CS482: Monte Carlo Ray Tracing:

Sung-Eui Yoon
(윤성의)

http://sglab.kaist.ac.kr/~sungeui/ICG

KAIST

Questions

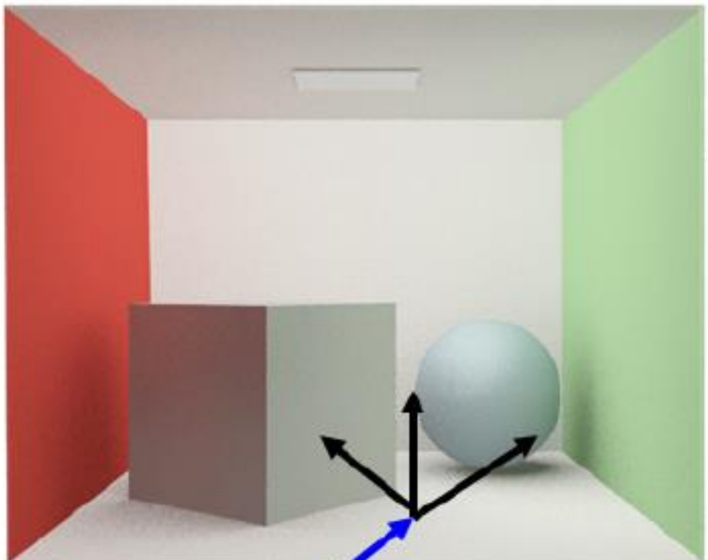
- **What is rule of thumb for choosing right amount of samples? Selecting few might result in bias and selecting too many would be meaningless since variance converges quickly. I wonder if there is some lower bound for sample numbers to get decent result.**

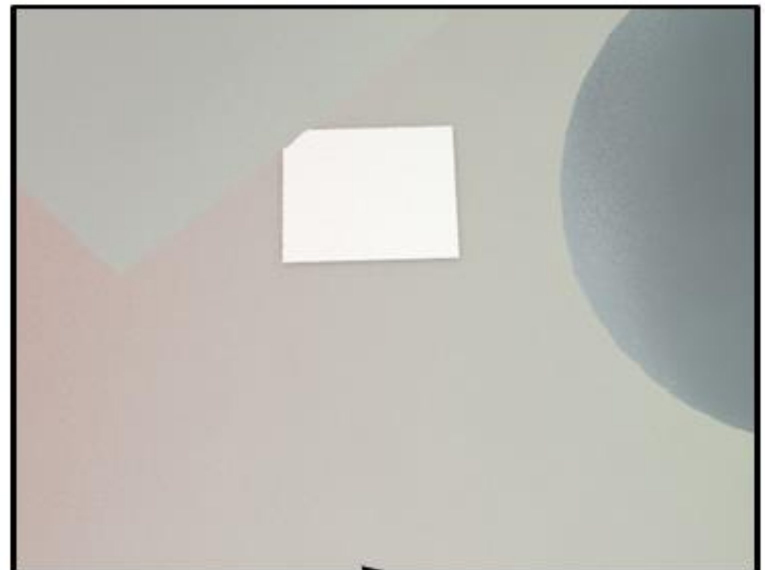
Class Objectives (Ch. 15)

- Understand a basic structure of Monte Carlo ray tracing
  - Russian roulette for its termination
  - Path tracing

- Last time:
  - Monte Carlo integration: sampling approach for solving the rendering equation
  - Estimator and its variance

