UCLA

CS174A : Introduction to Computer Graphics

5200 Math Science
TT 2-4pm

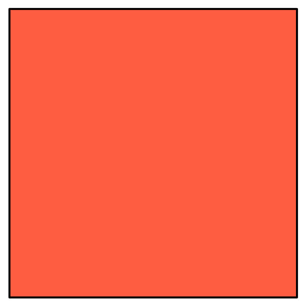
Scott Friedman, Ph.D
UCLA Institute for Digital Research and Education

Where are we at…

- Assignment #2
  - Due (tomorrow) 10/29 at 11:55.
- Assignment #3 available on CCLE
  - Due 11/7
- Term project proposal
  - Due next Tuesday 11/4
  - Should have your teams formed by now!
- Mid-Term
  - 11/6
  - Through Texture Mapping

Quick Review

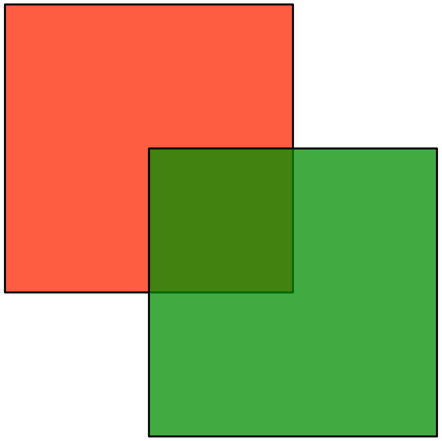
- Transparency order matters.
  - Red box (1,0,0), alpha = 0.75
  - Drawn over white background, alpha = 1.0



$$(R_{d'}, G_{d'}, B_{d'}, \alpha_{d'}) = (\alpha_s R_s + (1-\alpha_s) R_d, \alpha_s G_s + (1-\alpha_s) G_d, \alpha_s B_s + (1-\alpha_s) B_d, \alpha_s \alpha_d + (1-\alpha_s)\alpha_d)$$
$$(1.0, 0.25, 0.25, 1.0) = (0.75(1) + 0.25(1), 0.75(0) + 0.25(1), 0.75(0) + 0.25(1), 0.75(1) + 0.25(1)).$$

Quick Review

- Transparency order matters.
  - Green box (0,1,0), alpha = 0.75
  - Drawn *over* (i.e. after) the red box.

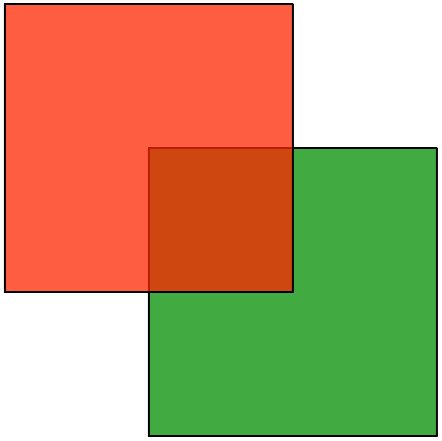


$$(R_{d'}, G_{d'}, B_{d'}, \alpha_{d'}) = (\alpha_s R_s + (1-\alpha_s)R_d, \alpha_s G_s + (1-\alpha_s)G_d, \alpha_s B_s + (1-\alpha_s)B_d, \alpha_s \alpha_d + (1-\alpha_s)\alpha_d)$$

$$(0.25, 0.8125, 0.0625, 1.0) = (0.75(0) + 0.25(1), 0.75(1) + 0.25(0.25), 0.75(0) + 0.25(.25), 0.75(1) + 0.25(1)).$$

Quick Review

- Transparency order matters.
  - If we reverse the rendering order, however.
  - We get a different blending result.



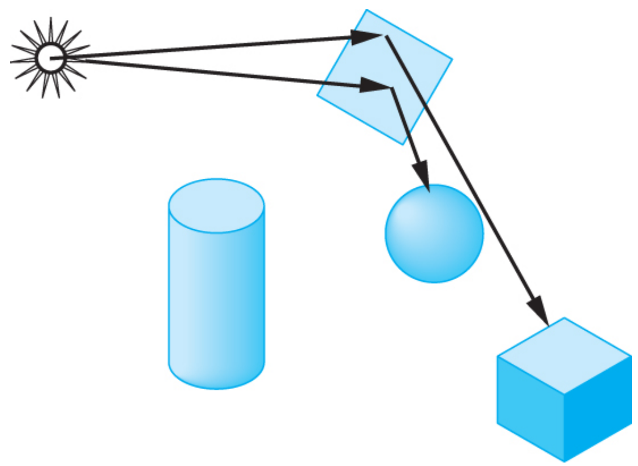
$$(R_{d'}, G_{d'}, B_{d'}, \alpha_{d'}) = (\alpha_s R_s + (1-\alpha_s) R_d, \alpha_s G_s + (1-\alpha_s) G_d, \alpha_s B_s + (1-\alpha_s) B_d, \alpha_s \alpha_d + (1-\alpha_s)\alpha_d)$$

