Computer Graphics (CS 543)
Lecture 9a: Environment Mapping (Reflections and Refractions)

Prof Emmanuel Agu

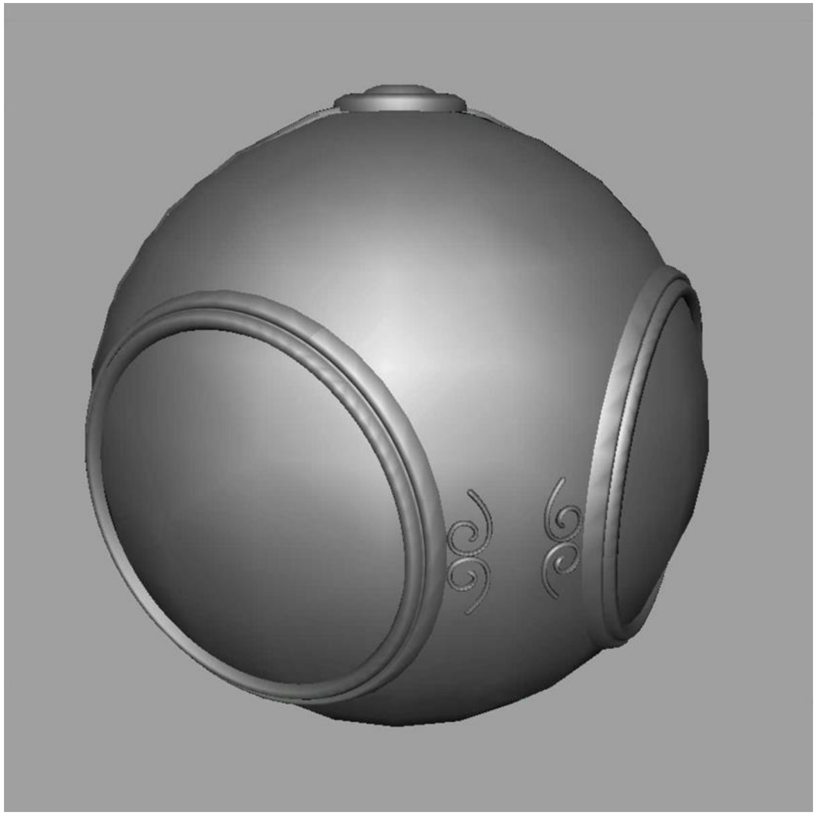
(Adapted from slides by Ed Angel)

Computer Science Dept.

Worcester Polytechnic Institute (WPI)

Environment Mapping

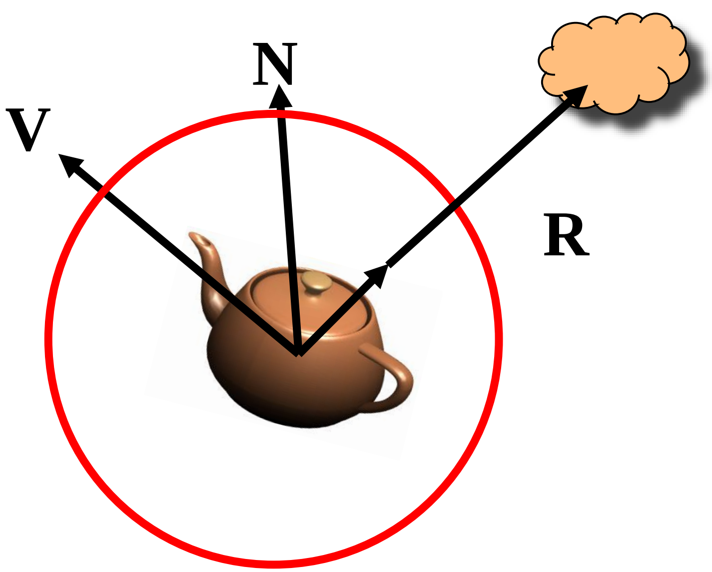
- Environmental mapping is way to create the appearance of highly **reflective** and **refractive** surfaces without ray tracing



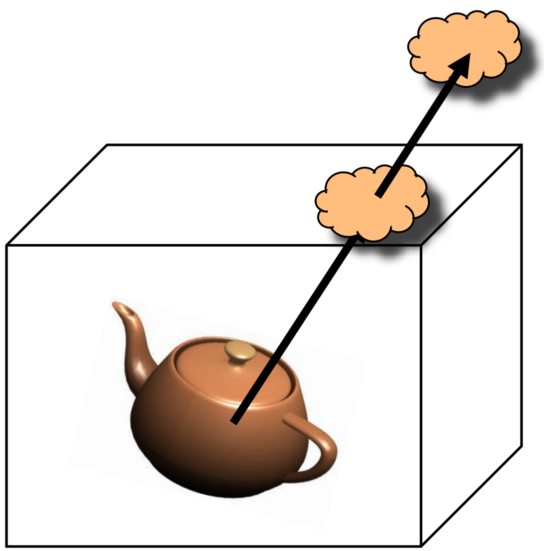
Types of Environment Maps

- Assumes environment infinitely far away
- Options: Store “object’s environment as

a) Sphere around object (sphere map)

