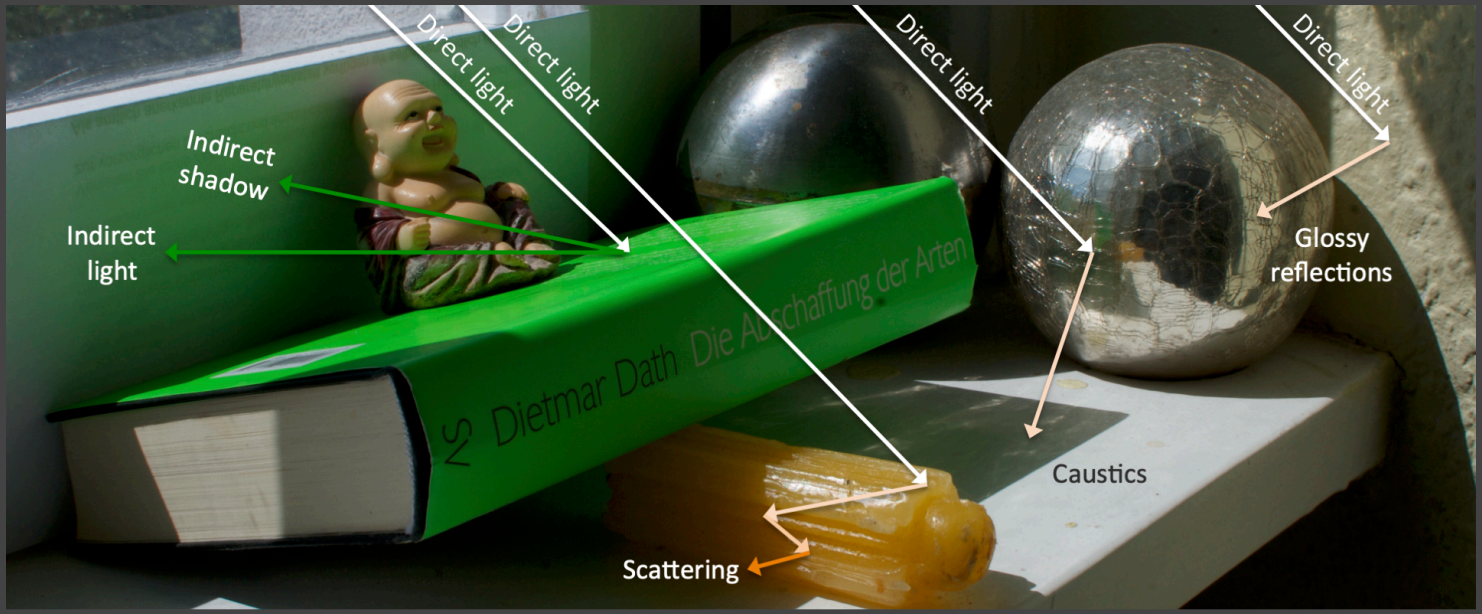
Today

- 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)

Introduction

- Global Illumination (GI) is important but complex



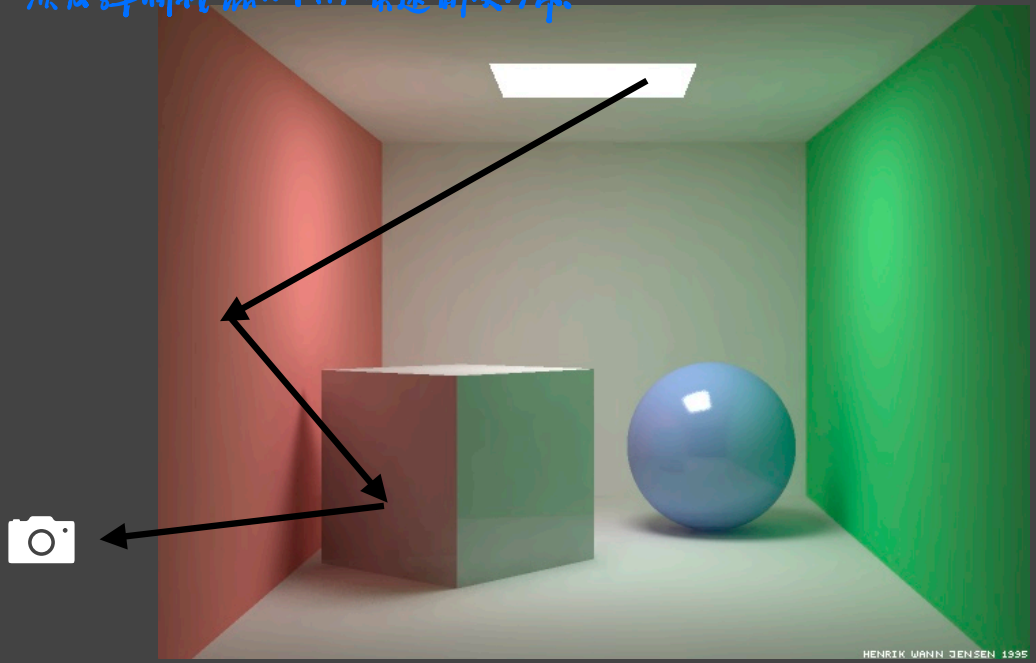
[Ritschel et al., The State of the Art in Interactive Global Illumination]

