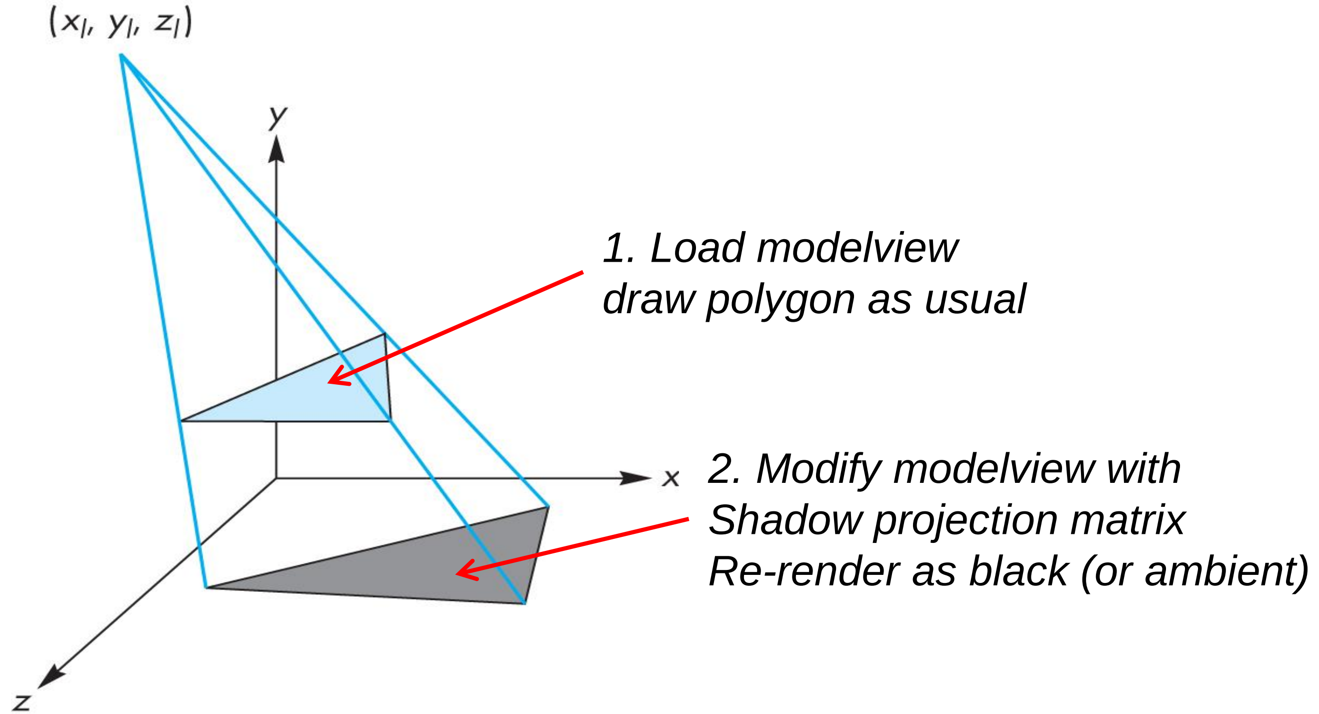
- Set up object (e.g a square) to be drawn

```
point4 square[4] = {vec4(-0.5, 0.5, -0.5, 1.0}
                   {vec4(-0.5, 0.5, -0.5, 1.0}
                   {vec4(-0.5, 0.5, -0.5, 1.0}
                   {vec4(-0.5, 0.5, -0.5, 1.0}
```

- Copy square to VBO
- Pass modelview, projection matrices to vertex shader

What next?

- Next, we load model_view as usual then draw original polygon
- Then load shadow projection matrix, change color to black, re-render polygon



Shadow projection Display( ) Function

```
void display( )
{
    mat4 mm;
    // clear the window
    glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);

    // render red square (original square) using modelview
    // matrix as usual (previously set up)
    glUniform4fv(color_loc, 1, red);
    glDrawArrays(GL_TRIANGLE_STRIP, 0, 4);
```

