Real-Time High Quality Rendering

CSE 274 [Fall 2015], Lecture 3

Shadow and Environment Mapping

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To Do

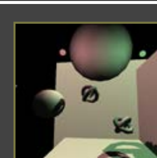
- By next Thu, e-mail me brief project description (can be done in groups of 2). Time to discuss next week
- A good idea is to choose to present papers relating to your intended project and vice-versa.
- This lecture discusses shadow and environment mapping
- Remember: Oct 6,8,13 student presentations of papers

Shadow and Environment Maps

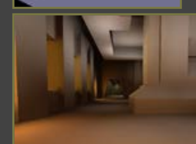
- Basic methods to add realism to interactive rendering
- Shadow maps: image-based way hard shadows
  - Very old technique. Originally Williams 78
  - Many recent (and older) extensions
  - Widely used even in software rendering (RenderMan)
  - Simple alternative to raytracing for shadows
- Environment 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

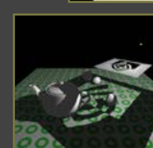
Projected planar shadows



Shadow volumes



Light maps



Hybrid approaches

This slide, others courtesy Mark Kilgard

Problems

Mostly tricks with lots of limitations

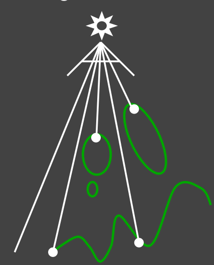
- Projected planar shadows
  works well only on flat surfaces
- Stenciled shadow volumes
  determining the shadow volume is hard work
- Light maps
  totally unsuited for dynamic shadows
- In general, hard to get everything shadowing everything

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.

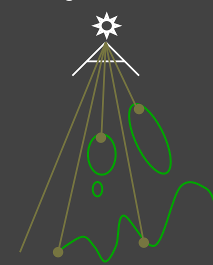
Phase 1: Render from Light

- Depth image from light source



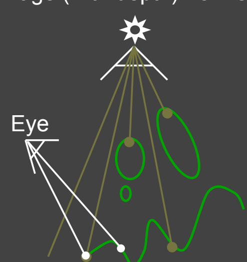
Phase 1: Render from Light

- Depth image from light source



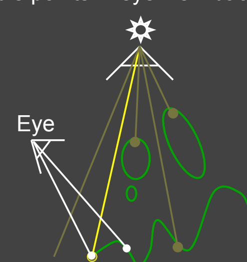
Phase 2: Render from Eye

- Standard image (with depth) from eye



Phase 2+: Project to light for shadows

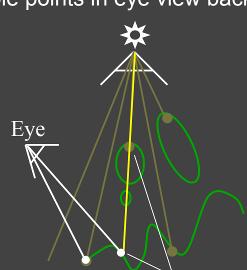
- Project visible points in eye view back to light source



(Reprojected) depths match for light and eye. VISIBLE

Phase 2+: Project to light for shadows

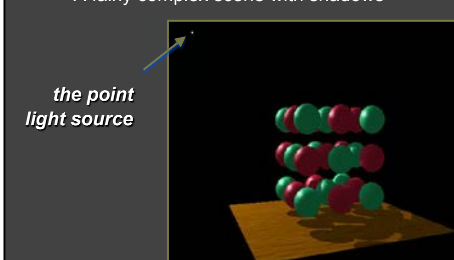
- Project visible points in eye view back to light source



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

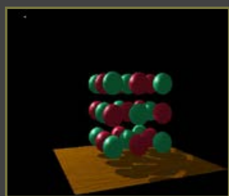
Visualizing Shadow Mapping

- A fairly complex scene with shadows

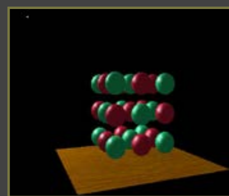


Visualizing Shadow Mapping

- Compare with and without shadows



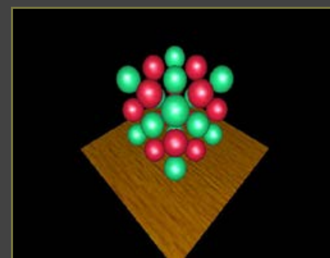
with shadows



without shadows

Visualizing Shadow Mapping

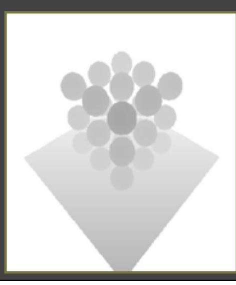
- The scene from the light's point-of-view



FYI: from the eye's point-of-view again

Visualizing Shadow Mapping

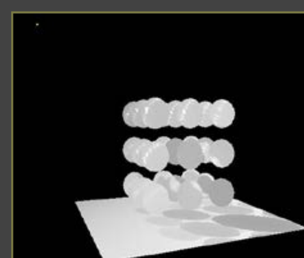
- The depth buffer from the light's point-of-view

