Real-Time High Quality Rendering

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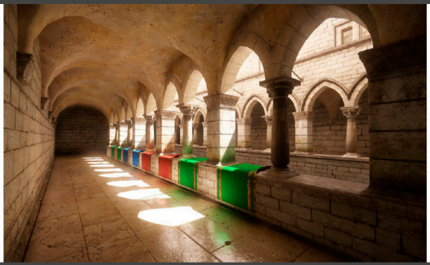
Lecture 7: Real-Time Global Illumination (in 3D)

Announcements

- GAMES101 homework submission reopening soon!
  - Recruiting graders!
- Homework 2 will be released soon
  - Ideally by the end of this week
  - Will be about PRT for diffuse scenes

Last Lecture

- Shadow from environment lighting
- Background knowledge
  - Frequency and filtering
  - Basis functions
- Real-time environment lighting (& global illumination)
  - Spherical Harmonics (SH)
  - Prefiltered env. lighting
  - Precomputed Radiance Transfer (PRT)

Today

- Finishing up
  - SH for glossy transport
  - Wavelet 小波
- Real-Time Global Illumination (in 3D)
  - Reflective Shadow Maps (RSM)
  - Light Propagation Volumes (LPV)
  - Voxel Global Illumination (VXGI)

Recap: PRT

- Precompute lighting and light transport
  for each individual shading point*

对每个 vertex.

$$L_o(\mathrm{p}, \omega_o) = \int_{\Omega^+} \boxed{L_i(\mathrm{p}, \omega_i)} \boxed{f_r(\mathrm{p}, \omega_i, \omega_o)\ \cos\theta_i\, V(\mathrm{p}, \omega_i)} \mathrm{d}\omega_i$$

Shading result

Lighting

Light transport

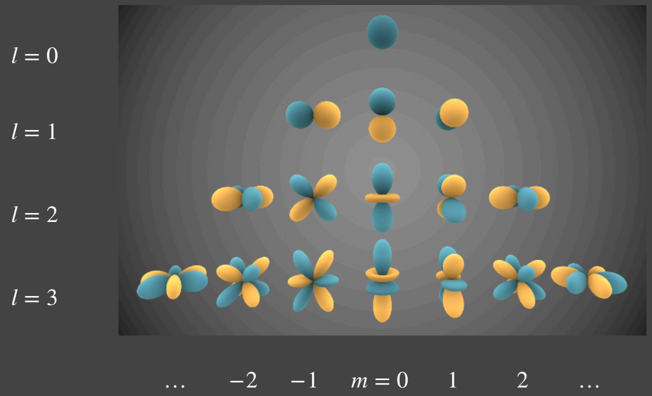
Recap: Spherical Harmonics (SH)

- A set of 2D basis functions with different frequencies

- Any 2D function can be projected to SH

$$f(x) = \sum_i c_i \cdot B_i(x)$$

- Any 2D function can be reconstructed from (a truncated number of) SH



PRT (Diffuse Case)

- A slightly different derivation than in the last lecture

- **Separately** precompute lighting and light transport

$$L_o(\mathrm{p},\omega_o) = \int_{\Omega^+} \boxed{L_i(\mathrm{p},\omega_i)}\,\boxed{f_r(\mathrm{p},\omega_i,\omega_o)\ \cos\theta_i\, V(\mathrm{p},\omega_i)}\,\mathrm{d}\omega_i$$

$$L(\omega_i) \approx \sum_p c_p B_p(\omega_i) \qquad\qquad T(\omega_i) \approx \sum_q c_q B_q(\omega_i)$$

lighting coefficient — basis function

light transport coefficient — basis function

PRT (Diffuse Case)

$$L_o(\mathrm{p}, \omega_o) = \int_{\Omega^+} \boxed{L_i(\mathrm{p}, \omega_i)} \boxed{f_r(\mathrm{p}, \omega_i, \omega_o) \cos\theta_i \, V(\mathrm{p}, \omega_i)} \, \mathrm{d}\omega_i$$

$$= \sum_p \sum_q c_p c_q \int_{\Omega^+} B_p(\omega_i) B_q(\omega_i) \, \mathrm{d}\omega_i$$

只有 p=q 时 积分值为1 否则为0.

$$\boxed{L(\omega_i) \approx \sum_p c_p B_p(\omega_i)}$$

$$\boxed{T(\omega_i) \approx \sum_q c_q B_q(\omega_i)}$$

- Why is it a dot product? (This seems to be $O(n^2)$ rather than $O(n)$?)
  - Hint: a property of SH 正交性.

