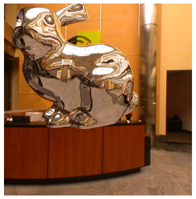
Cube Mapping



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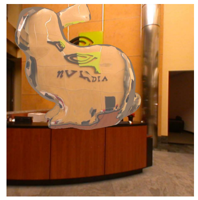
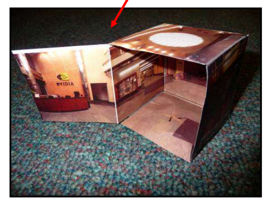


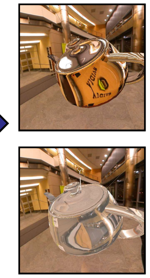
What is Cube Mapping?

Cube Mapping is the process of creating a representation of an object's surrounding environment as a collection of 6 images, grouped together as a single "cube map texture".

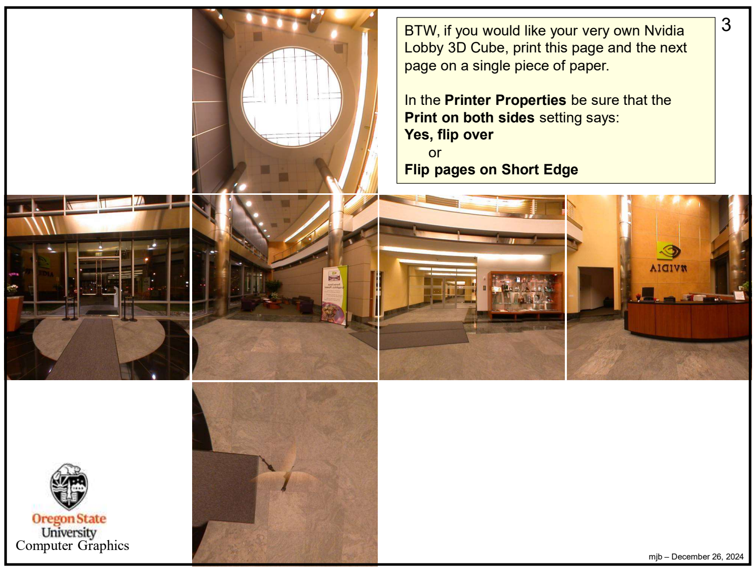
Think of it as a folding box.(BTW, I have this box on a 2-sided PowerPoint slide if you want to print and cutout your own.)

BTW, I have this box on a 2-sided PowerPoint if you want to print and cutout your own. Let me know.



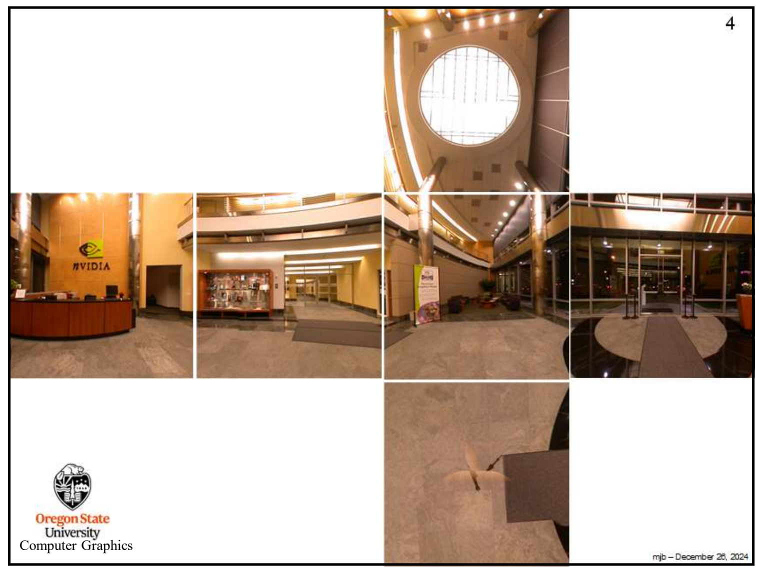


Note: as the scene observer, you are *inside* the box.