Introduction

全局光照：直接光照 + 间接光照

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

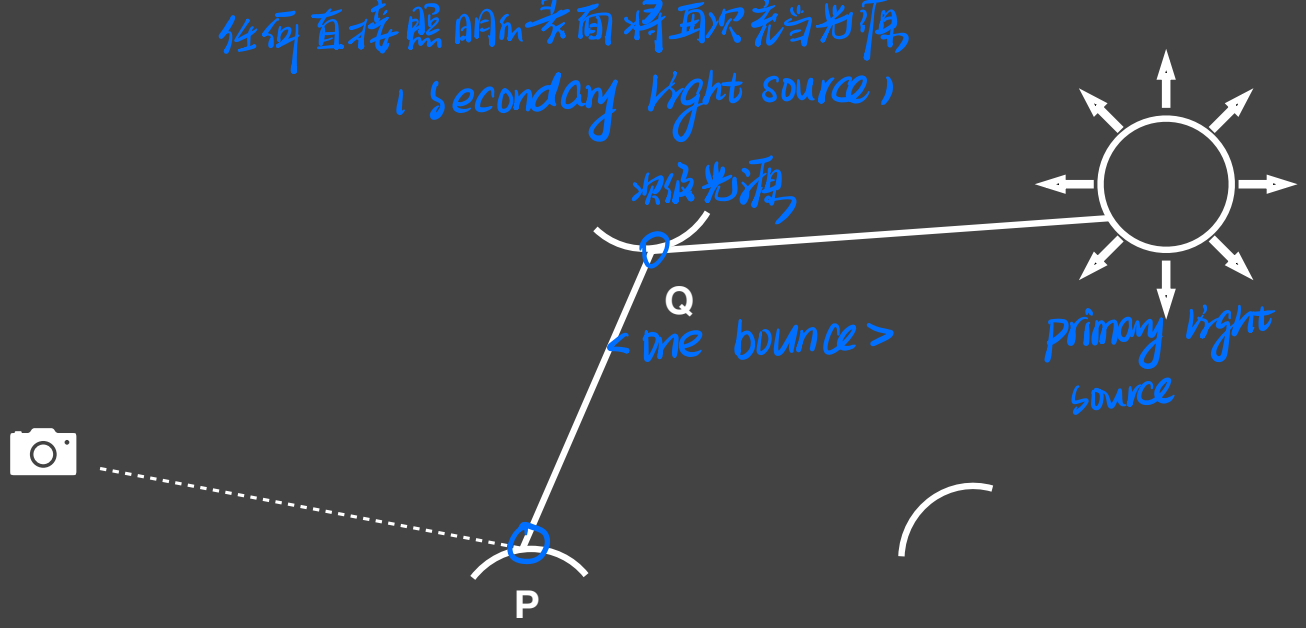
一次反弹间接照明的快速简便方案



[Image courtesy of Prof. Henrik Wann Jensen]

