Computer Graphics (CS 543)
Lecture 8 (Part 3): Environment Mapping (Reflections and Refractions)

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(Adapted from slides by Ed Angel)

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Environment Mapping

- Environmental mapping is a way to create the appearance of highly reflective and refractive surfaces without ray tracing.
Types of Environment Maps

- Assumes environment infinitely far away
- Options: Store “object’s environment (an image) as

a) Sphere around object (sphere map)

b) Cube around object (cube map)

- OpenGL supports **cube maps** and **sphere maps**
Cube mapping

- Need to compute reflection vector, \textbf{r}
- Use \textbf{r} for environment map lookup
Cube Map: How to Store

- Stores “environment” around objects as 6 sides of a cube (1 texture)
- Load 6 textures separately into 1 OpenGL cubemap
Cube Maps

- Loaded cube map texture can be accessed in GLSL through 1 cubemap sampler

  ```glsl
  vec4 texColor = textureCube(mycube, texcoord);
  ```

- Texture coordinates must be 3D
Creating Cube Map

- Use 6 cameras directions from scene center
  - each with a 90 degree angle of view
Indexing into Cube Map

• Compute \( \mathbf{R} = 2(\mathbf{N} \cdot \mathbf{V})\mathbf{N} - \mathbf{V} \)

• Object at origin

• Perform lookup:

\[
\text{vec4 texColor} = \text{textureCube(mycube, R)};
\]

• Largest magnitude component of \( \mathbf{R} \) \((x,y,z)\) used to determine face of cube

• Other 2 components give texture coordinates

More on this later....
Declaring Cube Maps in OpenGL

```c
glTextureMap2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X, level, rows, columns, border, GL_RGBA, GL_UNSIGNED_BYTE, image1)
```

- Repeat similar for other 5 images (sides)
- Make 1 cubemap texture object from 6 images
- Parameters apply to all six images. E.g.

```c
glTexParameteri( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MAP_WRAP_S, GL_REPEAT)
```

- **Note:** texture coordinates are in 3D space (s, t, r)
Cube Map Example (init)

// colors for sides of cube
GLubyte red[3] = {255, 0, 0};
GLubyte green[3] = {0, 255, 0};
GLubyte blue[3] = {0, 0, 255};
GLubyte cyan[3] = {0, 255, 255};
GLubyte magenta[3] = {255, 0, 255};
GLubyte yellow[3] = {255, 255, 0};

glEnable(GL_TEXTURE_CUBE_MAP);

// Create texture object
glGenTextures(1, tex);
glActiveTexture(GL_TEXTURE1);
glBindTexture(GL_TEXTURE_CUBE_MAP, tex[0]);

This example generates simple Colors as a texture
You can also just load 6 pictures of environment
Cube Map (init II)

Load 6 different pictures into 1 cube map of environment

```c
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, red);
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_X, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, green);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Y, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, blue);
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_Y, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, cyan);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Z, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, magenta);
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_Z, 0, 3, 1, 1, 0, GL_RGB, GL_UNSIGNED_BYTE, yellow);
glTexParameteri(GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MAG_FILTER, GL_NEAREST);
```
Cube Map (init III)

GLuint texMapLocation;
GLuint tex[1];

texMapLocation = glGetUniformLocation(program, "texMap");
glUniform1i(texMapLocation, tex[0]);

Connect texture map (tex[0]) to variable texMap in fragment shader (texture mapping done in frag shader)
void quad(int a, int b, int c, int d)
{
    static int i = 0;

    normal = normalize(cross(vertices[b] - vertices[a],
                              vertices[c] - vertices[b]));

    normals[i] = normal;
    points[i] = vertices[a];
    i++;

    // rest of data

    Calculate and set quad normals
Vertex Shader

out vec3 R;
in vec4 vPosition;
in vec4 Normal;
uniform mat4 ModelView;
uniform mat4 Projection;

void main() {
    gl_Position = Projection*ModelView*vPosition;
    vec4 eyePos = vPosition; // calculate view vector V
    vec4 NN = ModelView*Normal; // transform normal
    vec3 N = normalize(NN.xyz); // normalize normal
    R = reflect(eyePos.xyz, N); // calculate reflection vector R
}
Fragment Shader

in vec3 R;
uniform samplerCube texMap;

void main()
{
  vec4 texColor = textureCube(texMap, R); // look up texture map using R

  gl_FragColor = texColor;
}
Refraction using Cube Map

- Can also use cube map for refraction (transparent)
Reflection and Refraction

- At each vertex

\[ I = I_{amb} + I_{diff} + I_{spec} + I_{refl} + I_{tran} \]