光滑

Glossy Case

light transport 四维函数 { in 光照方向 / out 观察方向.

$$L(\mathbf{o}) = \int_{\Omega} L(\mathbf{i}) V(\mathbf{i}) \rho(\mathbf{i}, \mathbf{o}) \max(0, \boldsymbol{n} \cdot \mathbf{i}) d\mathbf{i}$$

$$L(\mathbf{o}) \approx \sum l_i T_i(\mathbf{o})$$

ω 是 out 的函数.

$$T_i(\mathbf{o}) \approx \sum t_{ij} B_j(\mathbf{o})$$

transport matrix

basis function

$$L(\mathbf{o}) \approx \sum_{j} \left(\sum_{i} l_i t_{ij} \right) B_j(\mathbf{o})$$

j 不同观察方向

reflected radiance coefficient

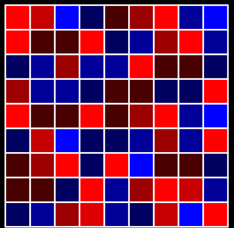
从不同方向看
得到的 radiance

≈

l_i

light coefficient

* i



transport matrix

- Rendering: vector-matrix multiplication

向量矩阵乘法.

Time Complexity

3→5阶

- #SH Basis : 9/**16**/25
- Diffuse Rendering
  - At each point: dot-product of size 16

点数16的向量点乘

- Glossy Rendering
  - At each point: vector(16) * matrix (16*16)

16向量 16×16矩阵

得到每个方向上的不同 radience

Glossy Rendering Results

No Shadows/Inter

Shadows

Shadows+Inter

两次 Bounce

- Glossy object, 50K mesh
- Runs at 3.6 fps on 2.2Ghz P4, ATI Radeon 8500

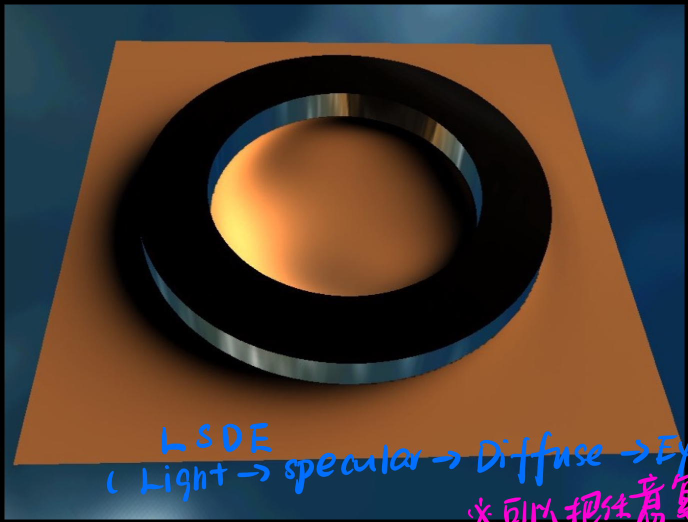
Interreflections and Caustics

interreflections

none

1 bounce

2 bounces



LSDE
(Light → specular → Diffuse → Eye)

※可以把任意复杂的 Light transport 预计算出来.

