Real-Time High Quality Rendering

GAMES202, Lingqi Yan, UC Santa Barbara

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
- 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*

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

Shading result: $L_o(\mathrm{p}, \omega_o)$

Lighting: $L_i(\mathrm{p}, \omega_i)$

Light transport: $f_r(\mathrm{p}, \omega_i, \omega_o) \cos\theta_i V(\mathrm{p}, \omega_i)$

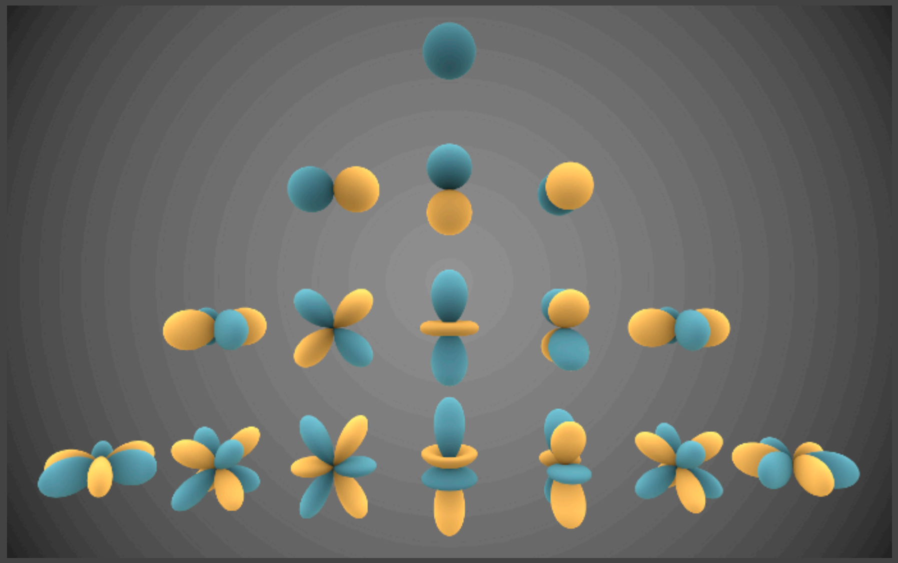
Recap: Spherical Harmonics (SH)

- 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



$l = 0$
$l = 1$
$l = 2$
$l = 3$

… -2 -1 $m = 0$ 1 2 …

PRT (Diffuse Case)

- A slightly different derivation than in the last lecture
- **Separately** precompute lighting and light transport

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

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

c_p: lighting coefficient; B_p: basis function

c_q: light transport coefficient; B_q: basis function

PRT (Diffuse Case)

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

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

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

$$L(\omega_i) \approx \sum_p c_p B_p(\omega_i)$$

$$T(\omega_i) \approx \sum_q c_q B_q(\omega_i)$$

Glossy Case

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

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

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

t_{ij}: transport matrix

$B_j(\mathbf{o})$: basis function

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

- Rendering: vector-matrix multiplication

Time Complexity

- #SH Basis : 9/**16**/25
- Diffuse Rendering
  - At each point: dot-product of size 16
- Glossy Rendering
  - At each point: vector(16) * matrix (16*16)

