# CS580:
# MC Ray Tracing:
# Part III, Acceleration and Biased Tech.

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(윤성의)

**Course URL:**
**http://sglab.kaist.ac.kr/~sungeui/GCG**

# Class Objectives:

- **Extensions to the basic MC path tracer**
  - **Bidirectional path tracer**
  - **Metropolis sampling**

- **Biased techniques**
  - **Irradiance caching**
  - **Photon mapping**

# General GI Algorithm

- Design path generators

- Path generators determine efficiency of GI algorithm

- Black boxes
  - Evaluate BRDF, ray intersection, visibility evaluations, etc

# Other Rendering Techniques

- Bidirectional path tracing
- Metropolis
- Biased techniques
  - Irradiance caching
  - Photon mapping



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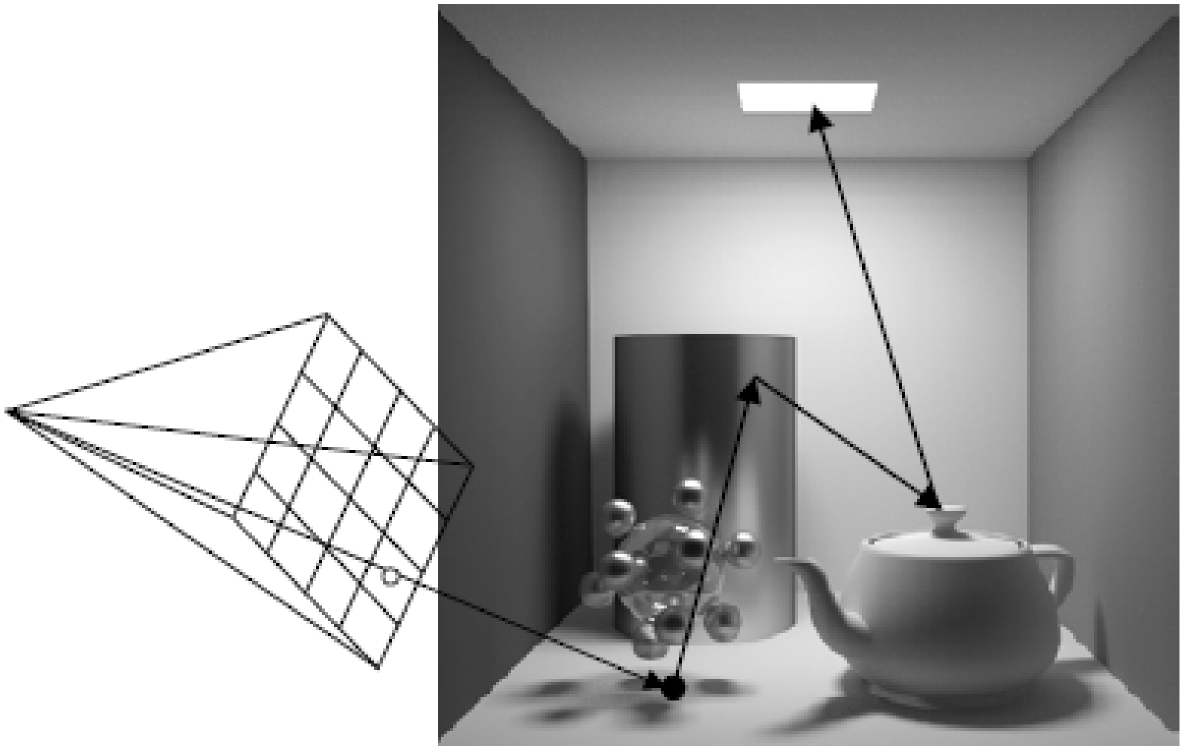
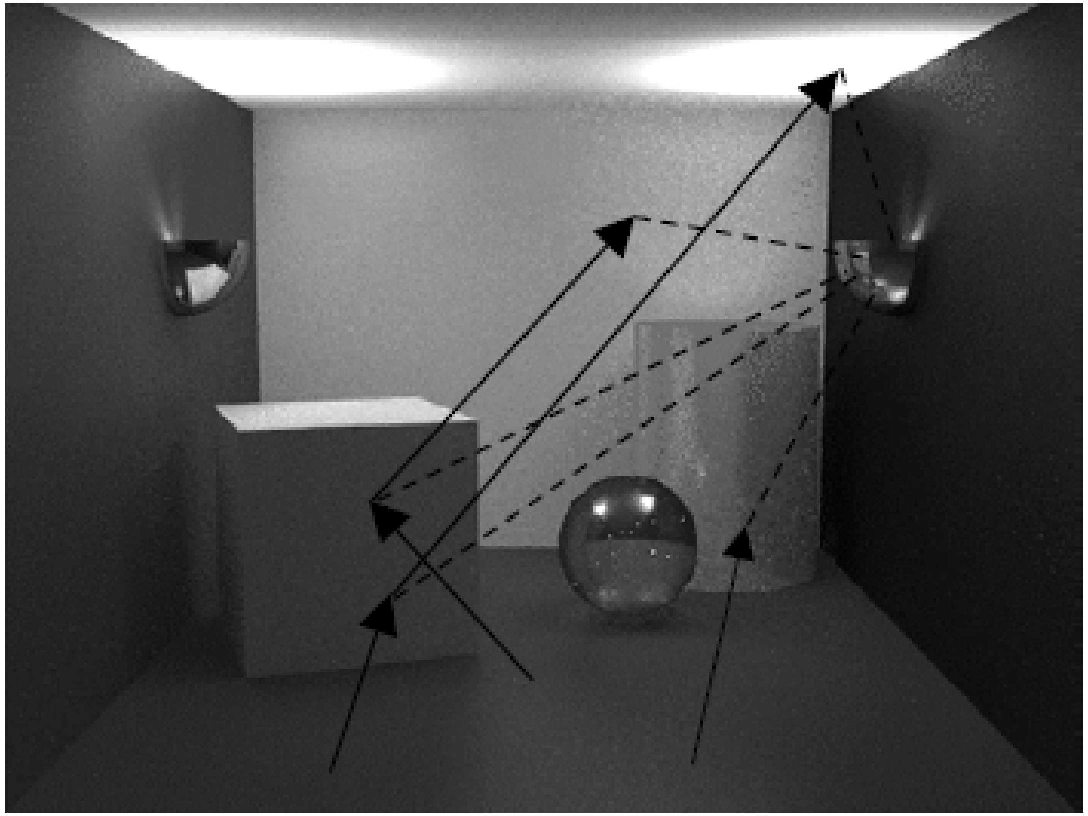
# Stochastic ray tracing: limitations