$$(0.8125, 0.25, 0.0625, 1.0) = (0.75(1) + 0.25(0.25), 0.75(0) + 0.25(1), 0.75(0) + 0.25(0.25), 0.75(1) + 0.25(1)).$$

UCLA

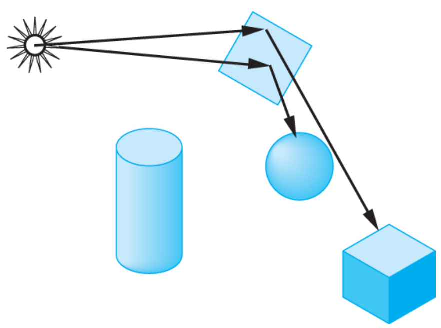
Environment Mapping

- Reflection of a **fixed** environment.
    - Sometimes called reflection mapping.
    - Reflections could be computed via ray tracing.
        - Too slow for real-time environments, generally.
    - However, a texture map can be used to approximate the effect.



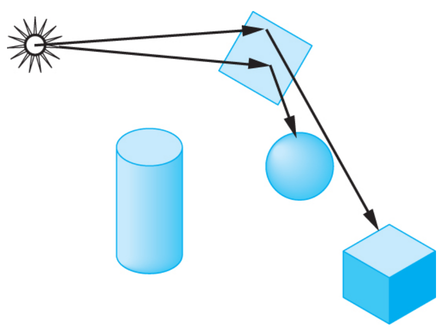
Environment Mapping

- How can we do it?
    - Take advantage of the fact that we can compute the reflection vector. (i.e. eye -> surface -> reflect -> world).
    - Intersect that ray with the scene and compute the color (shading) value.
    - Good, except this is essentially ray tracing!



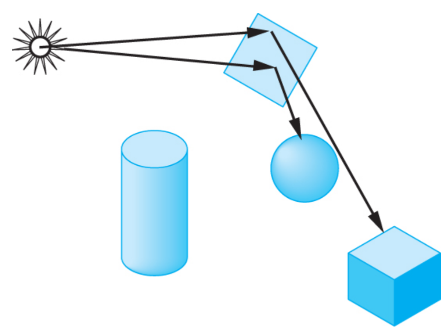
Environment Mapping

- How can we do it?
  - Approximate things with a two-pass method.
  - Place camera at the location of the mirror object.
  - Facing in direction of mirror surface normal.
  - Render scene, without mirror – into texture map
  - Render scene normally with texture map applied to mirror.
    - Camera in original position and mirror back in scene



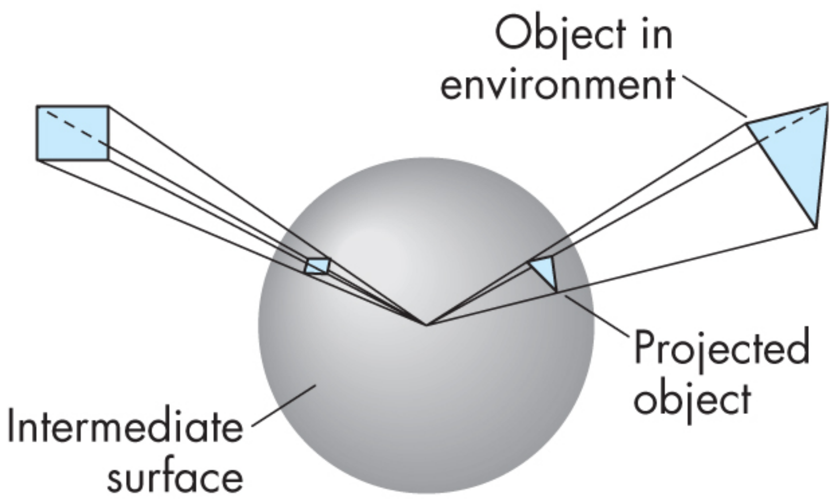
Environment Mapping

- How can we do it?
  - There are several problems with this approach.
    - Where exactly to put the camera?
    - Mirror is missing from first render pass
      - » Which can mess up lighting / mirror occludes something.
    - Projection from mirror can be tricky – off-axis
    - Have to re-render texture every time camera or mirror moves.



