Environment Mapping

Computer Graphics

CSE 167

Lecture 13

CSE 167: Computer graphics

- Environment mapping
  - An image-based lighting method
  - Approximates the appearance of a surface using a precomputed texture image (or images)
  - In general, the fastest method of rendering a surface

More realistic illumination

- In the real world, at each point in a scene, light arrives from all directions (not just from a few point light sources)
  - Global illumination is a solution, but is computationally expensive
  - An alternative to global illumination is an environment map
    - Store “omni-directional” illumination as images
    - Each pixel corresponds to light from a certain direction
    - Sky boxes make for great environment maps

Based on slides courtesy of Jurgen Schulze

Reflection mapping

- Early (earliest?) non-decal use of textures
- Appearance of shiny objects
  - Phong highlights produce blurry highlights for glossy surfaces
  - A polished (shiny) object reflects a sharp image of its environment
- The whole key to a shiny-looking material is providing something for it to reflect

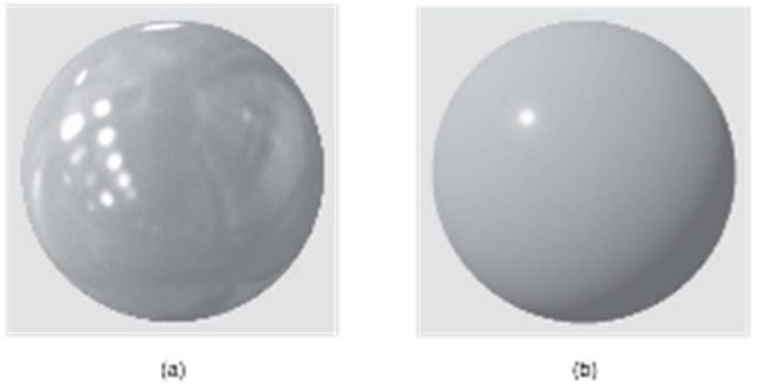


Figure 2. (a). A shiny sphere rendered under photographically acquired real-world illumination. (b). The same sphere rendered under illumination by a point light source.

[Dror, Willsky, & Adelson 2004]