- Generate a path from the eye to the light source



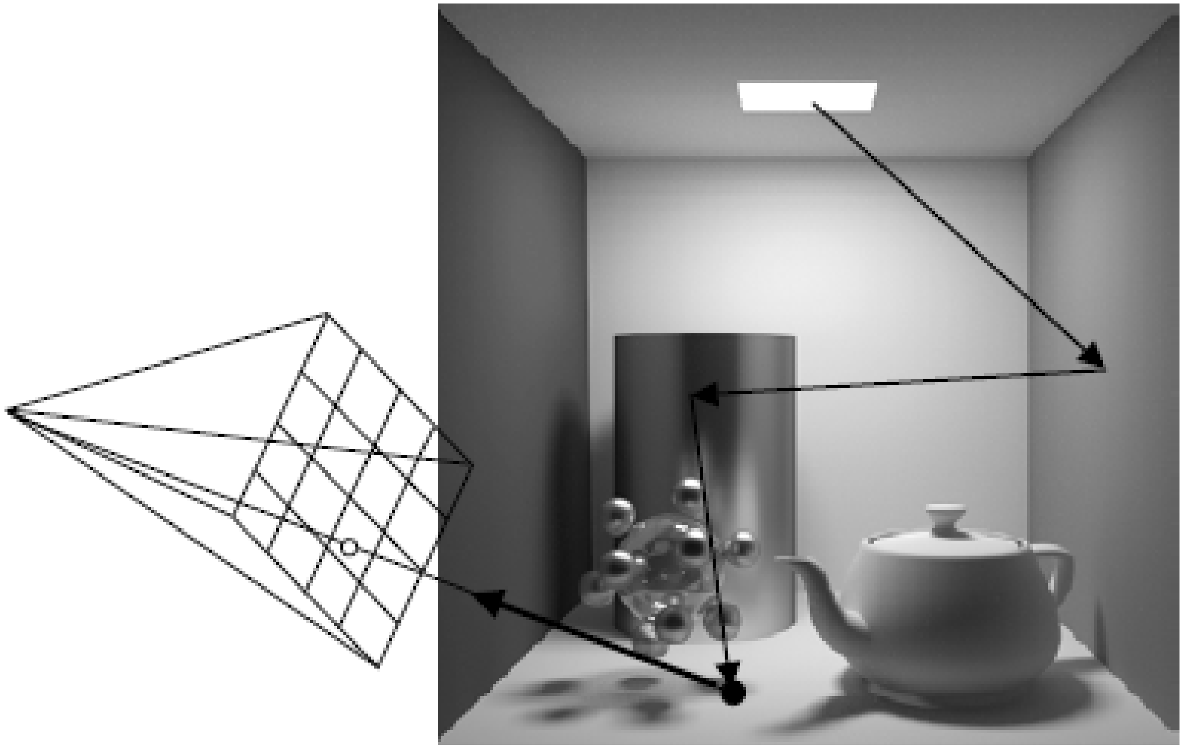
# When does it not work?

- Scenes in which indirect lighting dominates



# Bidirectional Path Tracing

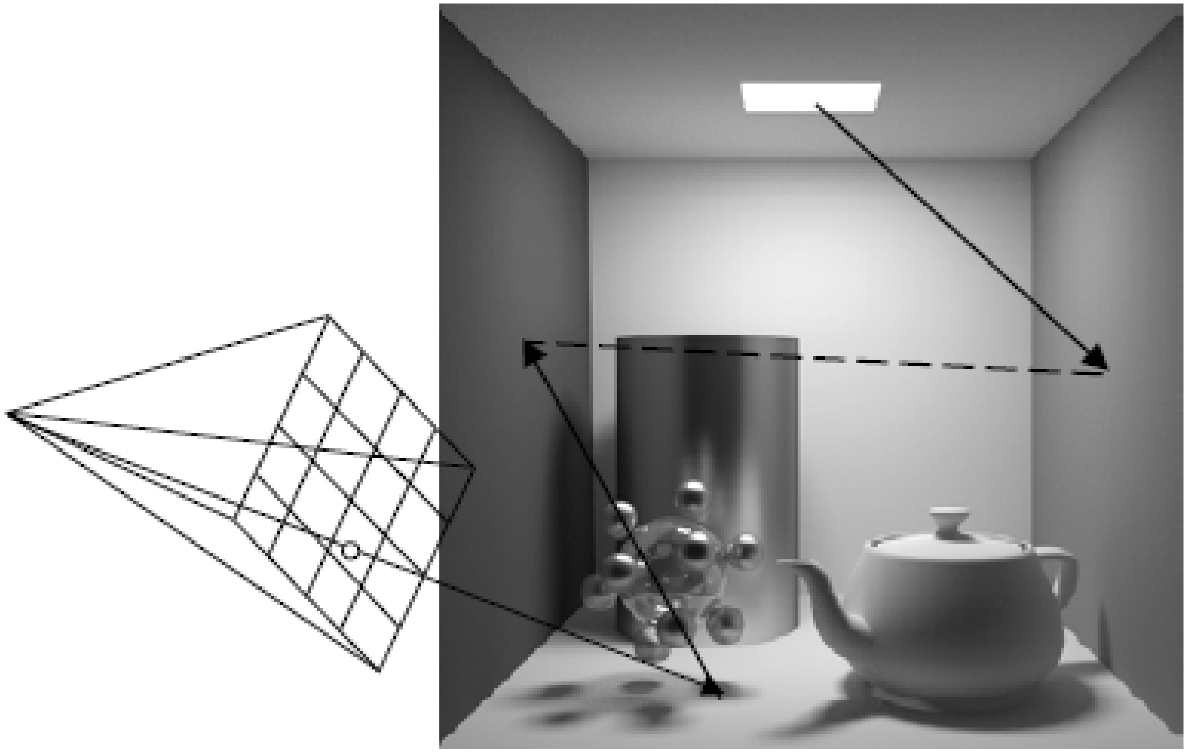
- So … we can generate paths starting from the light sources!



