Recall: 6 Main Steps to Apply Texture

1. Create texture object
2. Specify the texture
   - Read or generate image
   - assign to texture (hardware) unit
   - enable texturing (turn on)
3. Assign texture (corners) to Object corners
4. Specify texture parameters
   - wrapping, filtering
5. Pass textures to shaders
6. Apply textures in shaders

still haven't talked about setting texture parameters

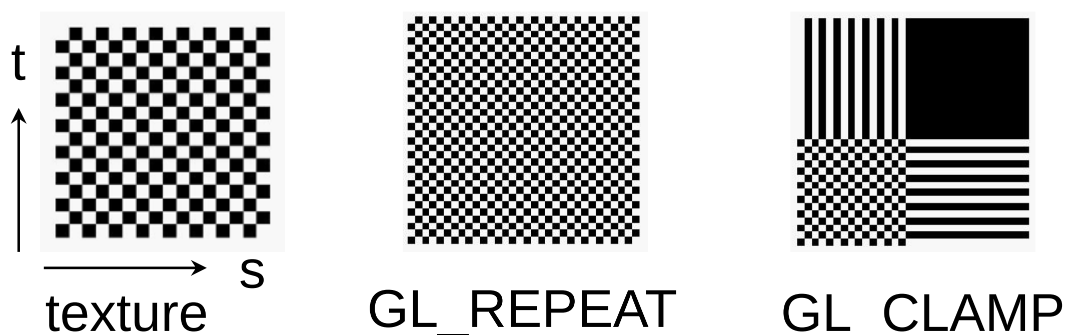
Recall: Step 4: Specify Texture Parameters

- Texture parameters control how texture is applied
  - Wrapping parameters used if s,t outside (0,1) range

    Clamping: if s,t > 1 use 1, if s,t <0 use 0

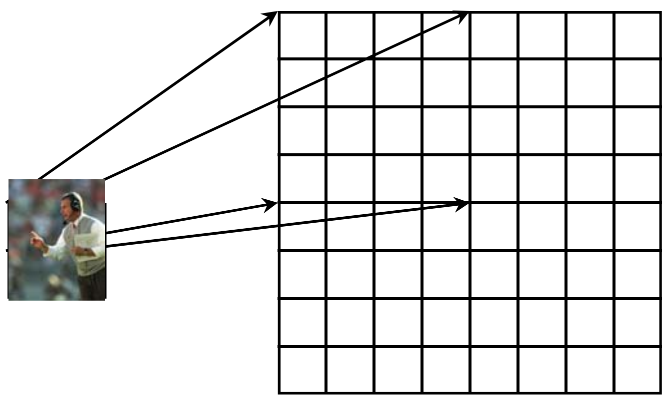
    Wrapping: use s,t modulo 1

```
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_CLAMP )
glTexParameteri( GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT )
```

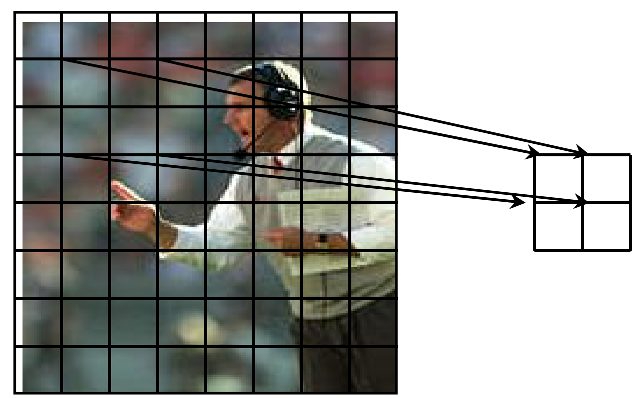


Magnification and Minification

Magnification: Stretch small texture to fill many pixels
Minification: Shrink large texture to fit few pixels