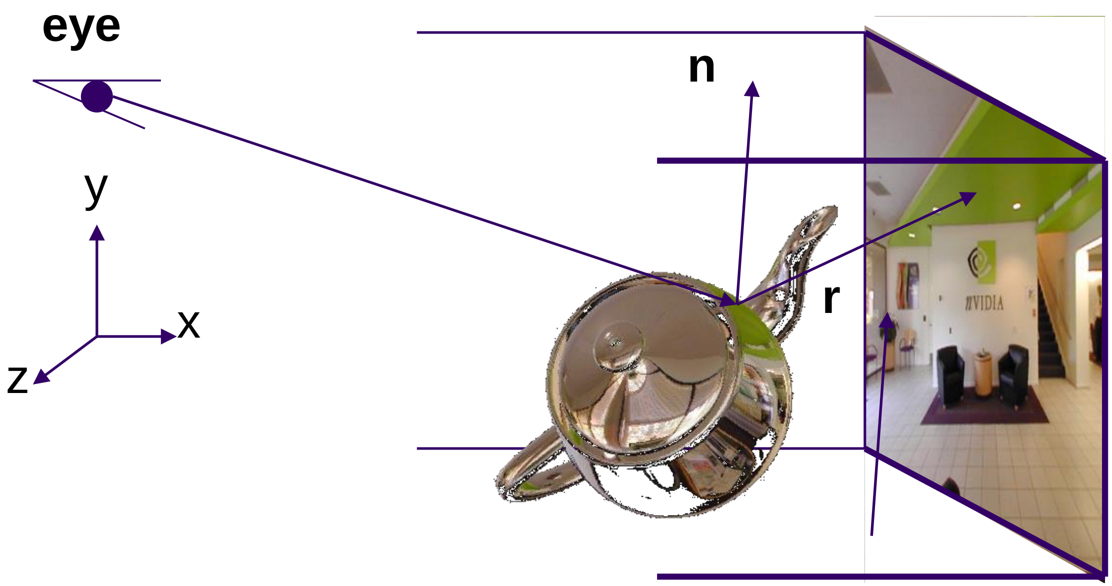


b) Cube around object (cube map)



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

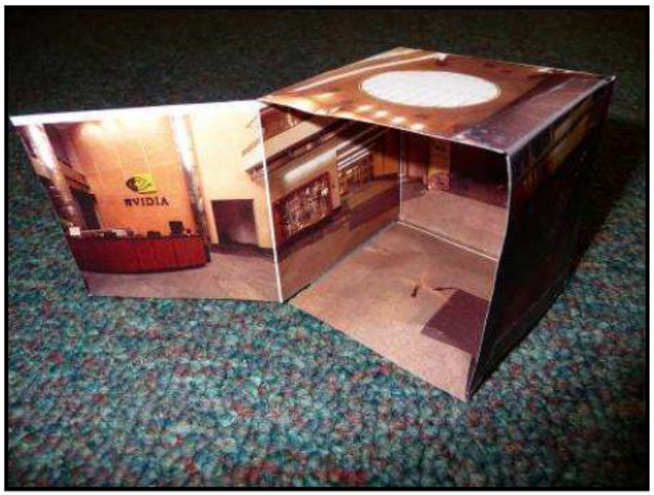
Cube mapping

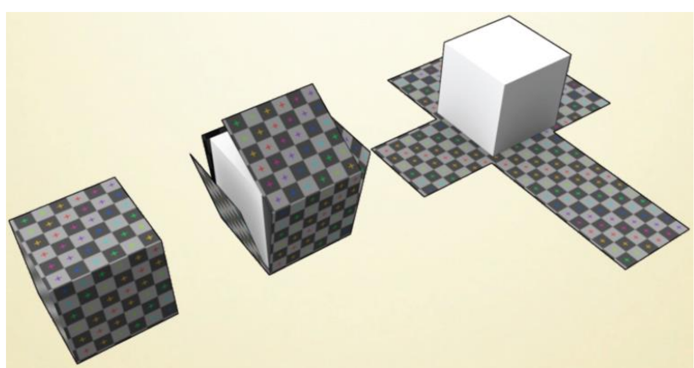


- Need to compute reflection vector, $\mathbf{r}$
- Use $\mathbf{r}$ by for environment map lookup