- Refracted component \( I_T \) is along transmitted direction \( t \)
Finding Transmitted (Refracted) Direction

- Transmitted direction obeys **Snell’s law**
- Snell’s law: relationship holds in diagram below

\[
\frac{\sin(\theta_2)}{c_2} = \frac{\sin(\theta_1)}{c_1}
\]

$c_1, c_2$ are speeds of light in medium 1 and 2
Finding Transmitted Direction

- If ray goes into denser medium (e.g. air to glass), ray is bent **towards** normal
- If ray goes into less dense medium (e.g. glass to air), ray is bent **away** from normal
- $c_1/c_2$ is important. Usually measured for medium-to-vacuum. E.g water to vacuum
- Some measured relative $c_1/c_2$ are:
  - Air: 99.97%
  - Glass: 52.2% to 59%
  - Water: 75.19%
  - Sapphire: 56.50%
  - Diamond: 41.33%
Transmission Angle

- Vector for transmission angle can be found as

\[ t = \frac{c_2}{c_1} \text{dir} + \left( \frac{c_2}{c_1} (\text{m} \cdot \text{dir}) - \cos(\theta_2) \right) \text{m} \]

where

\[ \cos(\theta_2) = \sqrt{1 - \left( \frac{c_2}{c_1} \right) \left( 1 - (\text{m} \cdot \text{dir})^2 \right)} \]

Or just use GLSL built-in function `refract` to get T
Refraction Vertex Shader

out vec3 T;
in vec4 vPosition;
in vec4 Normal;
uniform mat4 ModelView;
uniform mat4 Projection;

void main() {
    gl_Position = Projection*ModelView*vPosition;
    vec4 eyePos = vPosition; // calculate view vector V
    vec4 NN = ModelView*Normal; // transform normal
    vec3 N = normalize(NN.xyz); // normalize normal
    T = refract(eyePos.xyz, N, iorefr); // calculate refracted vector T
}

Was previously
R = reflect(eyePos.xyz, N);
Refraction Fragment Shader

in vec3 T;
uniform samplerCube RefMap;

void main()
{
    vec4 refractColor = textureCube(RefMap, T);  // look up texture map using T
    refractcolor = mix(refractColor, WHITE, 0.3);  // mix pure color with 0.3 x white

    gl_FragColor = refractcolor;
}
Caustics occur when light is focussed on diffuse surface.

Courtesy Chris Wyman, Univ Iowa
Recall: Indexing into Cube Map

- Compute \( R = 2(N \cdot V)N - V \)
- Object at origin
- Use largest magnitude component of \( R \) to determine face of cube
- Other 2 components give texture coordinates
Cube Map Layout

There are 6 faces
Which face to retrieve RGB from?
Cube Map Texture Lookup:
Given an \((s, t, p)\) direction vector, what \((r, g, b)\) does that correspond to?

- Let \(L\) be the texture coordinate of \((s, t, p)\) with the largest magnitude.
- \(L\) determines which of the 6 2D texture “walls” is being hit by the vector \((-X\) in this case).
- The texture coordinates in that texture are the remaining two texture coordinates divided by \(L\): \((a/L, b/L)\).

Built-in GLSL functions:

\[
\text{vec3 ReflectVector} = \text{reflect( vec3 eyeDir, vec3 normal )};
\]

\[
\text{vec3 RefractVector} = \text{refract( vec3 eyeDir, vec3 normal, float Eta )};
\]
Example

- \( \mathbf{R} = (-4, 3, -1) \)
- Same as \( \mathbf{R} = (-1, 0.75, -0.25) \)
- Retrieve RGB from face \( X = -1 \) and \( y = 0.75, z = -0.25 \)
- Not quite right since cube defined by \( x, y, z = \pm 1 \) rather than \([0, 1]\) range needed for texture coordinates
- Remap by from \([-1,1]\) to \([0,1]\) range
  - \( s = \frac{1}{2} + \frac{1}{2} y \), \( t = \frac{1}{2} + \frac{1}{2} z \)
  - \( s = \frac{1}{2} + \frac{1}{2} \times 0.75 \), \( t = \frac{1}{2} + \frac{1}{2} \times -0.25 \)
- Hence, \( s = 0.875 \), \( t = 0.375 \)
References

- Real Time Rendering by Akenine-Moller, Haines and Hoffman