Rendering Equation



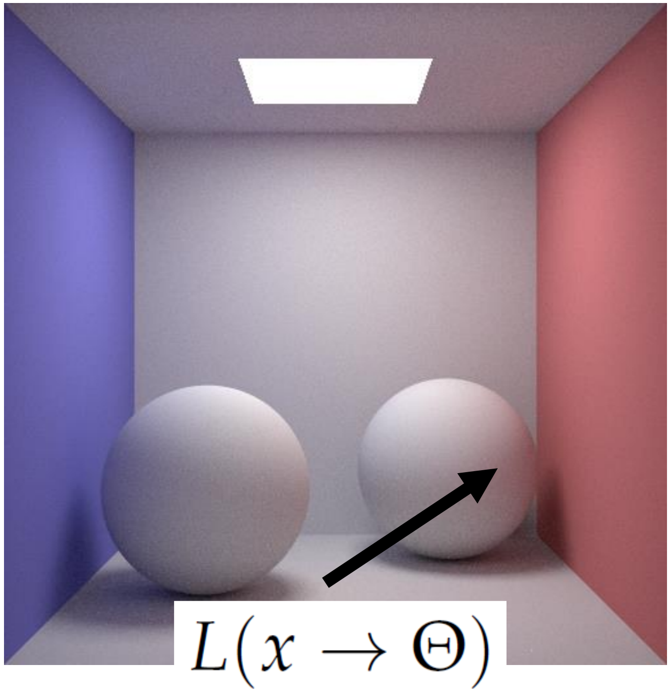


Incoming radiance on the hemisphere

$$L_r(x \rightarrow \Theta) = \int_{\Psi} L(x \leftarrow \Psi) f_r(x, \Psi \rightarrow \Theta) \cos\theta_x dw_{\Psi}$$

Evaluation

- **To compute** $L(x \to \Theta)$ **:**
  - **Check** $L_e(x \to \Theta)$
  - **Evaluate** $L_r(x \to \Theta)$



$$L_r(x \to \Theta) = \int_{\Psi} L(x \leftarrow \Psi) f_r(x, \Psi \to \Theta) \cos\theta_x dw_{\Psi}$$

Evaluation

- **Use Monte Carlo**
- **Generate random directions on hemisphere Ψ using pdf p(Ψ)**

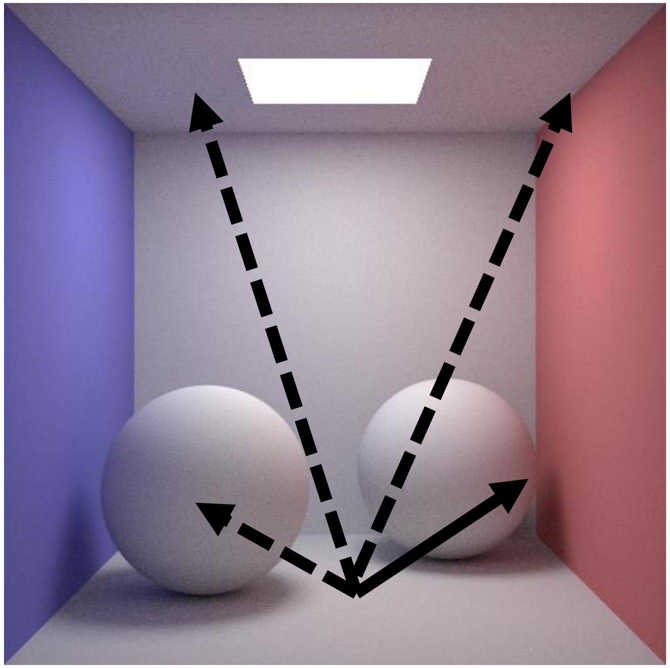
$$L_r(x \to \Theta) = \int_\Psi L(x \leftarrow \Psi) f_r(x, \Psi \to \Theta) \cos\theta_x dw_\Psi$$

$$\hat{L}_r(x \to \Theta) = \frac{1}{N} \sum_{i=1}^{N} \frac{L(x \leftarrow \Psi_i) f_r(x, \Psi_i \to \Theta) \cos\theta_x}{p(\Psi_i)}$$

- **How about** $L(x \leftarrow \Psi_i)$ **?**

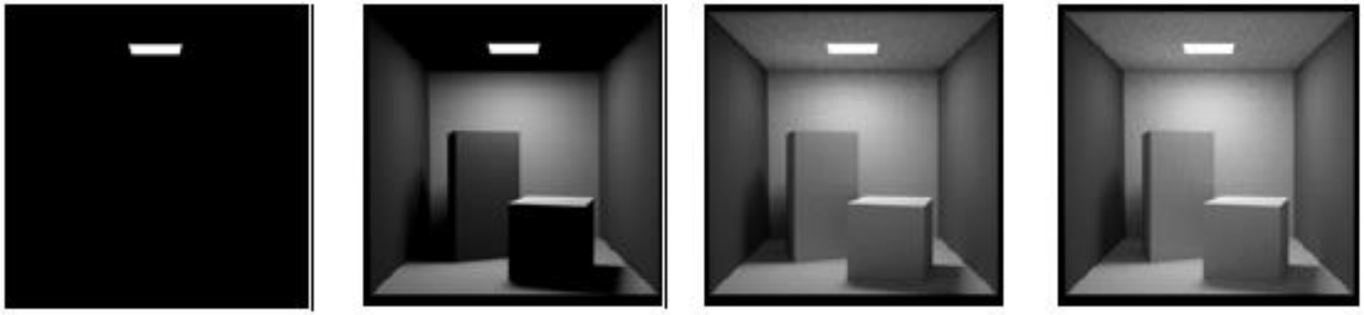
Evaluation

- How about $L(x \leftarrow \Psi_i)$?