Glossy Rendering Results

No Shadows/Inter

Shadows

Shadows+Inter

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

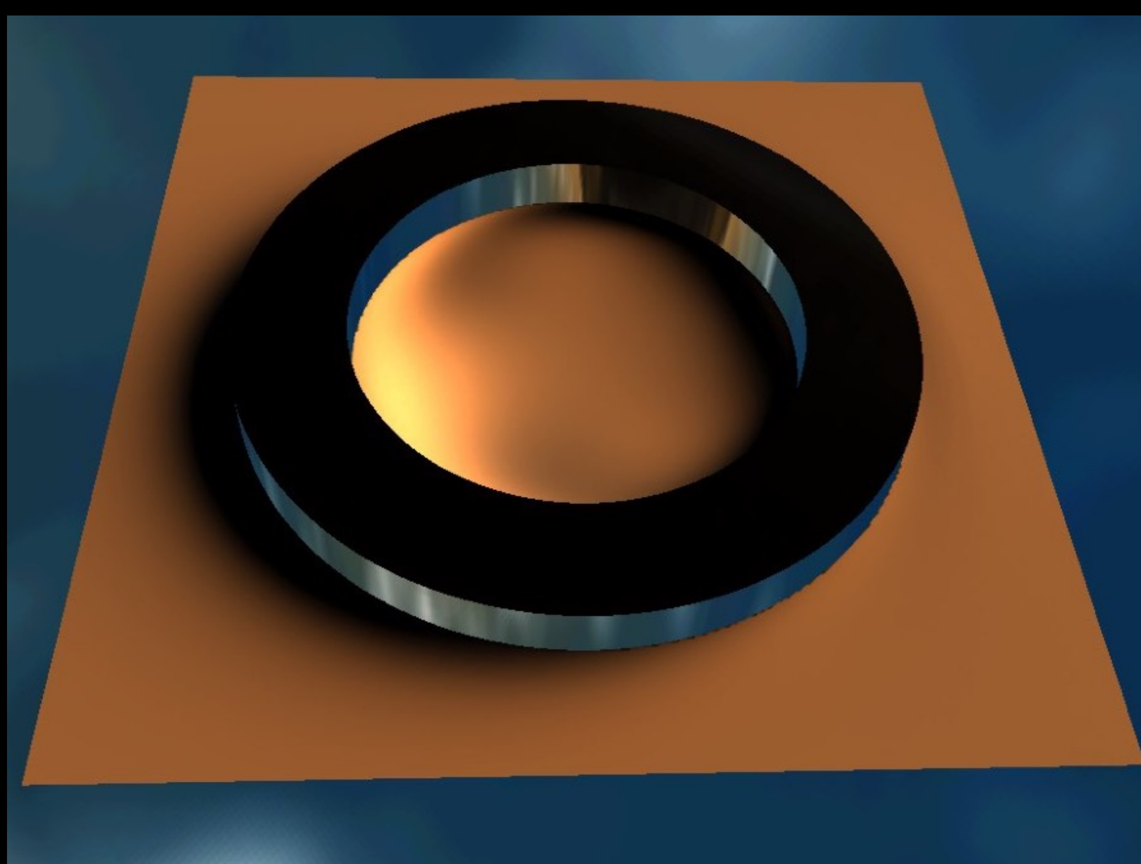
Interreflections and Caustics

interreflections

none

1 bounce

2 bounces



caustics

Transport Paths

LE

LGE

L(D|G)*E

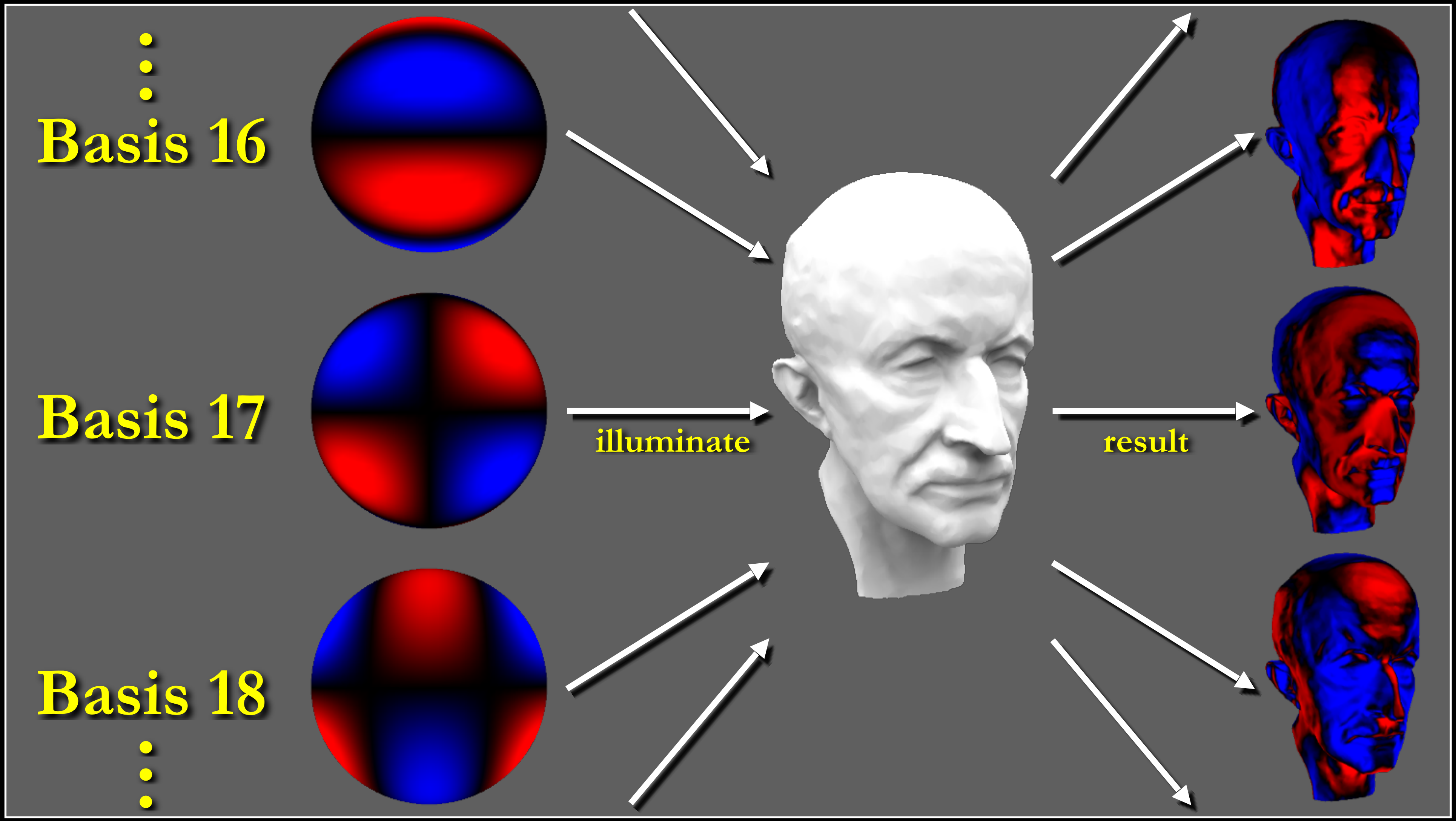
LS*(D|G)*E

Runtime is independent of transport complexity

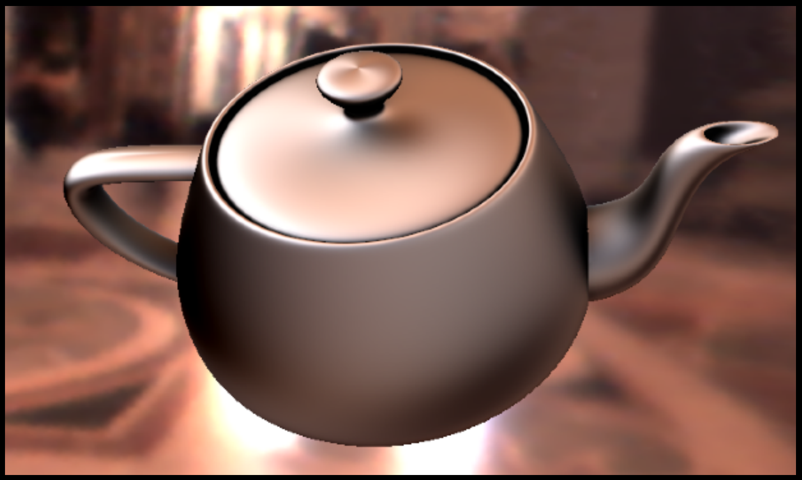
Recall: Precomp. of light transport

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

- Just regular computation with some weird lighting

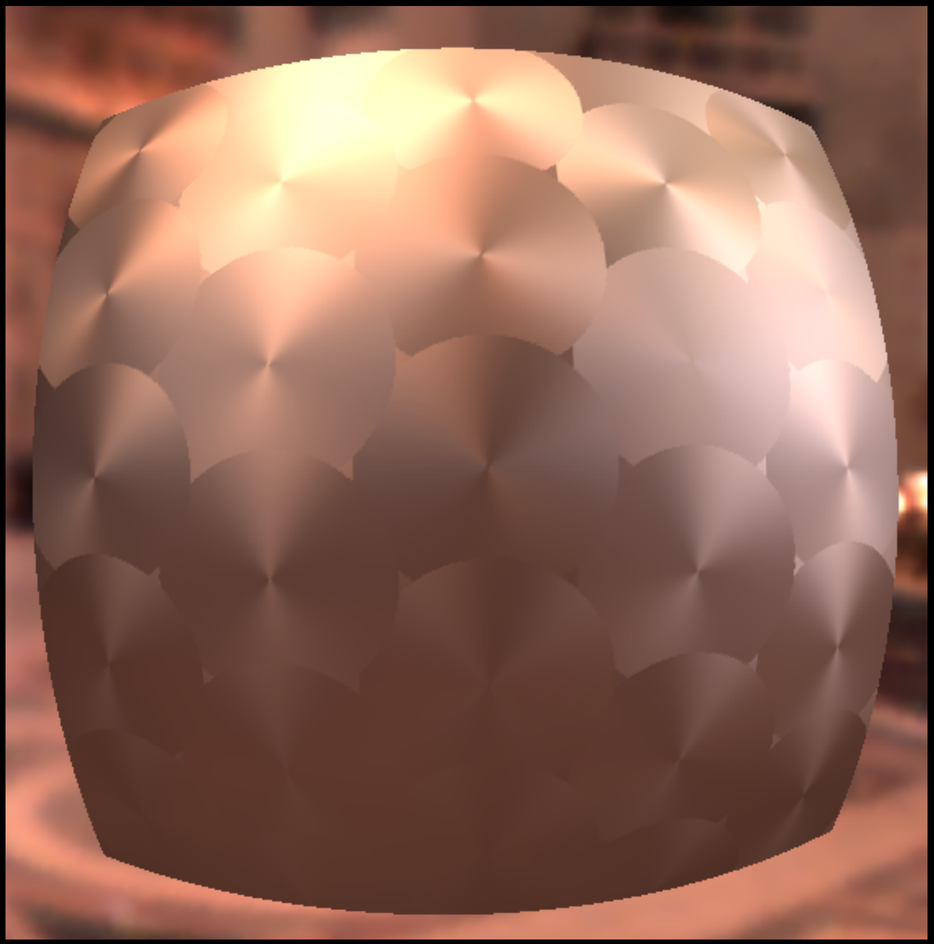


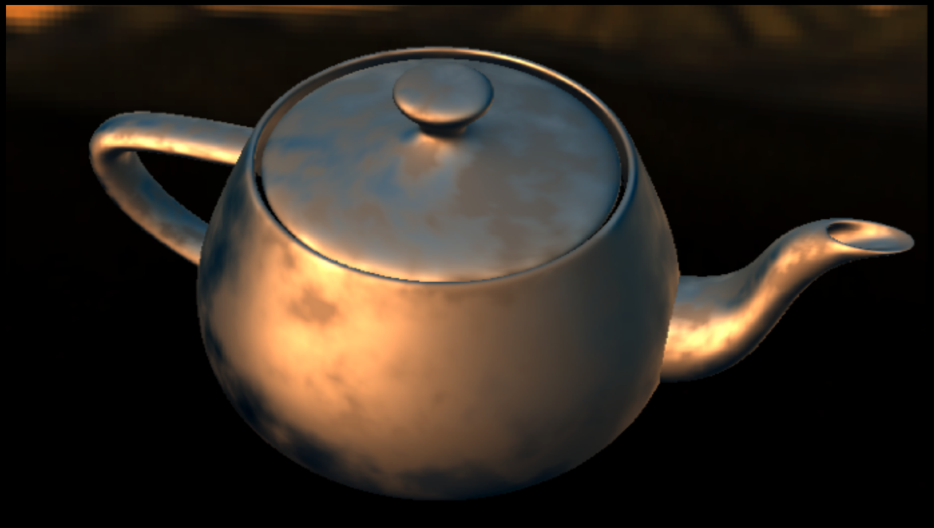
Arbitrary BRDF Results



