CSE 167:
Introduction to Computer Graphics
Lecture #13: Environment Mapping

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Announcements

- Homework assignment #6 due Friday, Nov 12
- No class this Thursday (Veterans Day)
- This Thursday’s lab office hours moved to:
  - Haili: Wed 5-6pm
  - Han: Fri 9:30-11:30am
  - Phi: Fri 1-2pm
- CAPE: on-line, email notification at beginning of week 9
  - [http://www.cape.ucsd.edu](http://www.cape.ucsd.edu)
Final Project

- Problem description will go on-line this Thursday
- Must be done in teams of two or three
- Application design description (min. 300 words) due Friday, November 19. Email to the instructor at: jschulze@ucsd.edu
- Project due to be presented on Friday, Dec 3rd, between 3 and 5pm, venue TBD
- No late submissions accepted!
StarCAVE Tour

- Location: Atkinson Hall, 1st floor
- 18 Dell XPS PCs with Quad Core Intel CPUs
- CentOS 5.3 Linux
- Dual Nvidia Quadro 5600 graphics cards per node
- 34 JVC HD2k projectors (1920x1080 pixels): ~34 megapixels per eye
- Passive stereo with circular polarization filters
- 15 screens, ~8 x 4 feet each
- Floor projection
- Optical, wireless tracking system
- Software: COVISE
- Programming Language: C++

Tour Date:
- Friday, Nov 19, 4:00-5:00pm

Location:
Immersive Visualization Laboratory
1st floor Atkinson Hall
Turn right at main entrance
Rational Curves

- Weight causes point to “pull” more (or less)
- Can model circles with proper points and weights,
- Below: rational quadratic Bézier curve with three control points
Lecture Overview

- Advanced surface modeling

Advanced Shader Effects

- Environment mapping
- Toon shading
Advanced Surface Modeling

- B-spline/NURBS patches
- For the same reason as using B-spline/NURBS curves
  - More flexible (can model spheres)
  - Better mathematical properties, 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
  - no bottom
  - 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
[Sloan et al.]

Reflection mapping
Cubic Environment Maps

- Store incident light on six faces of a cube instead of on sphere.
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 \texttt{_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 in GLSL

Application Setup

- Load and bind a cube environment map
  ```glsl
  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 Irradiance Environment Map

- Given a scene with $k$ directional lights, light directions $d_1 \ldots d_k$ and intensities $i_1 \ldots i_k$, 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

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Advanced Shader Effects

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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
  \[
  \text{diffuse} = \mathbf{n} \cdot \mathbf{L} \quad \text{specular} = (\mathbf{n} \cdot \mathbf{h})^s
  \]

- Use 1D textures diffuseramp, speculararramp to map diffuse and specular shading to colors

- Final color:
  
  ```
  uniform sampler1D diffuseramp;
  uniform sampler1D speculararramp;
  c = \mathbf{e} \cdot (\text{texture1D(diffuse,diffuseramp)} + 
  \text{texture1D(specular,speculararramp)});
  ```
More on Shaders

- OpenGL shading language book

- NVidia shader library
  - Most shaders are in HLSL (DirectX’s shader language)

- NVidia Cg toolkit
  - Current version: Cg 2.1
  - Predecessor of GLSL
  - Lots of example shaders
Next Lecture (Tuesday November 16th)

- Shadow mapping
- Shadow volumes