- Shoot ray to camera to see what pixels get contributions

# Bidirectional Path Tracing

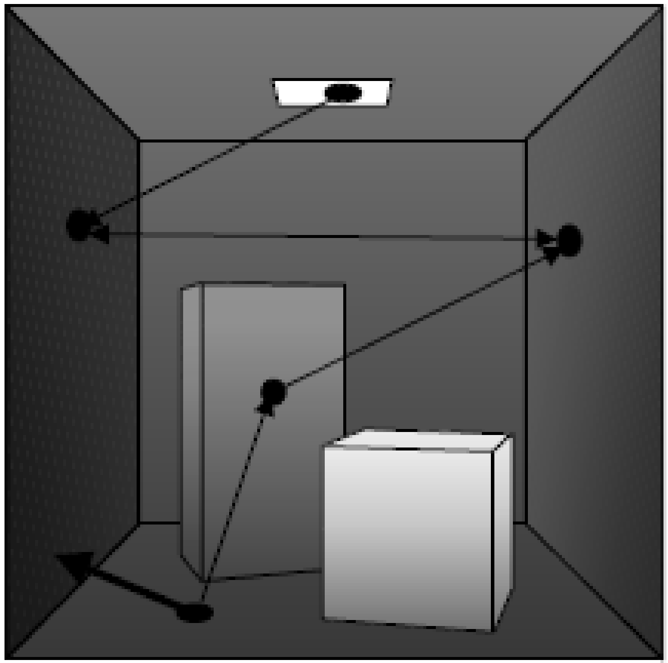
- Or paths generated from both camera and source at the same time ...!



- Connect endpoints to compute final contribution

# Complex path generators

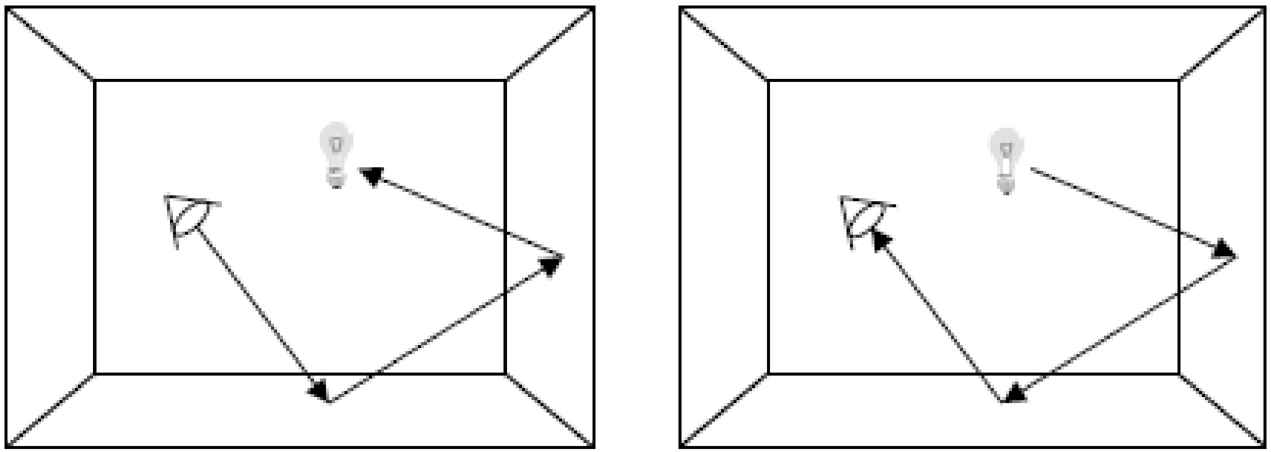
- Bidirectional ray tracing
  – shoot a path from light source
  – shoot a path from receiver
  – connect end points



# Why? BRDF - Reciprocity

- Direction in which path is generated, is not important: Reciprocity

$$f(\Psi \rightarrow \Theta) = f(\Theta \rightarrow \Psi) = f(\Psi \leftrightarrow \Theta)$$



- Algorithms:
  - trace rays from the eye to the light source
  - trace rays from light source to eye
  - any combination of the above

# Bidirectional ray tracing

- Parameters
  - eye path length = 0: shooting from source
  - light path length = 0: gathering at receiver
- When useful?
  - Light sources difficult to reach
  - Specific brdf evaluations (e.g., caustics)

# Other Rendering Techniques

- **Metropolis**

- **Biased techniques**
  - **Irradiance caching**
  - **Photon mapping**

# Metropolis

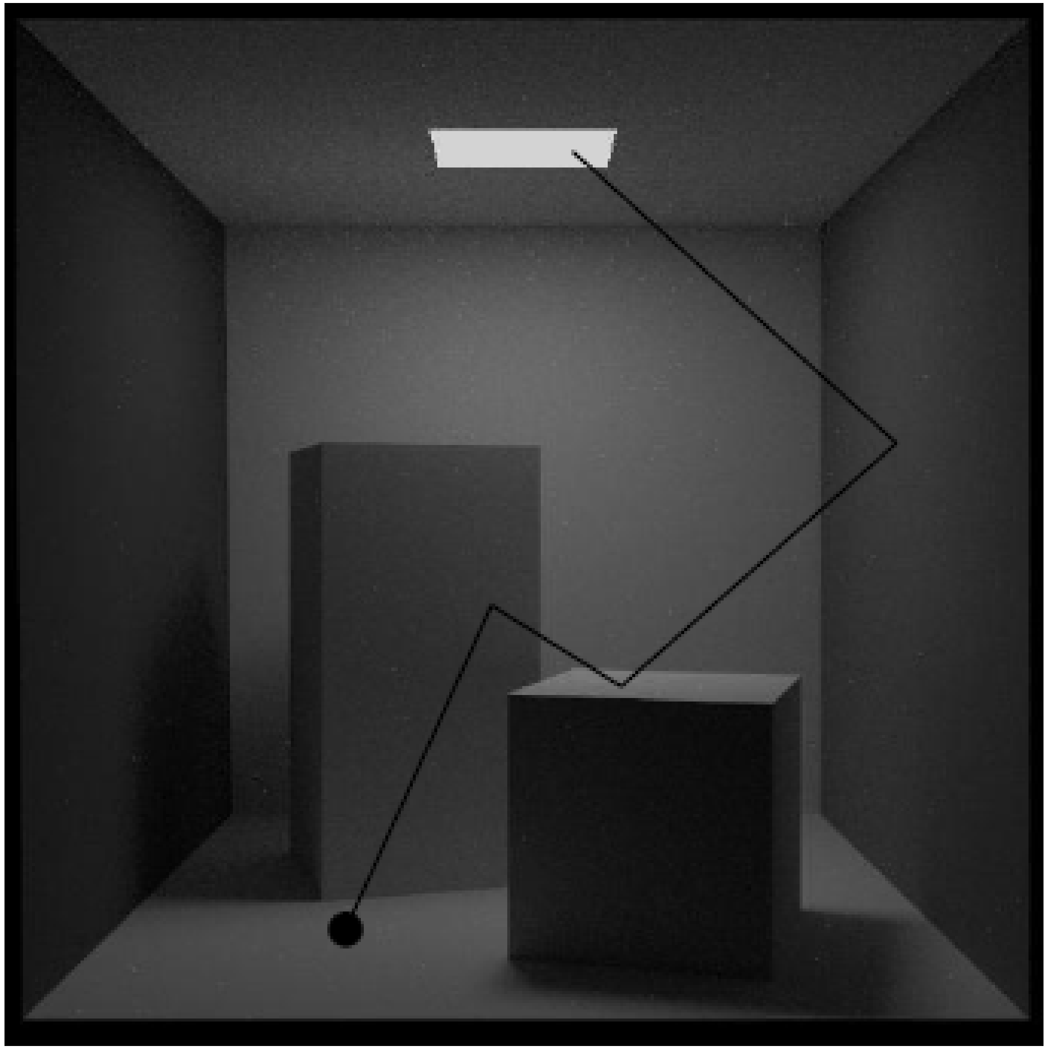
- Based on Metropolis sampling (1950's)
  - Introduced by Veach and Guibas to CG