Environment Mapping

- How can we do it?
  - Projection of scene onto a sphere centered at COP.
  - Viewer cannot tell difference between object and projection.
  - Common example is the experience inside of a planetarium.



Environment Mapping

- How can we do it?
  - The result looks like this. (360x360 degree view)
  - Given a reflection vector we can look up the shaded color in the scene directly.
  - Google Street View, QuicktimeVR are variations of this

Environment Mapping

- How can we do it?
  - OpenGL supports this method directly
    - Given a reflection vector - determining texture coordinates *s* and *t* is straightforward.

$$\mathbf{r} = \begin{bmatrix} r_x \\ r_y \\ r_z \end{bmatrix} = 2(\mathbf{n} \bullet \mathbf{v})\mathbf{n} - \mathbf{v}$$

$$f = 2\sqrt{r_x^2 + r_y^2 + (r_z + 1)^2}$$

$$s = \frac{r_x}{f} + \frac{1}{2}$$

$$t = \frac{r_y}{f} + \frac{1}{2}$$

Environment Mapping

- How can we do it?
  - Not really correct (but good enough)
    - – Created at a specific location (origin)
      - » Which is not the location of the mirrored surface
    - – Needs to be recomputed if what is in scene changes.

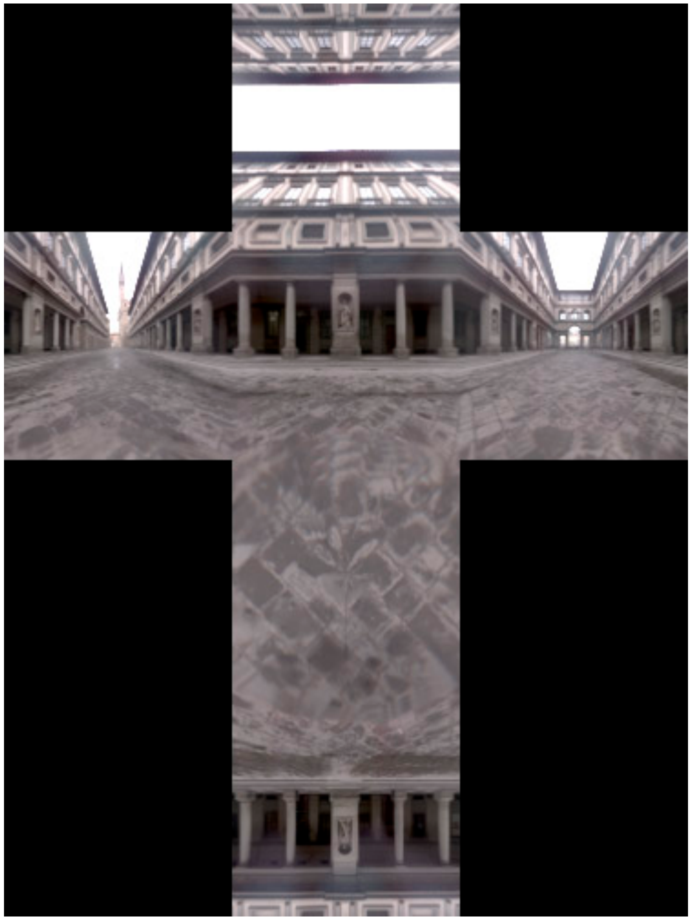
Environment Mapping

- How can we do it?
  - Difficult, but doable to create map.
    - Real cameras have spherical lenses (Google Street View)
  - OpenGL has a simpler way.
    - We can use the projections we have already developed.

