Real-Time High Quality Rendering
CSE 274 [Fall 2015], Lecture 3
Shadow and Environment Mapping
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To Do
- By next Thu, e-mail me brief project description (can be done in groups of 2). Time to discuss next week
- A good idea is to choose to present papers relating to your intended project and vice-versa.
- This lecture discusses shadow and environment mapping
- Remember: Oct 6,8,13 student presentations of papers

Shadow and Environment Maps
- Basic methods to add realism to interactive rendering
- Shadow maps: image-based way hard shadows
  - Very old technique. Originally Williams 78
  - Many recent (and older) extensions
  - Widely used even in software rendering (RenderMan)
  - Simple alternative to raytracing for shadows
- Environment maps: image-based complex lighting
  - Again, very old technique. Blinn and Newell 76
  - Huge amount of recent work (some covered in course)
- Together, give most of realistic effects we want
  - But cannot be easily combined!! Some of the course is about ways to get around this limitation
  - See Annen 08 [real-time all-frequency shadows dynamic scenes] for one approach: convolution soft shadows

Common Real-time Shadow Techniques
- Shadow Mapping
  - Lance Williams: Brute Force in image space (shadow maps in 1978, but other similar ideas like Z buffer, bump mapping using textures and so on)
  - Completely image-space algorithm
    - no knowledge of scene’s geometry is required
    - must deal with aliasing artifacts
  - Well known software rendering technique
    - Basic shadowing technique for Toy Story, etc.

Problems
- Mostly tricks with lots of limitations
  - Projected planar shadows
    - works well only on flat surfaces
  - Stencilled shadow volumes
t  - determining the shadow volume is hard work
  - Light maps
    - totally unsuited for dynamic shadows
  - In general, hard to get everything shadowing everything

This slide, others courtesy Mark Kilgard
Phase 1: Render from Light
- Depth image from light source

Phase 1: Render from Light
- Depth image from light source

Phase 2: Render from Eye
- Standard image (with depth) from eye

Eye

Phase 2+: Project to light for shadows
- Project visible points in eye view back to light source

Eye

(Reprojected) depths match for light and eye. VISIBLE

Phase 2+: Project to light for shadows
- Project visible points in eye view back to light source

Eye

(Reprojected) depths from light, eye not the same. BLOCKED!

Visualizing Shadow Mapping
- A fairly complex scene with shadows

the point light source
Visualizing Shadow Mapping

- Compare with and without shadows
  - with shadows
  - without shadows

Visualizing Shadow Mapping

- The scene from the light’ s point-of-view
  - FYI: from the eye’ s point-of-view again

Visualizing Shadow Mapping

- The depth buffer from the light’ s point-of-view
  - FYI: from the light’ s point-of-view again

Visualizing Shadow Mapping

- Projecting the depth map onto the eye’s view
  - FYI: depth map for light’s point-of-view again

Visualizing Shadow Mapping

- Comparing light distance to light depth map
  - Green is where the light planar distance and the light depth map are approximately equal
  - Non-green is where shadows should be

Visualizing Shadow Mapping

- Scene with shadows
  - Notice how specular highlights never appear in shadows
  - Notice how curved surfaces cast shadows on each other
Hardware Shadow Map Filtering

“Percentage Closer” filtering
- Normal texture filtering just averages color components
- Averaging depth values does NOT work
- Solution [Reeves, SIGGRAPH 87]
  - Hardware performs comparison for each sample
  - Then, averages results of comparisons
- Provides anti-aliasing at shadow map edges
  - Not soft shadows in the umbra/penumbra sense

GL_NEAREST: blocky  GL_LINEAR: antialiased edges

Problems with shadow maps

- Hard shadows (point lights only)
- Quality depends on shadow map resolution
  (general problem with image-based techniques)
- Involves equality comparison of floating point depth values means issues of scale, bias, tolerance
- Some of these addressed in papers presented

Reflection Maps

Blinn and Newell, 1976

Environment Maps

Miller and Hoffmann, 1984

Interface, Chou and Williams (ca. 1985)
Environment Maps

Reflectance Maps

- Reflectance Maps (Index by N)
- Horn, 1977
- Irradiance (N) and Phong (R) Reflection Maps
- Miller and Hoffman, 1984

Cubical Environment Map

180 degree fisheye

Photo by R. Packo

Cylindrical Panoramas

Mirr or Sphere
Chrome Sphere
Matte Sphere

Irradiance Environment Maps

- Assumptions
  - Diffuse surfaces
  - Distant illumination
  - No shadowing, interreflection

Hence, Irradiance a function of surface normal

Diffuse Reflection

Analytic Irradiance Formula

Lambertian surface acts like low-pass filter

\[ E_{lm} = A_l L_{lm} \]

Ramamoorthi and Hanrahan 01
Basel and Jacobs 01
### 9 Parameter Approximation

**Exact image**

**Order 0**

1 term

RMS error = 25%

**Order 1**

4 terms

RMS Error = 8%

**Order 2**

9 terms

RMS Error = 1%

For any illumination, average error < 3% [Basri Jacobs 01]

### Real-Time Rendering

\[ E(n) = n^t M n \]

Simple procedural rendering method (no textures)
- Requires only matrix-vector multiply and dot-product
- In software or NVIDIA vertex programming hardware

Widely used in Games (AMPE for Microsoft Xbox), Movies (Pixar, Framestore CFC, ...)

\[
\text{surface float1 irradmat(matrix4 M, float3 v) \{}
\text{  float4 n = \{v, 1\};}
\text{  return dot(n, M*n);}
\text{\}}
\]

### Environment Map Summary

- Very popular for interactive rendering
- Extensions handle complex materials
- Shadows with precomputed transfer
- But cannot directly combine with shadow maps
- Limited to distant lighting assumption

### Resources

- OpenGL red book (latest includes GLSL)
- Web tutorials: [http://www.lighthouse3d.com/tutorials](http://www.lighthouse3d.com/tutorials)
- Older books: OpenGL Shading Language book (Rost), The Cg Tutorial, ...
- Real-Time Rendering by Moller and Haines
  - [http://www.realtimerendering.com](http://www.realtimerendering.com)
- Links to Miller and Hoffman original, Haeberli/Segal
  - [http://www.cs.ucsd.edu/~ravir/papers/envmap](http://www.cs.ucsd.edu/~ravir/papers/envmap)
- Also papers by Heidrich, Cabral, ...
- Lots of information available on web...