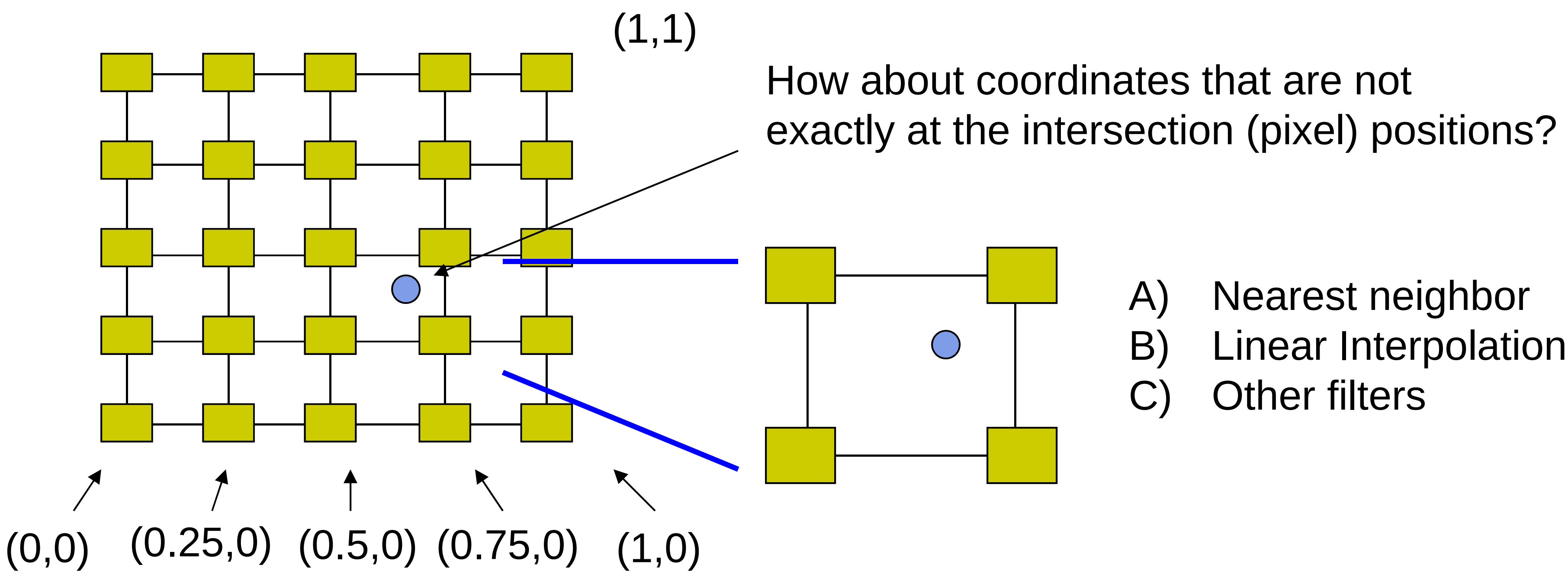


Texture Polygon
Magnification



Texture Polygon
Minification

Step 4: Specify Texture Parameters
Texture Value Lookup



A) Nearest neighbor
B) Linear Interpolation
C) Other filters

Example: Texture Magnification

- 48 x 48 image projected (stretched) onto 320 x 320 pixels

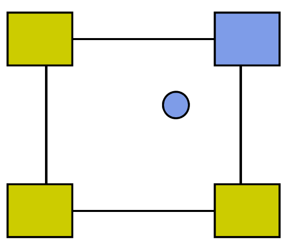
Nearest neighbor filter

Bilinear filter
(avg 4 nearest texels)

Cubic filter
(weighted avg. 5 nearest texels)

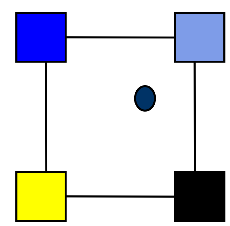
Texture mapping parameters

1) Nearest Neighbor (lower image quality)



glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_NEAREST);

2) Linear interpolate the neighbors (better quality, slower)

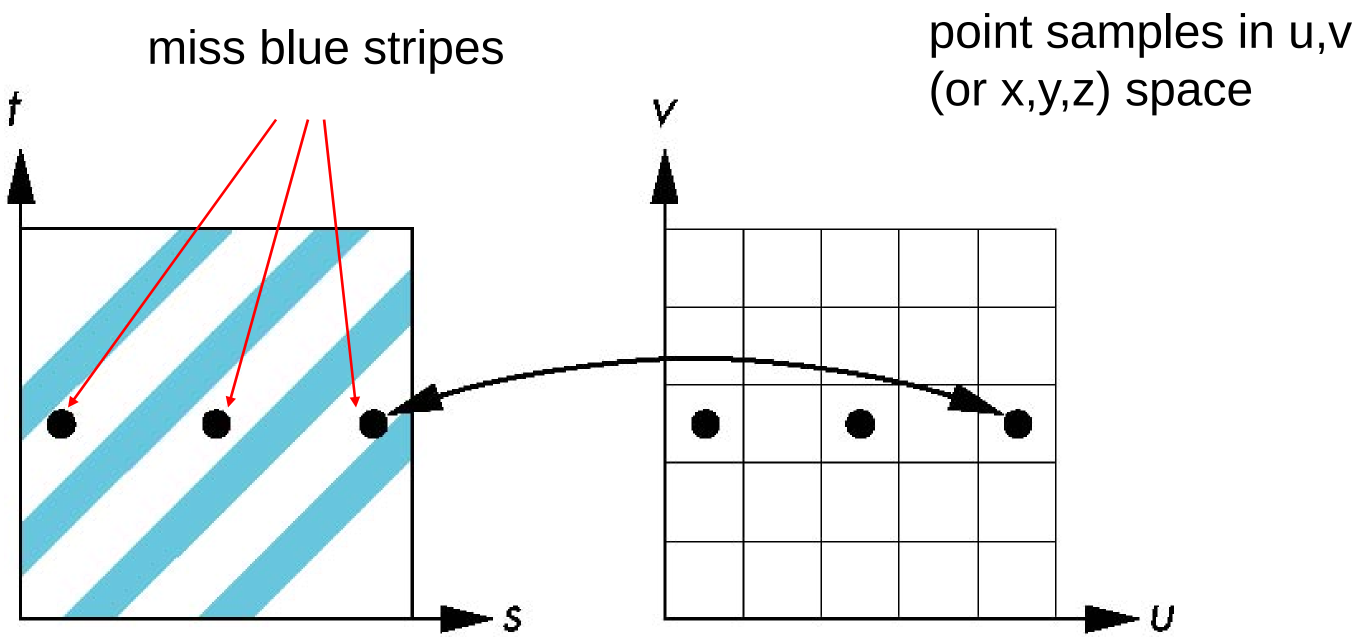


glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR)