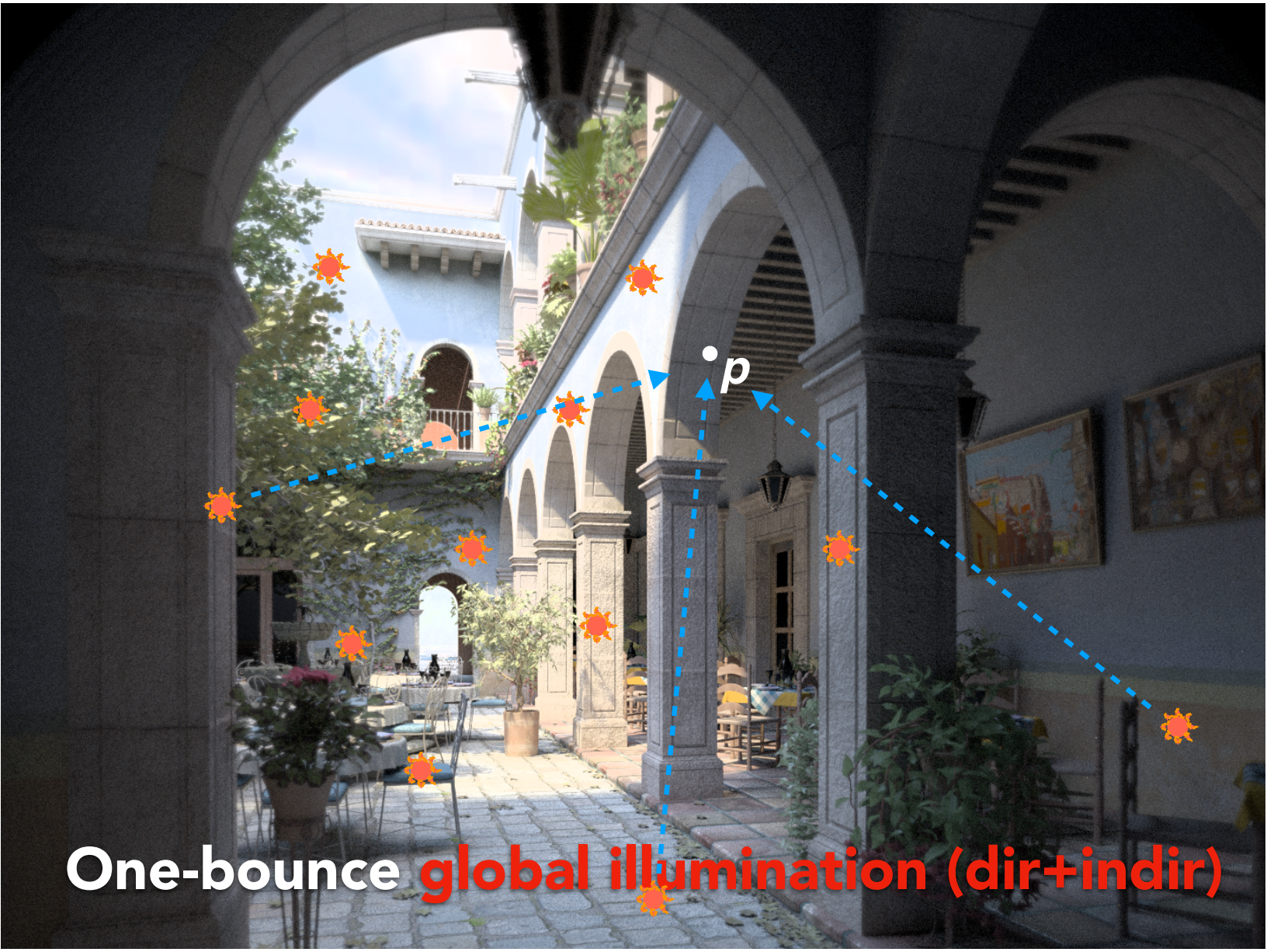
Understanding

- 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?

哪些位置(曲面片)被直接照亮。

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

每个被直接照亮的曲面片对 p 的贡献多少.

- Q2: What is the contribution from each surface patch to p

得所有贡献求和

  - Then sum up all the surface patches' contributions
  - Hint: each surface patch is like an area light

ps. 每个曲面片就相当一个区域光.