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



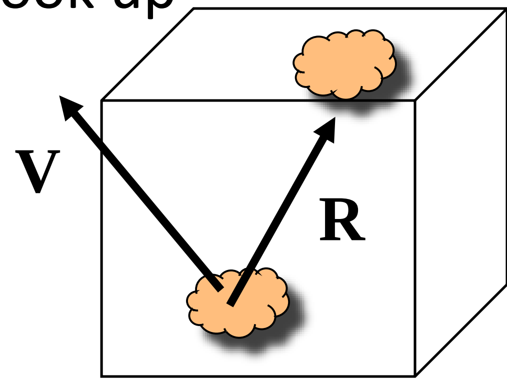


Cube Maps

- Loaded cube map texture can be accessed in GLSL through cubemap sampler
- Compute reflection vector **R** = 2(**N·V**)**N**-**V**
- Perform cubemap lookup using **R** vector (texcoord)

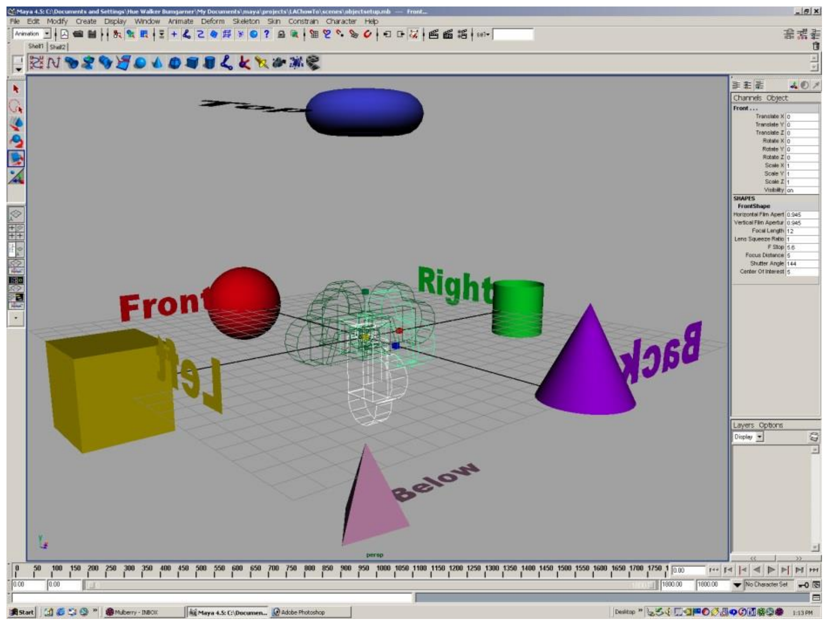
vec4 texColor = textureCube(mycube, **R**);

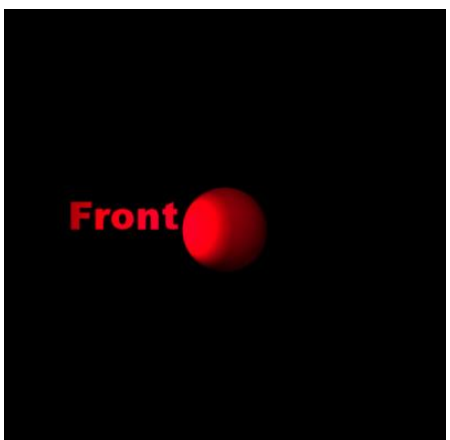
- R is 3D vector, so texture coordinates must be 3D (x, y, z)
- OpenGL figures out which face of cube **R** hits, to look up
- More details on lookup later