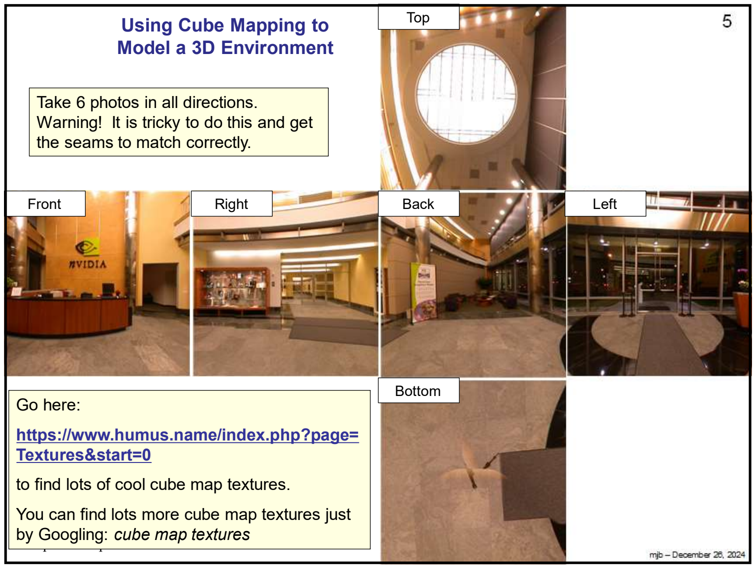
BTW, if you would like your very own Nvidia Lobby 3D Cube, print this page and the next page on a single piece of paper.

In the **Printer Properties** be sure that the **Print on both sides** setting says:
Yes, flip over
or
Flip pages on Short Edge



Using Cube Mapping to Model a 3D Environment

Take 6 photos in all directions.
Warning! It is tricky to do this and get the seams to match correctly.



Go here:

https://www.humus.name/index.php?page=Textures&start=0

to find lots of cool cube map textures.

You can find lots more cube map textures just by Googling: *cube map textures*

Cube Map of the Kelley Engineering Center Atrium

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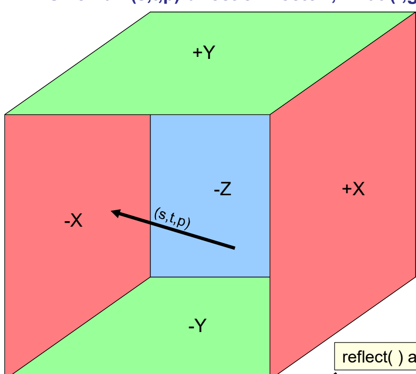
Cube Map Texture Lookup: Given an (s,t,p) direction vector , what (r,g,b) does that correspond to?



- 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: (s=a/L,t=b/L)

reflect( ) and refract( ) are built-in GLSL functions

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

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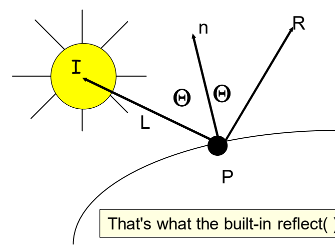
Remember Angle-of-Reflection-Equals-Angle-of-Incidence from Lighting?



That's what the built-in reflect( ) function does.

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Using the Cube Map for Reflection

Using the Cube Map for Reflection

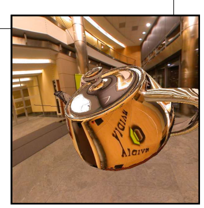
Vertex shader

```
out vec3                vNormal;
out vec3                vEyeDir;
out vec3                vMC;

void
main( )
{
        vec4 newVertex = gl_Vertex;
                // could possibly apply displacements to newVertex here
        vMC = newVertex.xyz;
        vec3 ECposition = ( gl_ModelViewMatrix * newVertex).xyz;
        vEyeDir = ECposition – vec3(0.,0.,0.);          // vector from eye to pt
        vNormal = normalize( gl_NormalMatrix * gl_Normal );
                                // or newNormal if you have displaced vertices
        gl_Position = gl_ModelViewProjectionMatrix * newVertex;
}
```

