CSE 167:
Introduction to Computer Graphics
Lecture #15: Shader Effects

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Announcements

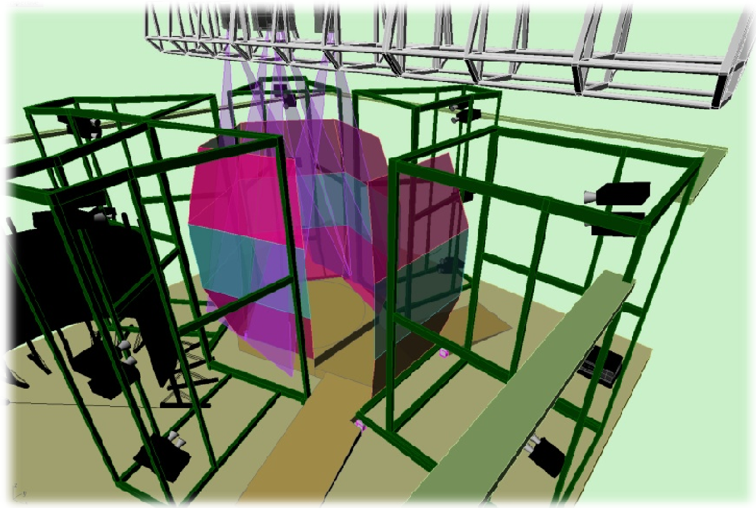
- Homework assignment #6 due Friday, Nov 18
- CAPE: on-line, email notification at beginning of week 9
  - Period: Monday 11/21 to Monday 12/5
  - http://www.cape.ucsd.edu
- Final project description is on-line

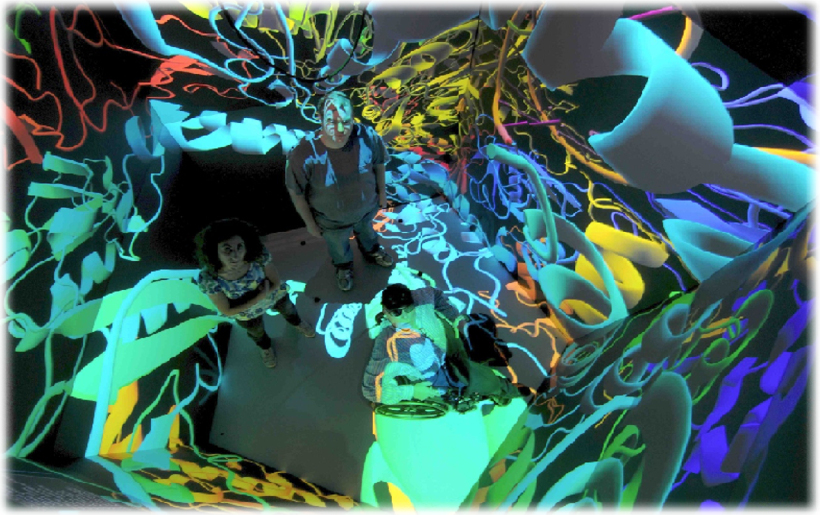
StarCAVE Tour

- Location: Atkinson Hall, 1st floor
- Time: Today after class, until 5pm
- Location:
  - Immersive Visualization Laboratory
  - 1st floor Atkinson Hall
  - Turn right at main entrance
  - Door on left, will be open

The StarCAVE

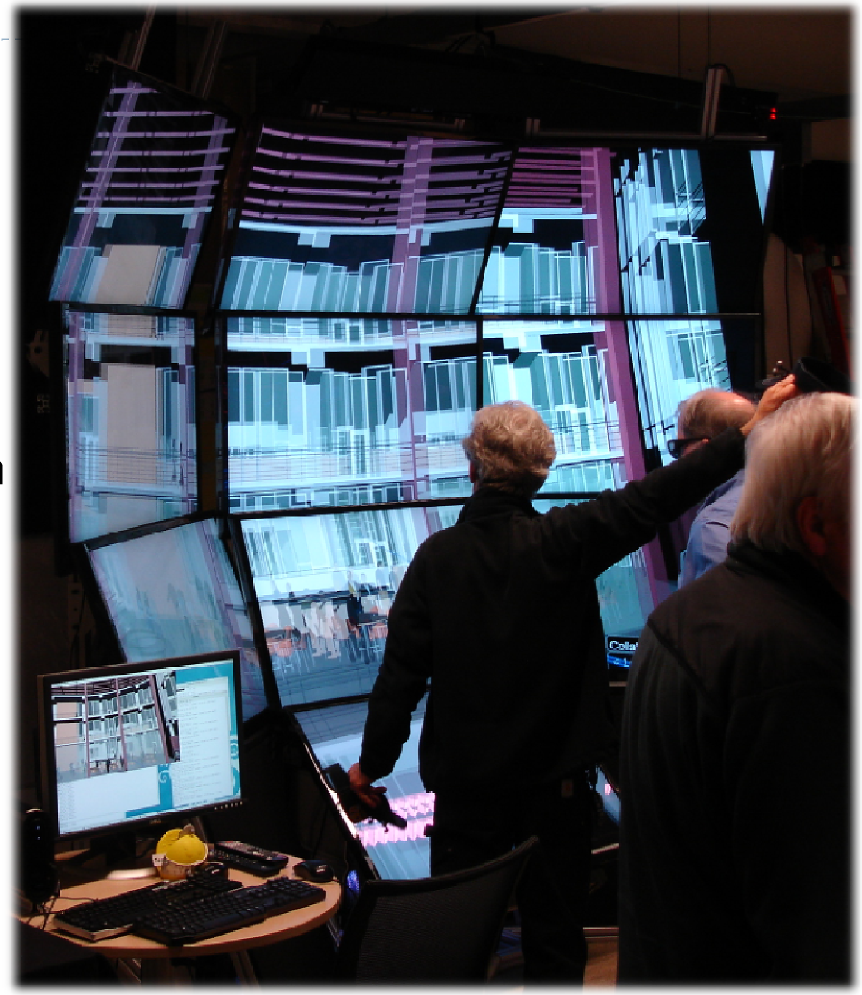
- 18 Dell XPS 710 PCs
- Dual Nvidia Quadro 5600 graphics cards
- CentOS 5.3 Linux
- 34 JVC HD2k projectors (1920x1080 pixels): ~34 megapixels per eye
- 360 degrees immersion
- Passive stereo, circular polarization
- 15 screens on 5 walls, ~8 x 4 foot each, plus floor projection
- 4-camera optical tracking system