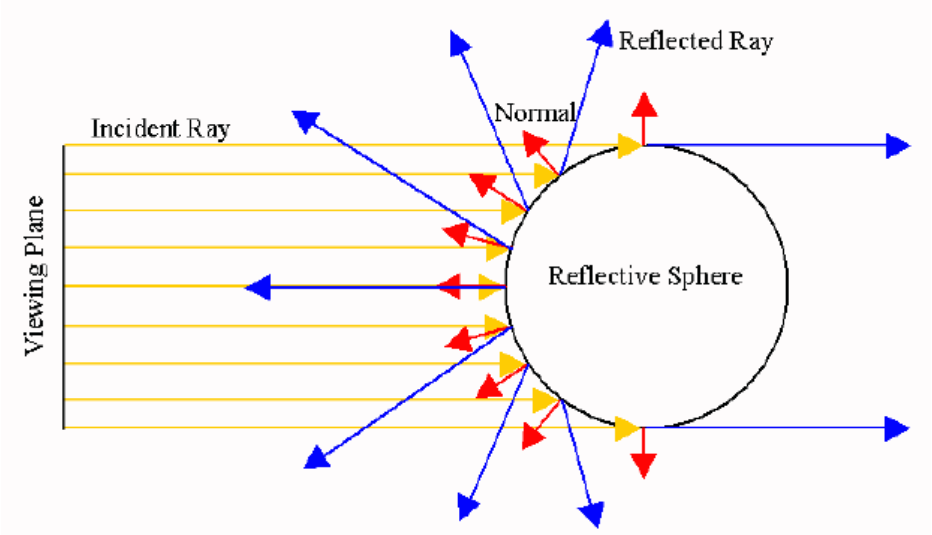
Reflection mapping

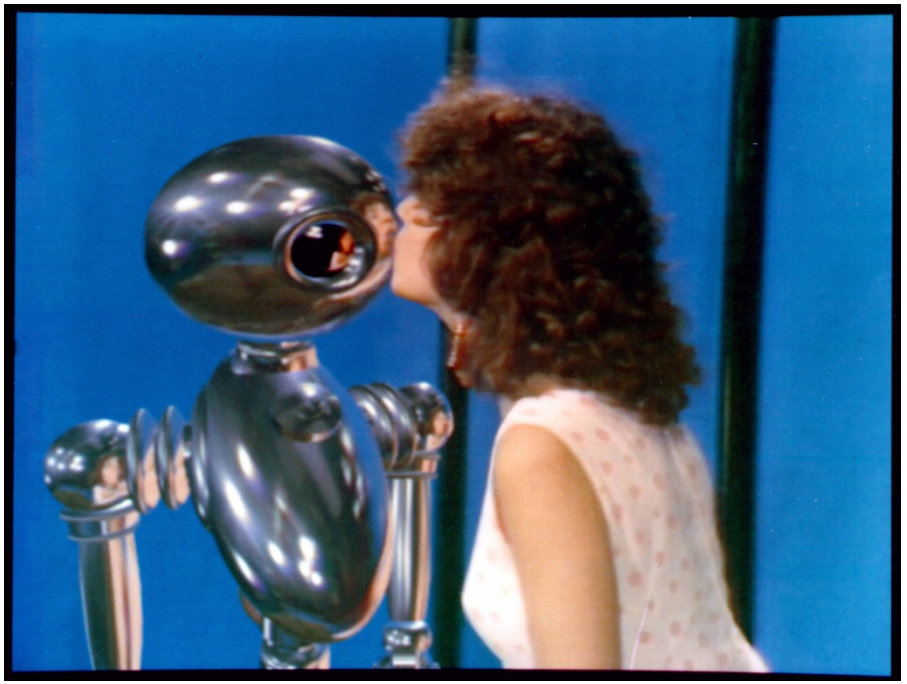
- A function from the sphere to colors, stored as a texture

[Blinn & Newell 1976]

Reflection mapping

- Interface (Lance Williams, 1985)

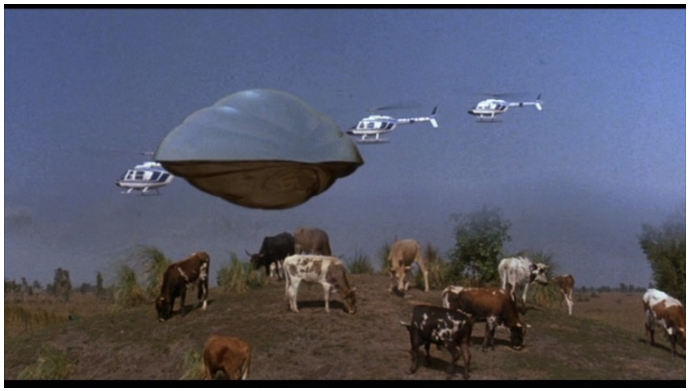


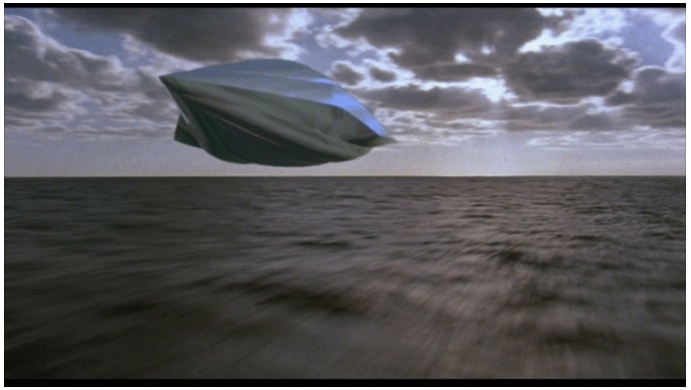


Video

Reflection mapping

- Flight of the Navigator (1986)