UCLA

Environment Mapping

- Make things even simpler
- Cube mapping
  - Render six images
  - Each centered on an axis
  - Results in the inside of a cube
    - unfolded
  - FOV must be 90 deg.
  - Edges have to match



Environment Mapping

- Cube mapping
  - Given we are passing correctly transformed surface normals into the vertex shader.
  - We can compute the reflection vector
    - and pass it on to the fragment shader.

```
attribute vec4 vPosition;
attribute vec4 normal;
varying vec3 reflection;

uniform mat4 ModelView;
uniform mat4 Projection;

void main( void )
{
  gl_Position = Projection * ModelView * vPosition;
  vec3 eyePos = vPosition.xyz;
  reflection = reflect( eyePos, normalize( (ModelView * normal).xyz );
}
```

Environment Mapping

- Cube mapping
    - The reflection vector is interpolated for us in fragment shader.
    - So the rest is simple
    - Notice
        - samplerCube type (similar in function to sampler2D)
        - textureCube function

```
varying vec3 reflection;
uniform samplerCube cubeMap;  // passed this in from our application

void main( void )
{
  gl_FragColor = textureCube( cubeMap, reflection );
}
```

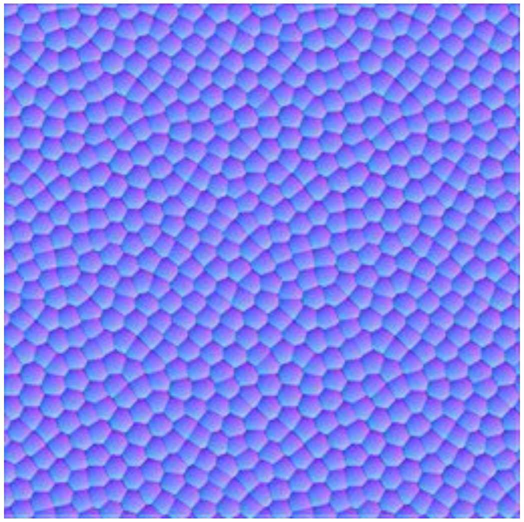
UCLA

Bump Mapping

- Bump mapping
  - Bump mapping is really Displacement Mapping.
  - A texture map stores displacements to the surface.
  - This requires computing a normal at the new, displaced, surface point.
  - Partial derivatives must be found to solve this.
    - Finite differences can be used.
    - Slow-ish when solving for every fragment.
  - Advantage is we can use the result to perturb the normal in *object* space.

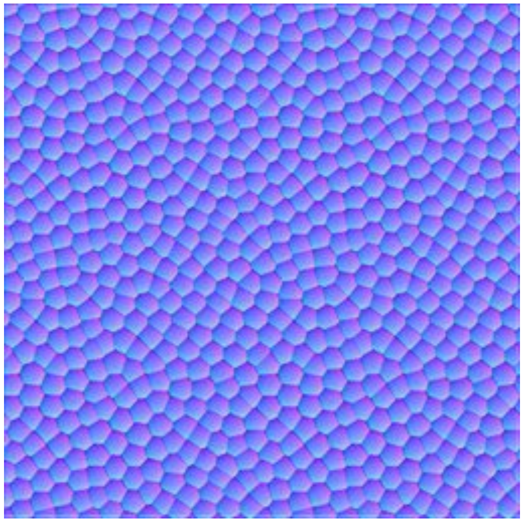
Bump Mapping

- Normal mapping
  - What we typically think of as Bump Mapping.
  - Here we store ***normals*** in a texture map.
    - x, y and z components of a normal vector are stored in the R, G and B channels of the texture map.



Bump Mapping

- Normal mapping
  - We have to map the [-1,1] range of our normal components to the [0,1] range of color values.
  - Easily done by $[R,G,B]=([x,y,z]+1)/2$



Bump Mapping

- Normal mapping
  - This is not enough.
  - Normal maps require a new ***coordinate frame***.
  - *Tangent Space* or TBN space
    - Lighting for surfaces with normal maps applied will be computed in TBN space.
    - **TBN** = **T**angent, **B**i-tangent, **N**ormal space
    - The **T**angent is the tangent to the surface at point **p**
    - The **B**i-tangent is the cross product of the normal and tangent.
    - The **N**ormal is the surface normal at point **p**

Bump Mapping

- Normal mapping
  - The TBN vectors define a new frame at the point we are lighting on the surface.
  - We align the T and B vectors with the *s* and *t* dimensions of our normal map.
  - We can get from object space to tangent space by a vector transformation.

$$\begin{bmatrix} T_x & T_y & T_z \\ B_x & B_y & B_z \\ N_x & N_y & N_z \end{bmatrix}$$

Bump Mapping

- Normal mapping
  - We transform the light vector by this matrix.
  - The light and normal map vectors are in the same coordinate system so lighting equations are correct.