NexCAVE

- 10 42" JVC Xpol displays:
  LCD panels with polarizing filters,
  1920x1080 pixels
- 5 rendering PCs: Dell XPS 710
- Nvidia GeForce 480 GPUs
- 2-camera ART TrackPack tracking system



Lecture Overview

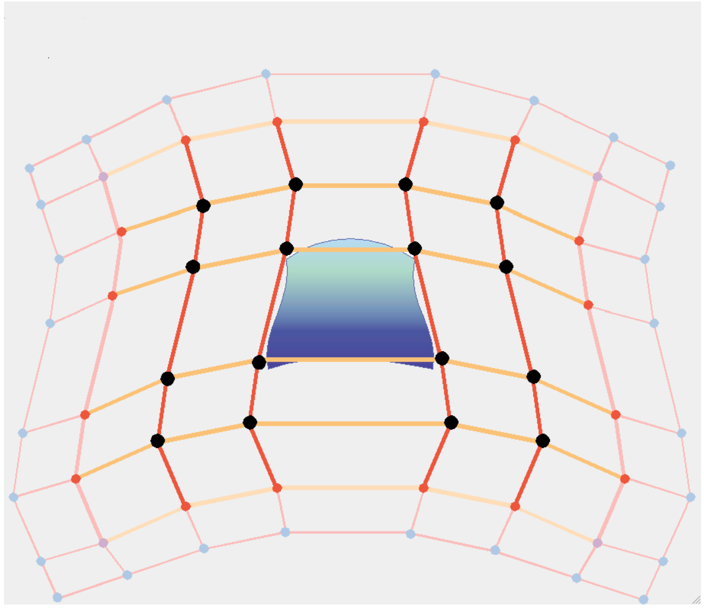
- Advanced surface modeling

Advanced Shader Effects

- Environment mapping
- Toon shading
- Ambient Occlusion

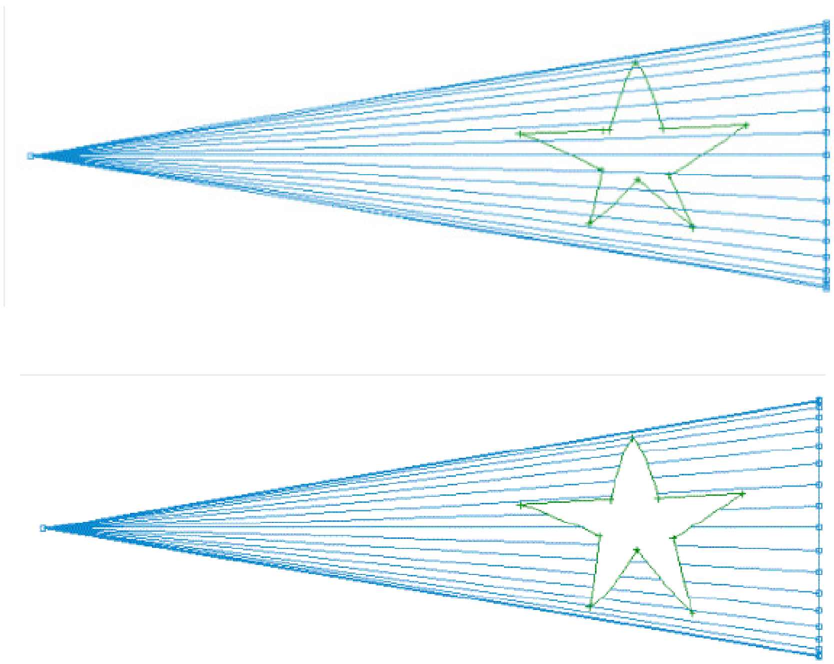
