CSE 167:
Introduction to Computer Graphics
Lecture #16: Environment Mapping

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Announcements

- Final project blog #2 due this Sunday
- No grading this Friday
- Office hours as usual
- Midterm return

Midterm Statistics

Midterm #	1	2
Average score	62.4	57.5
Highest score	80	78
Lowest score	34	25.5
70-80	14	4
60-70	26	18
50-60	10	19
40-50	7	7
30-40	1	3
# Exams submitted	58	52

Lecture Overview

Advanced Shader Effects

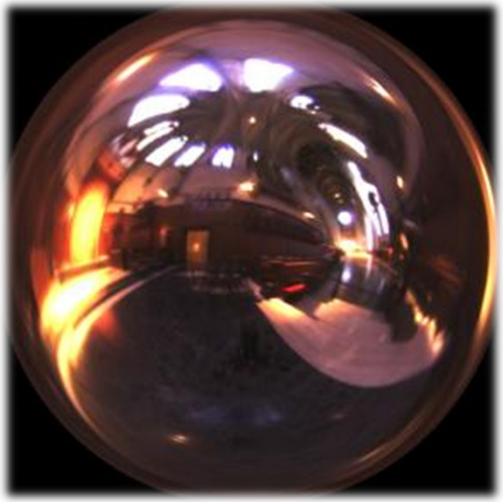
- Environment mapping
- Toon shading

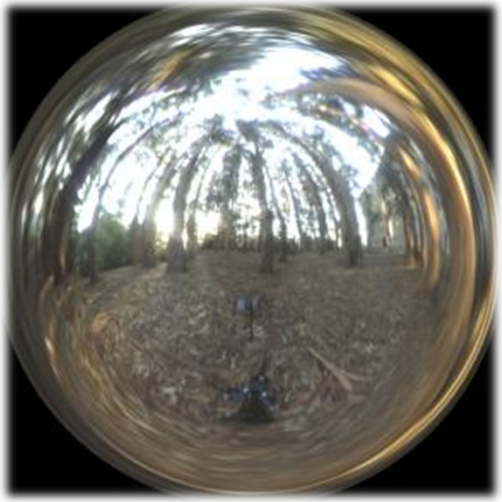
More Realistic Illumination

- In the real world:
  At each point in scene light arrives from all directions
  - Not just from a few point light sources
  - → Global Illumination is a solution, but computationally expensive
- Environment Maps
  - Store "omni-directional" illumination as images
  - Each pixel corresponds to light from a certain direction

Capturing Environment Maps

- "360 degrees" panoramic image
- Instead of 360 degrees panoramic image, take picture of mirror ball (light probe)





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

Environment Maps as Light Sources

Simplifying Assumption

- Assume light captured by environment map is emitted from infinitely far away
- Environment map consists of directional light sources
  - Value of environment map is defined for each **direction**, independent of position in scene
- Approach uses same environment map at each point in scene
  → Approximation!

Applications for Environment Maps

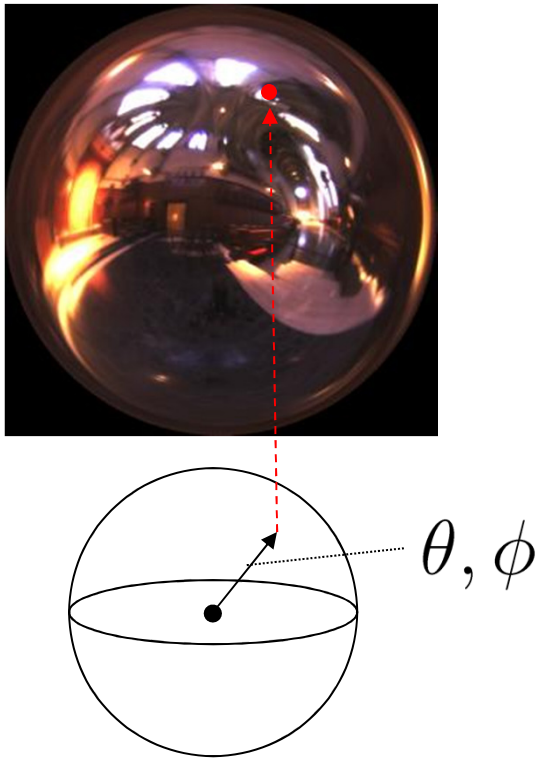
- Use environment map as "light source"