Or GL_TEXTURE_MAX_FILTER

Dealing with Aliasing

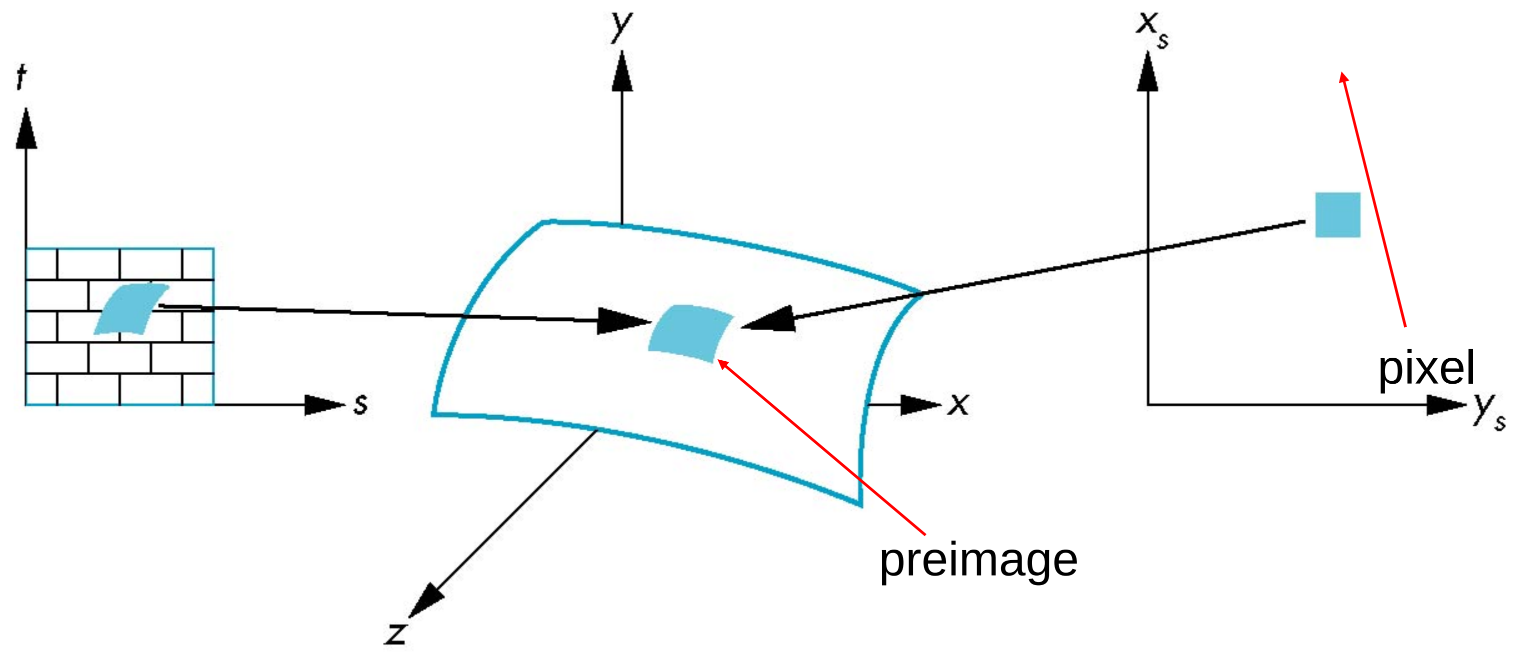
- Point sampling of texture can lead to aliasing errors



point samples in texture space

Area Averaging

Better but slower option is ***area averaging***



Other Stuff

- Wrapping texture onto curved surfaces. E.g. cylinder, can, etc

$$s = \frac{\theta - \theta_a}{\theta_b - \theta_a} \qquad t = \frac{z - z_a}{z_b - z_a}$$

- Wrapping texture onto sphere

$$s = \frac{\theta - \theta_a}{\theta_b - \theta_a} \qquad t = \frac{\phi - \phi_a}{\phi_b - \phi_a}$$

- Bump mapping: perturb surface normal by a quantity proportional to texture

Computer Graphics (CS 4731)
Lecture 20: Environment Mapping (Reflections and Refractions)

Prof Emmanuel Agu

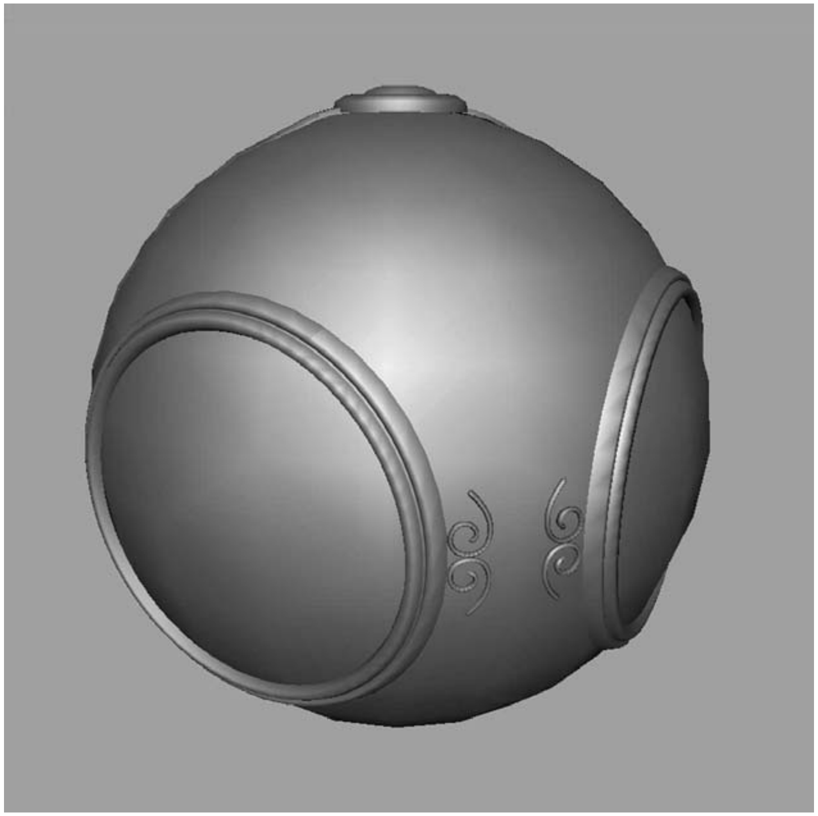
(Adapted from slides by Ed Angel)

Computer Science Dept.