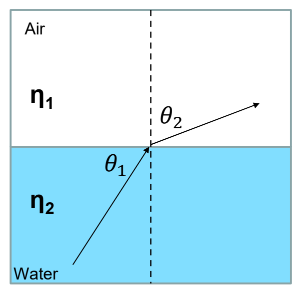

Using the Cube Map for Reflection

Fragment shader

```
in vec3                 vNormal;
In vec3                 vEyeDir;
In vec3                 vMC;
uniform samplerCube     uReflectUnit;

void
main( )
{
        vec3 normal = vNormal;
                // if you are bump-mapping, apply noise to normal here using vMC
        vec3 reflectVector = reflect( vEyeDir, normal );
        vec4 reflectColor = texture( uReflectUnit, reflectVector );    // on Macs, use textureCube( )
        gl_FragColor = vec4( reflectColor.rgb, 1. );
}
```



The Index of Refraction, η (eta)



The Index of Refraction (IOR) is a measure of how much light slows down as it passes through a particular material. The larger the IOR, the slower the speed of light in that material.

Snell's Law of Refraction says that:

$$\frac{sin\theta_2}{sin\theta_1} = \frac{\eta_1}{\eta_2}$$

Or:

$$sin\theta_2 = sin\theta_1 \frac{\eta_1}{\eta_2}$$

That's what the built-in refract( ) function does.

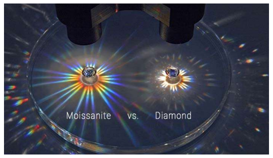
Notice that there are certain combinations of the η's that require $\sin\Theta_2$ to be outside the range -1. → +1., which is not possible. This indicates that the refraction has actually become a **Total Internal Reflection**.

https://en.wikipedia.org/wiki/Snell's_law

Common Indices of Refraction

Material	η
Air	1.000237
Ice	1.31
Water	1.33
Pyrex	1.47
Window Glass	1.52
Quartz	1.54
Cubic Zirconia	2.16
Diamond	2.42
Moissanite	2.69

https://en.wikipedia.org/wiki/List_of_refractive_indices



https://discover.charlesandcolvard.com/our-brand/everything-you-need-to-know-about-moissanite-vs-diamonds/

Using the Cube Map for Refraction

Using the Cube Map for Refraction

Vertex shader

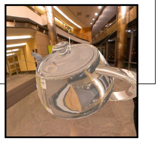
```
out vec3                vNormal;
out vec3                vEyeDir;
out vec3                vMC;

void
main( )
{
        vec4 newVertex = gl_Vertex;
                // could possibly apply displacements to newVertex here
        vMC = newVertex.xyz;
        vec3 ECposition = ( gl_ModelViewMatrix * newVertex).xyz;
        vEyeDir = ECposition – vec3(0.,0.,0.);          // vector from eye to pt
        vNormal = normalize( gl_NormalMatrix * gl_Normal );
                                        // or newNormal if you have displaced vertices
        gl_Position = gl_ModelViewProjectionMatrix * newVertex;
}
```