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

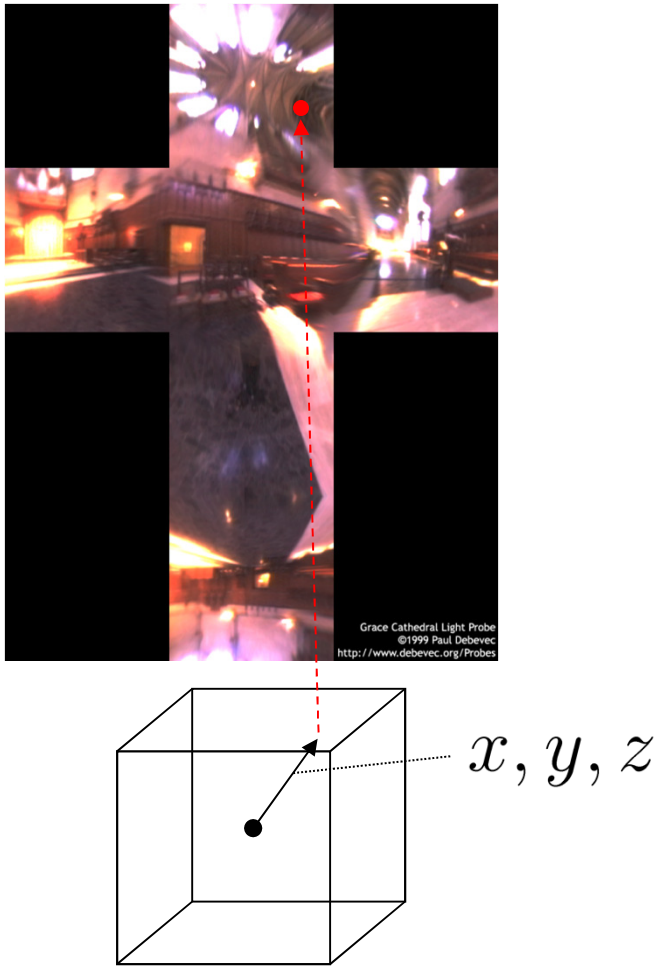
Reflection mapping [Terminator 2, 1991]