- Perform ray casting backward
- Compute radiance from those visible points to x
  - Assume reciprocity
- Recursively perform the process
  - Each additional bounce supports one more indirect illumination

When to end recursion?



From kavita's slides

- Contributions of further light bounces become less significant
  - Max recursion
  - Some threshold for radiance value

- If we just ignore them, estimators will be biased

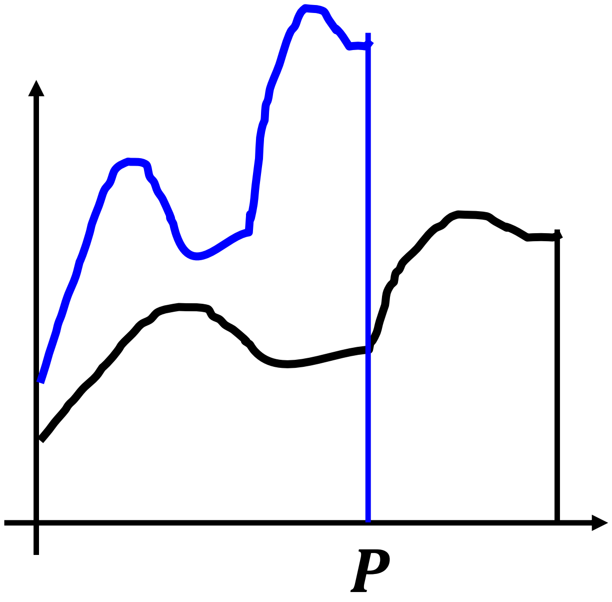
Russian Roulette

- **Integral: Substitute $y = Px$**

$$I = \int_0^1 f(x)dx = \int_0^P \frac{f(y/P)}{P} dy.$$

- **Estimator**

$$\hat{I}_{roulette} = \begin{cases} \frac{f(x_i)}{P} & \text{if } x_i \leq P, \\ 0 & \text{if } x_i > P. \end{cases}$$



- **Variance?**

Russian Roulette

- Pick absorption probability, $\alpha = 1\text{-}P$
  - Recursion is terminated

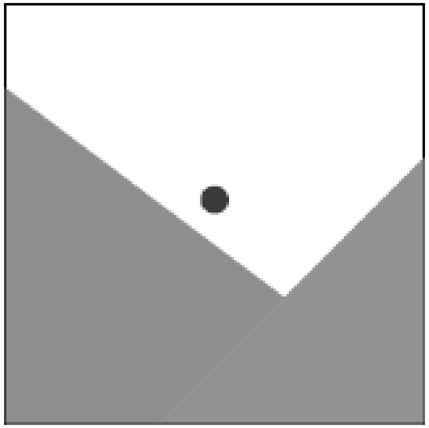
- 1- α, i.e., P, is commonly to be equal to the reflectance of the material of the surface
  - Darker surface absorbs more paths

Algorithm so far

- Shoot primary rays through each pixel
- Shoot indirect rays, sampled over hemisphere
- Terminate recursion using Russian Roulette

Pixel Anti-Aliasing

- **Compute radiance only at the center of pixel**
  - **Produce jaggies**



- **We want to evaluate using MC**

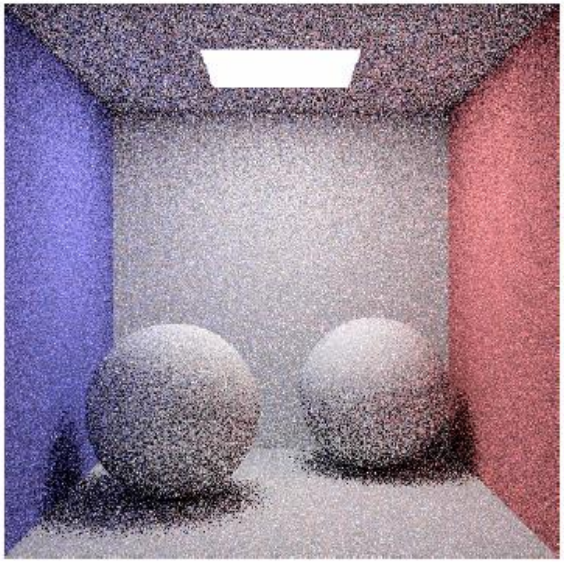
- **Simple box filter**
  - **The averaging method**