- Deals with hard to find light paths
  - Robust
- Hairy math, but it works
  - Not that easy to implement

# Metropolis

- **Generate paths**
- **Once a valid path is found, mutate it to generate new valid paths**

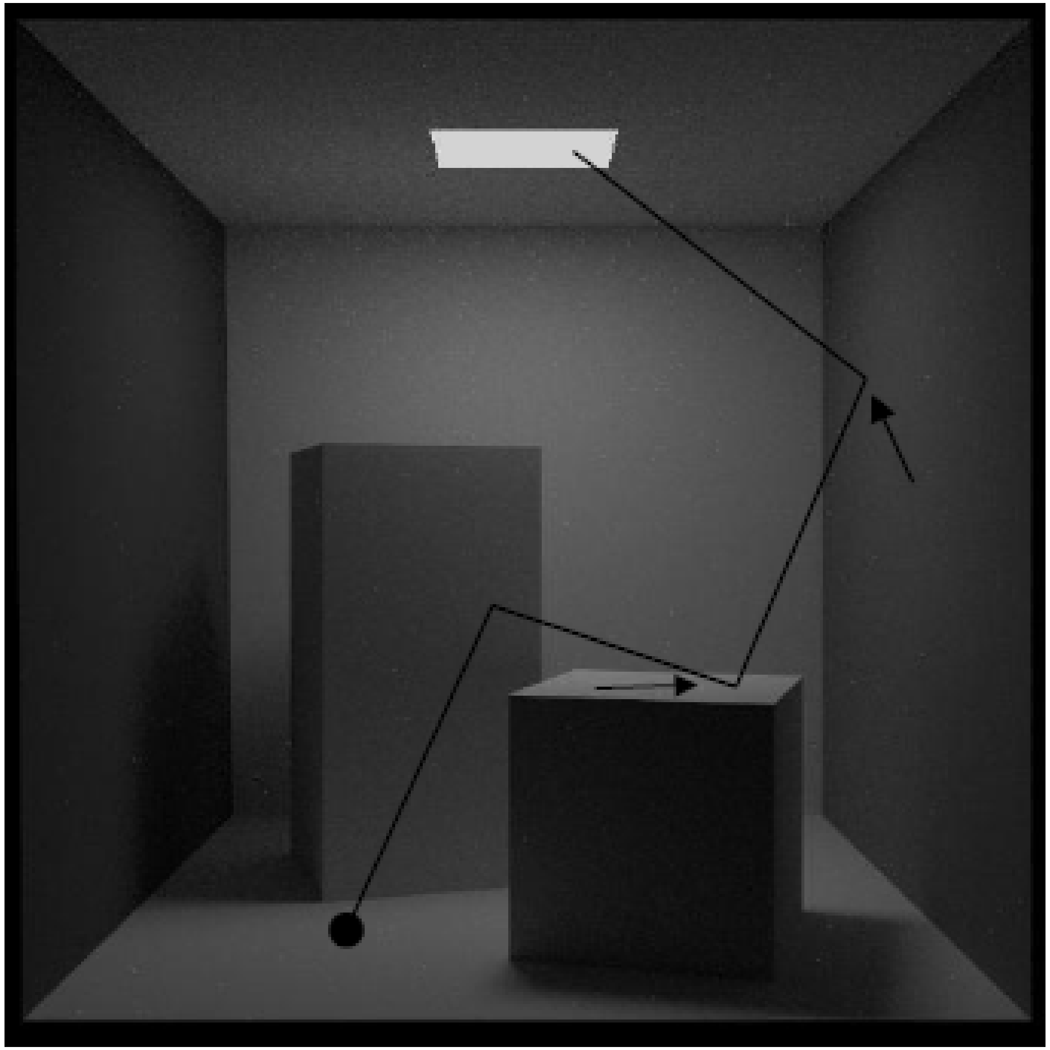
# Metropolis





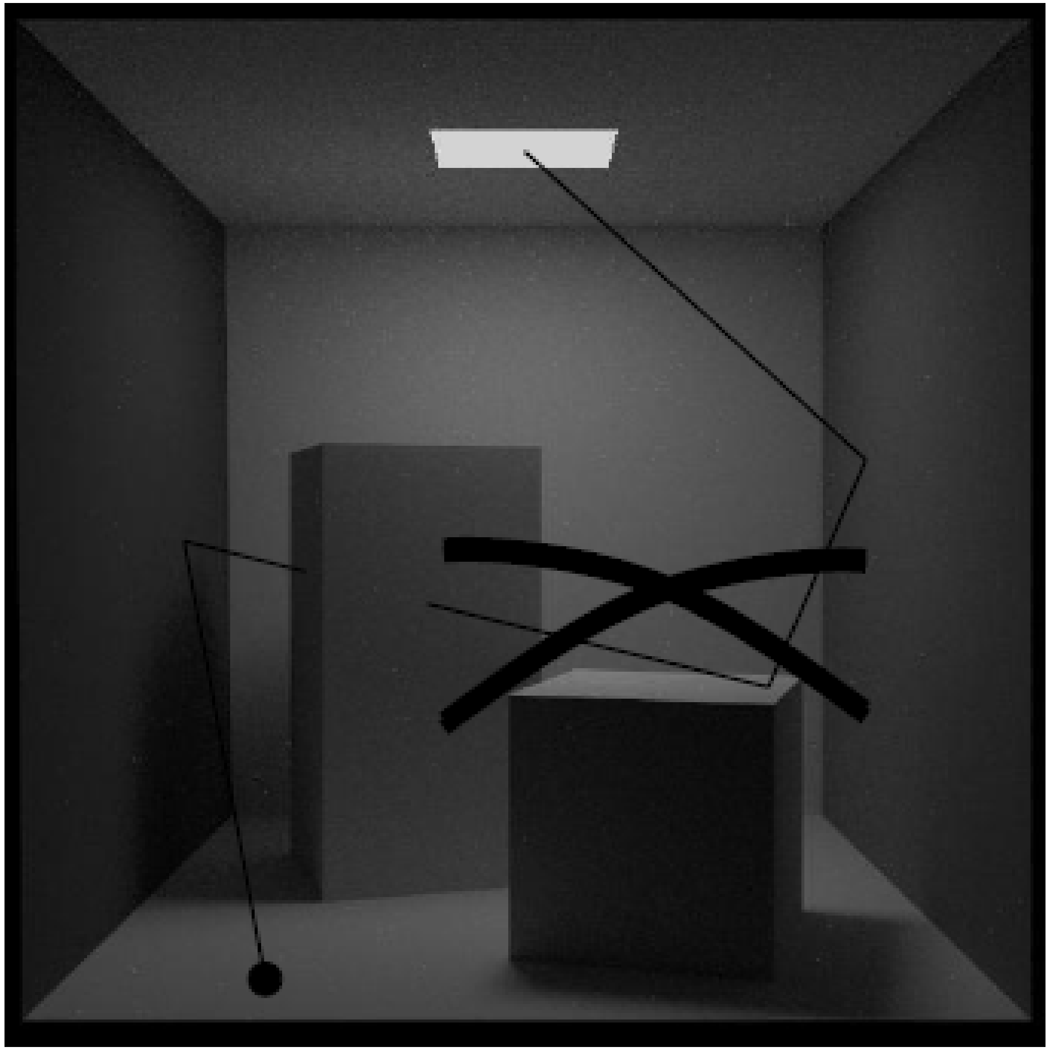
valid path

# Metropolis



small perturbations

# Metropolis



Accept mutations based on energy transport

# Metropolis

- **Advantages**
  - **Robust**
  - **Good for hard to find light paths; use local exploration, and once a good path is found, mutate it to find other such paths**

- **Disadvantage**
  - **Slow convergence for many important paths**
  - **Tricky to implement and get right**

# Unbiased vs. Consistent

- **Unbiased**