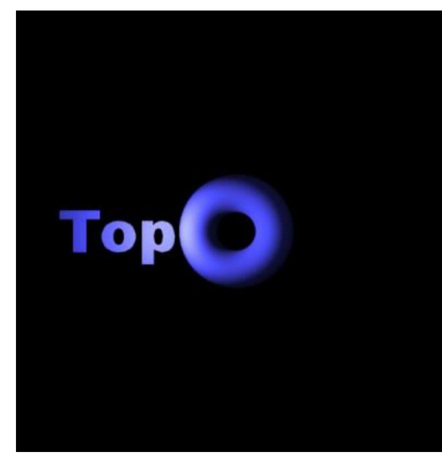


Creating Cube Map

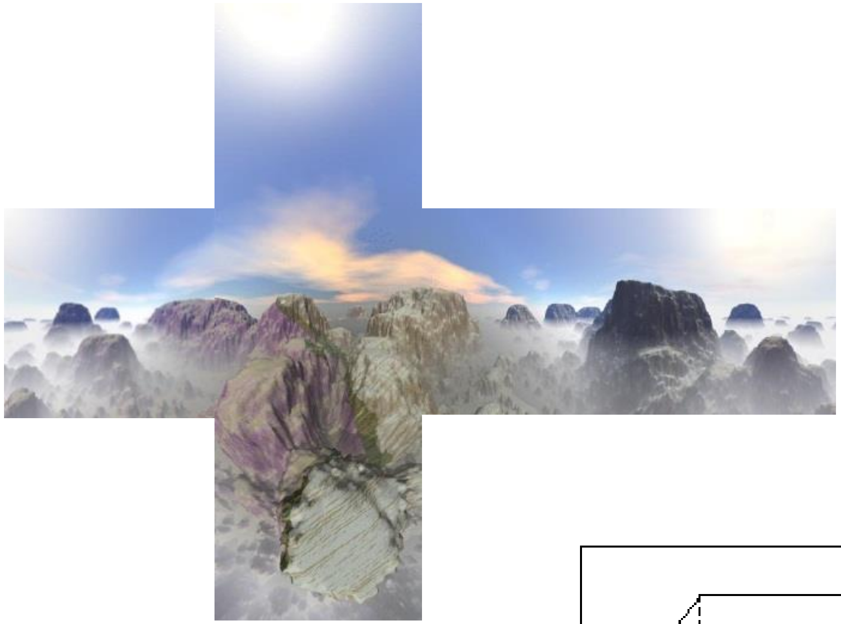
- Use 6 cameras directions from scene center
  - each with a 90 degree angle of view



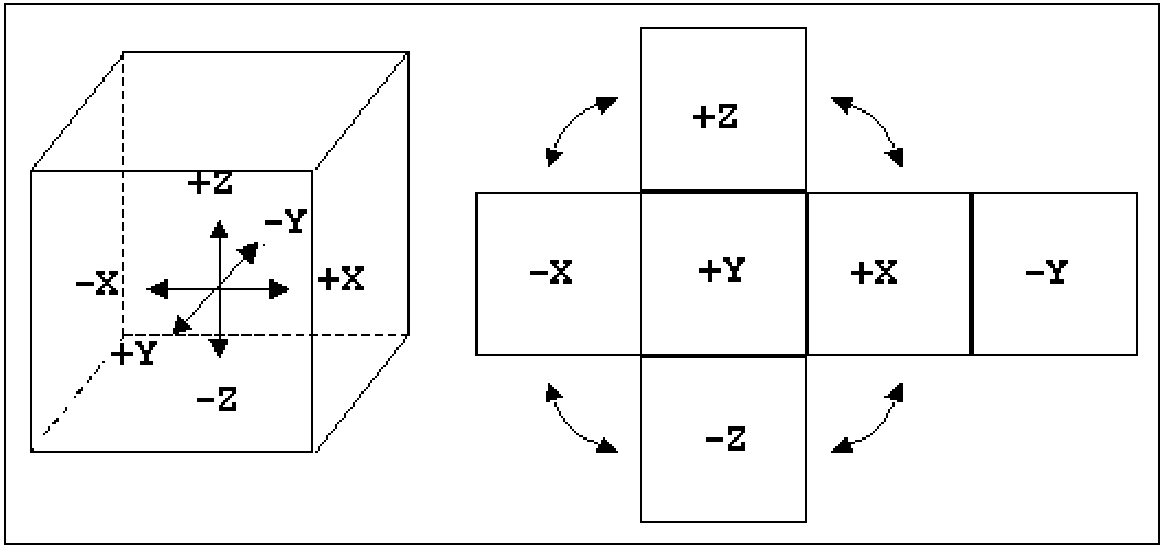




Cube Map Layout

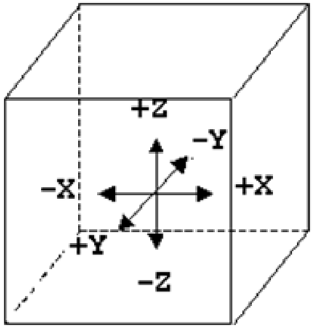


Make 1 cubemap texture object from 6 images



Declaring Cube Maps in OpenGL

- Declare each of 6 sides of cube map separately.