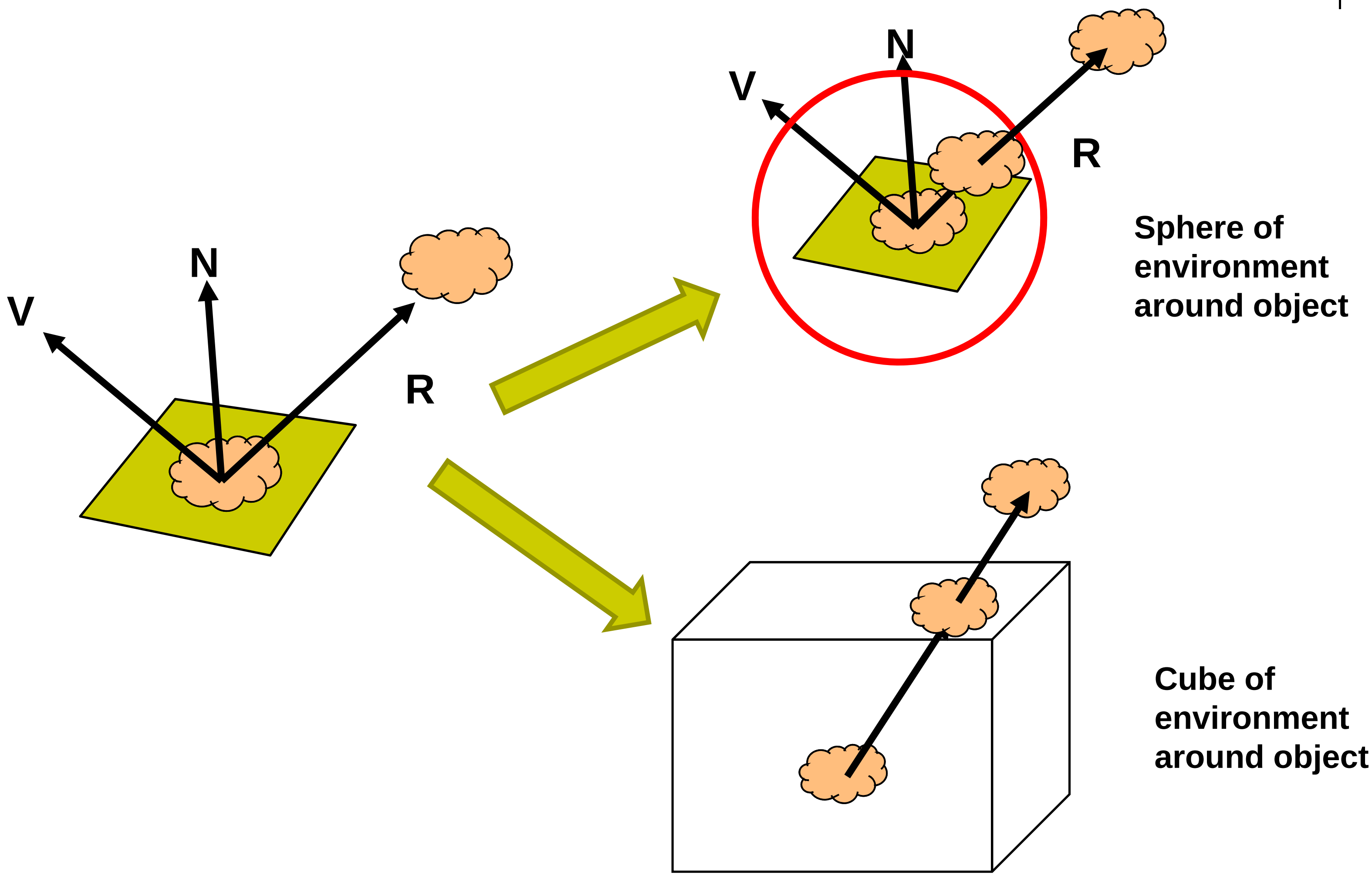
Worcester Polytechnic Institute (WPI)