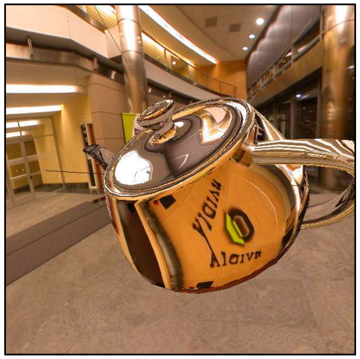
Same as for reflection…

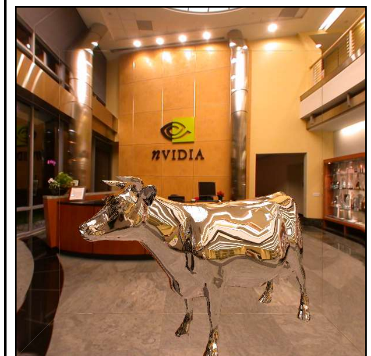
Using the Cube Map for Refraction

Fragment shader

```
in vec3                 vNormal;
in vec3                 vEyeDir;
in vec3                 vMC;

uniform float           uEta;
uniform samplerCube     uReflectUnit;
uniform samplerCube     uRefractUnit;
uniform float           uMix, uWhiteMix;

const vec3 WHITE = vec3( 1.,1.,1. );

void main( )
{
        vec3 normal = vNormal;
                                // if you are bump-mapping, apply noise to normal here using vMC
        vec3 reflectVector = reflect( vEyeDir, normal );
        vec3 reflectColor  = texture( uReflectUnit, reflectVector ).rgb;        // on Macs, use textureCube( )

        vec3 refractVector = refract( vEyeDir, normal, uEta );
        vec3 refractColor;
        if( all( equal( refractVector, vec3(0.,0.,0.) ) ) )     // like saying “if all elements of the refractVector are == 0.0 …”
        {
                refractColor = reflectColor;                    // . . . then treat this as a total internal reflection
        }
        else
        {
                refractColor = texture( uRefractUnit, refractVector ).rgb;      // on Macs, use textureCube( )
                refractColor = mix( refractColor, WHITE, uWhiteMix );
        }
        vec3 color = mix( refractColor, reflectColor, uMix );
        color = mix( color, WHITE, uWhiteMix );
        gl_FragColor = vec4(color, 1. );
}
```







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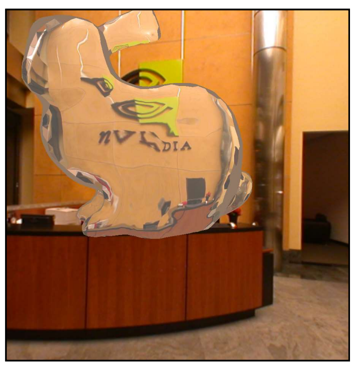

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Cube Mapping in glman

.glib file

```
##OpenGL GLIB
Perspective 70

Vertex      texture.vert
Fragment texture.frag
Program  Texture  TexUnit 6

Texture2D  6  nvposx.bmp
QuadYZ 5. 5. 10 10
Texture2D  6  nvnegx.bmp
QuadYZ -5. 5. 10 10
Texture2D  6  nvposy.bmp
QuadXZ 5. 5. 10 10
Texture2D  6  nvnegy.bmp
QuadXZ -5. 5. 10 10
Texture2D  6  nvposz.bmp
QuadXY 5. 5. 10 10
Texture2D  6  nvnegz.bmp
QuadXY -5. 5. 10 10

CubeMap  5 nvposx.bmp nvnegx.bmp  nvposy.bmp nvnegy.bmp   nvposz.bmp nvnegz.bmp
CubeMap  6 nvposx.bmp nvnegx.bmp  nvposy.bmp nvnegy.bmp   nvposz.bmp nvnegz.bmp

Vertex      refract.vert
Fragment  refract.frag
Program   Refract  uReflectUnit 5  uRefractUnit 6    uEta  <.1 1.1 5.>    uMix <0. 0. 1.>

Teapot
```

These have nothing to do with the cube mapping. They are here to create the six walls, without which the cube mapping looks ridiculous.

These must be listed in the order: +X, -X, +Y, -Y, +Z, -Z

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Cube Mapping in a C/C++ Program


```
GLSLProgram   Pattern;

GLuint              CubeName;

char *              FaceFiles[6]
{
            "kec.posx.bmp",
            "kec.negx.bmp",
            "kec.posy.bmp",
            "kec.negy.bmp",
            "kec.posz.bmp",
            "kec.negz.bmp"
};
```