Advanced Surface Modeling

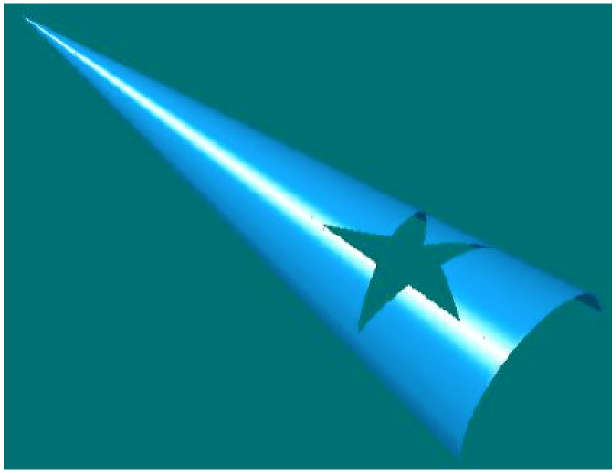
- B-spline/NURBS patches
- For the same reason as using B-spline/NURBS curves
  - More flexible (can model spheres)
  - Better continuity



Advanced Surface Modeling

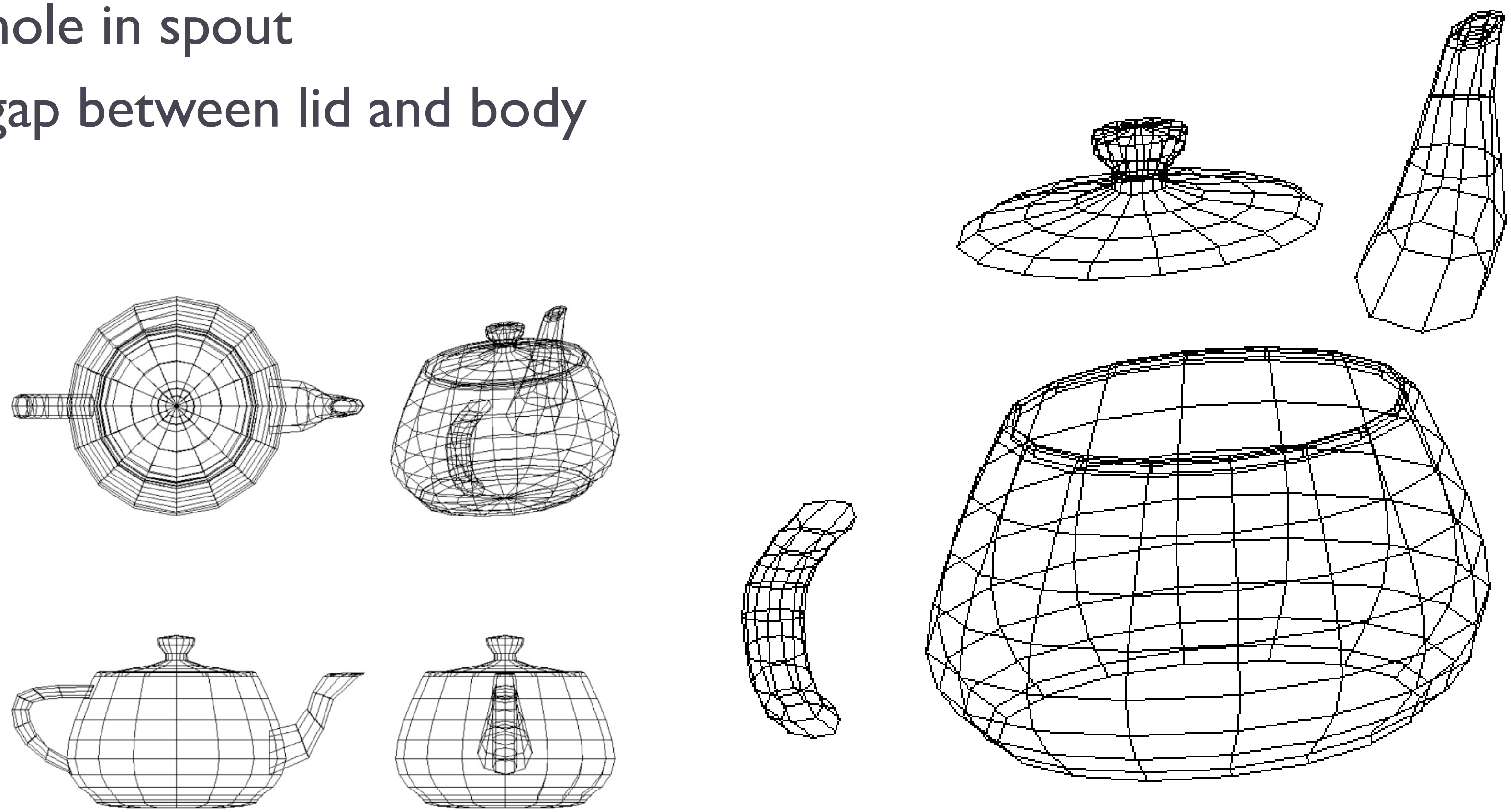
- Trim curves: cut away part of surface
  - Implement as part of tessellation/rendering