Environment Mapping

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



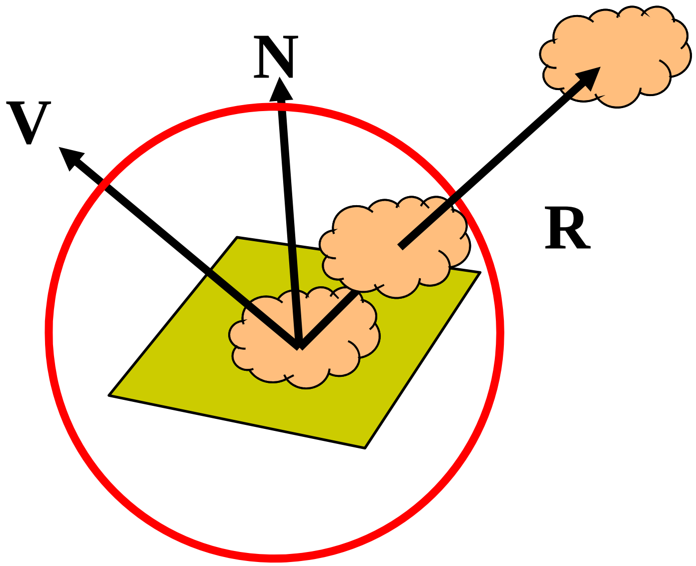
Reflecting the Environment



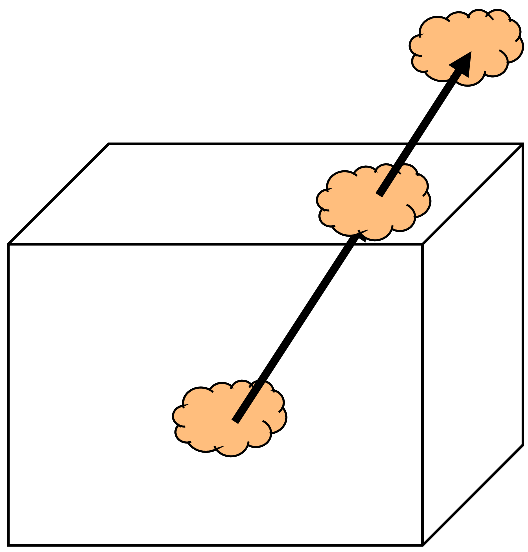
Types of Environment Maps

- Assumes environment infinitely far away
- Options: Store "object's environment as

a) Sphere around object (sphere map)

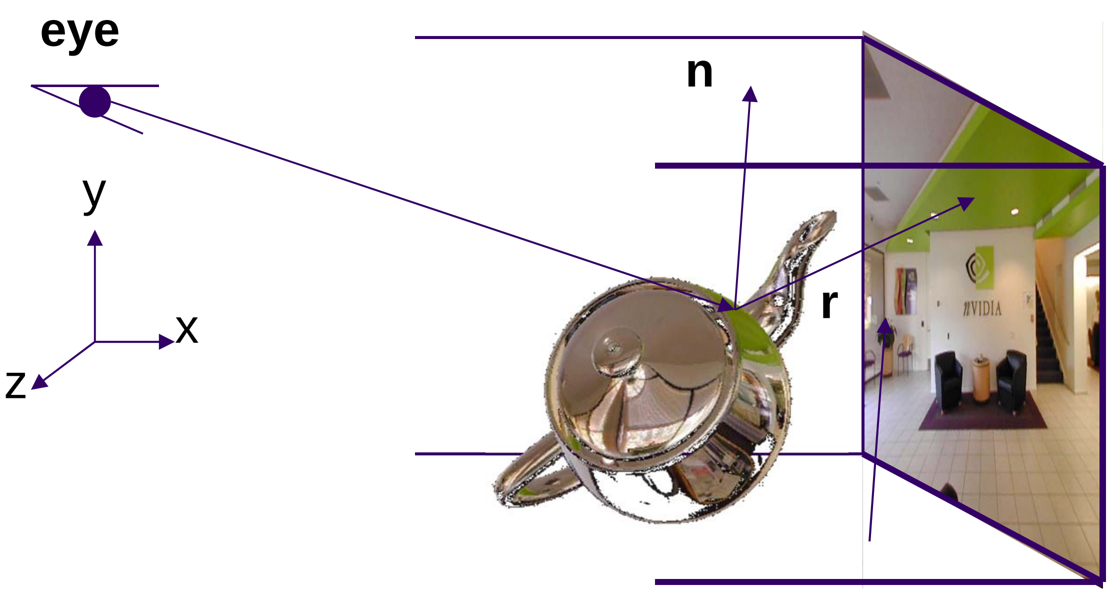


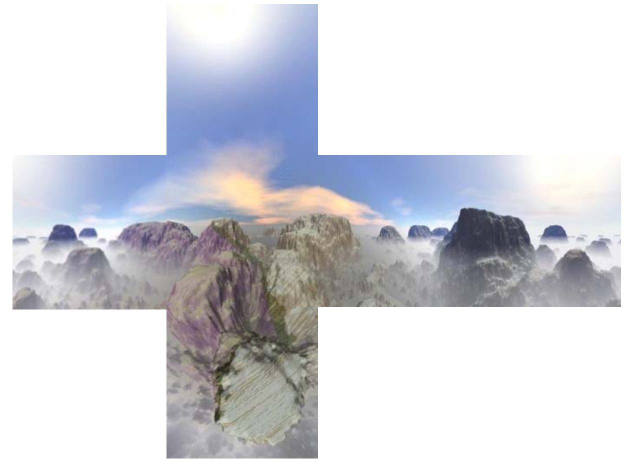
b) Cube around object (cube map)