caustics

Transport Paths

Light → Eye

LE

Light → Glossy → Eye

LGE

L(D|G)*E

L → { Diffuse / Glossy } × 次 → Eye

LS*(D|G)*E

Runtime is independent of transport complexity

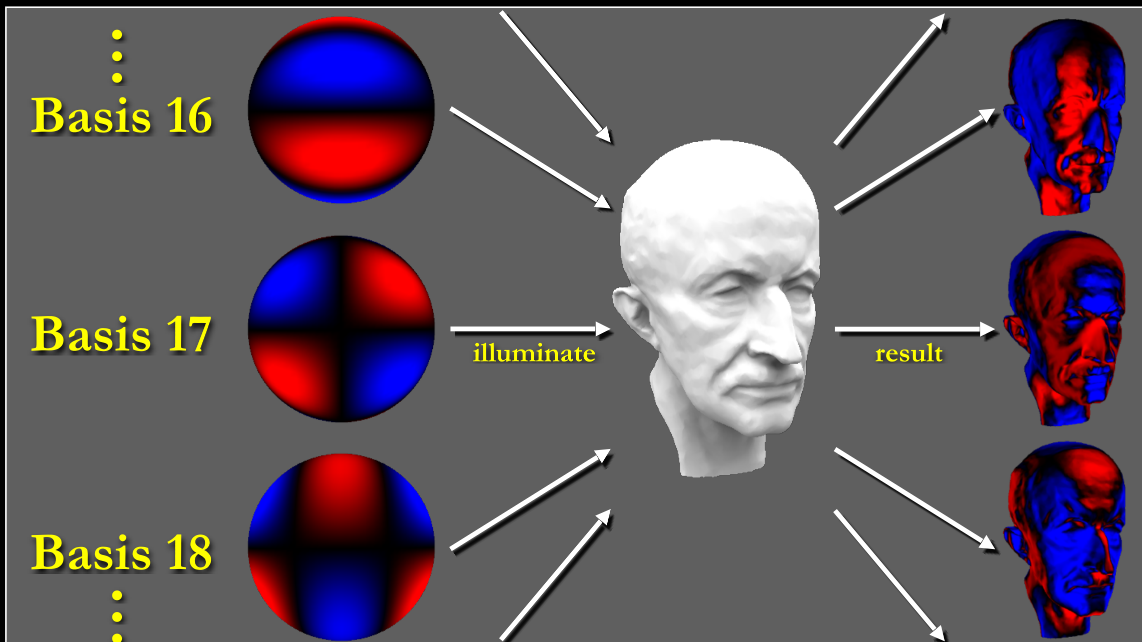
"运行时间独立于传输复杂性"

Recall: Precomp. of light transport

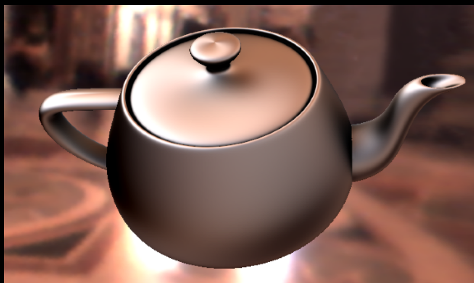
light transport $$T_i \approx \int_\Omega B_i(\mathbf{i})\,\underline{V(\mathbf{i})\max(0,\boldsymbol{n}\cdot\mathbf{i})}\,d\mathbf{i}$$

预计算就是一个渲染过程.