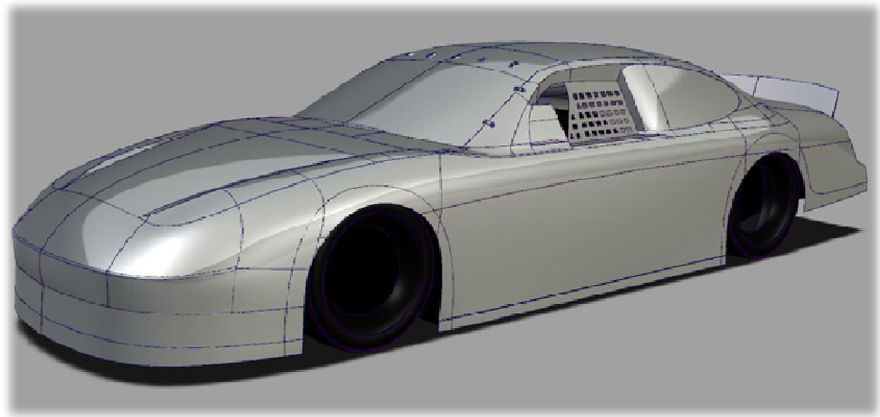
Modeling Headaches

- Original teapot is not "water tight"
  - spout & handle intersect with body
  - hole in spout
  - gap between lid and body



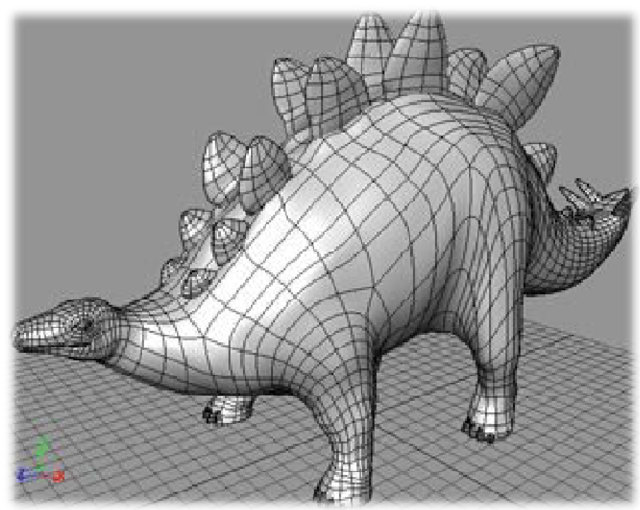
Modeling Headaches

- **NURBS surfaces are versatile**
  - Conic sections
  - Can blend, merge, trim…



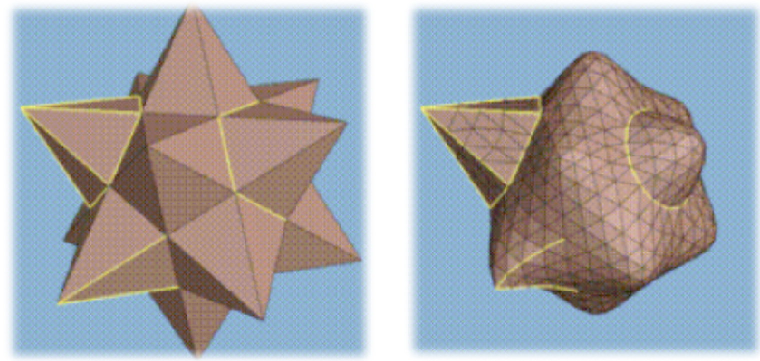
- **But:**
  - Any surface will be made of quadrilateral patches (quadrilateral topology)

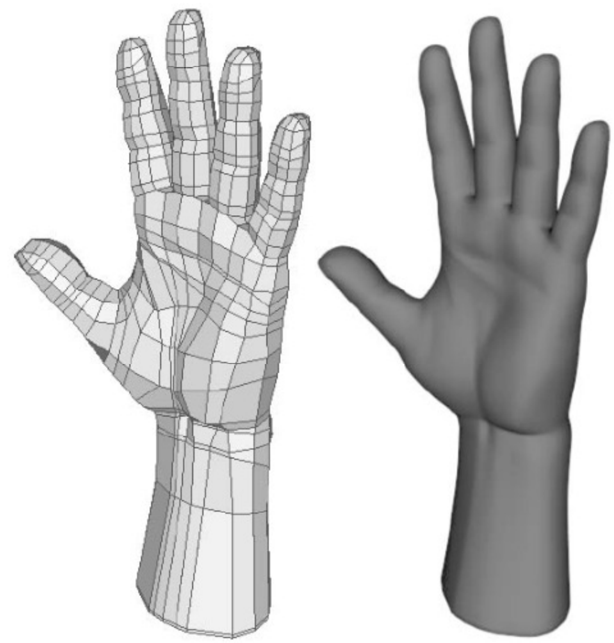
- **This makes it hard to**
  - Join or abut curved pieces
  - Build surfaces with complex topology or structure