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

Cube mapping

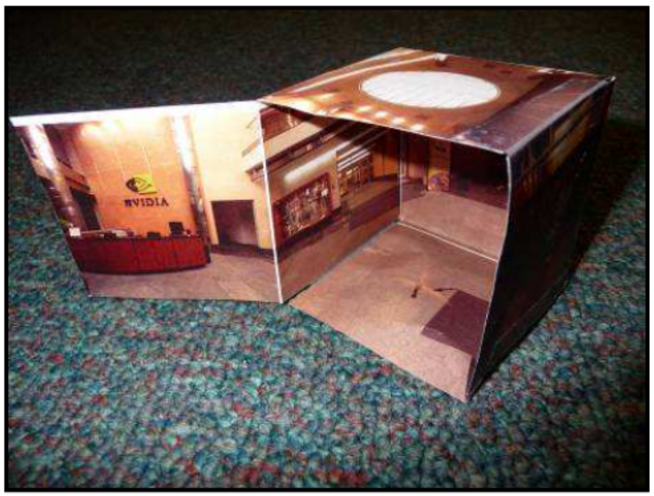


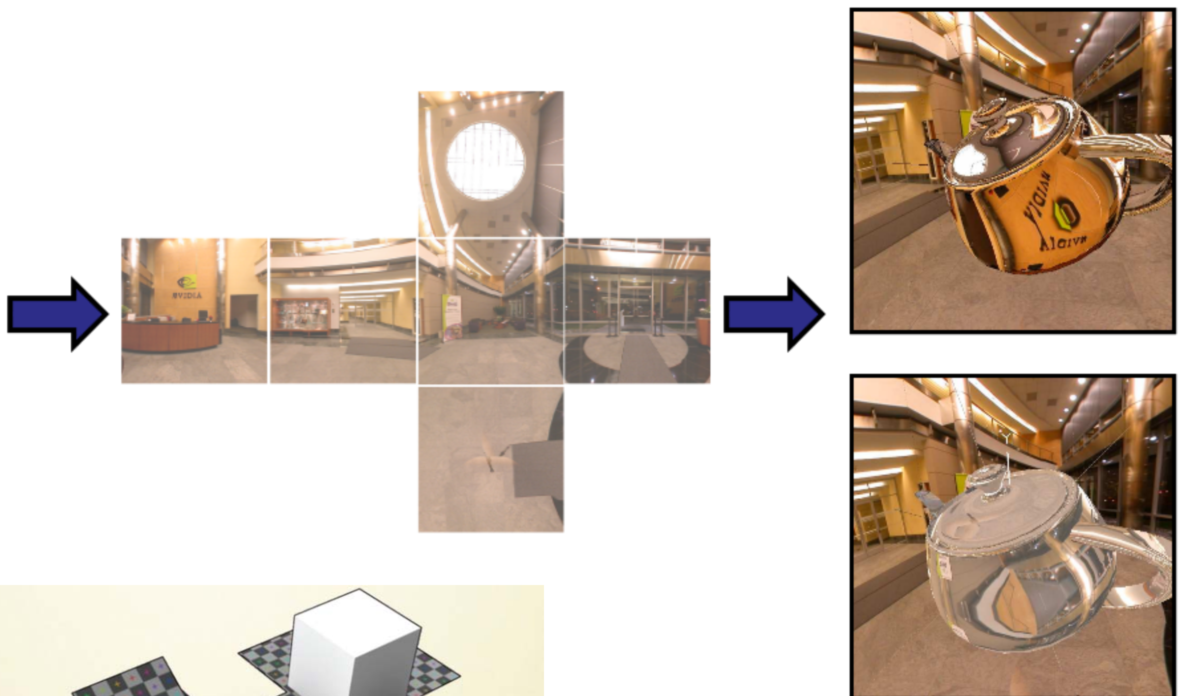


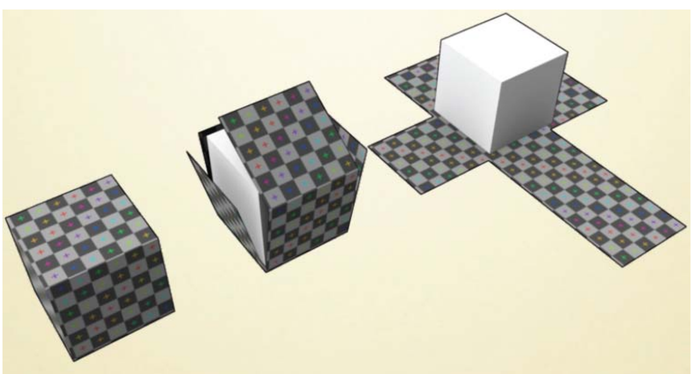
- Need to compute reflection vector, $\mathbf{r}$
- Use $\mathbf{r}$ by for environment map lookup

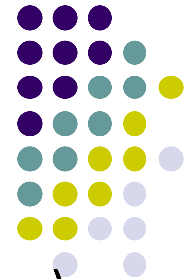
Cube Map: How to Store

- Stores "**environment"** around objects as 6 sides of a cube (1 texture)
- Load 6 textures separately into 1 OpenGL cubemap