Anisotropic BRDFs

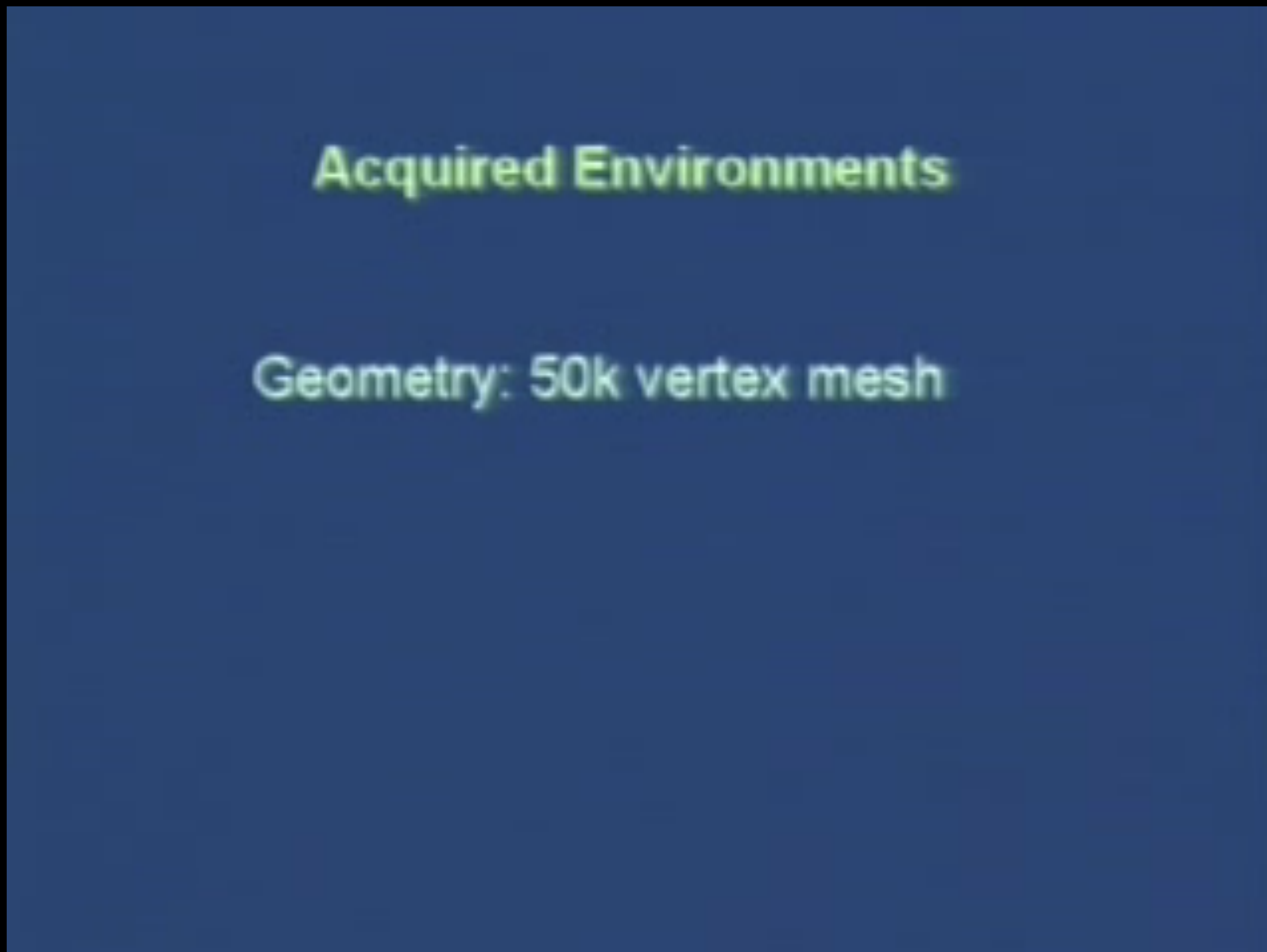
Other BRDFs





Spatially Varying

Results

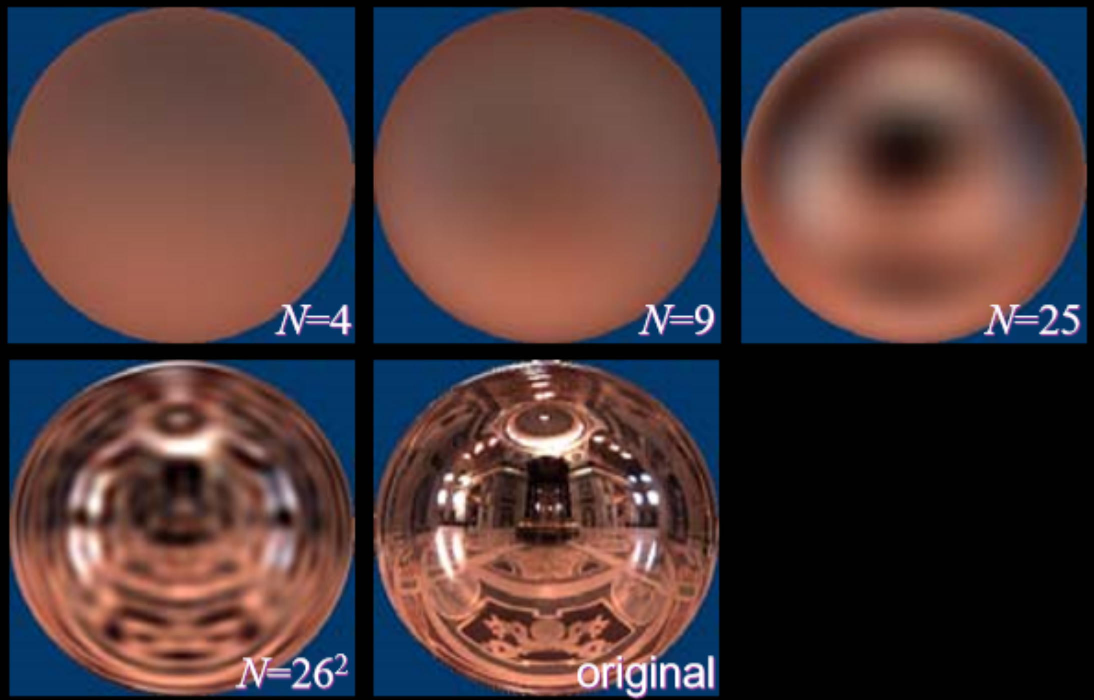


Summary of [Sloan 02]

- 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
  - Due to the nature of SH
- Dynamic lighting, but static scene/material
  - Changing scene/material invalidates precomputed light transport
- Big precomputation data



Follow up works

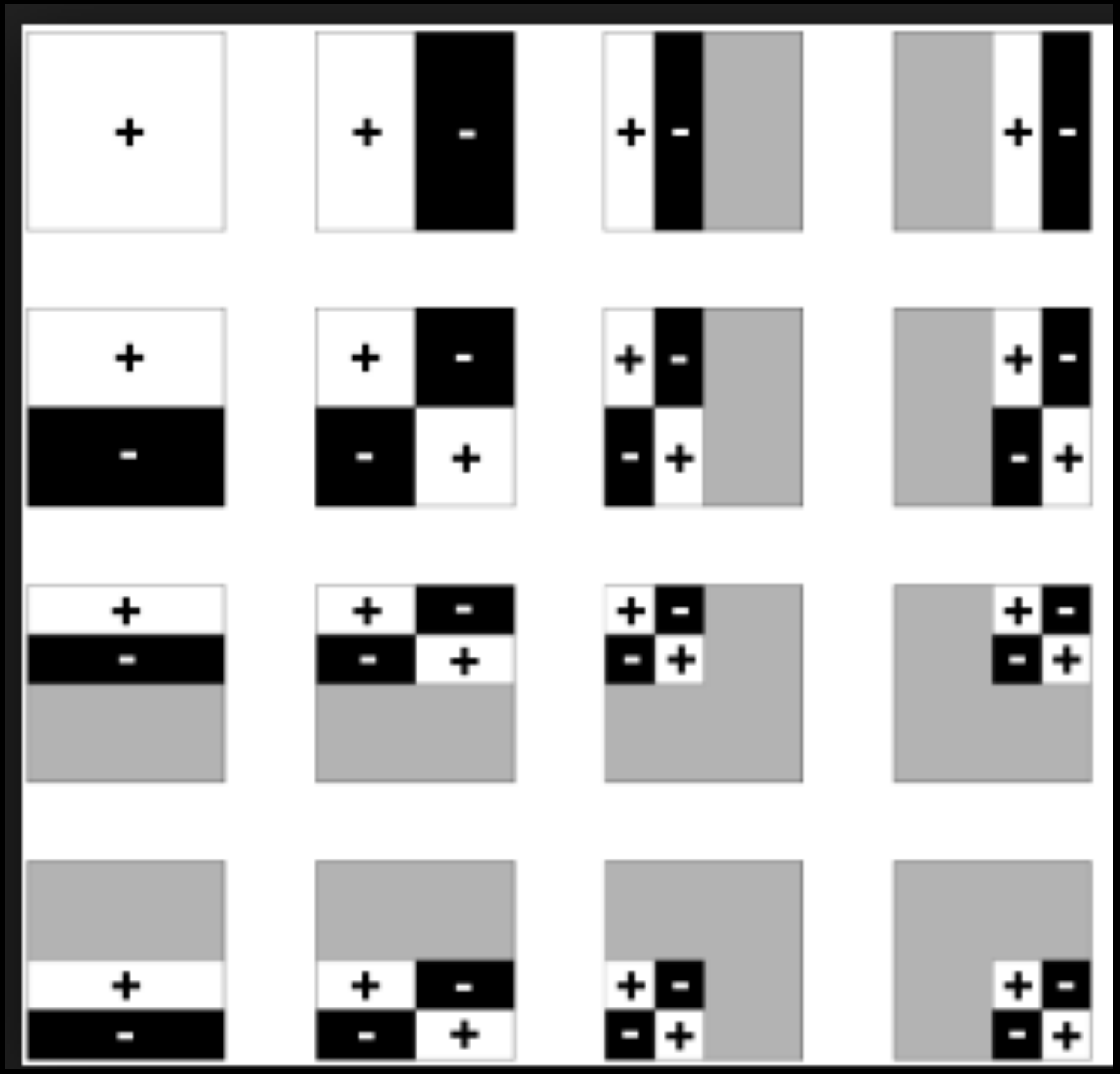
- More basis functions
- dot product => triple products
- Static scene => dynamic scene
- Fix material => dynamic material
- Other effects: translucent, hair, …
- Precomputation => analytic computation
- …