- E.g. to declare +X image

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

- Repeat similar for other 5 images (sides)
- Parameters apply to all six images. E.g

glTexParameteri(GL_TEXTURE_CUBE_MAP,
GL_TEXTURE_MAP_WRAP_S, GL_REPEAT)

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]);
```

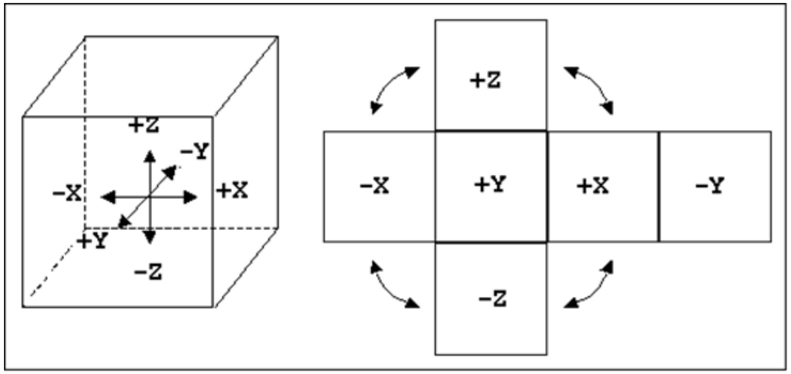
This example generates simple
Colors as a texture

You can also just load
6 pictures of environment

Cube Map (init II)

Load 6 different pictures into
1 cube map of environment

```
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)