反射阴影贴图

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

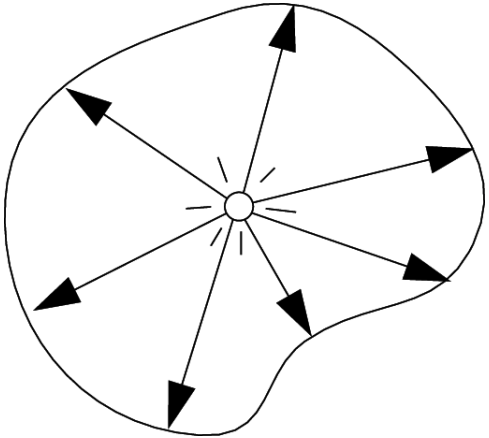
shadow map 中每个像素对应一个小曲面片，可以认为一个次级光源（离散化）

- The exact outgoing radiance for each pixel is known
  - But only for the direction to the camera

- Assumption
  - Any reflector is diffuse 假设每个次级光源（反射物）为 diffuse.
  - Therefore, outgoing radiance is uniform toward all directions

（出射的 radiance 在所有方向上都是均匀的.
（不要求点 p 是 diffuse）

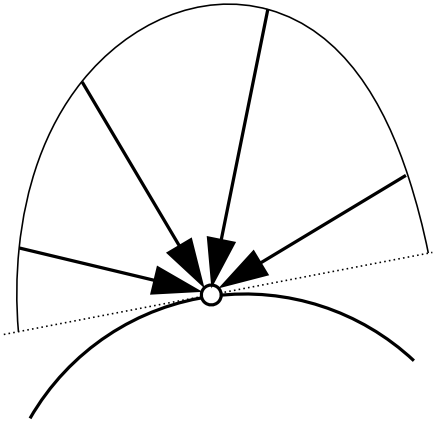
Recall: Light Measurements of Interest



Light Emitted From A Source

单位立体角上的能量

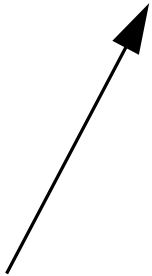
"Radiant Intensity"



Light Falling On A Surface

在单位面积上对应能量

"Irradiance"



Light Traveling Along A Ray

单位立体角的单位面积上能量

"Radiance"

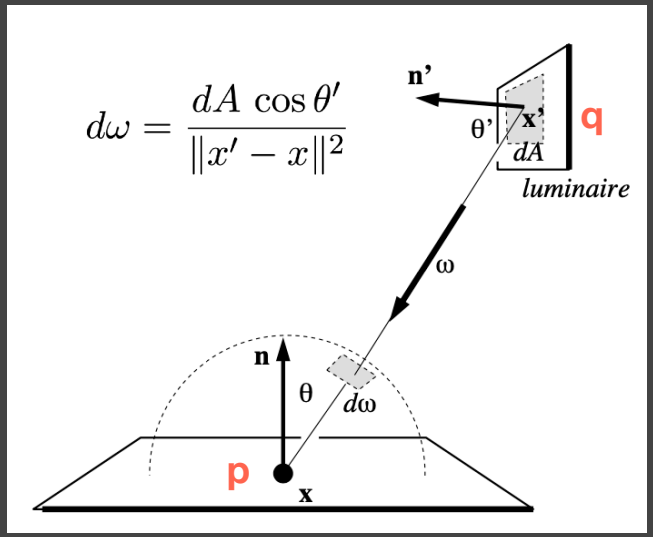
Reflective Shadow Maps (RSM)

先考虑单个面片对 p 的贡献.

- 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

计算面片覆盖的立体角度上的积分.

可转化为对面片面积积分.



Reflective Shadow Maps (RSM)