More basis functions

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

Wavelet [Ng 03]

- 2D Haar wavelet
- Projection:
  - Wavelet Transformation
  - Retain a small number of non-zero coefficients
- A non-linear approximation
- All-frequency representation



Non-linear Wavelet Light Approximation

Wavelet Transform

Non-linear Wavelet Light Approximation

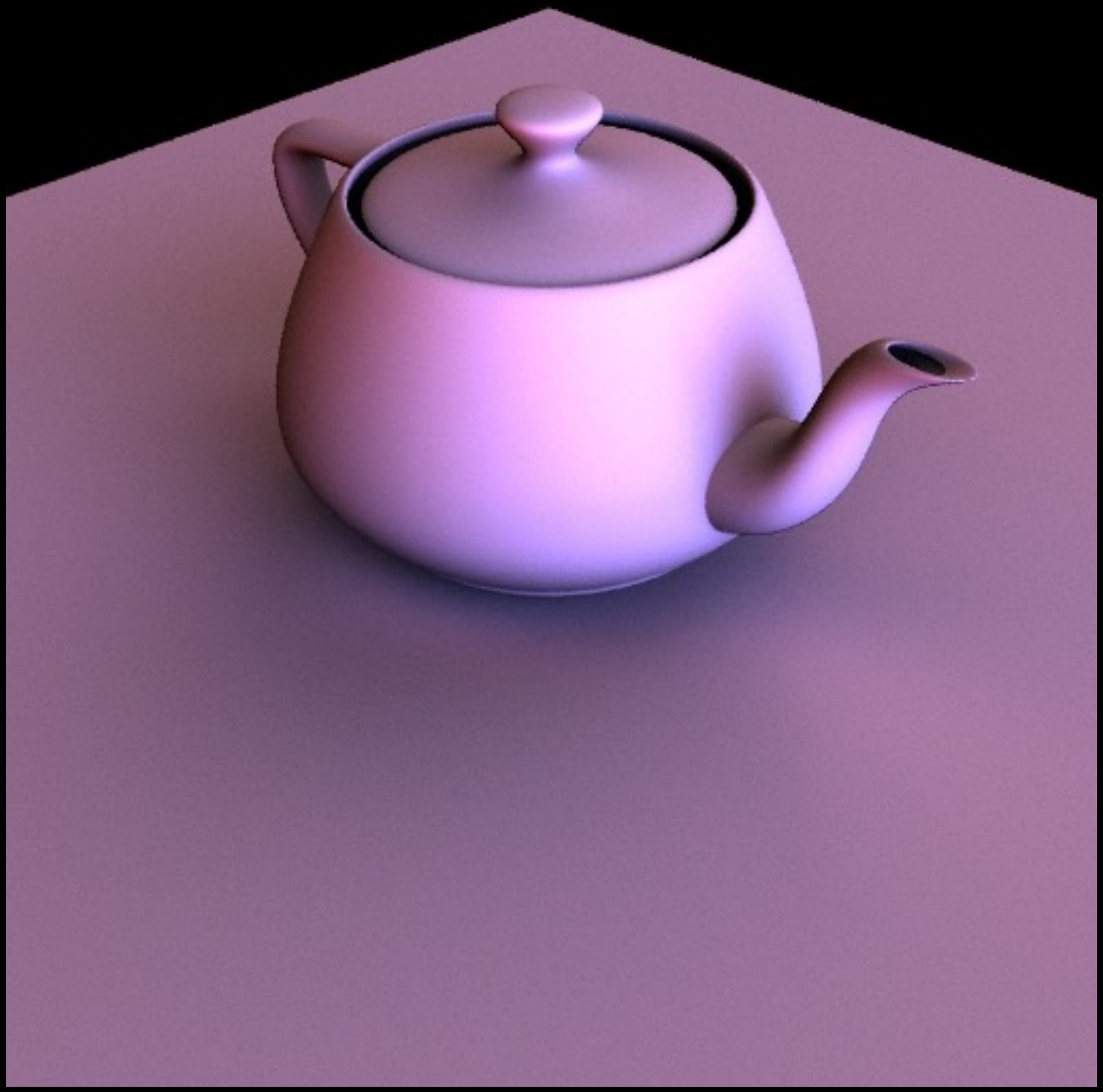
$$\begin{bmatrix} 0 \\ L_2 \\ 0 \\ 0 \\ 0 \\ L_6 \\ \boxed{?} \\ 0 \end{bmatrix}$$

Non-linear Approximation

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?

Today

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- Real-Time Global Illumination (in 3D)
  - Reflective Shadow Maps (RSM)
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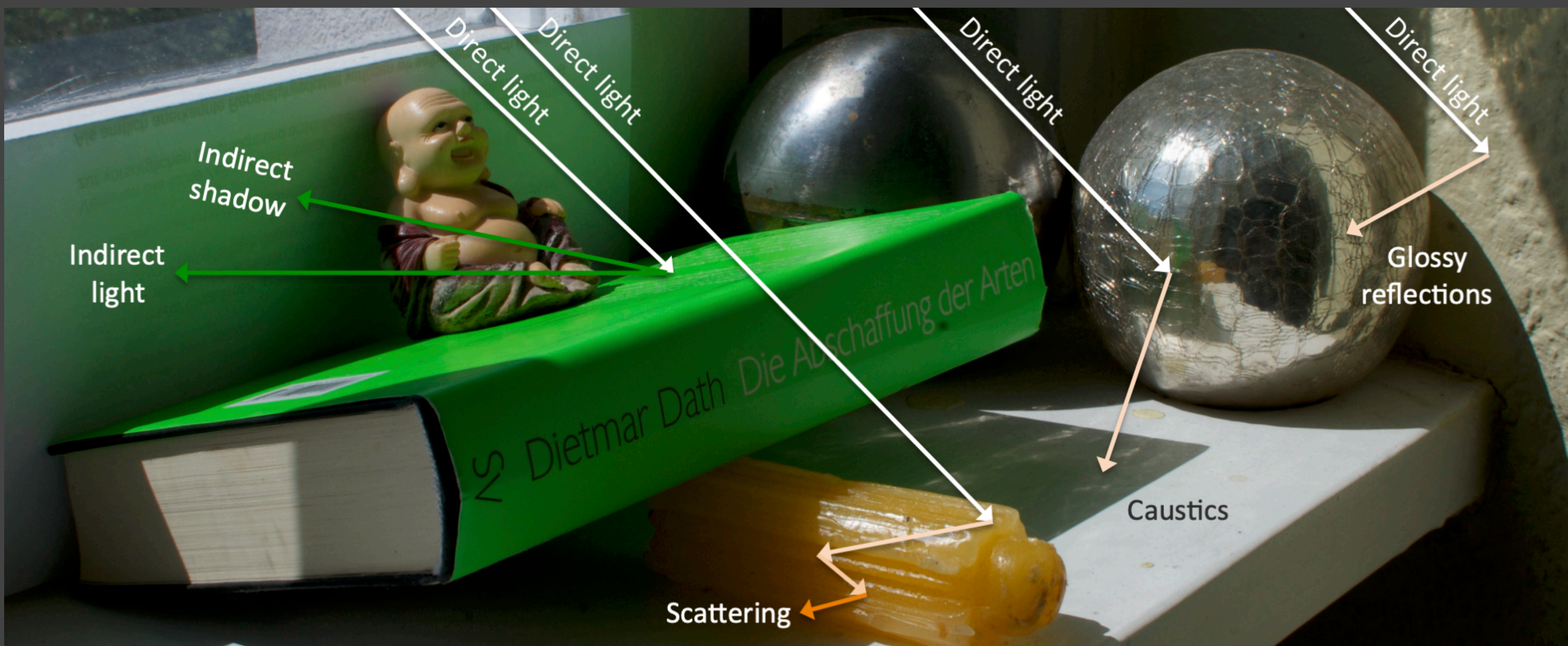
Introduction