Stochastic Ray Tracing

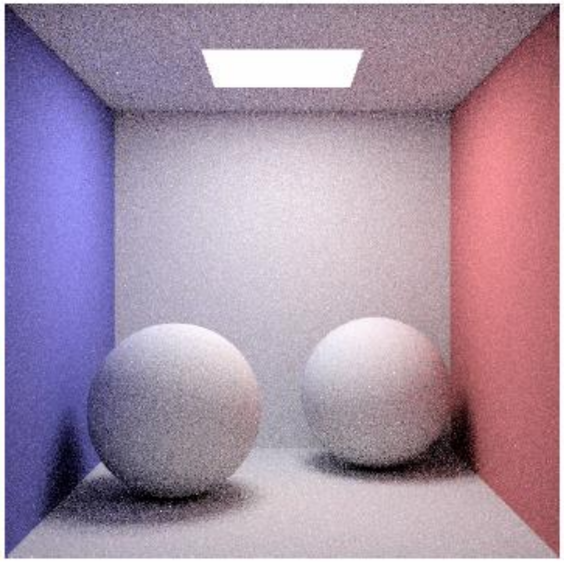
- Parameters
  - Num. of starting ray per pixel
  - Num. of random rays for each surface point (branching factor)

- Path tracing
  - Branching factor = 1

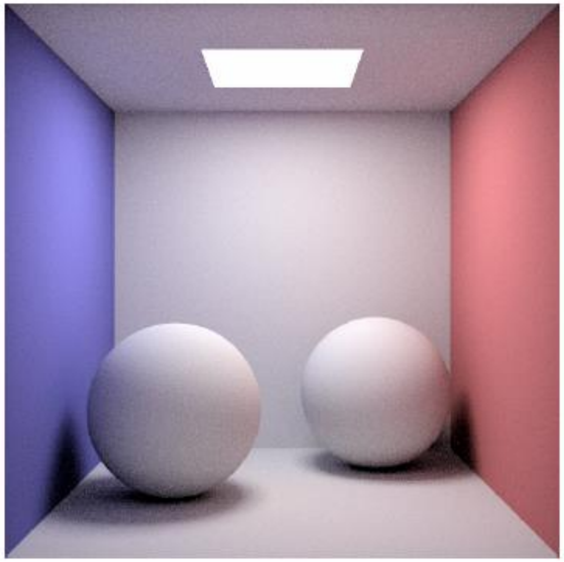
Path Tracing



1 spp
(samples per pixel)