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

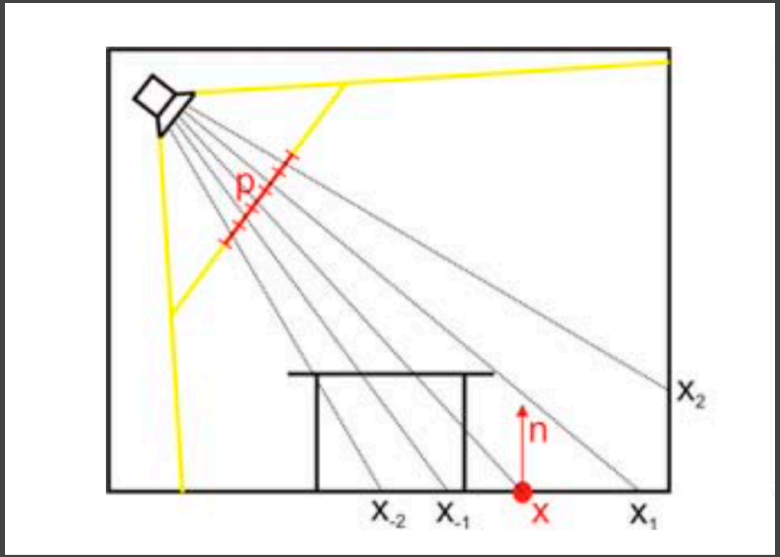
$$= \int_{A_{\text{patch}}} L_i(\mathrm{q}\to\mathrm{p})\, V(\mathrm{p},\omega_i) f_r(\mathrm{p},\mathrm{q}\to\mathrm{p},\omega_o)\, \frac{\cos\theta_p \cos\theta_q}{\|q-p\|^2}\,\mathrm{d}A$$

- 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,

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

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

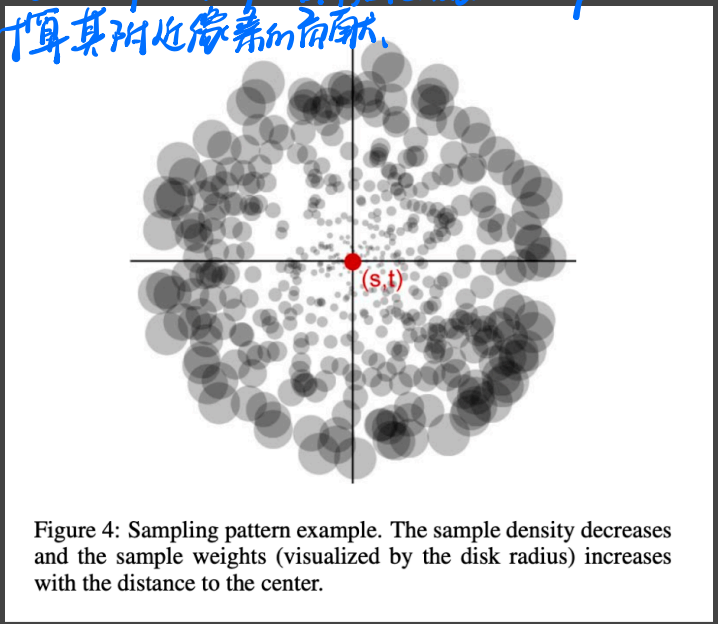
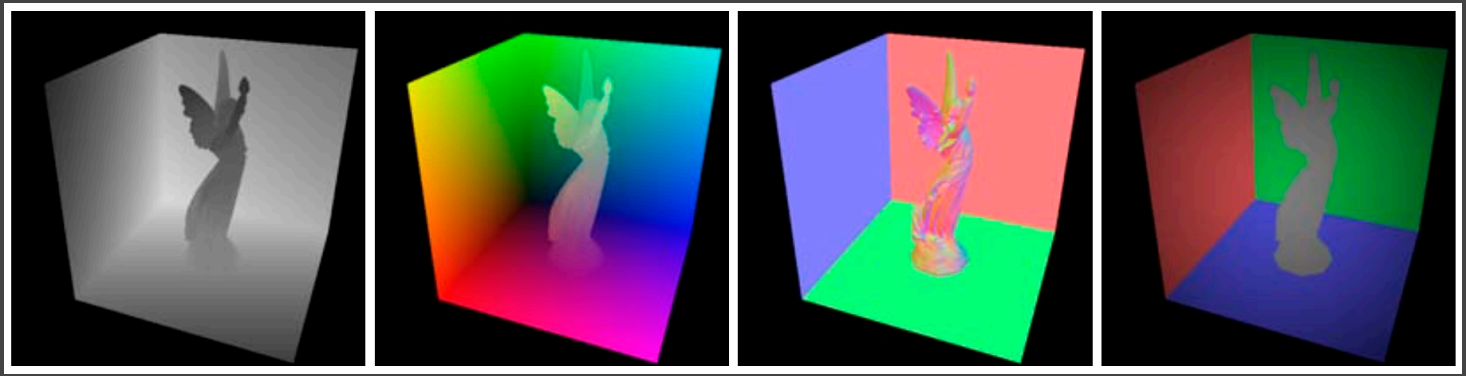


Figure 4: Sampling pattern example. The sample density decreases and the sample weights (visualized by the disk radius) increases with the distance to the center.