Subdivision Surfaces

- Arbitrary mesh of control points, not quadrilateral topology
  - No global u,v parameters
- Can make surfaces with arbitrary topology or connectivity
- Work by recursively subdividing mesh faces
  - Per-vertex annotation for weights, corners, creases
- Used in particular for character animation
  - One surface rather than collection of patches
  - Can deform geometry without creating cracks





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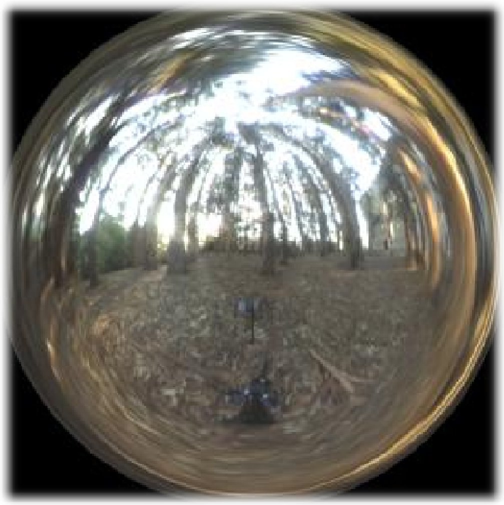
More Realistic Illumination

- In real world:
  At each point in scene light arrives from all directions
  - Not just from 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

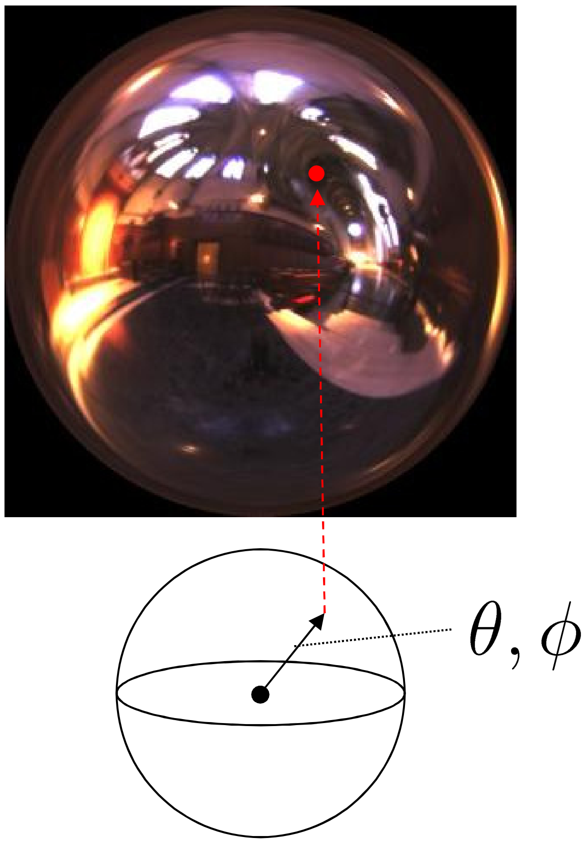
- Use environment map as "light source"

Global illumination with precomputed radiance transfer [Sloan et al. 2002]

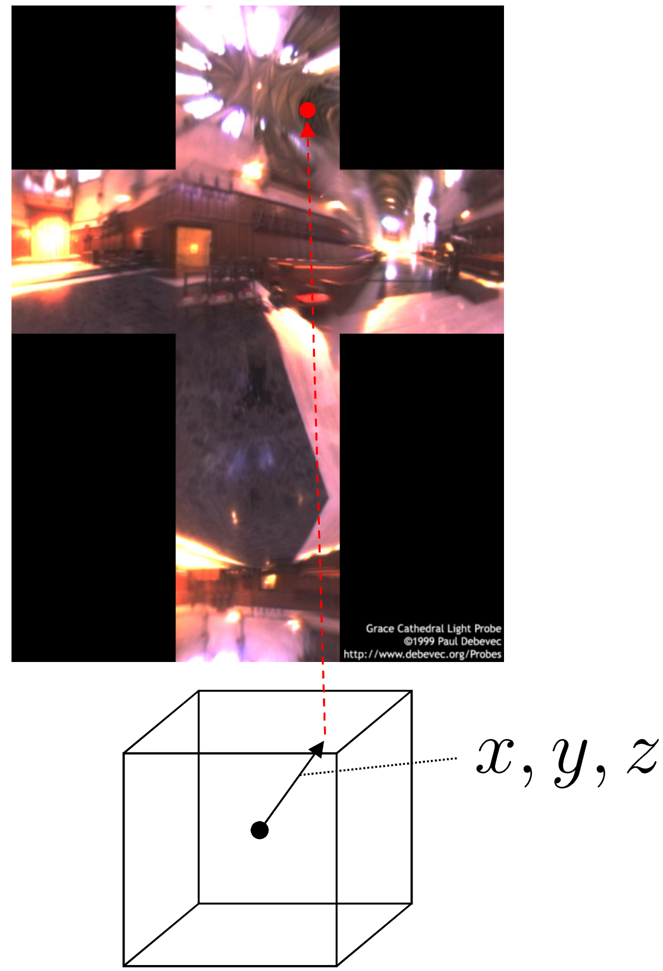
Reflection mapping [Terminator 2, 1991]