Cubic Environment Maps

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



Spherical map



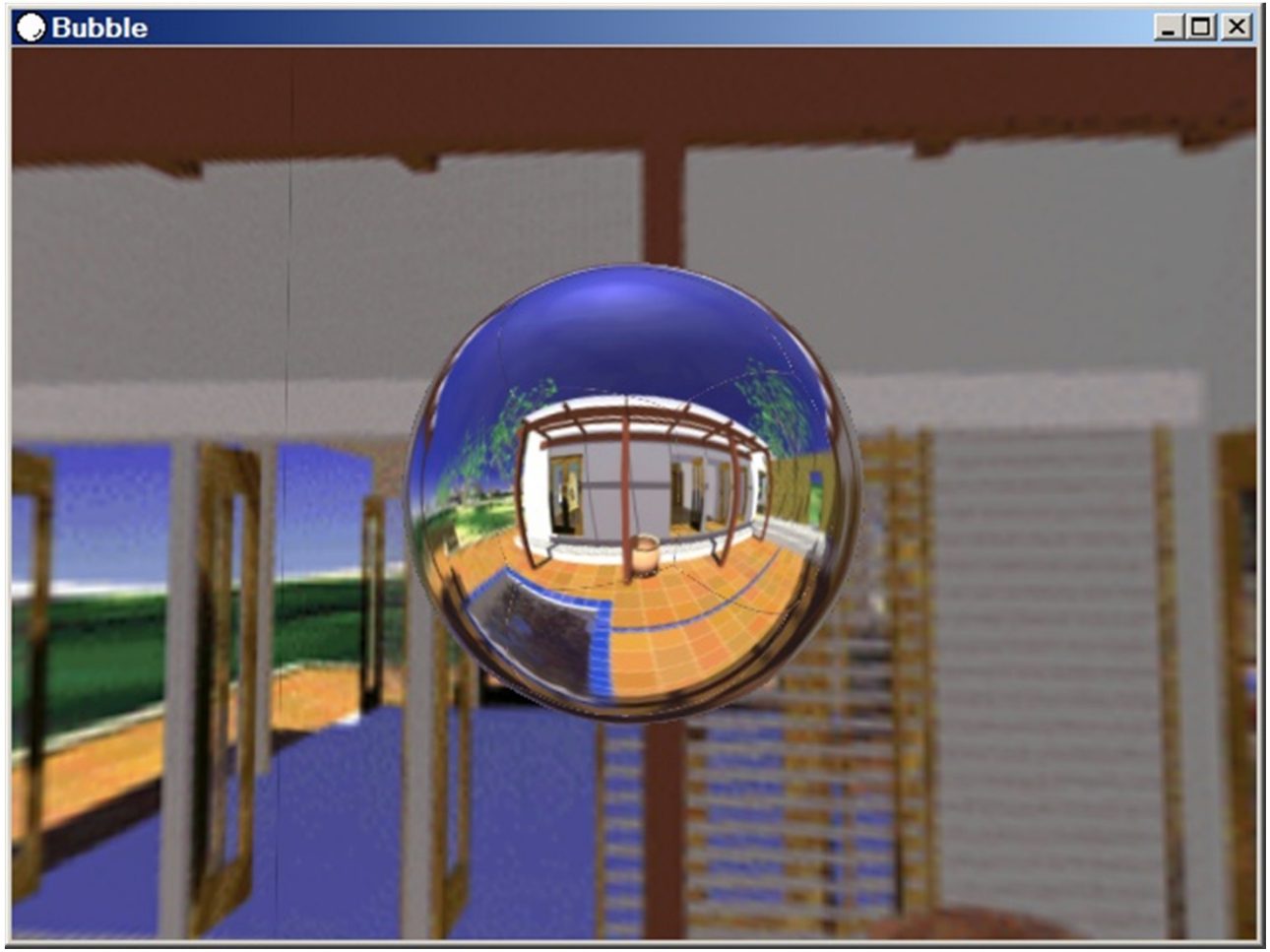
Cube map

UCSD

Cubic 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

Bubble Demo



http://download.nvidia.com/downloads/nZone/demos/nvidia/Bubble.zip

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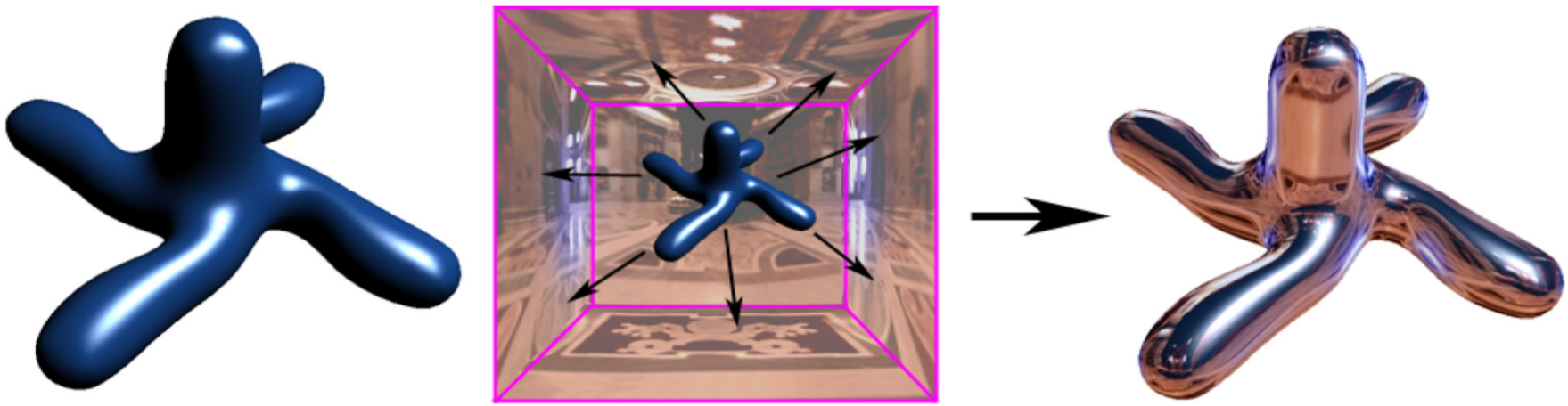
Cubic Environment Maps

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`

Reflection Mapping

- 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 mapping

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);
```

Reflection Mapping in GLSL

Vertex shader

- Compute viewing direction
- Reflection direction
  - Use `reflect` function
- Pass reflection direction to fragment shader

Fragment shader

- Look up cube map using interpolated reflection direction

```
varying float3 refl;
uniform samplerCube envMap;
textureCube(envMap, refl);
```

Environment Maps as Light Sources

- Covered so far: shading of a specular surface

→ How do you compute shading of a diffuse surface?

Diffuse Irradiace 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: $B = c \sum_{j=1..k} \max(0, d_j \cdot n) i_j$
- Cost of computing B proportional to number of texels in environment map!
- → Precomputation of diffuse reflection
- 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
- 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 Irradiace Environment Map

- Two cubic environment maps:
  - Reflection map
  - Diffuse map

- Diffuse shading vs. shading w/diffuse map

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