Adding Normals

```
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)

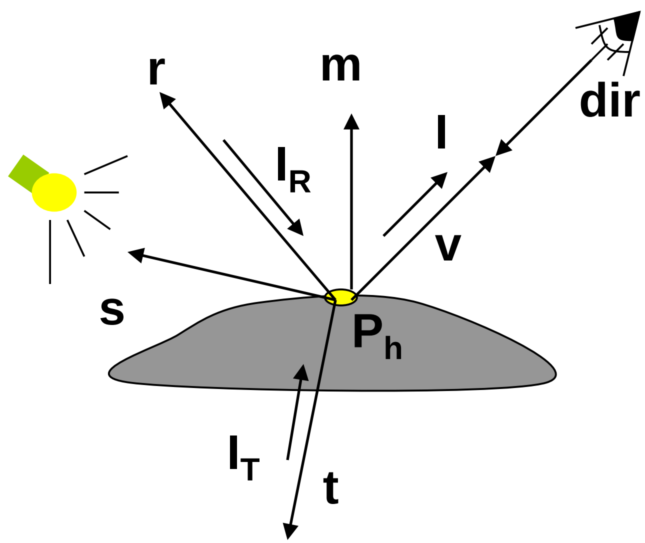
Reflection

Refraction

Reflection and Refraction

- At each vertex

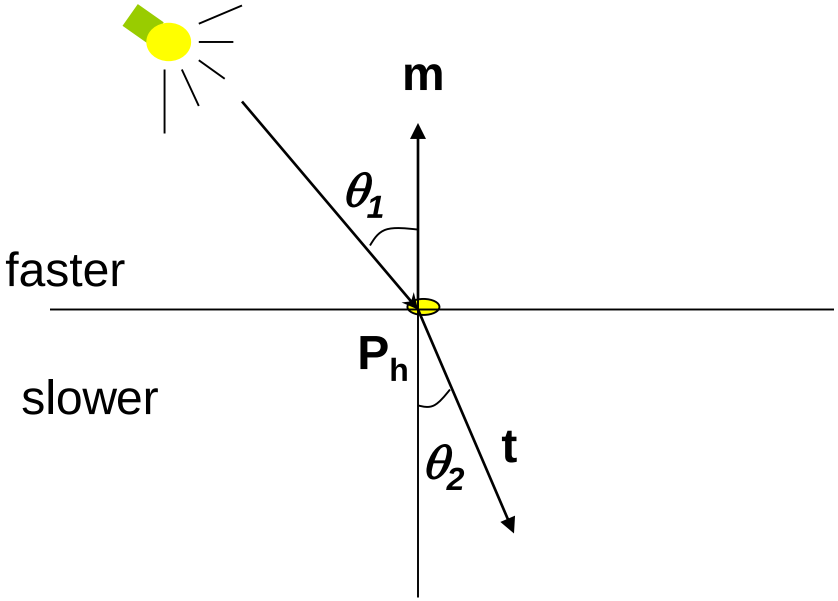
$$I = I_{amb} + I_{diff} + I_{spec} + I_{refl} + I_{tran}$$



- 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

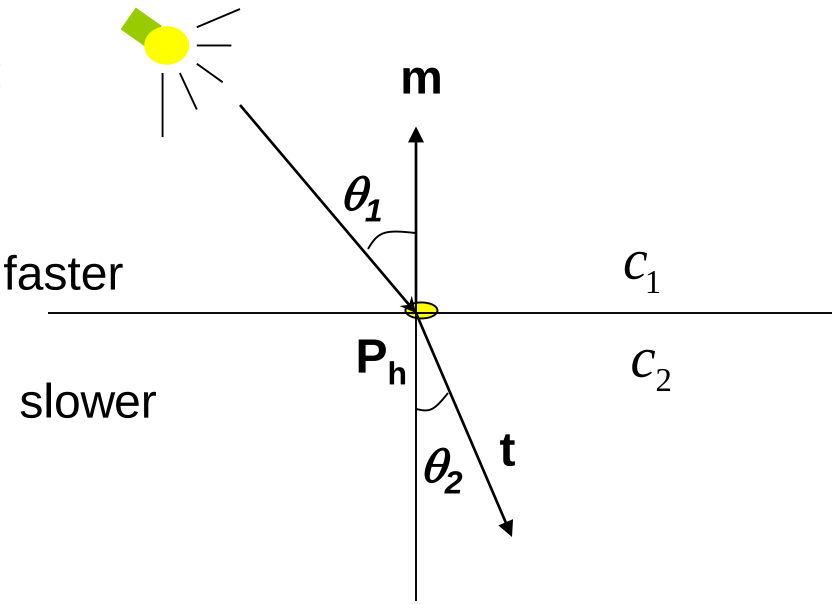


$$\frac{\sin(\theta_2)}{c_2} = \frac{\sin(\theta_1)}{c_1}$$

c_1, c_2 are speeds of light in medium 1 and 2

Finding Transmitted Direction

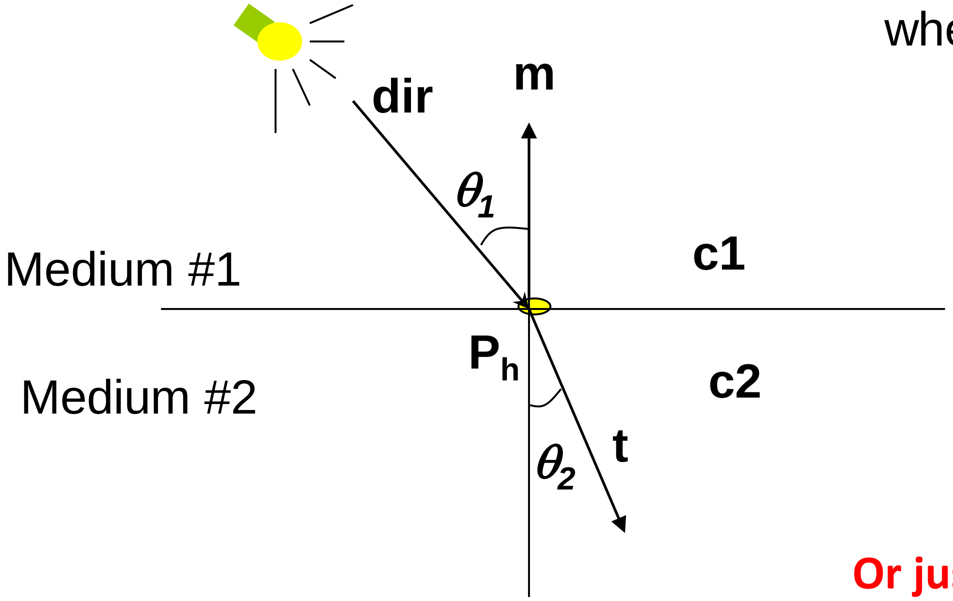
- If ray goes from faster to slower medium (e.g. air to glass), ray is bent **towards** normal