Cubic Environment Maps

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



Spherical map

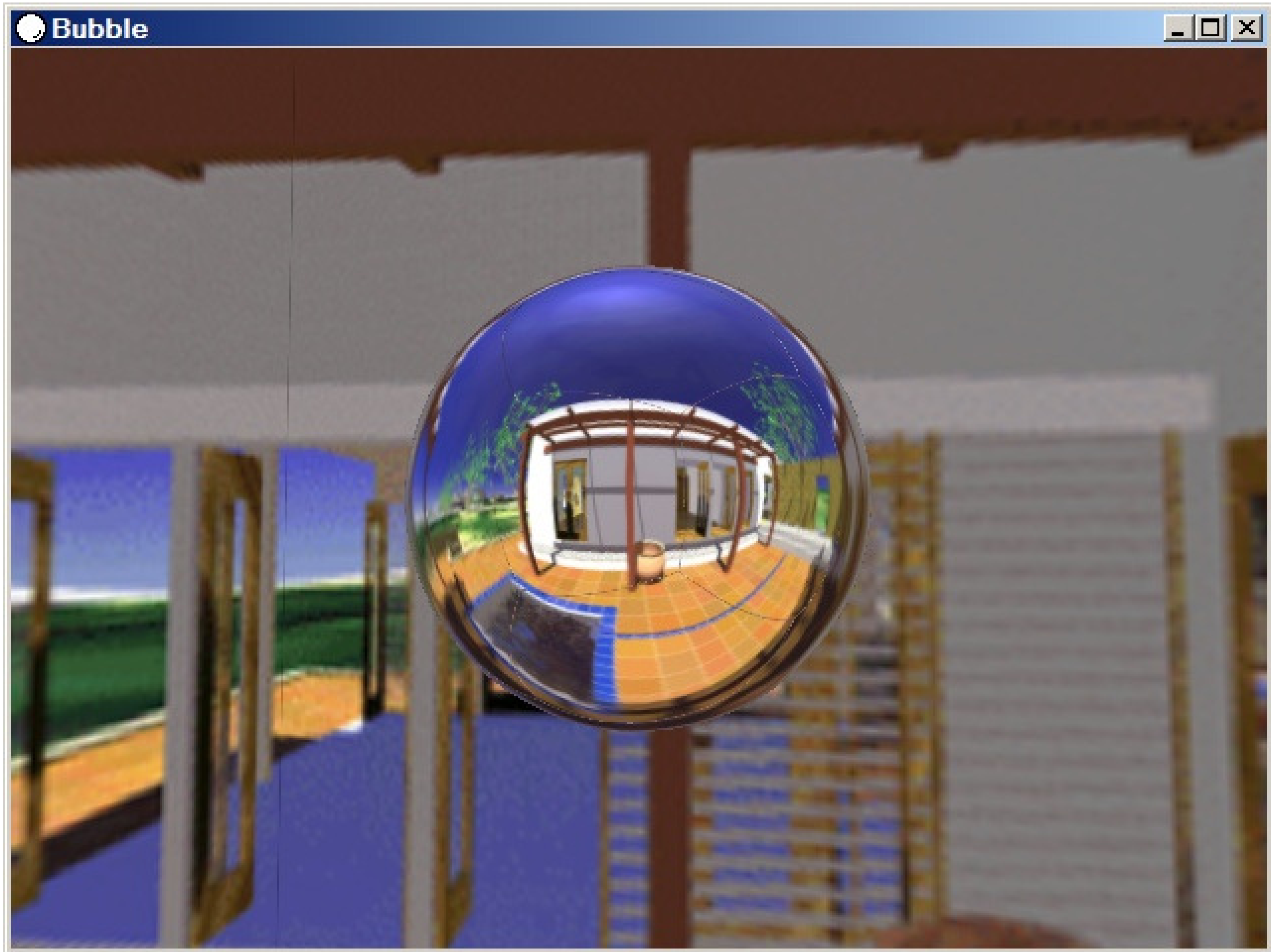


Cube map

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

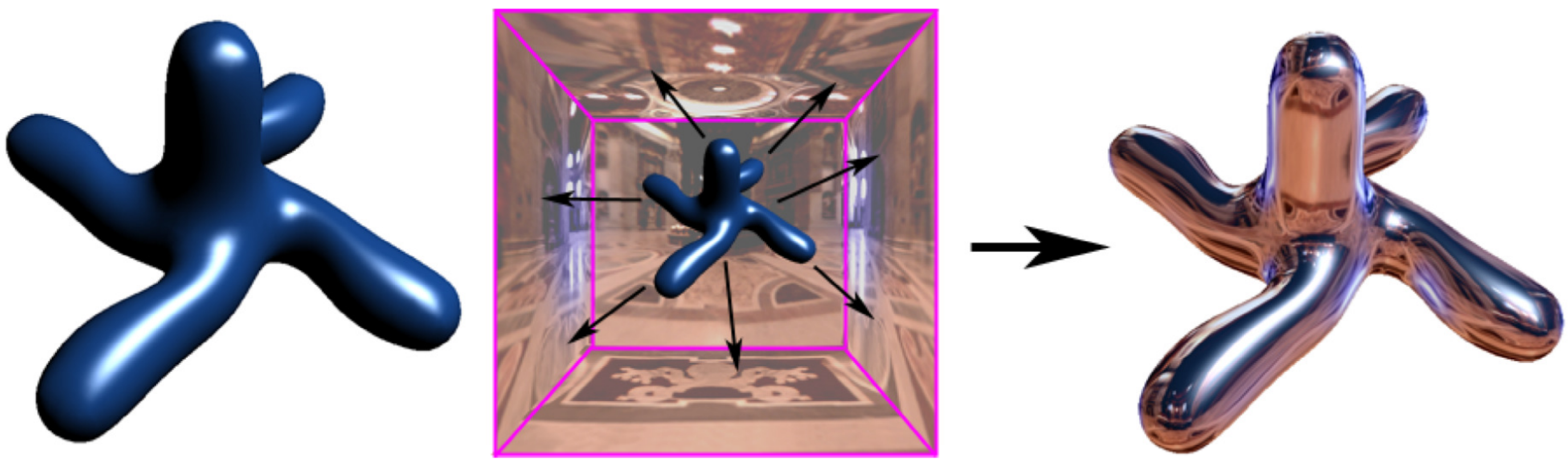
Cubic Environment Maps

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

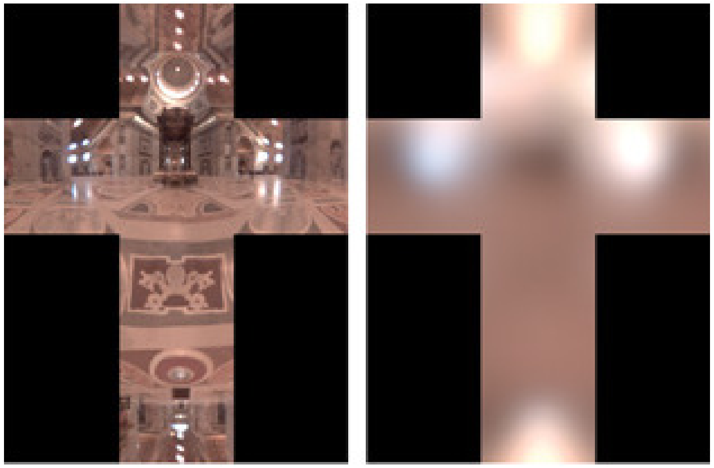