  - **No systematic error**
  - $E[I_{estimator}] = I$
  - **Better results with larger N**

- **Consistent**
  - **Converges to correct results with more samples**
  - $E[I_{estimator}] = I + \varepsilon$, **where** $\lim_{n \to \infty} \varepsilon = 0$

# Biased Methods

- **MC methods**
  - **Too noisy and slow**
  - **Nose is objectionable**

- **Biased methods: store information (caching)**
  - **Irradiance caching**
  - **Photon mapping**

# Irradiance Caching

- Introduced by Greg Ward 1988
- Implemented in RADIANCE
  - Public-domain software
- Exploits smoothness of irradiance
  - Cache and interpolate irradiance estimates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# Irradiance Caching

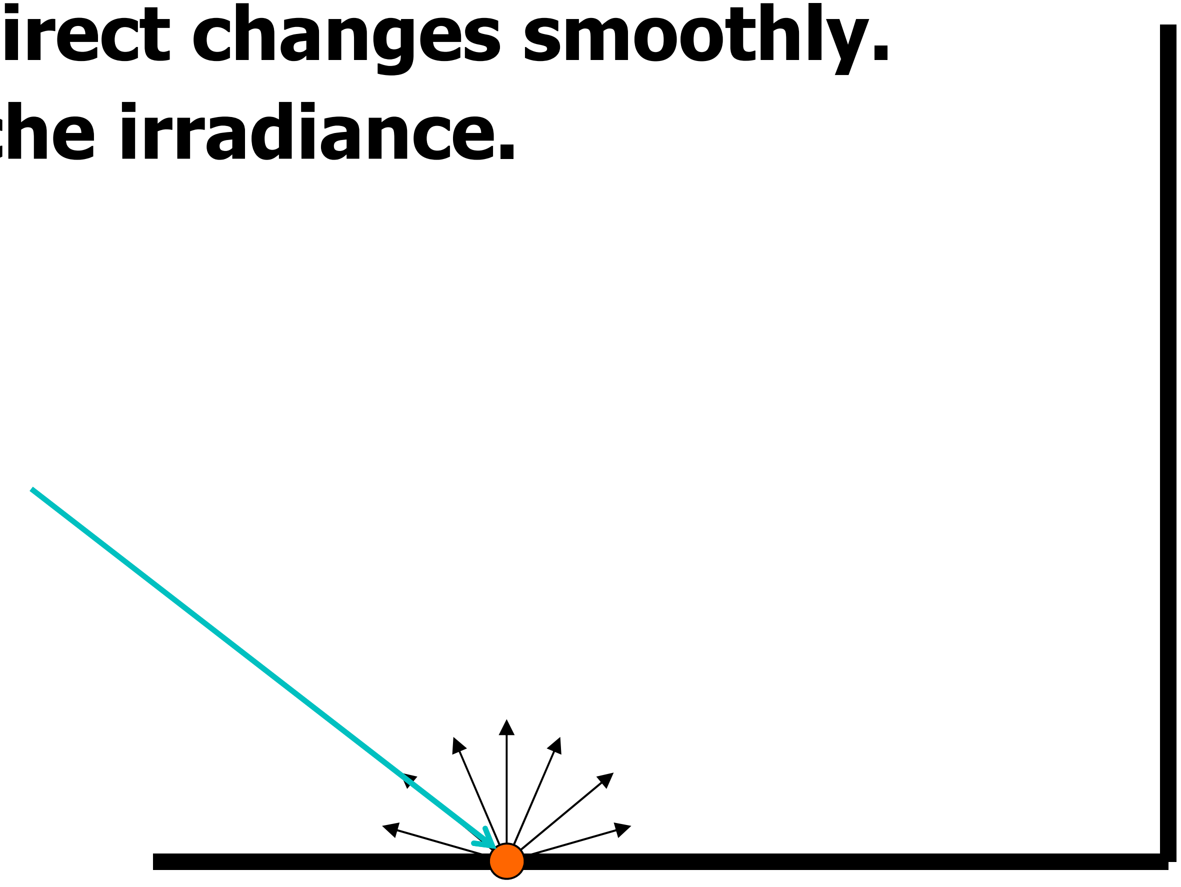
- Indirect changes smoothly.