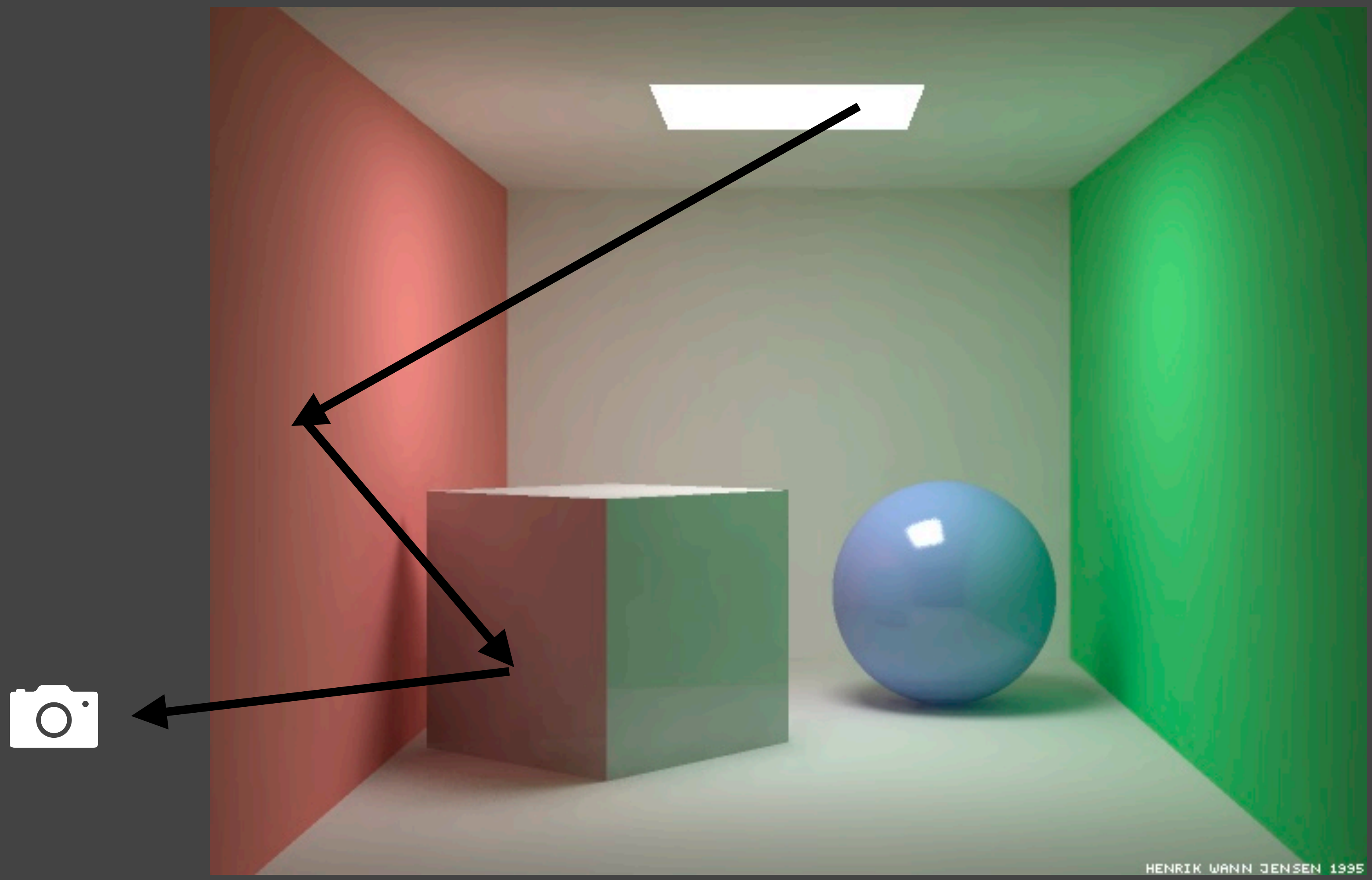
- Global Illumination (GI) is important but complex



[Ritschel et al., The State of the Art in Interactive Global Illumination]

Introduction

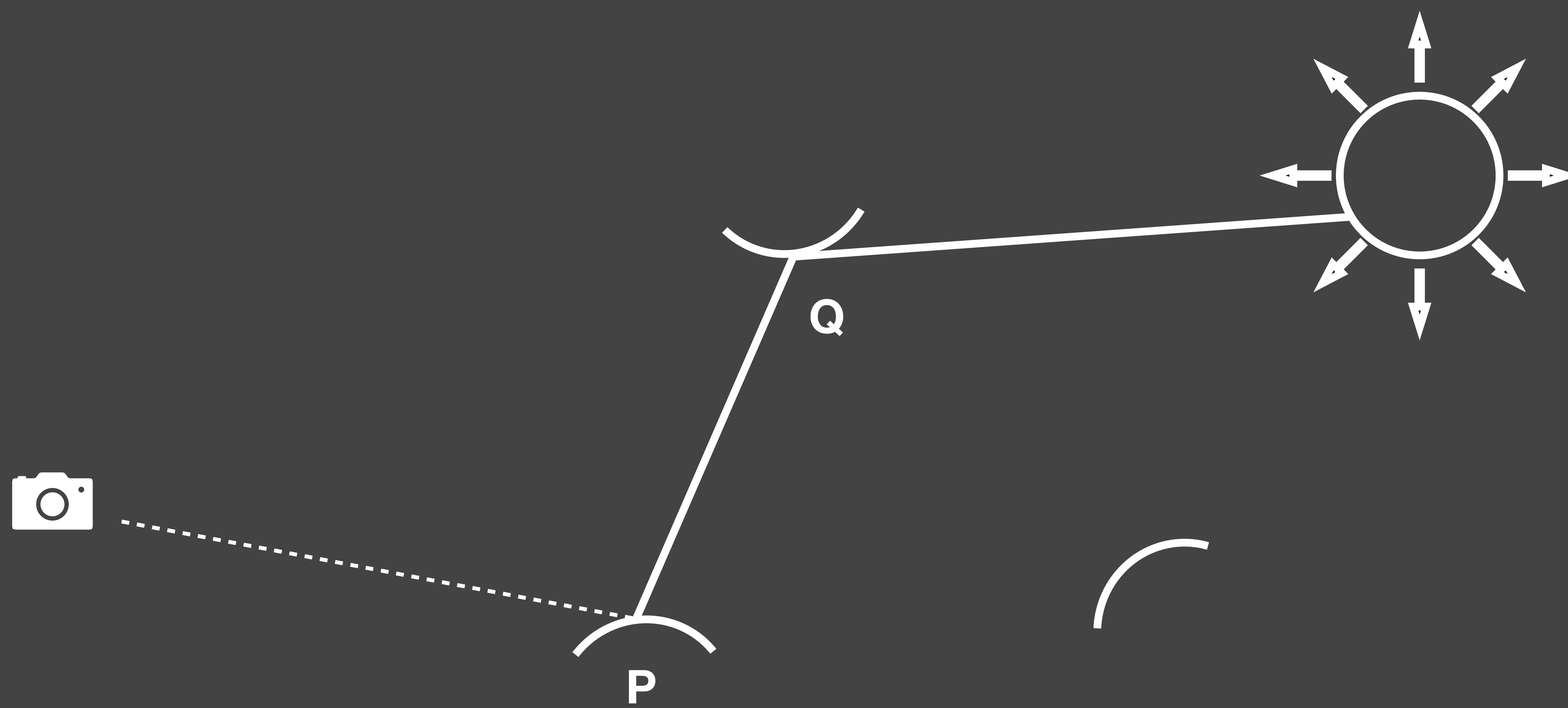
- In RTR, people seek simple and fast solutions to one bounce indirect illumination