4 spp



16 spp

- **Pixel sampling + light source sampling folded into one method**

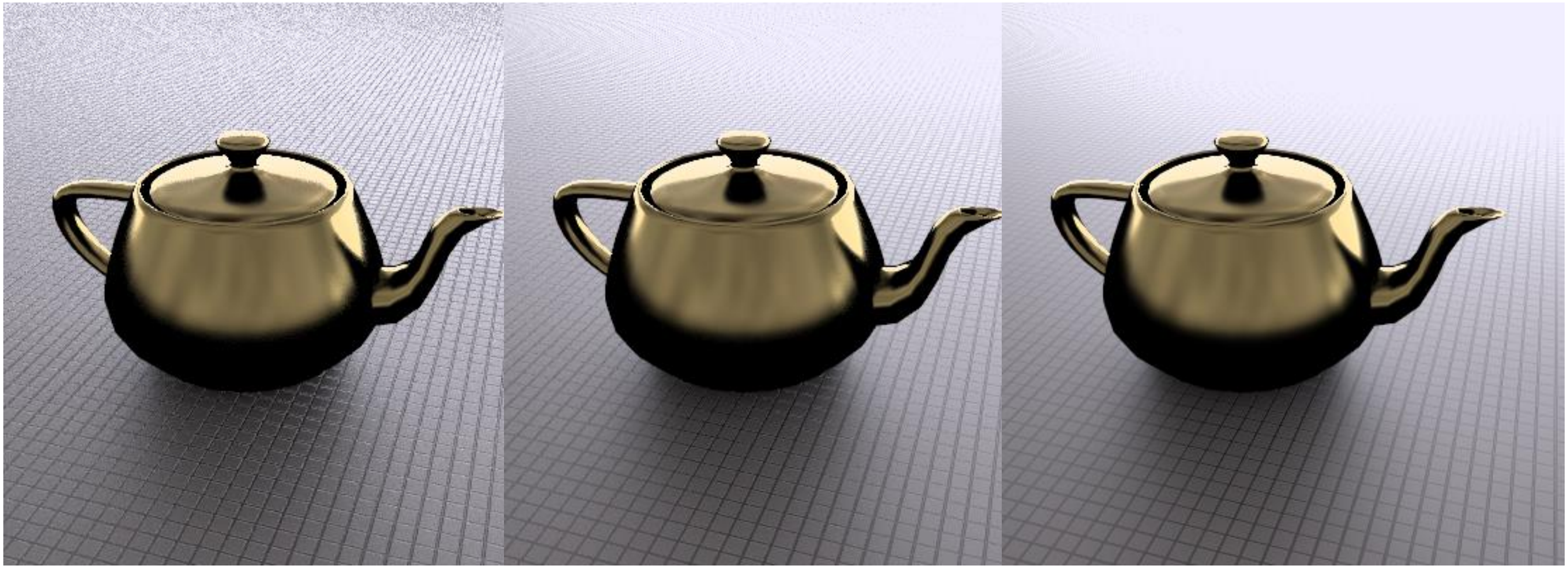
Algorithm so far

- **Shoot primary rays through each pixel**
- **Shoot indirect rays, sampled over hemisphere**
  - **Path tracing shoots only 1 indirect ray**
- **Terminate recursion using Russian Roulette**

Performance

- Want better quality with smaller # of samples
  - Fewer samples/better performance
  - Quasi Monte Carlo: well-distributed samples
  - Adaptive sampling

Some Example

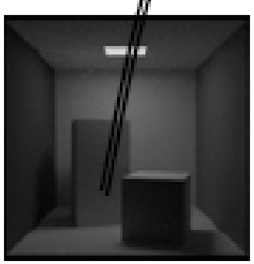


Uniform sampling (64 samples per pixel) | **Adaptive sampling** | **Reference**

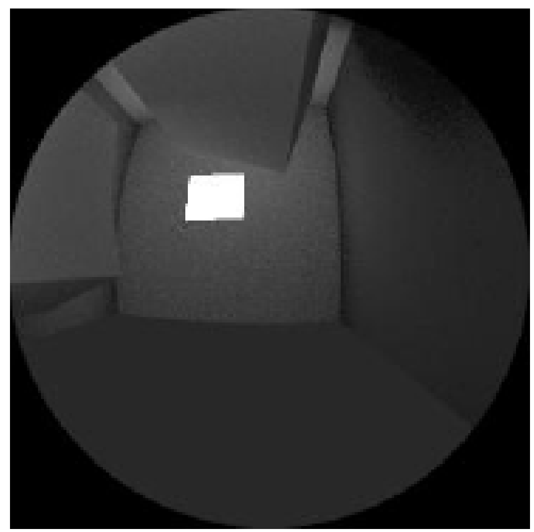
Importance Sampling

$$L(x \to \Theta) = L_e(x \to \Theta) + \int_{\Omega_x} f_r(\Psi \leftrightarrow \Theta) \cdot L(x \leftarrow \Psi) \cdot \cos(\Psi, n_x) \cdot d\omega_\Psi$$