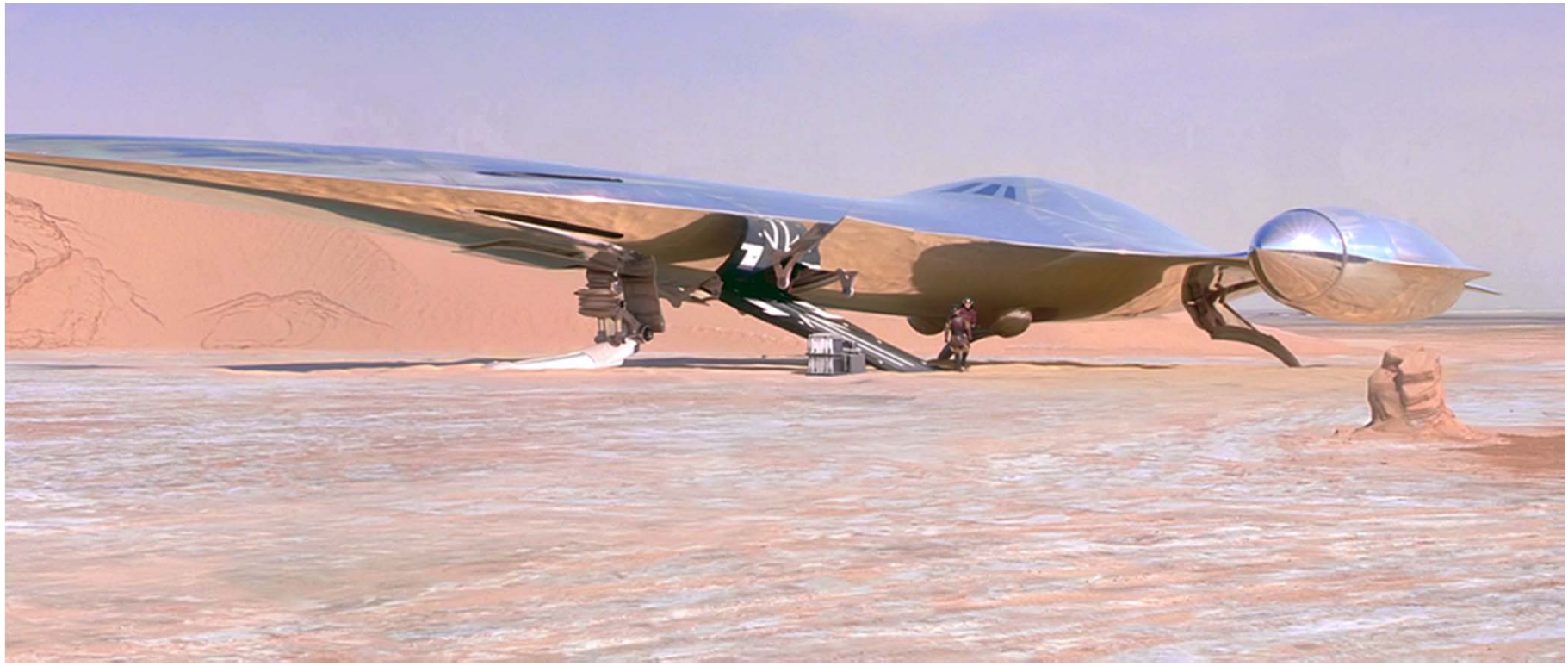


Reflection mapping

- Terminator 2 (1991)

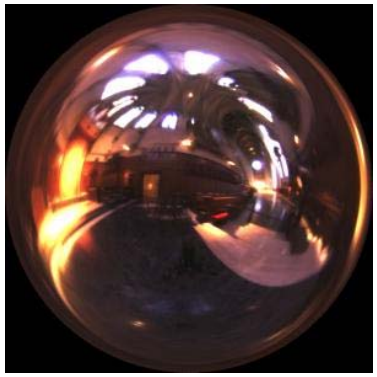
Reflection mapping

- Star Wars: Episode I *The Phantom Menace* (1999)



Creating environment maps

- An environment map is a spherical panoramic image
- Capturing a spherical panoramic image
  - Use a 360 degree camera
  - Take a picture of a mirrored ball (called a light probe)



Light Probes by Paul Debevec http://www.debevec.org/Probes/

Environment maps as light sources

- Key assumption: light captured by an environment map is emitted from infinitely far away
- As such, an environment map consists of directional light sources
  - An environment map value is defined for each direction, independent of position in scene
  - The same environment map is used at each point in the scene