[Image courtesy of Prof. Henrik Wann Jensen]

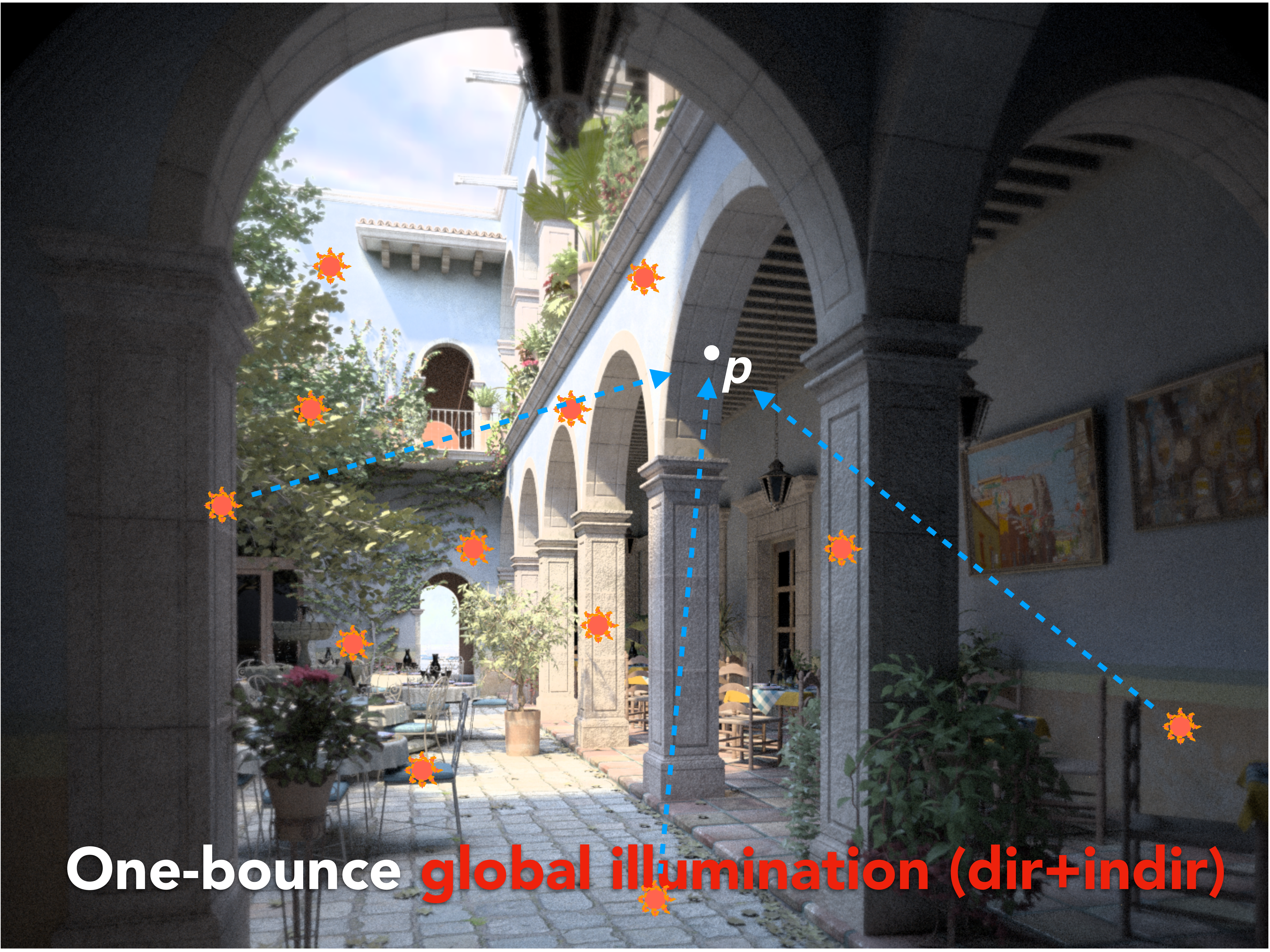
Understanding

- From GAMES101 (Lecture 16):
  Any directly lit surface will act as a light source again



[Image courtesy of Prof. Henrik Wann Jensen]


p
Direct illumination


p
One-bounce global illumination (dir+indir)

Key Observations

- What are needed to illuminate any point p with indirect illumination?

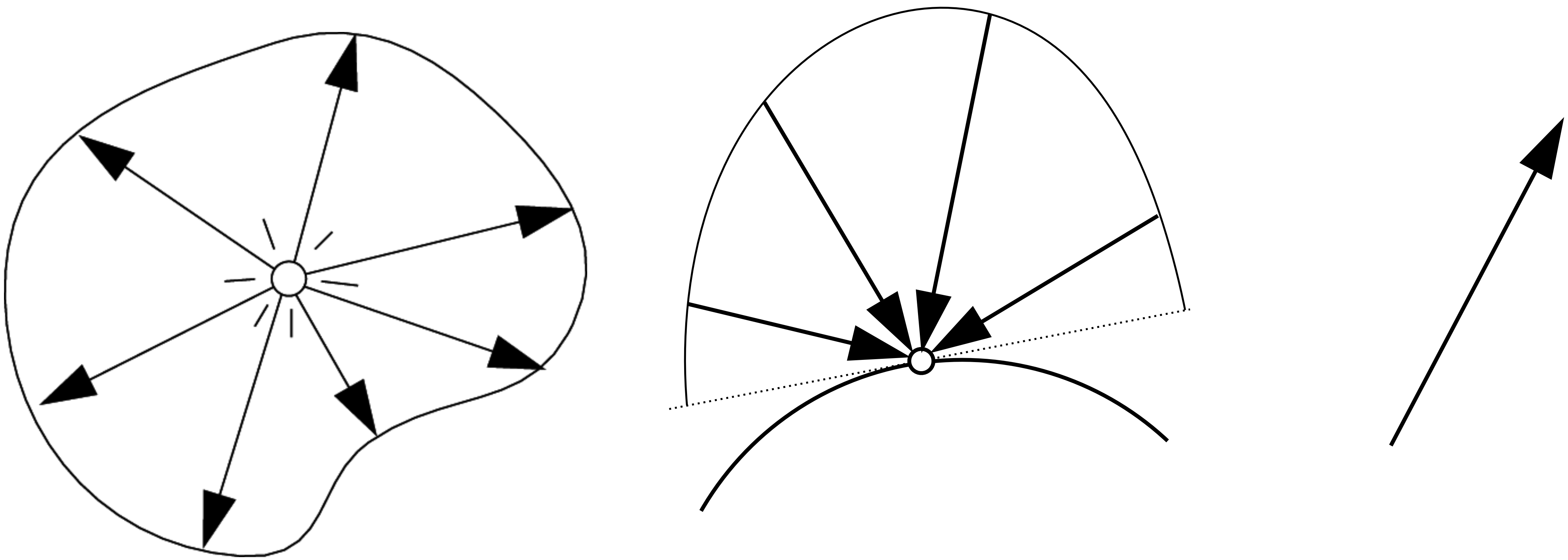
- Q1: Which surface patches are directly lit
  - Hint: what technique tells you this?