→ How do you compute shading of a diffuse surface?

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

Source: http://http.developer.nvidia.com/GPUGems2/gpugems2_chapter10.html

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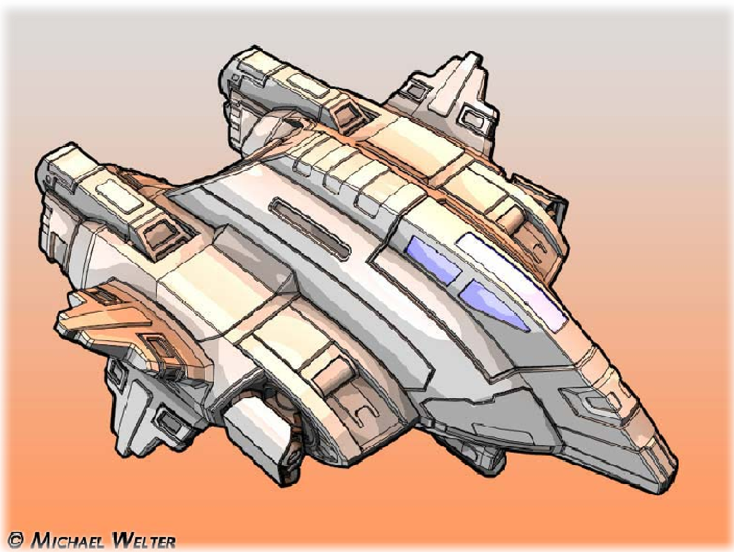
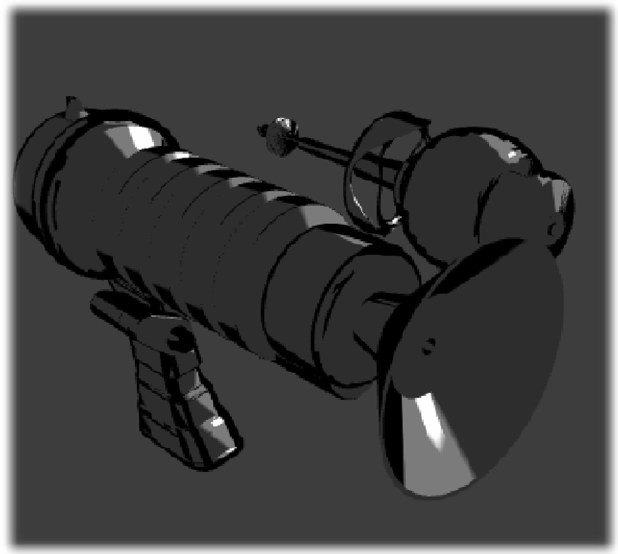
Toon Shading