- If ray goes from slower to faster medium (e.g. glass to air), ray is bent **away** from normal
- c1/c2 is important. Usually measured for medium-to-vacuum. E.g water to vacuum
- Some measured relative c1/c2 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

$$\mathbf{t} = \frac{c_2}{c_1}\mathbf{dir} + \left(\frac{c_2}{c_1}(\mathbf{m} \bullet \mathbf{dir}) - \cos(\theta_2)\right)\mathbf{m}$$



where

$$\cos(\theta_2) = \sqrt{1 - \left(\frac{c_2}{c_1}\right)\left(1 - (\mathbf{m} \bullet \mathbf{dir})^2\right)}$$

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);

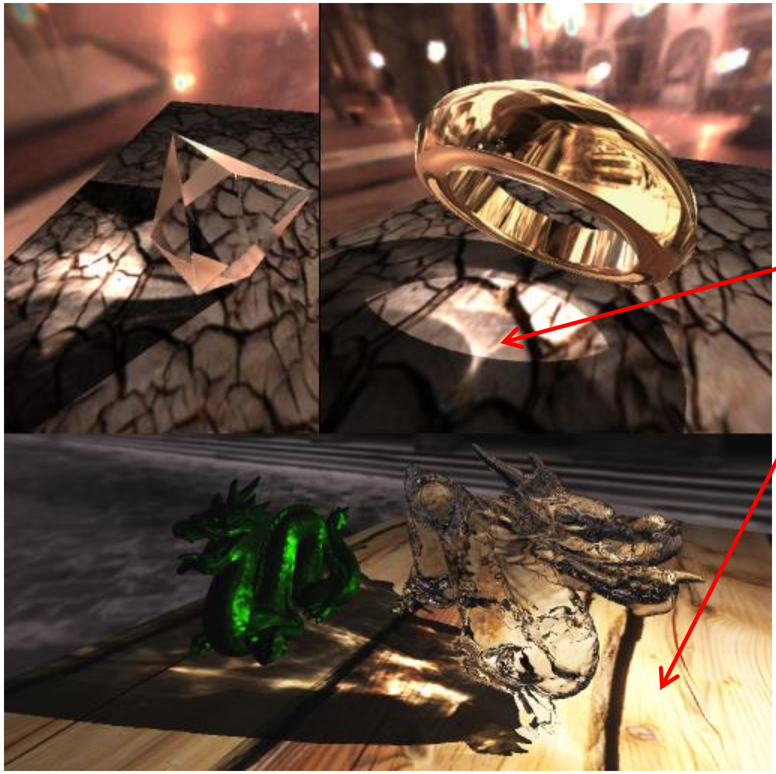
Refraction Fragment Shader