From Wang's slides

# Irradiance Caching

- Indirect changes smoothly.
- Cache irradiance.

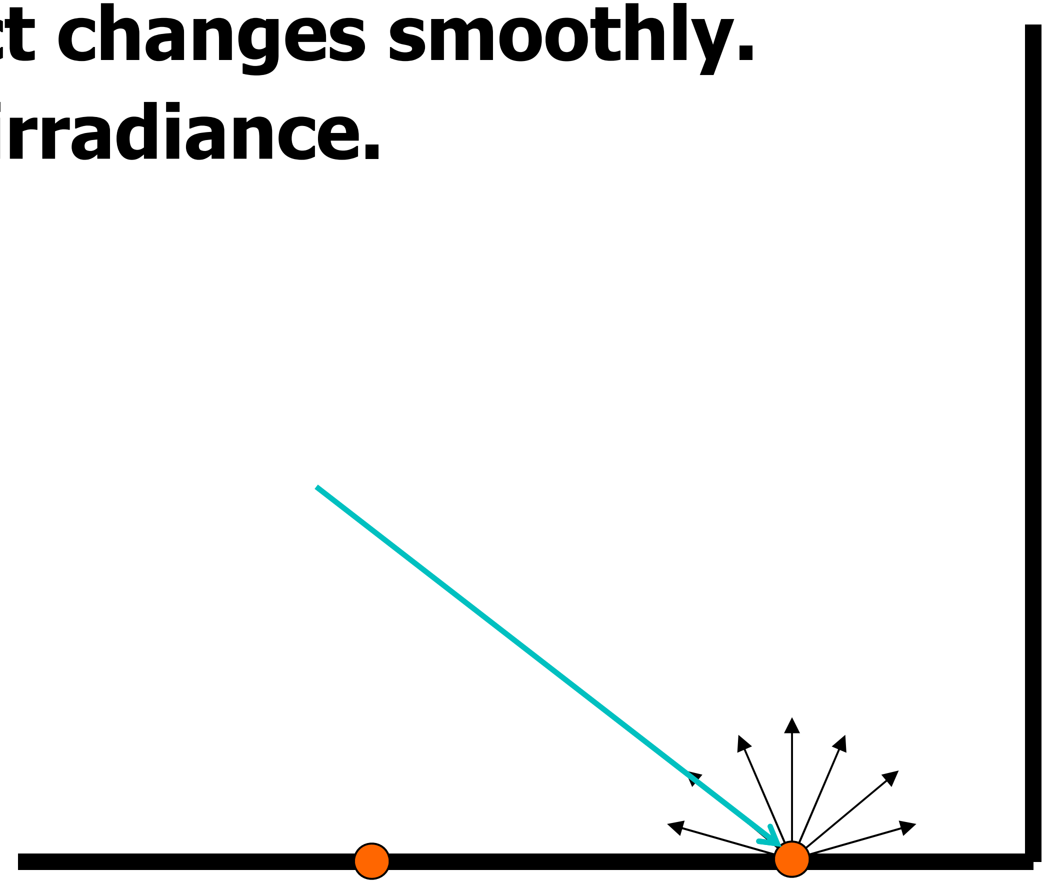




From Wang's slides

# Irradiance Caching

- Indirect changes smoothly.
- Cache irradiance.

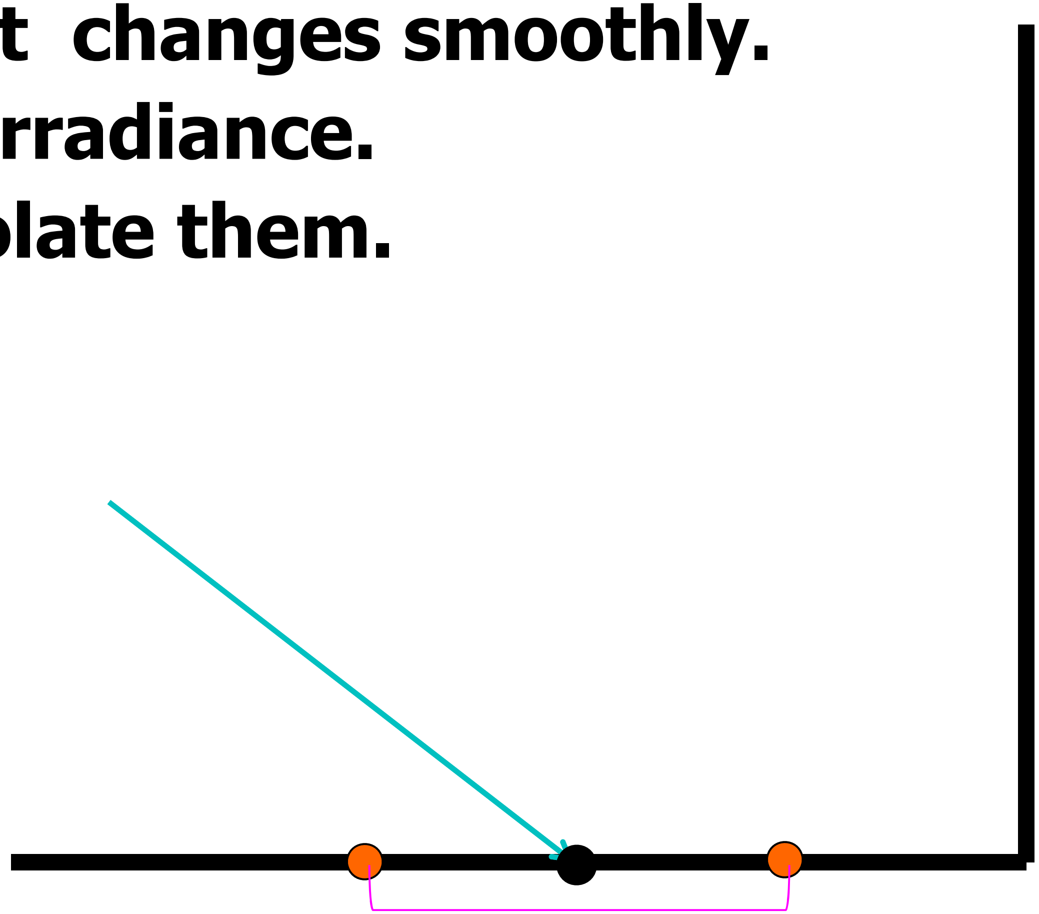




From Wang's slides

# Irradiance Caching

- Indirect  changes smoothly.
- Cache irradiance.
- Interpolate them.