Environment maps

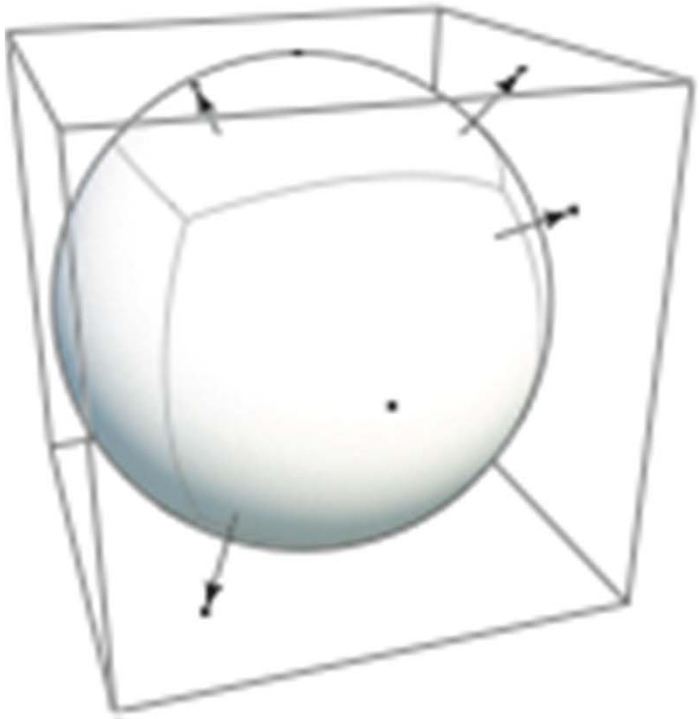
Global illumination with pre-computed radiance transfer [Sloan et al. 2002]

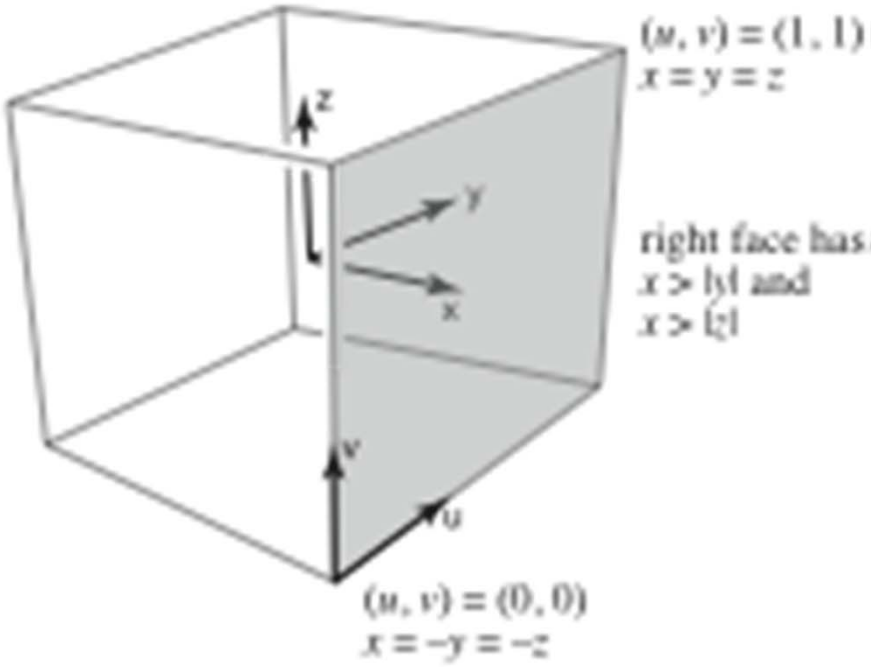
Reflection mapping
[Georg-Simon Ohm University of Applied Sciences]

Environment maps

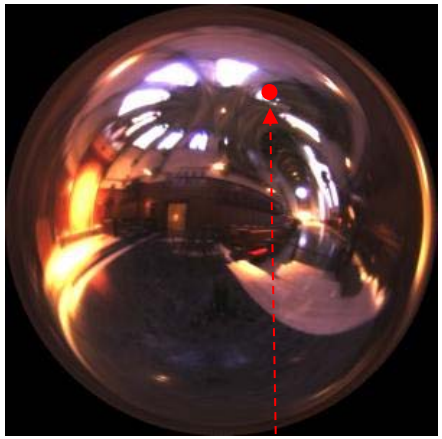
Cube environment map

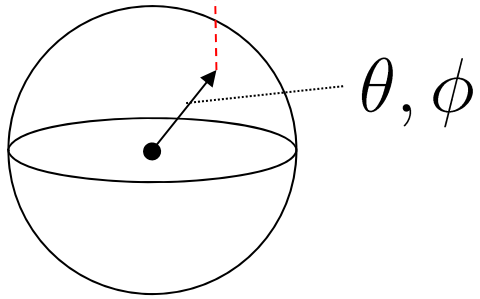
- Store incident light on six faces of a cube instead of on sphere