```
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 white

   gl_FragColor = refractcolor;
}
```

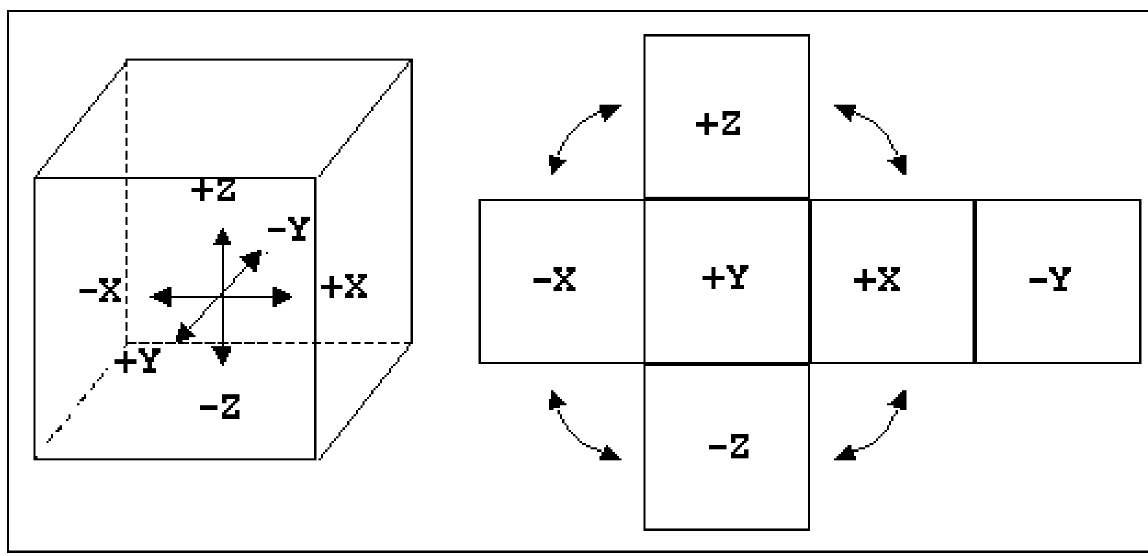
Caustics



Caustics occur when light is focussed on diffuse surface

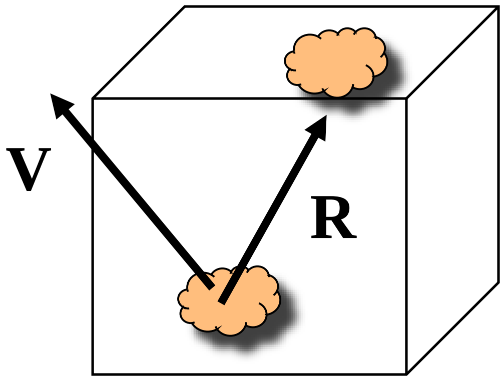
Courtesy Chris Wyman, Univ Iowa

Cube Map Layout

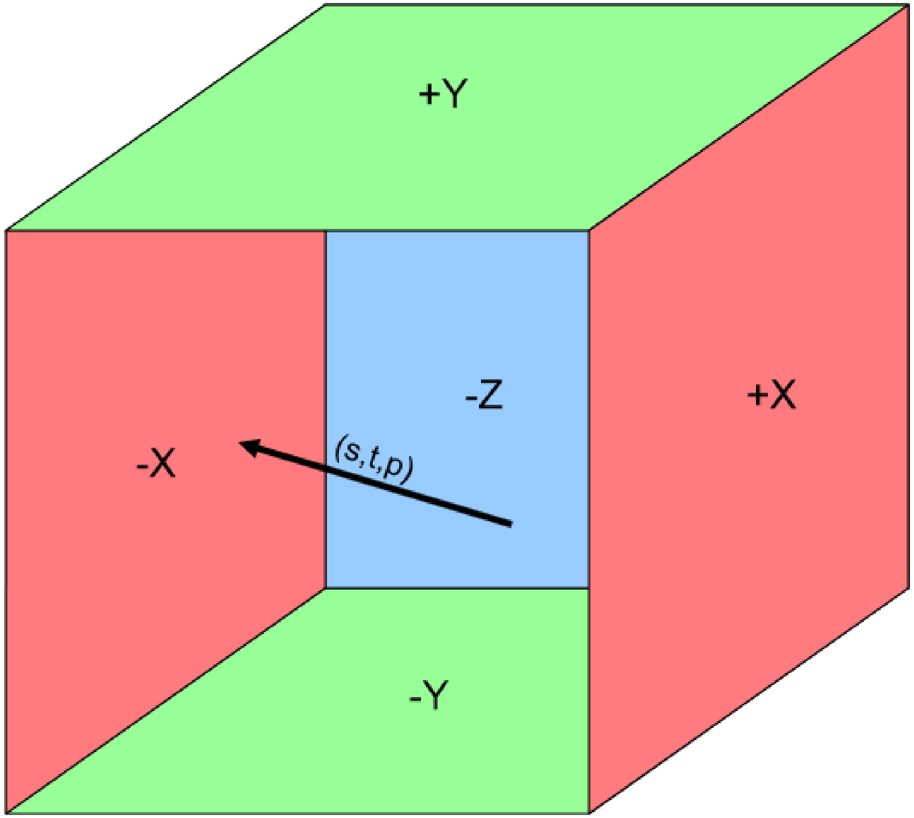


Indexing into Cube Map: How?

- Compute **R** = 2(**N·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 Texture Lookup:
Given an (s,t,p) direction vector , what (r,g,b) does that correspond to?



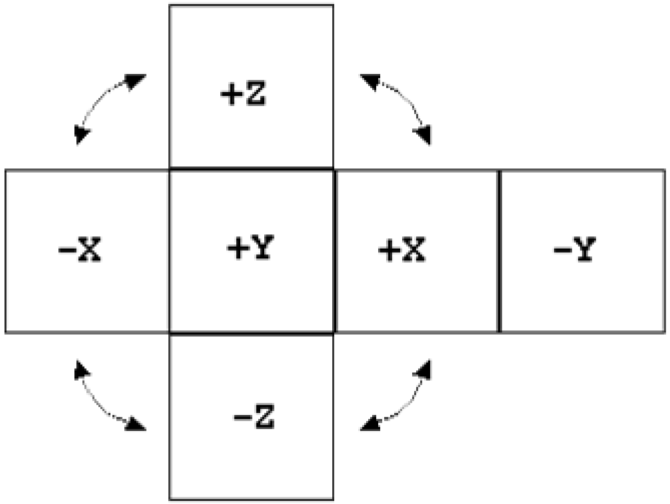
- Let L be the texture coordinate of (s, t, and p) with the largest magnitude
- L determines which of the 6 2D texture "walls" is being hit by the vector (-X in this case)
- The texture coordinates in that texture are the remaining two texture coordinates divided by L: (a/L,b/L)

Built-in GLSL functions

```
vec3 ReflectVector = reflect( vec3 eyeDir, vec3 normal );

vec3 RefractVector = refract( vec3 eyeDir, vec3 normal, float Eta );
```

Example



- **R** = (-4, 3, -1)
- Same as **R** = (-1, 0.75, -0.25)
- Look up face x = -1 and [y = 0.75, z = -0.25] as tex coords
- Not quite right since cube defined by x, y, z = ± 1 rather than [0, 1] range needed for texture coordinates
- Remap by from [-1,1] to [0,1] range
  - $s = \frac{1}{2} + \frac{1}{2}\,y$, $t = \frac{1}{2} + \frac{1}{2}\,z$
- Hence, s =0.875, t = 0.375

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