Shadow projection Display( ) Function

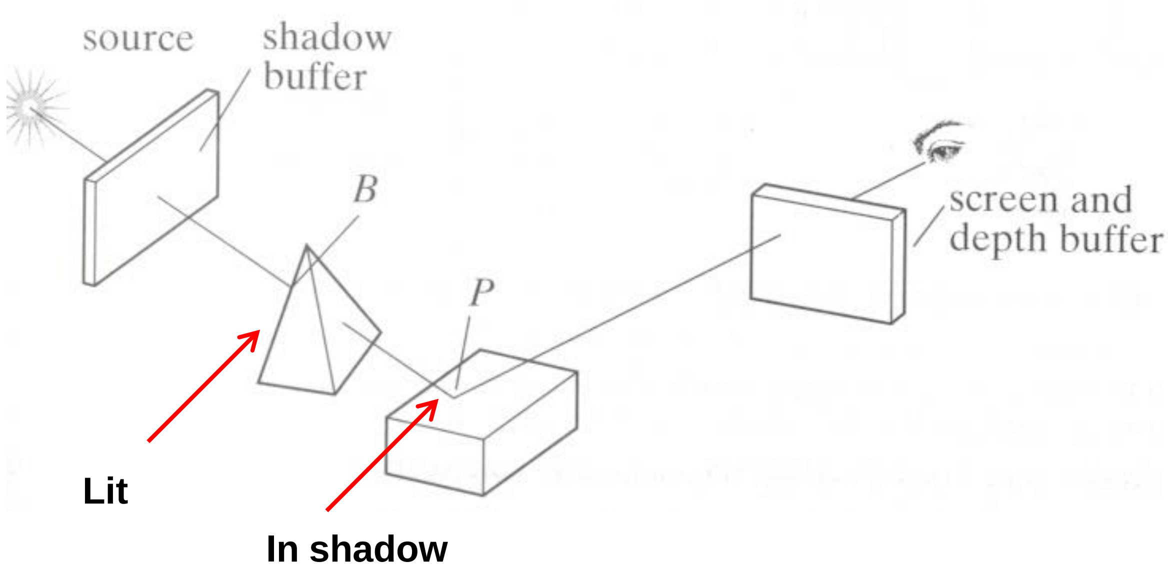
```
// modify modelview matrix to project square
// and send modified model_view matrix to shader
mm = model_view
     * Translate(light[0], light[1], light[2]
     *m
     * Translate(-light[0], -light[1], -light[2]);
glUniformMatrix4fv(matrix_loc, 1, GL_TRUE, mm);

//and re-render square as
// black square (or using only ambient component)
 glUniform4fv(color_loc, 1, black);
 glDrawArrays(GL_TRIANGLE_STRIP, 0, 4);
 glutSwapBuffers( );
}
```

$$M = \begin{bmatrix} 1 & 0 & 0 & x_l \\ 0 & 1 & 0 & y_l \\ 0 & 0 & 1 & z_l \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & \frac{1}{-y_l} & 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & -x_l \\ 0 & 1 & 0 & -y_l \\ 0 & 0 & 1 & -z_l \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

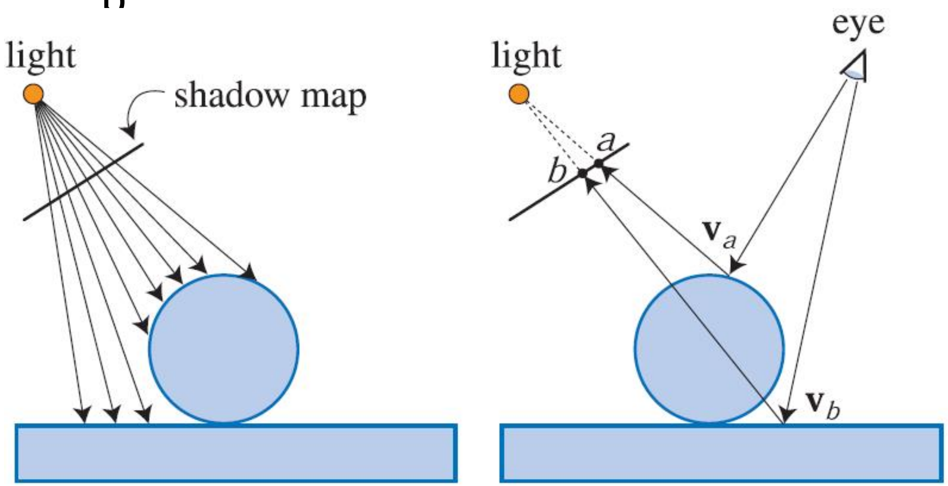
Shadow Buffer Theory

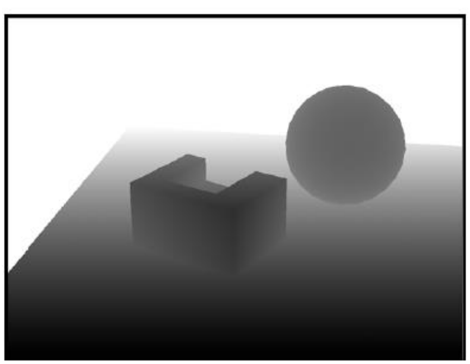
- Along each path from light
  - Only closest object is lit
  - Other objects on that path in shadow
- Shadow buffer stores closest object on each path