- Just regular computation with some weird lighting

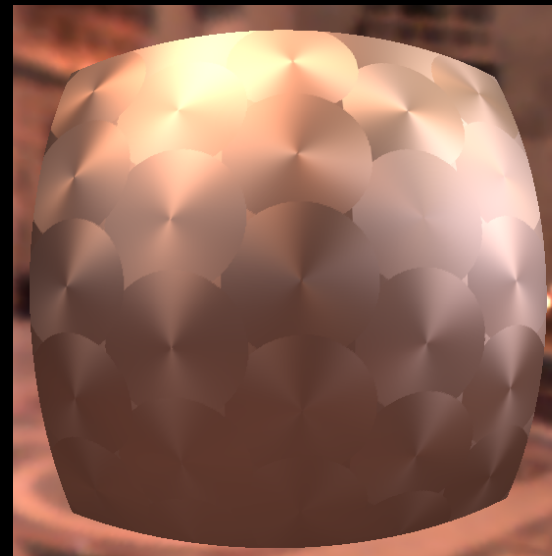


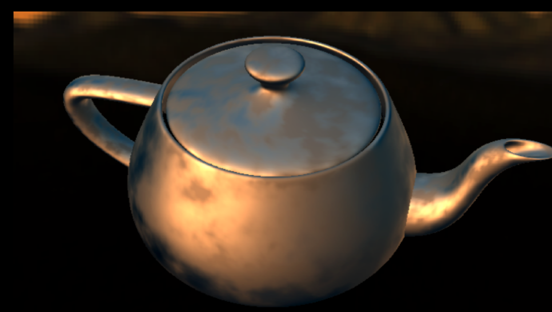
Arbitrary BRDF Results



Anisotropic BRDFs

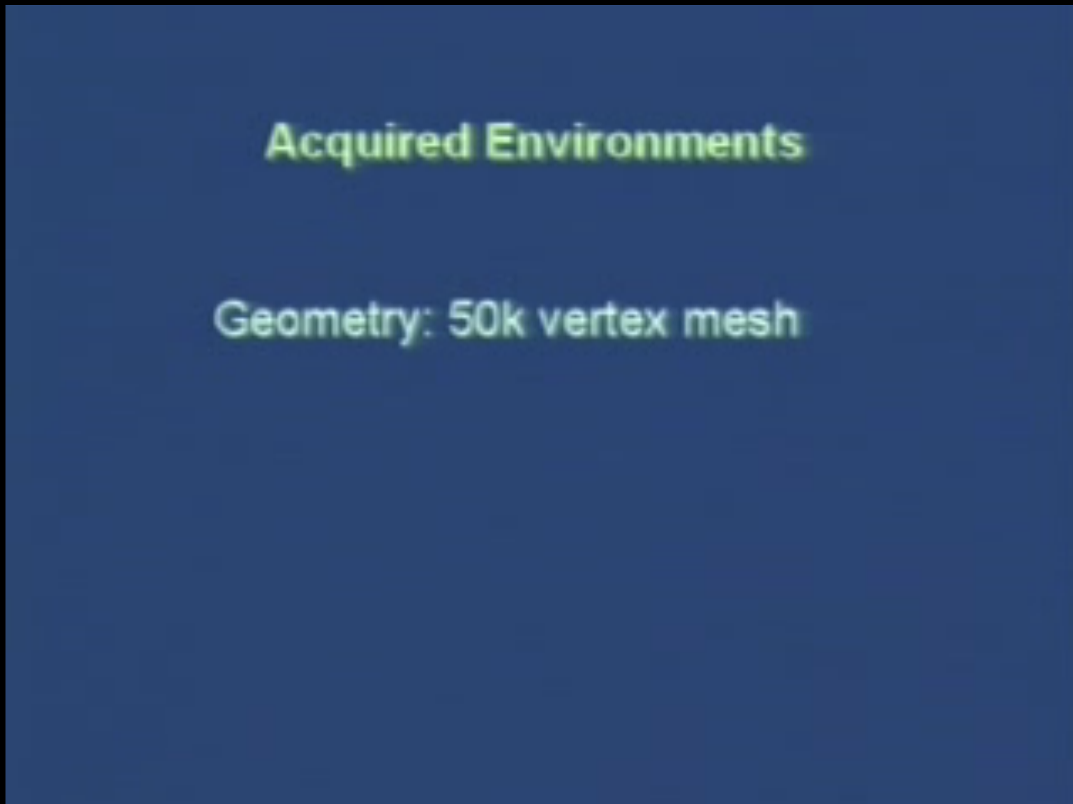
Other BRDFs





Spatially Varying

Results



Summary of [Sloan 02]

- Approximate Lighting and light transport using basis functions (SH)
  - Lighting -> lighting coefficients
  - light transport -> coefficients / matrices
- Precompute and store light transport
- Rendering reduced to:
  - Diffuse: dot product
  - Glossy: vector matrix multiplication