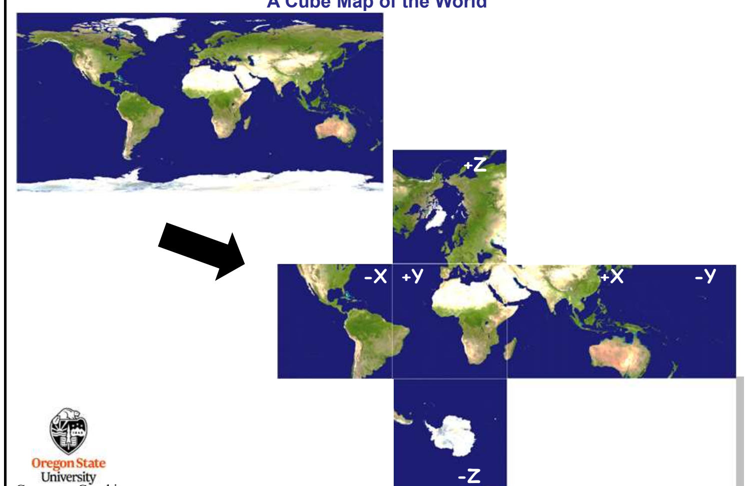

Cube Mapping in a C/C++ Program


```
void
InitGraphics( )
{
      // open the window . . .
      // setup the callbacks . . .
      // initialize glew . . .
      // create and compile the shader . . .

      glGenTextures( 1, &CubeName );
      glBindTexture( GL_TEXTURE_CUBE_MAP, CubeName );
      glTexParameterf( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_S, GL_REPEAT );
      glTexParameterf( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_T, GL_REPEAT );
      glTexParameterf( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_WRAP_R, GL_REPEAT );
      glTexParameterf( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MAG_FILTER, GL_LINEAR );
      glTexParameterf( GL_TEXTURE_CUBE_MAP, GL_TEXTURE_MIN_FILTER, GL_LINEAR );

      for( int file = 0; file < 6; file++ )
      {
            int nums, numt;
            unsigned char * texture2d = BmpToTexture( FaceFiles[file], &nums, &numt );
            if( texture2d == NULL )
                  fprintf( stderr, "Could not open BMP 2D texture '%s'",  FaceFiles[file] );
            else
                 fprintf( stderr, "BMP 2D texture '%s' read -- nums  = %d, numt = %d\n", FaceFiles[file], nums, numt );

            glTexImage2D( GL_TEXTURE_CUBE_MAP_POSITIVE_X + file, 0, 3, nums, numt, 0,
                  GL_RGB, GL_UNSIGNED_BYTE, texture2d );

            delete [ ] texture2d;
}
```

Cube Mapping in a C/C++ Program

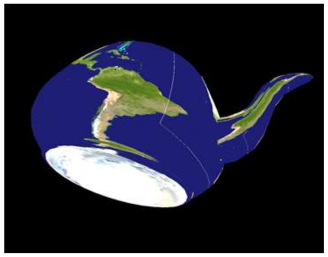

```
void
Display( )
{
      . . .
      int uReflectUnit = 5;
      int uRefractUnit = 6;
      float uAd = 0.1f;
      float uBd = 0.1f;
      float uEta = 1.4f;
      float uTol = 0.f;
      float uMix = 0.4f;

      Pattern.Use( );
      glActiveTexture( GL_TEXTURE0 + uReflectUnit );
      glBindTexture( GL_TEXTURE_CUBE_MAP, CubeName );
      glActiveTexture( GL_TEXTURE0 + uRefractUnit );
      glBindTexture( GL_TEXTURE_CUBE_MAP, CubeName );

      Pattern.SetUniformVariable( "uReflectUnit", uReflectUnit );
      Pattern.SetUniformVariable( "uRefractUnit", uRefractUnit );
      Pattern.SetUniformVariable( "uMix", uMix );
      Pattern.SetUniformVariable( "uEta", uEta )

      glCallList( SphereList );
      Pattern.UnUse;
}
```


Sidebar: You Can Also Use Cube Mapping to "Surround" an Object with a Texture: A Cube Map of the World



Sidebar: You Can Also Use Cube Mapping to "Surround" an Object with a Texture: A Cube Map of the World

Use the normal (n_x,n_y,n_z) as the (s,t,p) for the 3D lookup



(Some shapes map better than others…)

Sidebar: You Can Also Use Cube Mapping to "Surround" an Object with a Texture: A Cube Map of the World

Vertex shader

```
out vec3 vNormal;

void
main( )
{
        vNormal = normalize( gl_Normal );

        gl_Position = gl_ModelViewProjectionMatrix * gl_Vertex;
}
```

Use the normal (n_x,n_y,n_z) as the (s,t,p) for the 3D lookup

Fragment shader

```
uniform samplerCube uTexUnit;
in vec3 vNormal;

void
main( )
{
        vec4 newcolor = texture( uTexUnit, vNormal );
        gl_FragColor = vec4( newcolor.rgb, 1. );
}
```