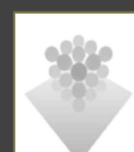


FYI: from the light's point-of-view again

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

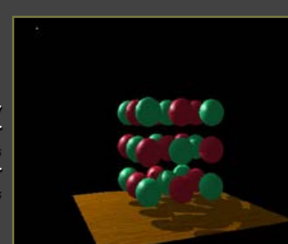
Green is where the light planar distance and the light depth map are approximately equal

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

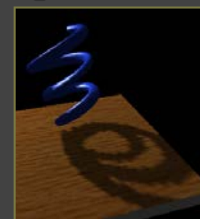
"Percentage Closer" filtering

- Normal texture filtering just averages color components
- Averaging depth values does NOT work
- Solution [Reeves, SIGGARPH 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

Hardware Shadow Map Filtering

GL_NEAREST: blocky

GL_LINEAR: antialiased edges



Low shadow map resolution used to heighten filtering artifacts

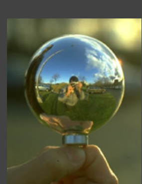
Problems with shadow maps

- 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 Hoffman, 1984

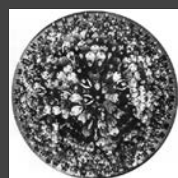
Environment Maps

Interface, Chou and Williams (ca. 1985)

Environment Maps

Cylindrical Panoramas

Cubical Environment Map

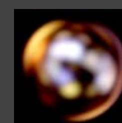


180 degree fisheye
Photo by R. Packo

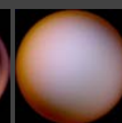
Reflectance Maps

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

Mirror Sphere

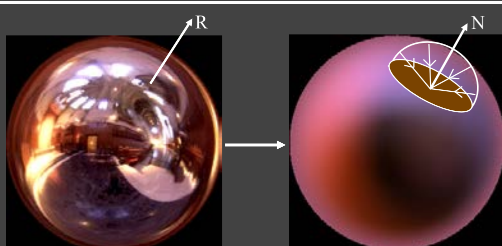


Chrome Sphere



Matte Sphere

Irradiance Environment Maps



Incident Radiance
(Illumination Environment Map)

Irradiance Environment Map

Assumptions

- Diffuse surfaces
- Distant illumination
- No shadowing, interreflection

Hence, Irradiance a function of surface normal

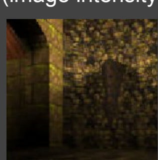
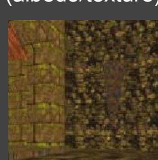
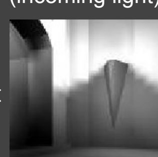
Diffuse Reflection

$$B = \rho E$$

Radiosity
(image intensity)

Reflectance
(albedo/texture)

Irradiance
(incoming light)

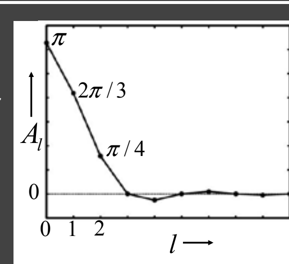
 =  × 

quake light map

Analytic Irradiance Formula

Lambertian surface
acts like low-pass filter

$$E_{lm} = A_l L_{lm}$$



Ramamoorthi and Hanrahan 01
Basri and Jacobs 01

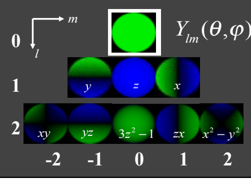
$$A_l = 2\pi \frac{(-1)^{\frac{l}{2}-1}}{(l+2)(l-1)} \left[\frac{l!}{2^l \left(\frac{l}{2}!\right)^2} \right] \quad l \text{ even}$$

9 Parameter Approximation

Exact image

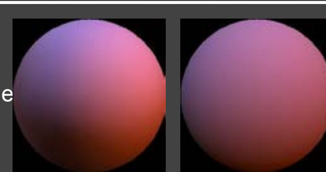
Order 0
1 term

RMS error = 25 %



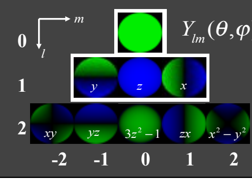
9 Parameter Approximation

Exact image



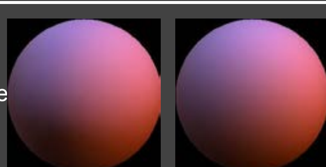
Order 1
4 terms

RMS Error = 8%



9 Parameter Approximation

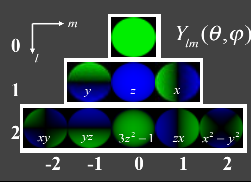
Exact image



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 (AMPED for Microsoft Xbox), Movies (Pixar, Framestore CFC, …)

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

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
- Older books: OpenGL Shading Language book (Rost), The Cg Tutorial, …
- Real-Time Rendering by Moller and Haines
  - http://www.realtimerendering.com
- Debevec http://www.debevec.org/ReflectionMapping/
  - Links to Miller and Hoffman original, Haeberli/Segal
- http://www.cs.ucsd.edu/~ravir/papers/envmap
  - Also papers by Heidrich, Cabral, …
- Lots of information available on web…