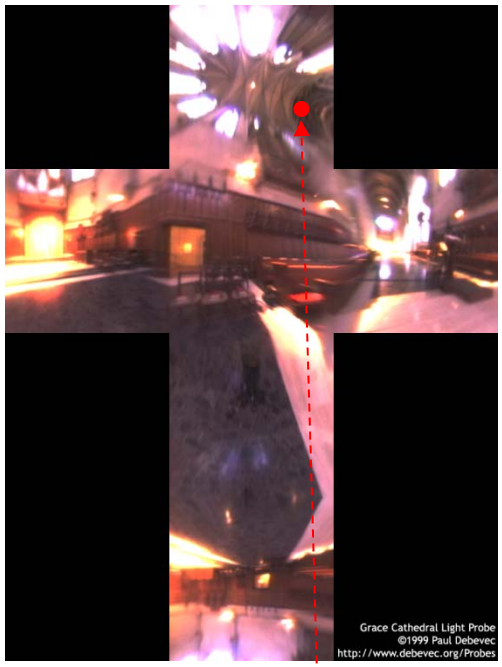


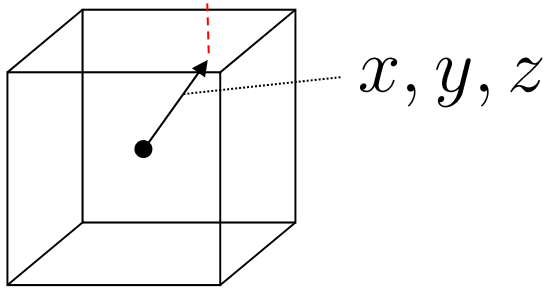
Cube environment map





Spherical map

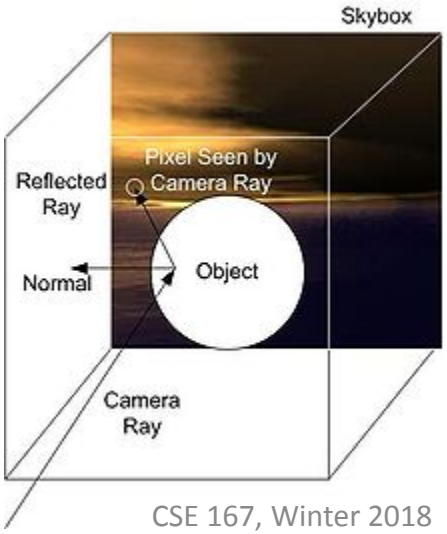




Cube map

Cube vs. spherical maps

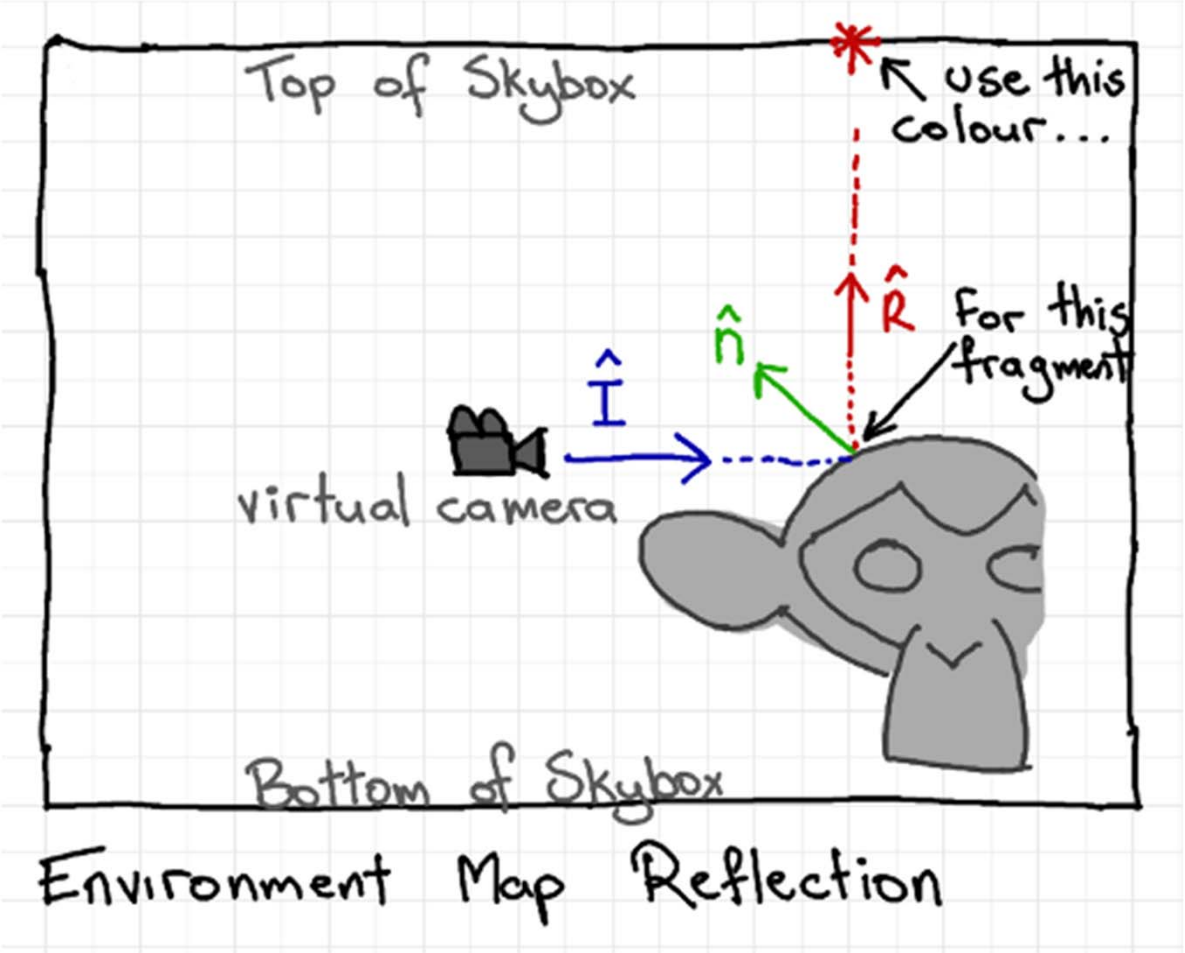
- Advantages of cube maps
  - More even texel sample density causes less distortion, allowing for lower resolution maps
  - Easier to dynamically generate cube maps for real-time simulated reflections



Cube environment map

- Cube map look-up
  - Given light direction (*x*,*y*,*z*)