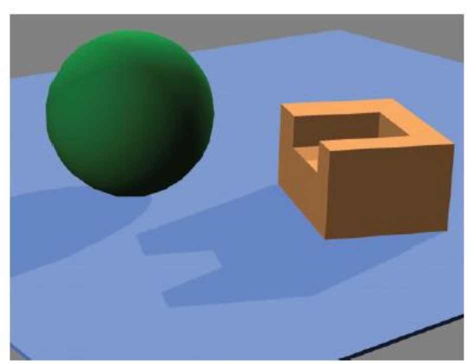


Shadow Map Illustrated

- Second dept buffer called the **shadow map** is used
- Point v_a stored in element a of shadow map: lit!
- Point v_b **NOT** in element b of shadow map: In shadow

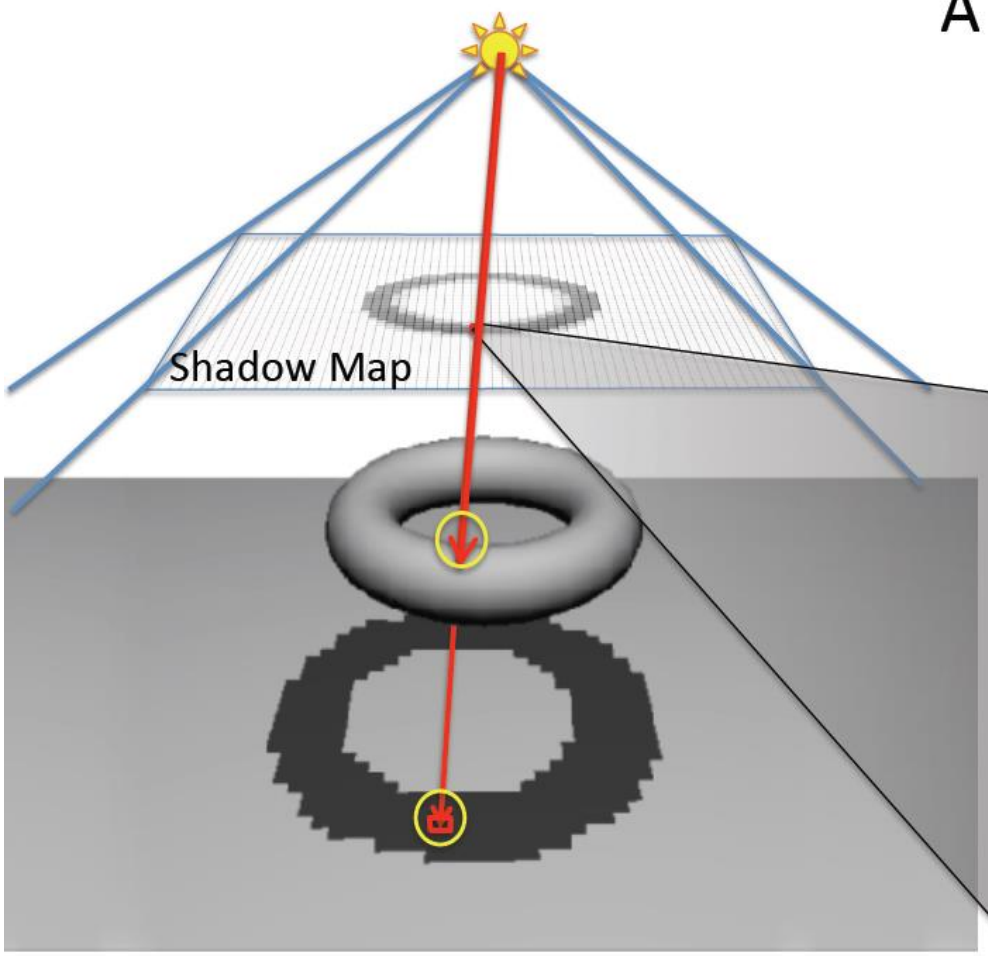




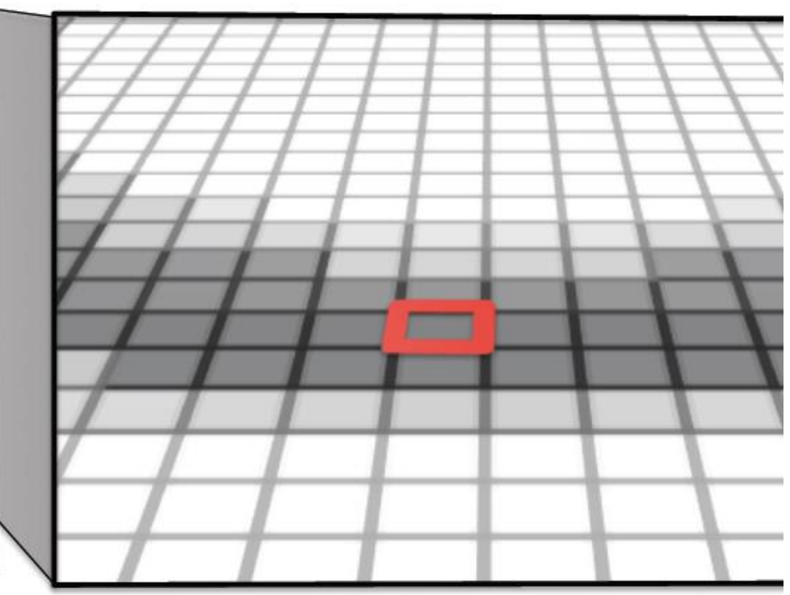


Not limited to planes

Shadow Map: Depth Comparison



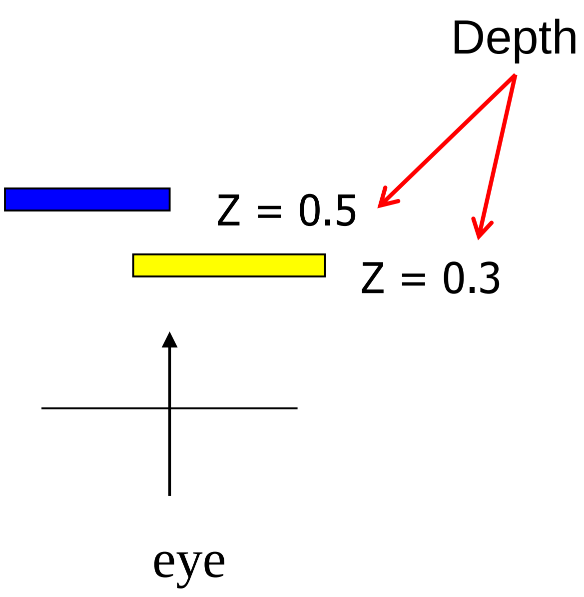
A fragment is in shadow if its depth is greater than the corresponding depth value in the shadow map



OpenGL Depth Buffer (Z Buffer)

- **Depth:** While drawing objects, depth buffer stores distance of each polygon from viewer