- Q2: What is the contribution from each surface patch to p
  - Then sum up all the surface patches' contributions
  - Hint: each surface patch is like an area light

Reflective Shadow Maps (RSM)

- Q1: Which surface patches are directly lit
  - Perfectly solved with a classic shadow map
  - Each pixel on the shadow map is a small surface patch
- The exact outgoing radiance for each pixel is known
  - But only for the direction to the camera
- Assumption
  - Any reflector is diffuse
  - Therefore, outgoing radiance is uniform toward all directions

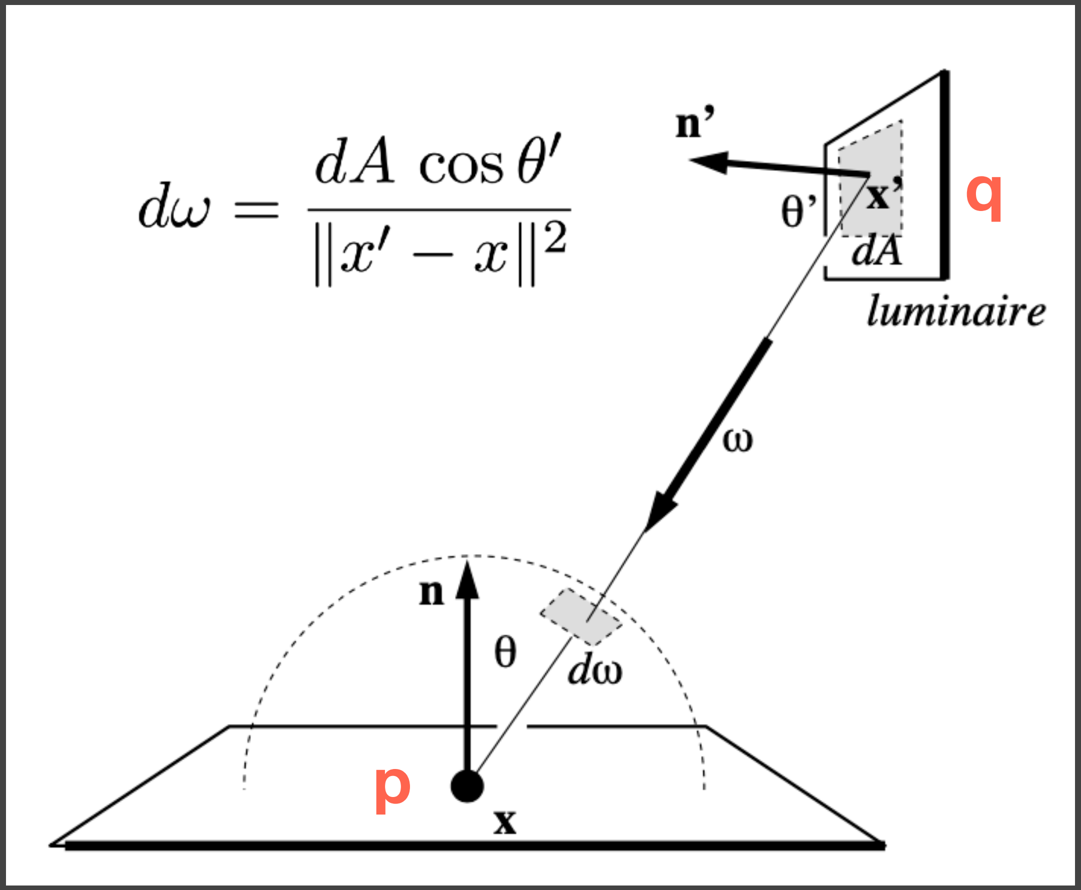
Recall: Light Measurements of Interest



Light Emitted From A Source	Light Falling On A Surface	Light Traveling Along A Ray
“Radiant Intensity”	“Irradiance”	“Radiance”

Reflective Shadow Maps (RSM)

- Q2: What is the contribution from each surface patch to p
  - An integration over the solid angle covered by the patch
  - Can be converted to the integration on the area of the patch



Reflective Shadow Maps (RSM)

$$L_o(\mathrm{p},\omega_o) = \int_{\Omega_{\text{patch}}} L_i(\mathrm{p},\omega_i)\, V(\mathrm{p},\omega_i) f_r(\mathrm{p},\omega_i,\omega_o)\, \cos\theta_i \,\mathrm{d}\omega_i$$

$$= \int_{A_{\text{patch}}} L_i(\mathrm{q}\to\mathrm{p})\, V(\mathrm{p},\omega_i) f_r(\mathrm{p},\mathrm{q}\to\mathrm{p},\omega_o)\, \frac{\cos\theta_p \cos\theta_q}{\|q-p\|^2}\,\mathrm{d}A$$

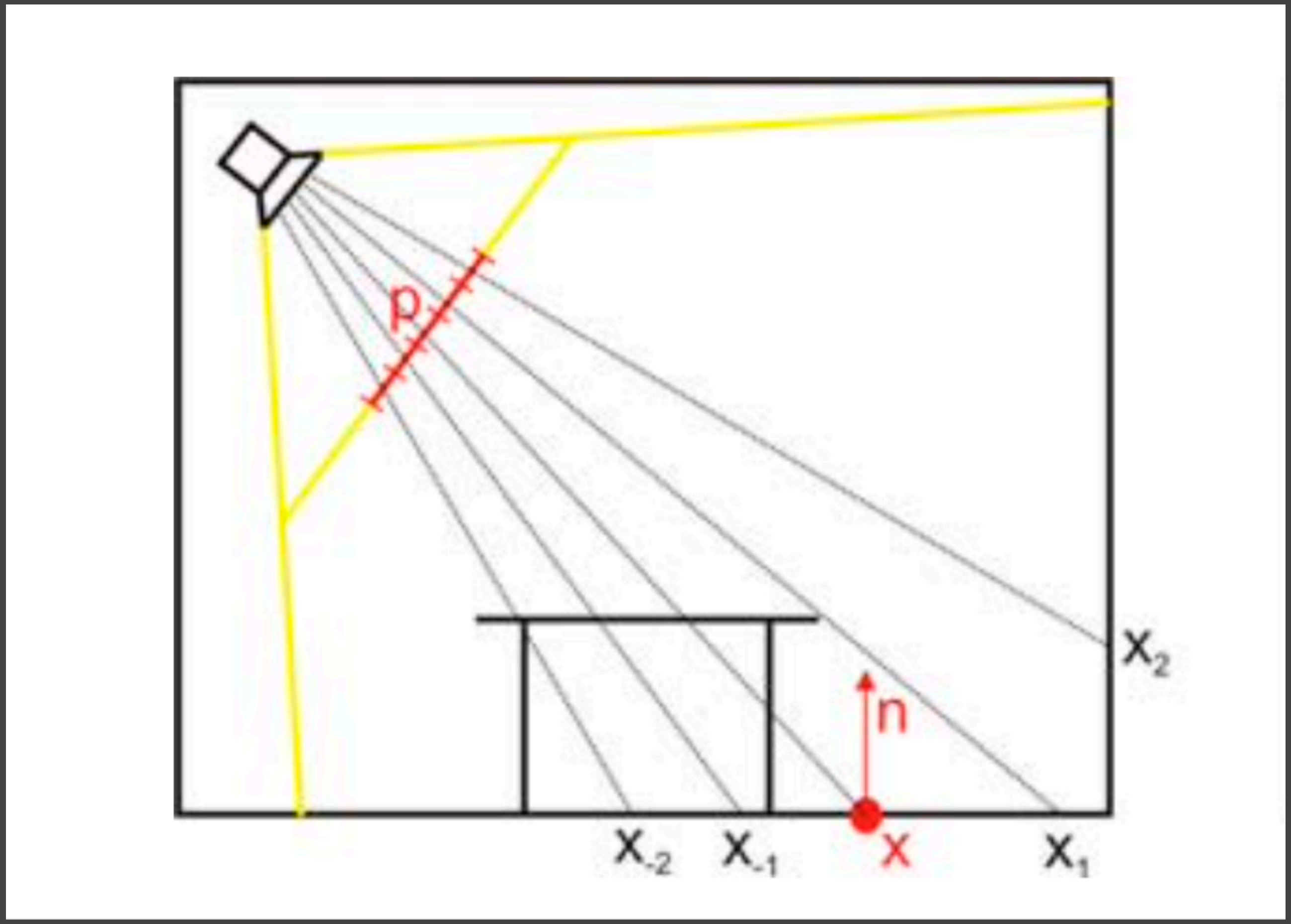
- For a diffuse reflective patch
  - $f_r = \rho/\pi$
  - $L_i = f_r \cdot \dfrac{\Phi}{dA}$ (Φ is the incident flux or energy)
  - Therefore,

$$E_p(x,n) = \Phi_p \frac{\max\{0,\langle n_p | x - x_p\rangle\}\max\{0,\langle n | x_p - x\rangle\}}{\|x - x_p\|^4}. \quad (1)$$

->2

Reflective Shadow Maps (RSM)

- Not all pixels in the RSM can contribute
  - Visibility (still, difficult to deal with)
  - Orientation
  - Distance



Reflective Shadow Maps (RSM)

- Acceleration
  - In theory, all pixels in the shadow map can contribute to p
  - Can we decrease the number?
  - Hint: Steps 1 and 3 in PCSS
- Sampling to the rescue