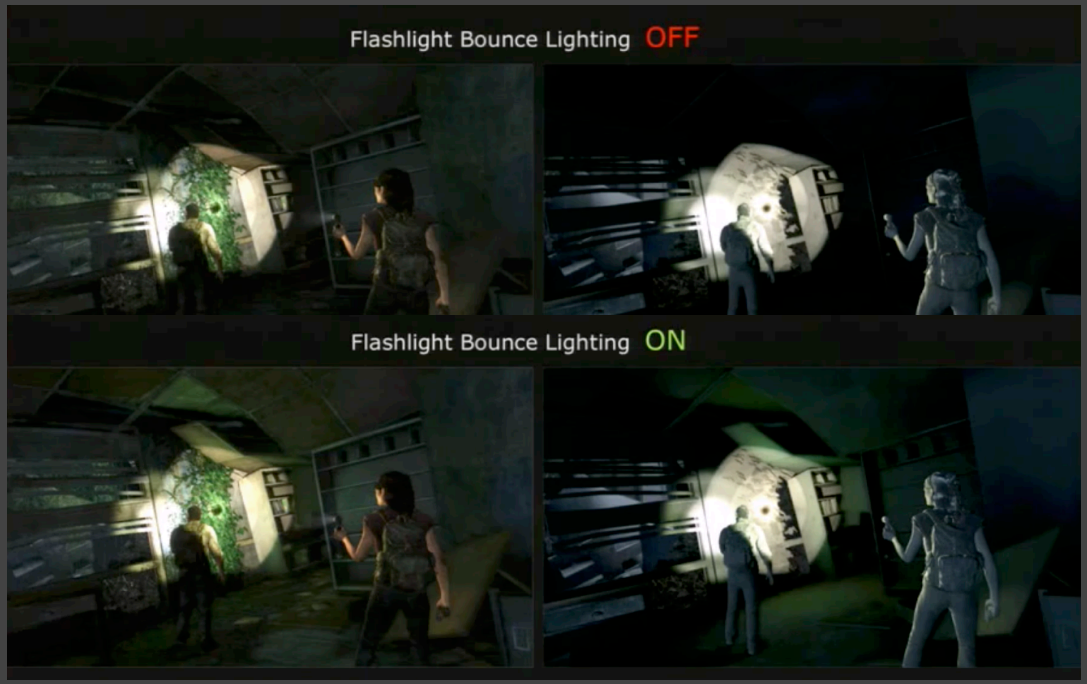
Reflective Shadow Maps (RSM)

- 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)

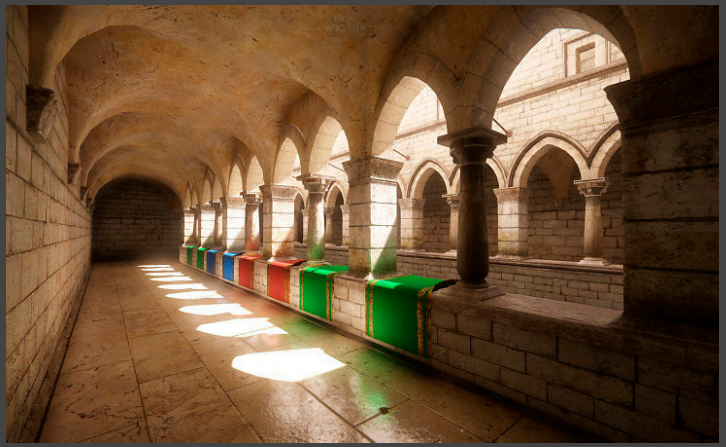
- Pros
  - Easy to implement
- Cons
  - Performance scales linearly w/ #lights
  - No visibility check for indirect illumination
  - Many assumptions: diffuse reflectors, depth as distance, etc.
  - Sampling rate / quality tradeoff

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!