- **Why?** If multiple polygons overlap a pixel, only closest one polygon is drawn

1.0	1.0	1.0	1.0
1.0	0.3	0.3	1.0
0.5	0.3	0.3	1.0
0.5	0.5	1.0	1.0



Setting up OpenGL Depth Buffer

- **Note:** You did this in order to draw solid cube, meshes

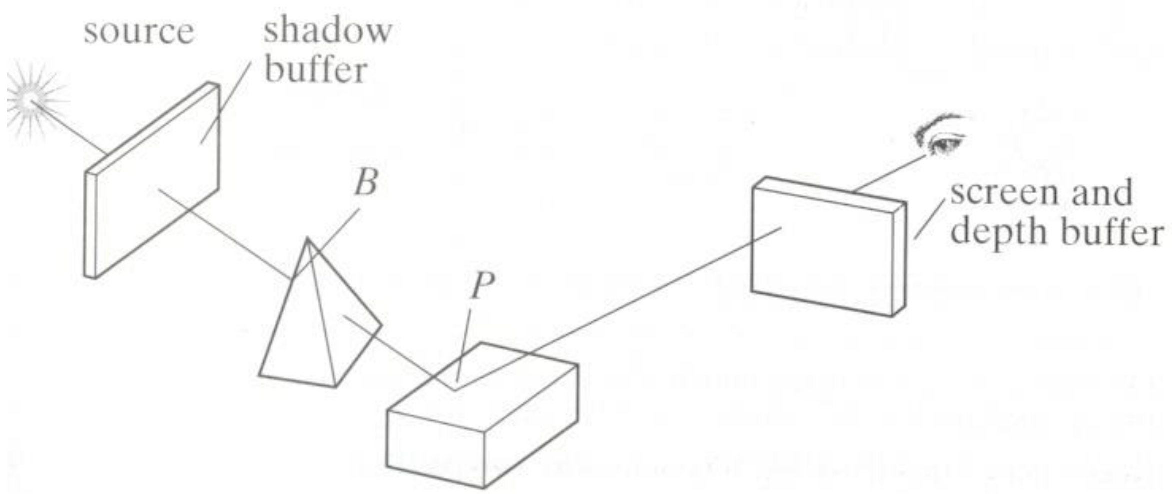
1. `glutInitDisplayMode(GLUT_DEPTH | GLUT_RGB)` instructs openGL to create depth buffer
2. `glEnable(GL_DEPTH_TEST)` enables depth testing
3. `glClear(GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT)` Initializes depth buffer every time we draw a new picture