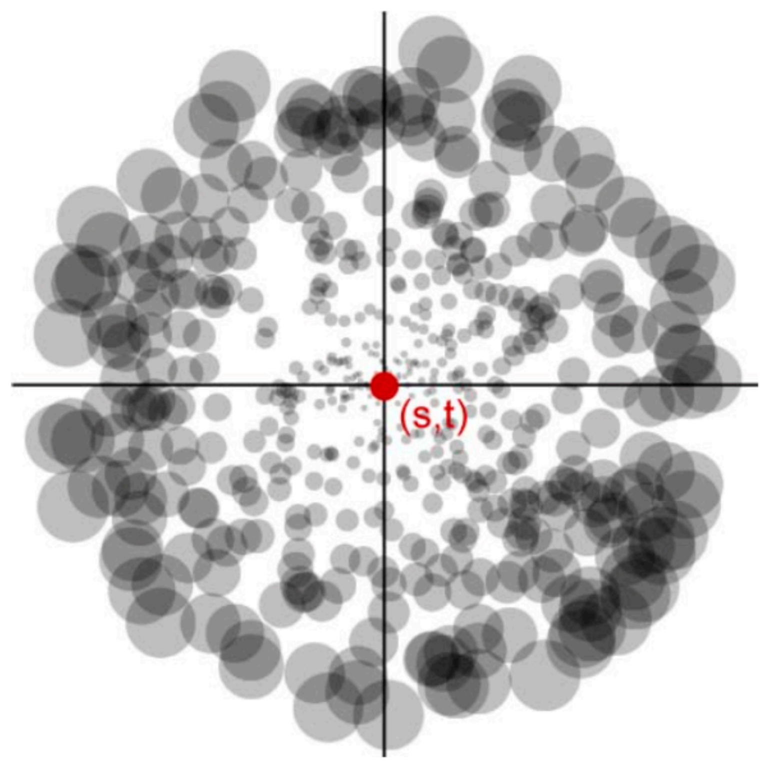
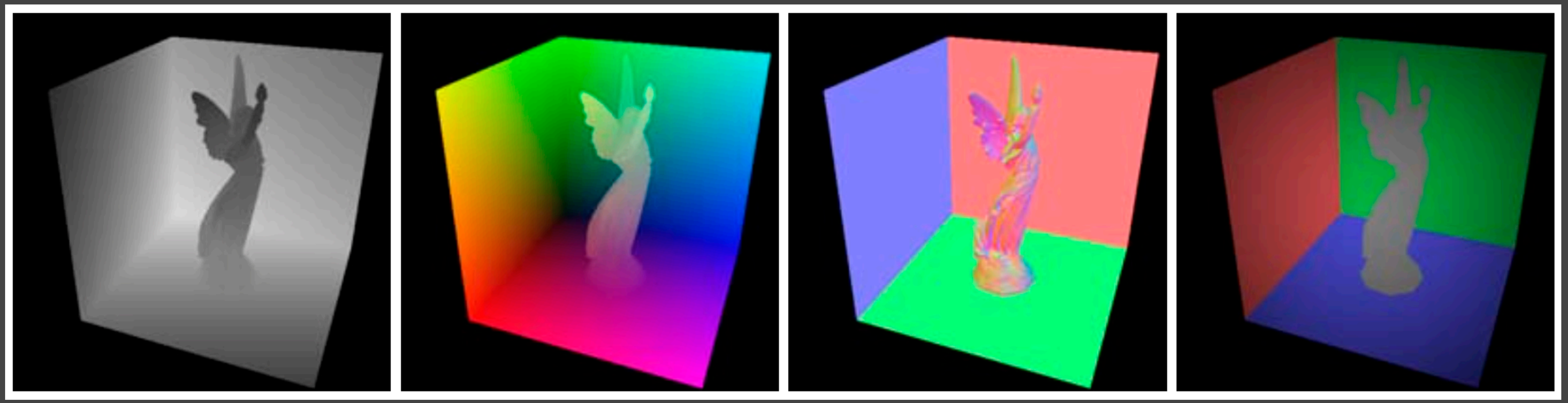


Figure 4: Sampling pattern example. The sample density decreases and the sample weights (visualized by the disk radius) increases with the distance to the center.

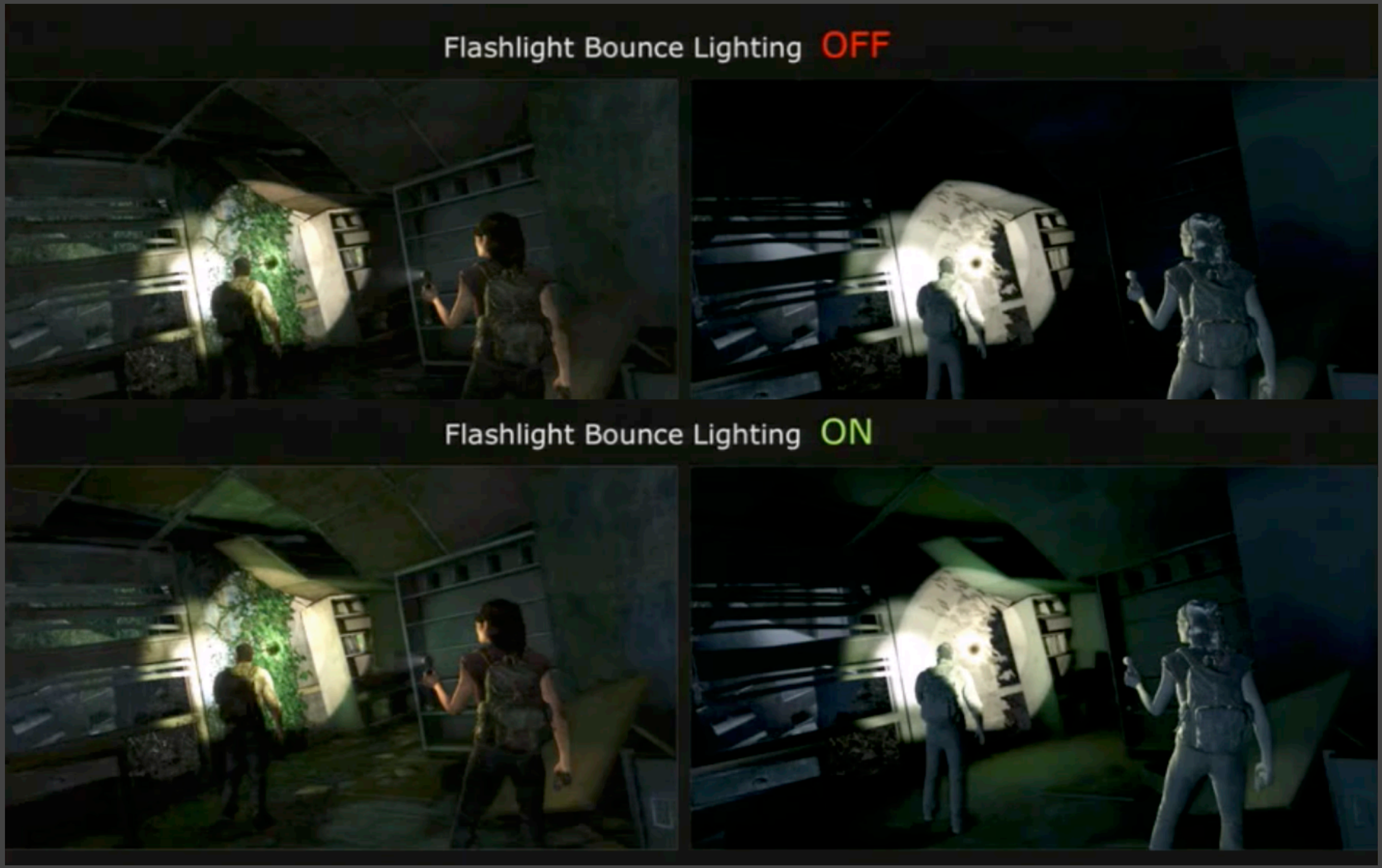
Reflective Shadow Maps (RSM)

- What is needed to record in an RSM?
  - Depth, world coordinate, normal, flux, etc.



Reflective Shadow Maps (RSM)

- Often used for flashlights in video games
  - Gears of War 4, Uncharted 4, The Last of US, etc.



https://www.gdcvault.com/play/1020475/In-Game-and-Cinematic-Lighting

Reflective Shadow Maps (RSM)

- Pros
  - Easy to implement
- Cons
  - Performance scales linearly w/ #lights
  - No visibility check for indirect illumination
  - Many assumptions: diffuse reflectors, depth as distance, etc.
  - Sampling rate / quality tradeoff

Questions?

Next Lecture

- Real-time global illumination cont.
  - In 3D (VXGI)
  - In the image space (SSAO, SSDO, SSR, etc.)

[SSDO]

[VXGI by NVIDIA]

Thank you!