From Wang's slides

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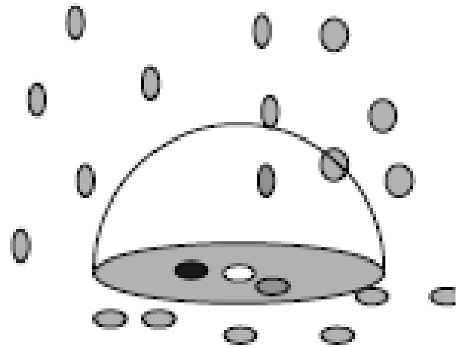
# Irradiance Caching Approach

- **Irradiance E(x) estimated using MC**
- **Cache irradiance when possible**
  - **Store in octree for fast access**
- **When do we use this cache of irradiance values?**

# Smoothness Measure

- When new sample requested
  - Query octree for samples near location
  - Check ε at x, $x_i$ is a nearby sample



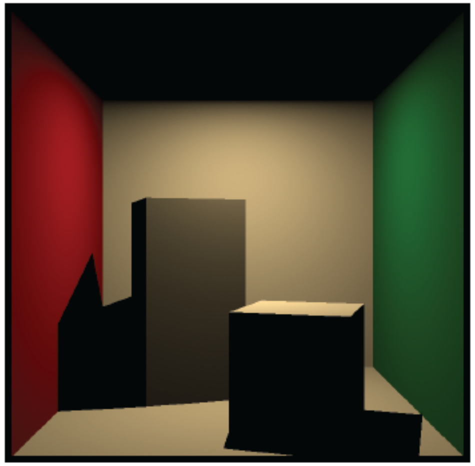
$$\varepsilon_i(x,\vec{n}) = \frac{\| x_i - x \|}{R_i} + \sqrt{1 - \vec{n} \bullet \vec{n}_i}$$

  - Weight samples inversely proportional to $\varepsilon_i$

$$E(x,\vec{n}) = \frac{\sum_{i, w_i > 1/a} w_i(x,\vec{n}) E_i(x_i)}{\sum_{i, w_i > 1/a} w_i(x,\vec{n})}$$

  - Otherwise, compute new sample

Direct Indirect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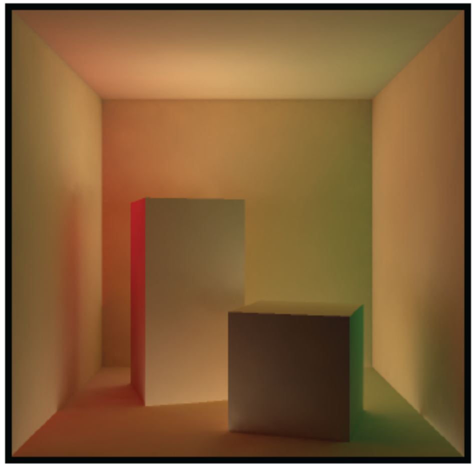
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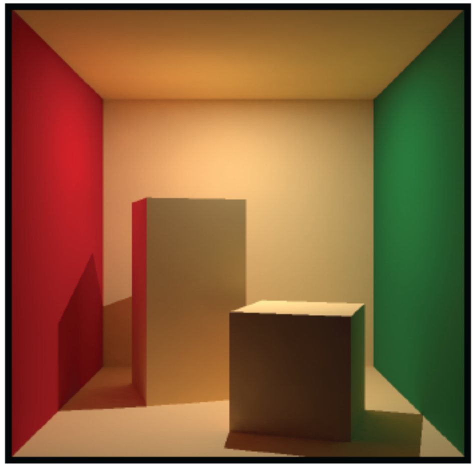
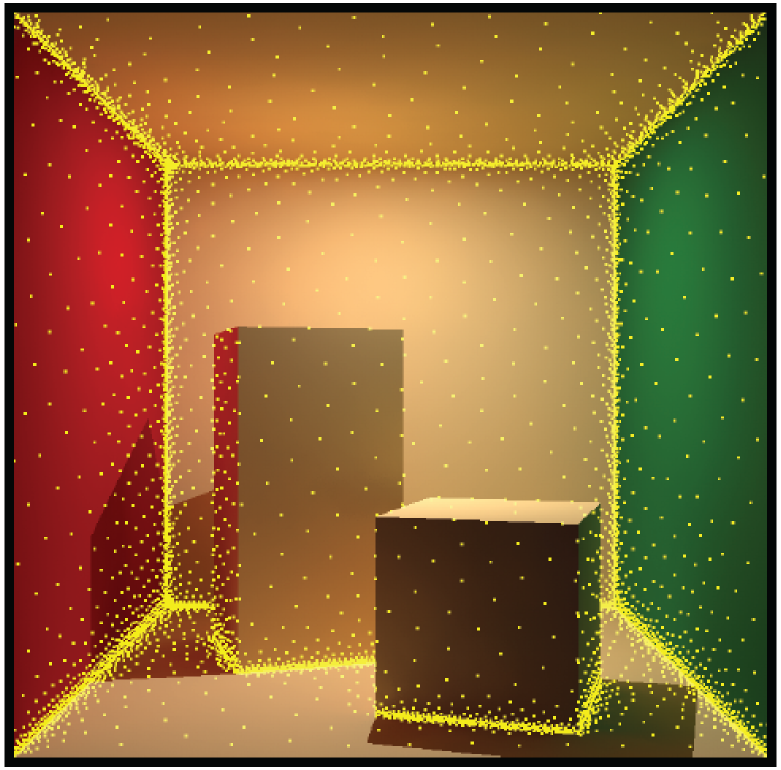