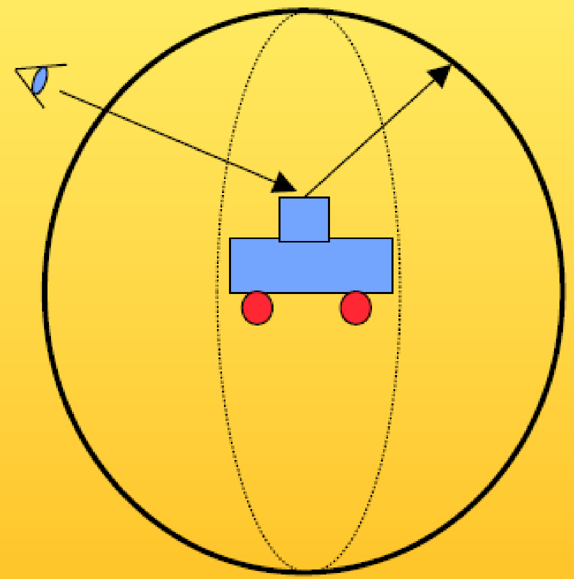
Cube Maps

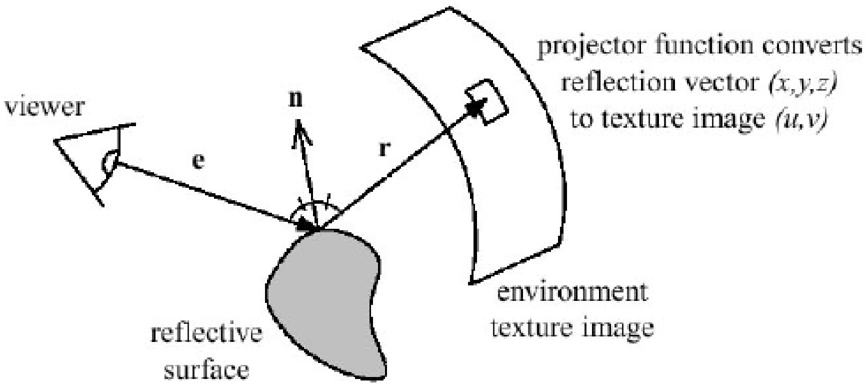
- Loaded cube map texture can be accessed in GLSL through cubemap sampler

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

- Texture coordinates must be 3D

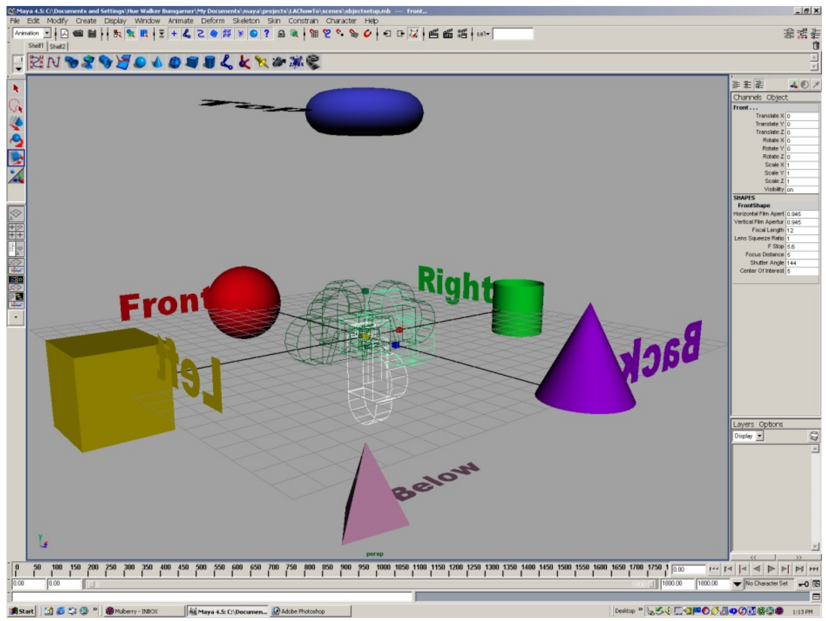
Environment mapping

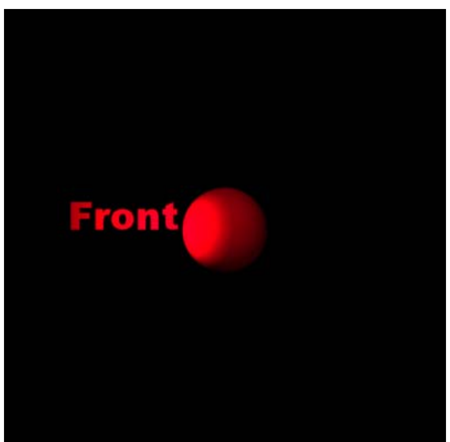




Creating Cube Map

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



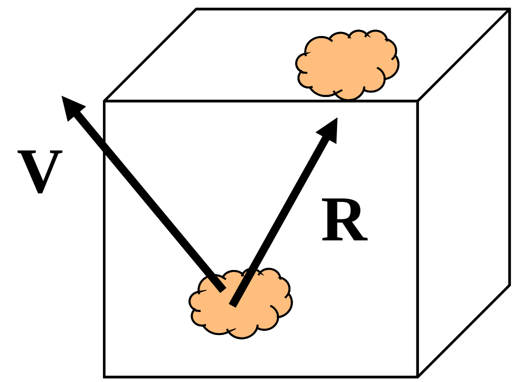


Indexing into Cube Map

- Compute **R** = 2(**N·V**)**N**-**V**
- Object at origin
- Perform lookup:

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

- **Largest magnitude component of 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

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

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

```
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

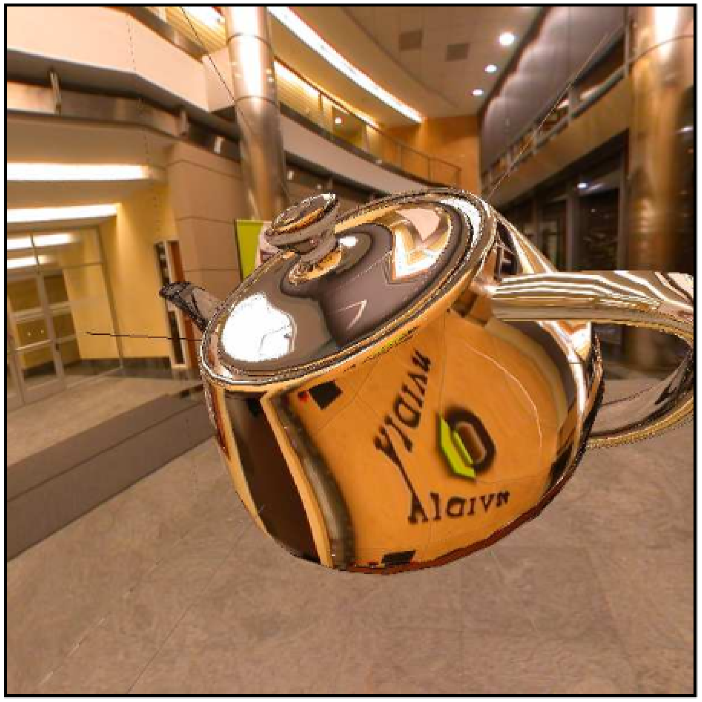
```
in vec3 R;
uniform samplerCube texMap;