  - Largest coordinate component determines cube map face
  - Dividing by magnitude of largest component yields coordinates within face
  - In GLSL:
    - Use (*x*,*y*,*z*) direction as texture coordinates to samplerCube

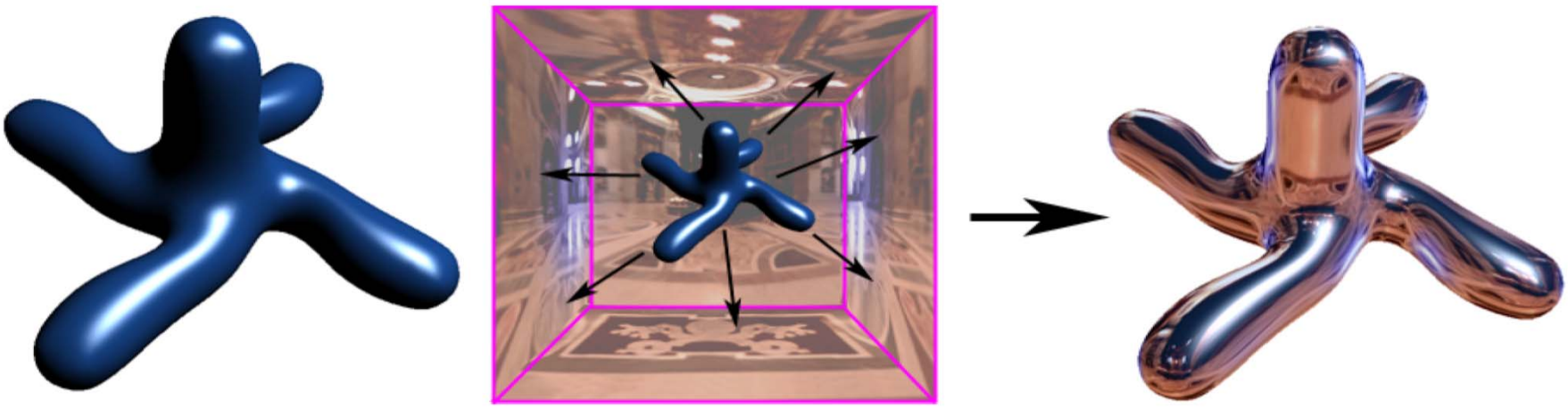
Environment mapping



Source: http://antongerdelan.net/opengl/cubemaps.html

Reflection maps

- Simulates mirror reflection
- Computes reflection vector at each pixel
- Use reflection vector to look up cube map
- Rendering cube map itself is optional (application dependent)