Radiance from light sources + radiance from other surfaces



$$= L_e + \int_{\Omega_x}$$

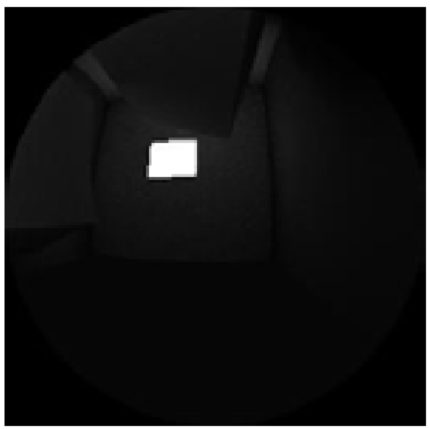


$$\cdot f_r \cdot \cos$$

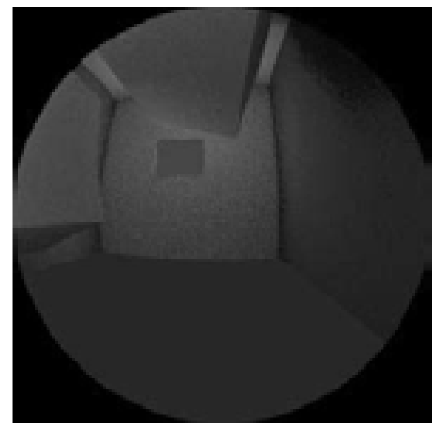
Importance Sampling

$$L(x \rightarrow \Theta) = L_e + L_{direct} + L_{indirect}$$

$$= L_e + \int_{\Omega_x}$$



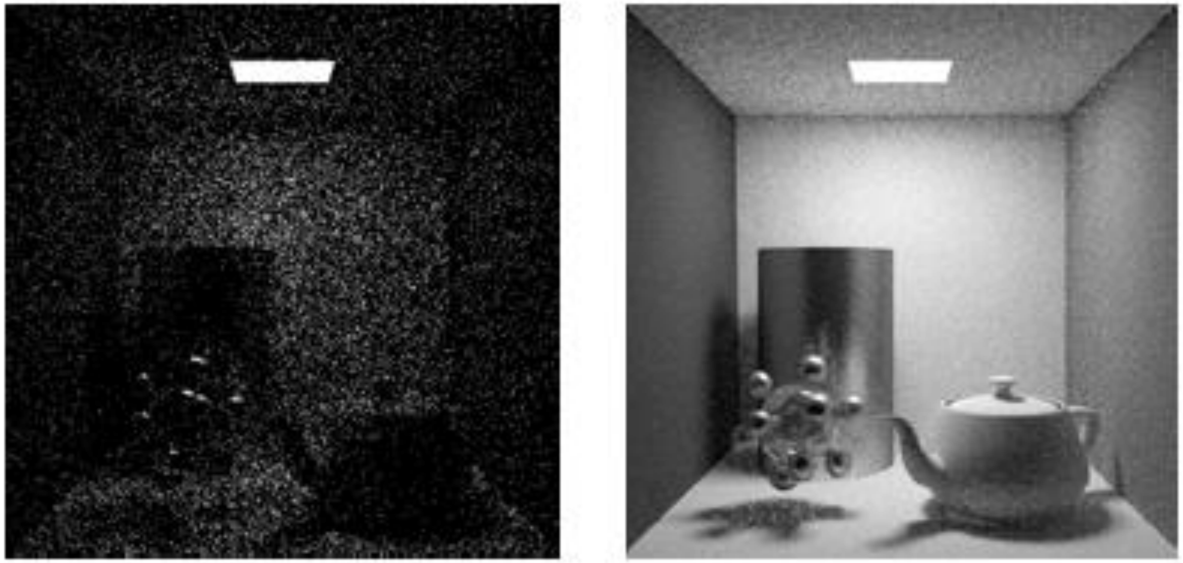
$$\cdot f_r \cdot \cos + \int_{\Omega_x}$$



$$\cdot f_r \cdot \cos$$

- So … sample direct and indirect with separate MC integration

Comparison



From kavita's slides

- **With and without considering direct illumination**
  - **16 samples / pixel**

Rays per pixel

1 sample/ pixel

4 samples/ pixel

16 samples/ pixel

256 samples/ pixel

Class Objectives were:

- **Understand a basic structure of Monte Carlo ray tracing**
  - **Russian roulette for its termination**
  - **Path tracing**

Class Objectives were:

- Understand a basic structure of Monte Carlo ray tracing
  - Russian roulette for its termination
  - Path tracing

Next Time…

- Acceleration techniques for global illumination methods

Homework

- Go over the next lecture slides before the class
- Watch 2 SIG/CVPR/ISMAR videos and submit your summaries every Mon. class
  - Just one paragraph for each summary
  - Any top-tier conf (e.g., ICRA) is okay

Example:

Title: XXX XXXX XXXX

Abstract: this video is about accelerating the performance of ray tracing. To achieve its goal, they design a new technique for reordering rays, since by doing so, they can improve the ray coherence and thus improve the overall performance.

Any Questions?

- **Submit four times in Sep./Oct.**
- **Come up with one question on what we have discussed in the class and submit at the end of the class**
  - **1 for typical questions**
  - **2 for questions that have some thoughts or surprise me**