- A.k.a. Cel Shading
- Simple cartoon-style shader
- Emphasizes silhouettes
- Discrete steps for diffuse shading, highlights
- Non-photorealistic rendering method (NPR)



Off-line toon shader



GLSL toon shader

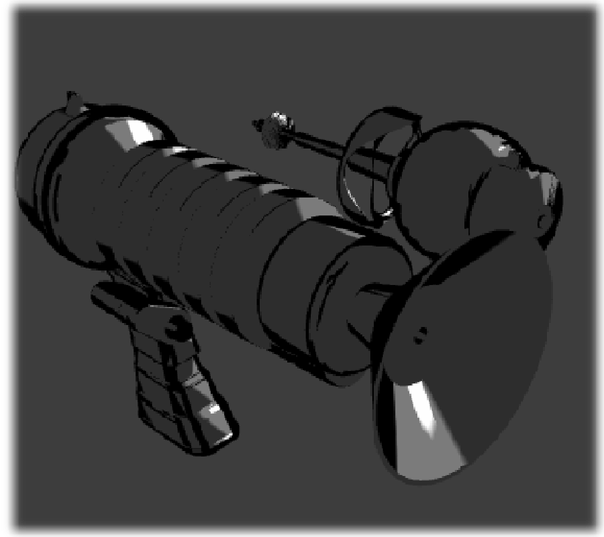
Toon Shading Demo

http://www.bonzaisoftware.com/npr.html

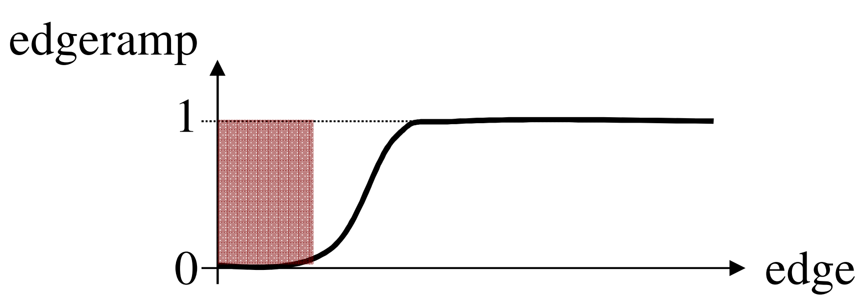
Toon Shading

- Silhouette edge detection
  - Compute dot product of viewing direction $\mathbf{v}$ and normal $\mathbf{n}$

$$\text{edge} = \max(0, \mathbf{n} \cdot \mathbf{v})$$



  - Use 1D texture to define edge ramp
    uniform sample1D edgeramp; e=texture1D(edgeramp,edge);



Toon Shading

- Compute diffuse and specular shading

$$\text{diffuse} = \mathbf{n} \cdot \mathbf{L} \qquad \text{specular} = (\mathbf{n} \cdot \mathbf{h})^s$$

- Use 1D textures diffuseramp, specularramp to map diffuse and specular shading to colors
- Final color:

```
uniform sampler1D diffuseramp;
uniform sampler1D specularramp;
c = e * (texture1D(diffuse,diffuseramp) +

texture1D(specular,specularramp));
```

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Screen Space Ambient Occlusion

- Screen Space Ambient Occlusion = SSAO
- Rendering technique for approximating ambient occlusion in real time
- Developed by Vladimir Kajalin while working at Crytek
- First use in 2007 PC game Crysis

SSAO component

SSAO Demo

- Video

SSAO Algorithm

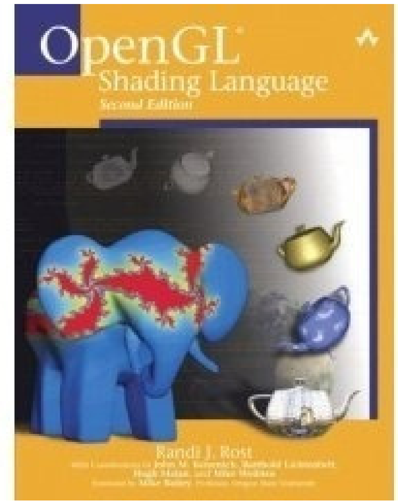
- Copy frame buffer to texture
- Pixel shader samples depth values around current pixel and tries to compute amount of occlusion
- Occlusion depends on depth difference between sampled point and current point
- SSAO shader code from Crysis available on-line

SSAO Discussion

- Advantages:
  - Independent from scene complexity.
  - No pre-processing, no memory allocation in RAM
  - Works with dynamic scenes
  - Works in the same way for every pixel
  - No CPU usage: executed completely on GPU
- Disadvantages:
  - Local and view-dependent (dependent on adjacent texel depths)
  - Hard to correctly smooth/blur out noise without interfering with depth discontinuities, such as object edges

More on Shaders

- OpenGL shading language book
  - "Orange Book"



- Shader Libraries
  - GLSL:
    - http://www.geeks3d.com/geexlab/shader_library.php
  - HLSL:
    - NVidia shader library
    - http://developer.download.nvidia.com/shaderlibrary/webpages/shader_library.html

Next Lecture

- Shadow mapping