Reflection maps

Images from *Illumination and Reflection Maps:*
Simulated Objects in Simulated and Real Environments
Gene Miller and C. Robert Hoffman
SIGGRAPH 1984 "Advanced Computer Graphics Animation" Course Notes

Reflection mapping in GLSL

- Application setup
  - Load and bind a cube environment map

```
glBindTexture(GL_TEXTURE_CUBE_MAP, …);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_X,…);
glTexImage2D(GL_TEXTURE_CUBE_MAP_NEGATIVE_X,…);
glTexImage2D(GL_TEXTURE_CUBE_MAP_POSITIVE_Y,…);
…
glEnable(GL_TEXTURE_CUBE_MAP);
```

Environment mapping: vertex shader

```
#version 400

in vec3 vp; // positions from mesh
in vec3 vn; // normals from mesh
uniform mat4 P, V, M; // proj, view, model matrices
out vec3 pos_eye;
out vec3 n_eye;

void main()
{
  pos_eye = vec3(V * M * vec4(vp, 1.0));
  n_eye = vec3(V * M * vec4(vn, 0.0));
  gl_Position = P * V * M * vec4(vp, 1.0);
}
```

Environment mapping: fragment shader

```
#version 400

in vec3 pos_eye;
in vec3 n_eye;
uniform samplerCube cube_texture;
uniform mat4 V; // view matrix
out vec4 frag_colour;

void main()
{
  // reflect ray around normal from eye to surface
  vec3 incident_eye = normalize(pos_eye);
  vec3 normal = normalize(n_eye);

  vec3 reflected = reflect(incident_eye, normal);
  // convert from eye to world space
  reflected = vec3(inverse(V) * vec4(reflected, 0.0));

  frag_colour = texture(cube_texture, reflected);
}
```

Diffuse irradiance environment map

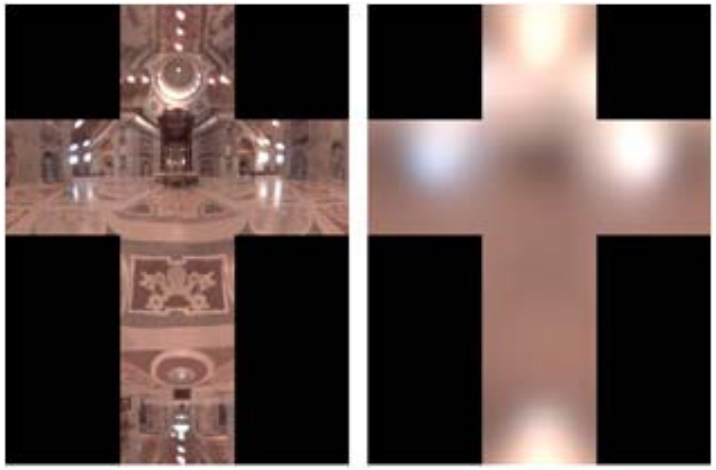
- Given a scene with *k* directional lights, light directions d_1, …, d_k, and intensities i_1, …, i_k illuminating a diffuse surface with normal *n* and color *c*
- Pixel intensity *B* is computed as $B = c \sum_{j=1..k} \max(0, d_j \cdot n) i_j$
- The cost of computing *B* is proportional to the number of texels in environment map
- Observations
  - All surfaces with normal direction *n* will return the same value for the sum
  - The sum is dependent on just the lights in the scene and the surface normal

Diffuse irradiance environment map

- Precompute diffuse reflections
  - Precompute sum for any normal *n* and store result in a second environment map, indexed by surface normal
- Second environment map is called diffuse irradiance environment map
- Allows to illuminate objects with arbitrarily complex lighting environments with single texture lookup

Diffuse irradiance environment map

- Two cubic environment maps
  - Reflection map
  - Diffuse map



Diffuse shading vs. shading with diffuse map

Image source: http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter10.html

Environment mapping

- Rendering with Natural Light (Paul Debevec, 1998)

Video