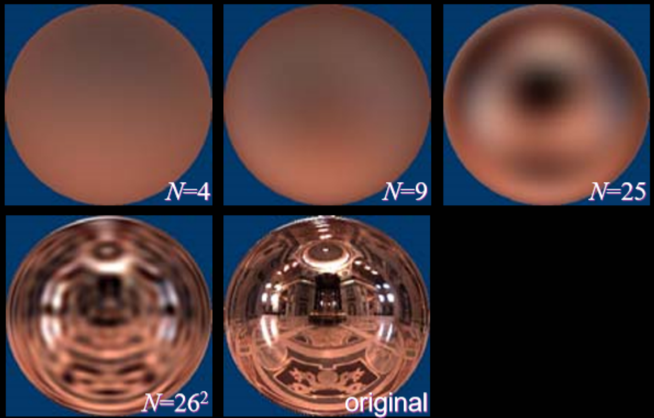
Limitations [Sloan 02]

- Low-frequency 更适合低频.
  - Due to the nature of SH

动态照明、但静态场景/材质.

- Dynamic lighting, but static scene/material
  - Changing scene/material invalidates precomputed light transport
- Big precomputation data

大量预计算.



Follow up works

- More basis functions
- dot product => triple products
- Static scene => dynamic scene
- Fix material => dynamic material
- Other effects: translucent, hair, …
  (半)透明
- Precomputation => analytic computation
  解析计算
  ※ the split sum
- …

More basis functions

- Spherical Harmonics (SH)
- Wavelet
- Zonal Harmonics
- Spherical Gaussian (SG)
- Piecewise Constant

Wavelet [Ng 03]

小波.

二维.

- 2D Haar wavelet

- Projection:
  - Wavelet Transformation
  - Retain a small number of non-zero coefficients

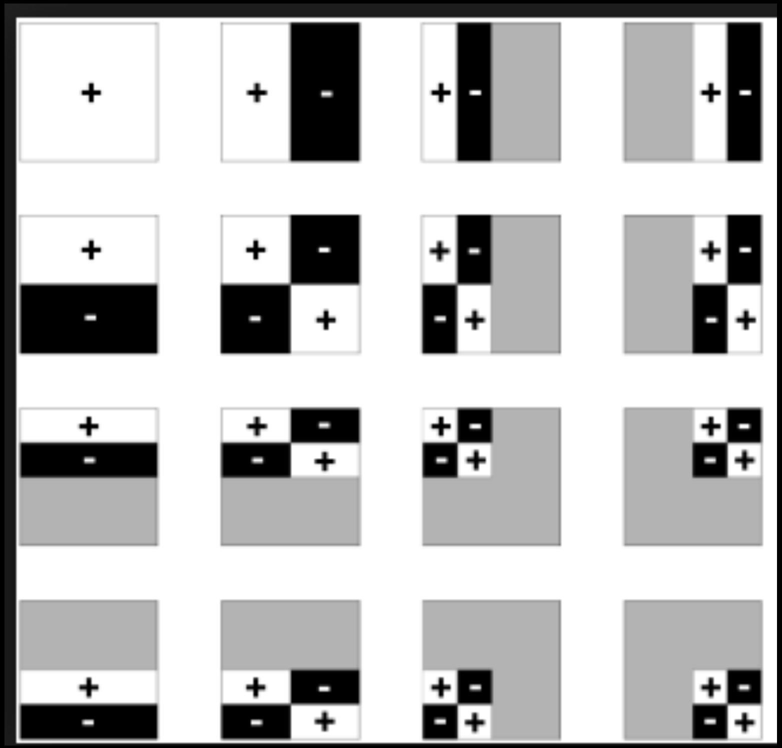
保留少量非0系数.

非线性近似

- A non-linear approximation

- All-frequency representation

全频率都适用.



我们用cube map.

Non-linear Wavelet Light Approximation

非线性小波光逼近

Wavelet Transform

小波变换

Cube Map.

Non-linear Wavelet Light Approximation

$$\begin{bmatrix} 0 \\ L_2 \\ 0 \\ 0 \\ 0 \\ L_6 \\ \boxed{?} \\ 0 \end{bmatrix}$$

Non-linear Approximation

非线性逼近

Retain 0.1% – 1% terms

low frequency vs all frequency

Teapot in Grace Cathedral

Low frequency (SH)

All frequency (Wavelet)

My First Paper

- Accurate Translucent Material Rendering under Spherical Gaussian Lights
- Pacific Graphics 2012

Questions?