Shadow Map Approach

- Rendering in two stages:
  - Loading shadow Map
  - Render the scene

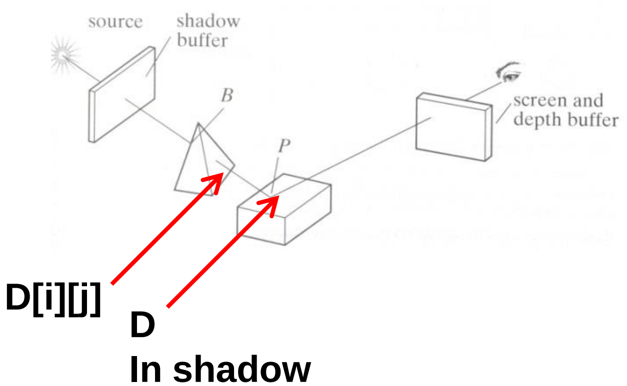
Loading Shadow Map

- Initialize each element to 1.0
- Position a camera at light source
- Rasterize each face in scene updating closest object
- Shadow map (buffer) tracks smallest depth on each path



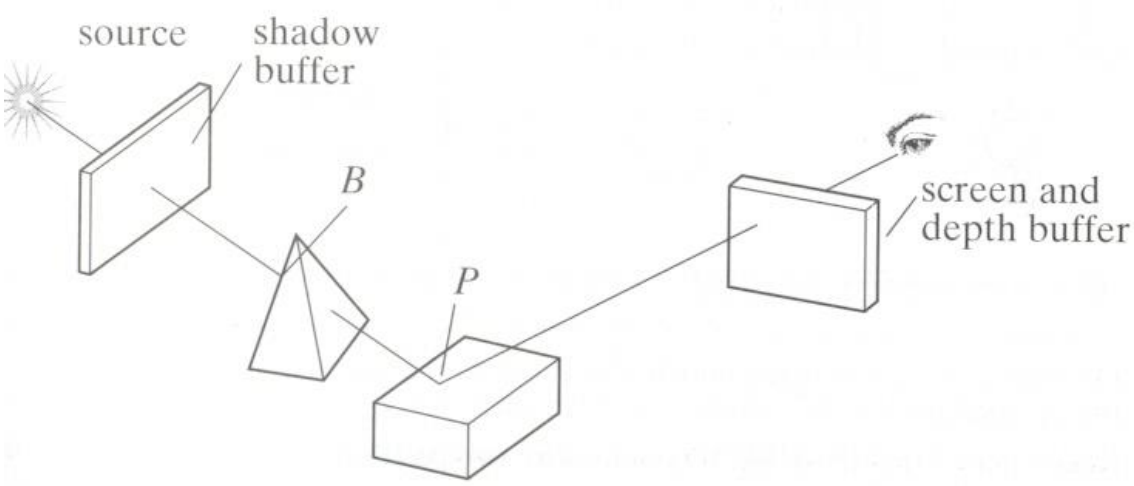
Shadow Map (Rendering Scene)

- Render scene using camera as usual
- While rendering a pixel find:
  - pseudo-depth D from light source to P
  - Index location [i][j] in shadow buffer, to be tested
  - Value d[i][j] stored in shadow buffer
- If d[i][j] < D (other object on this path closer to light)
  - point P is in shadow
  - lighting = ambient
- Otherwise, not in shadow
  - Lighting = amb + diffuse + specular



Loading Shadow Map

- Shadow map calculation is independent of eye position
- In animations, shadow map loaded once
- If eye moves, no need for recalculation
- If objects move, recalculation required



References

- Interactive Computer Graphics (6th edition), Angel and Shreiner
- Computer Graphics using OpenGL (3rd edition), Hill and Kelley
- Real Time Rendering by Akenine-Moller, Haines and Hoffman