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 vs Refraction

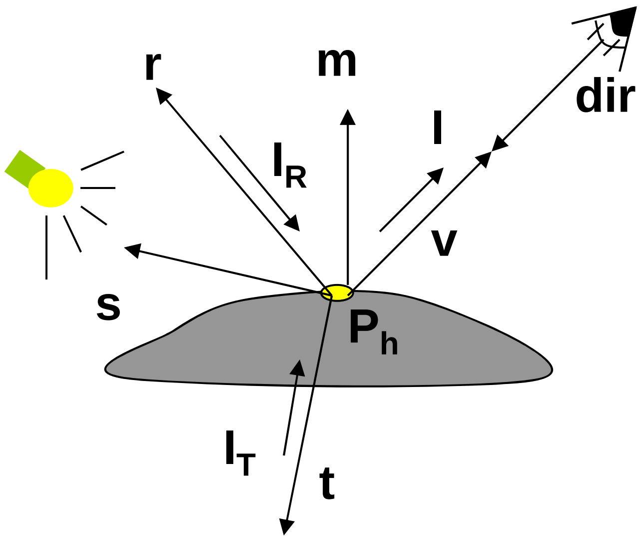
Reflection

Refraction

Reflection and Refraction

- At each vertex

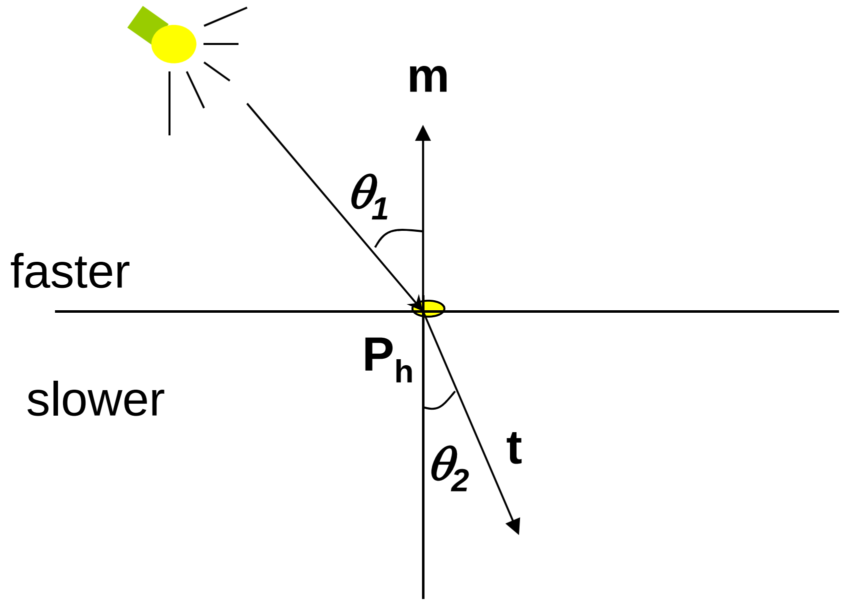
$$I = I_{amb} + I_{diff} + I_{spec} + I_{refl} + I_{tran}$$



- 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

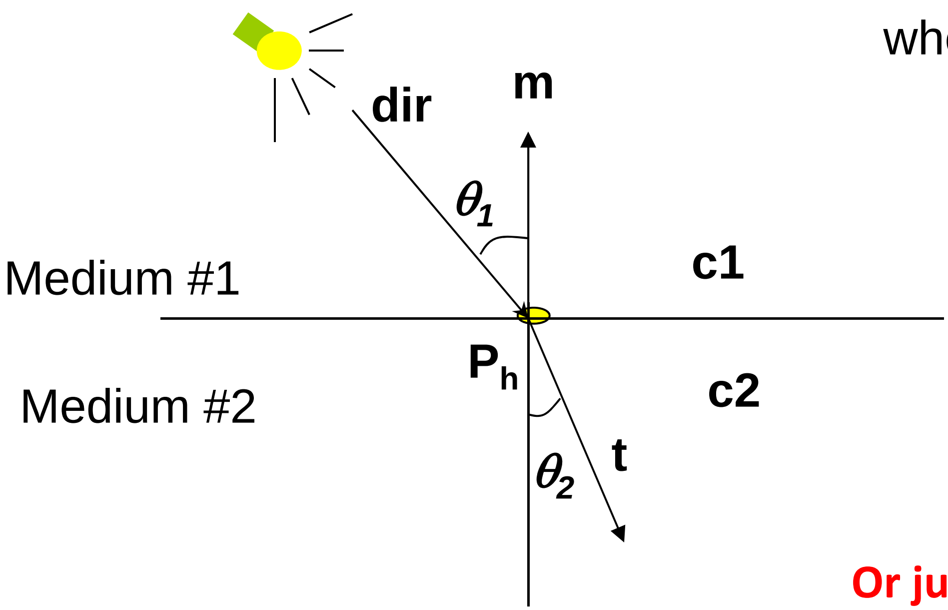
Finding Transmitted Direction

- 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;
}
```

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