Indirect ≈ 



From thesis of Jarosz

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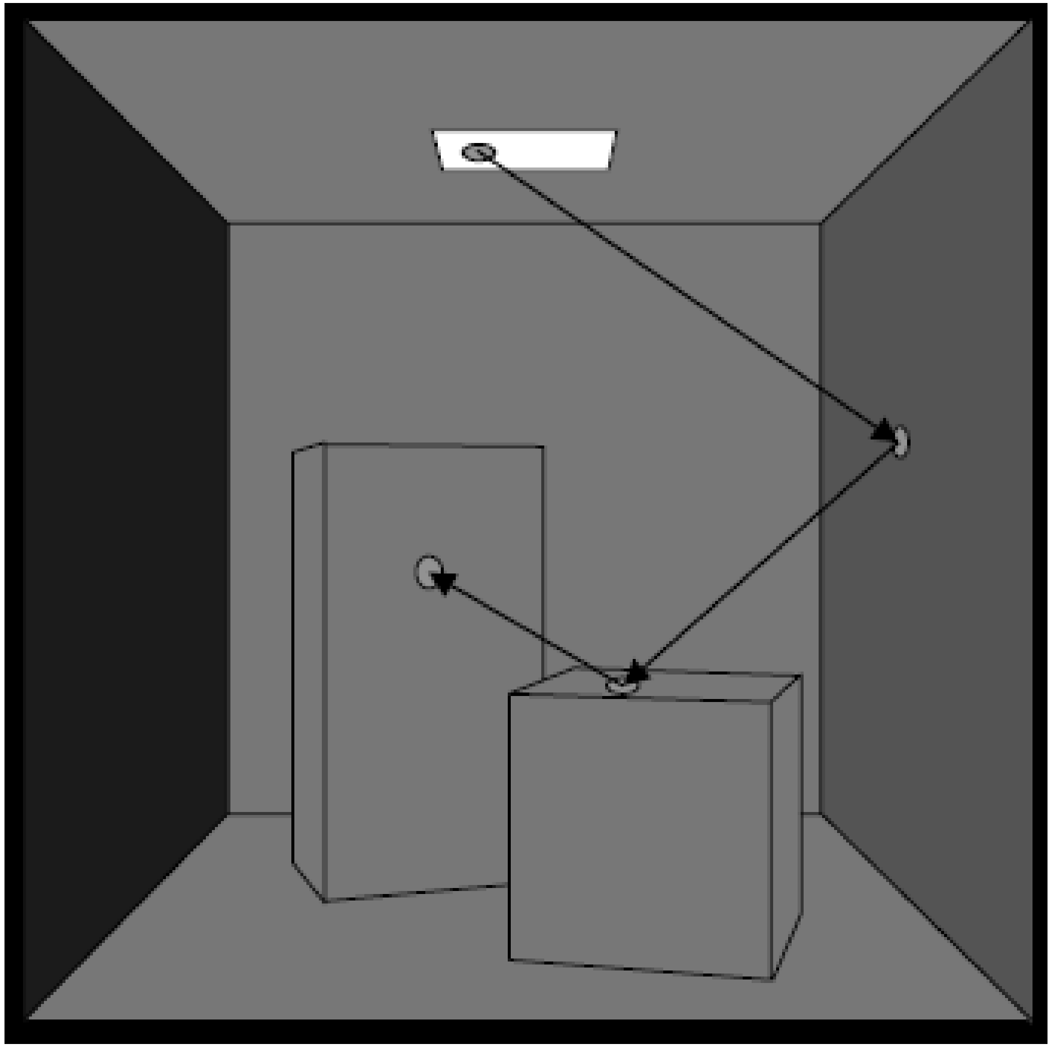
# Photon Mapping

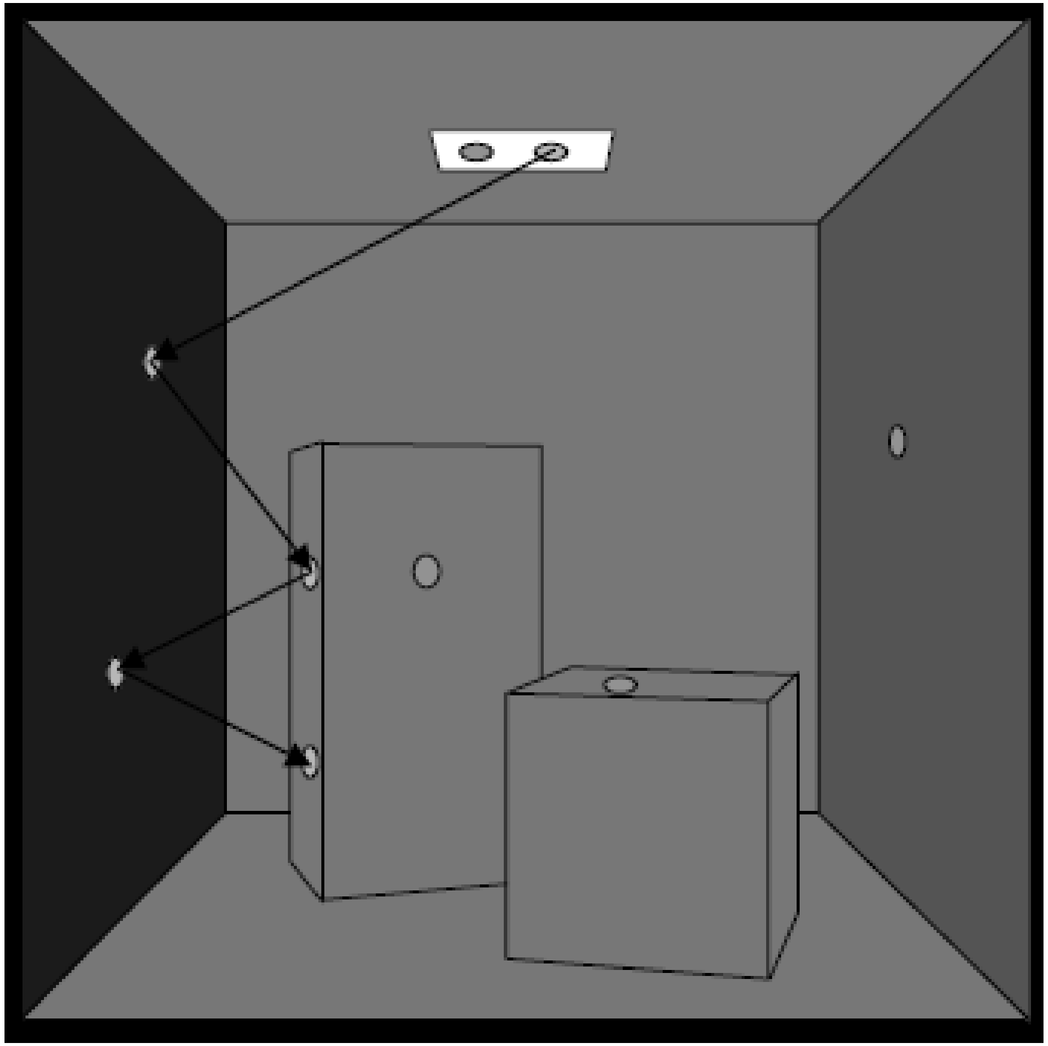
- 2 passes:
  - Shoot “photons” (light-rays) and record any hit-points
  - Shoot viewing rays and collect information from stored photons

# Pass 1: shoot photons



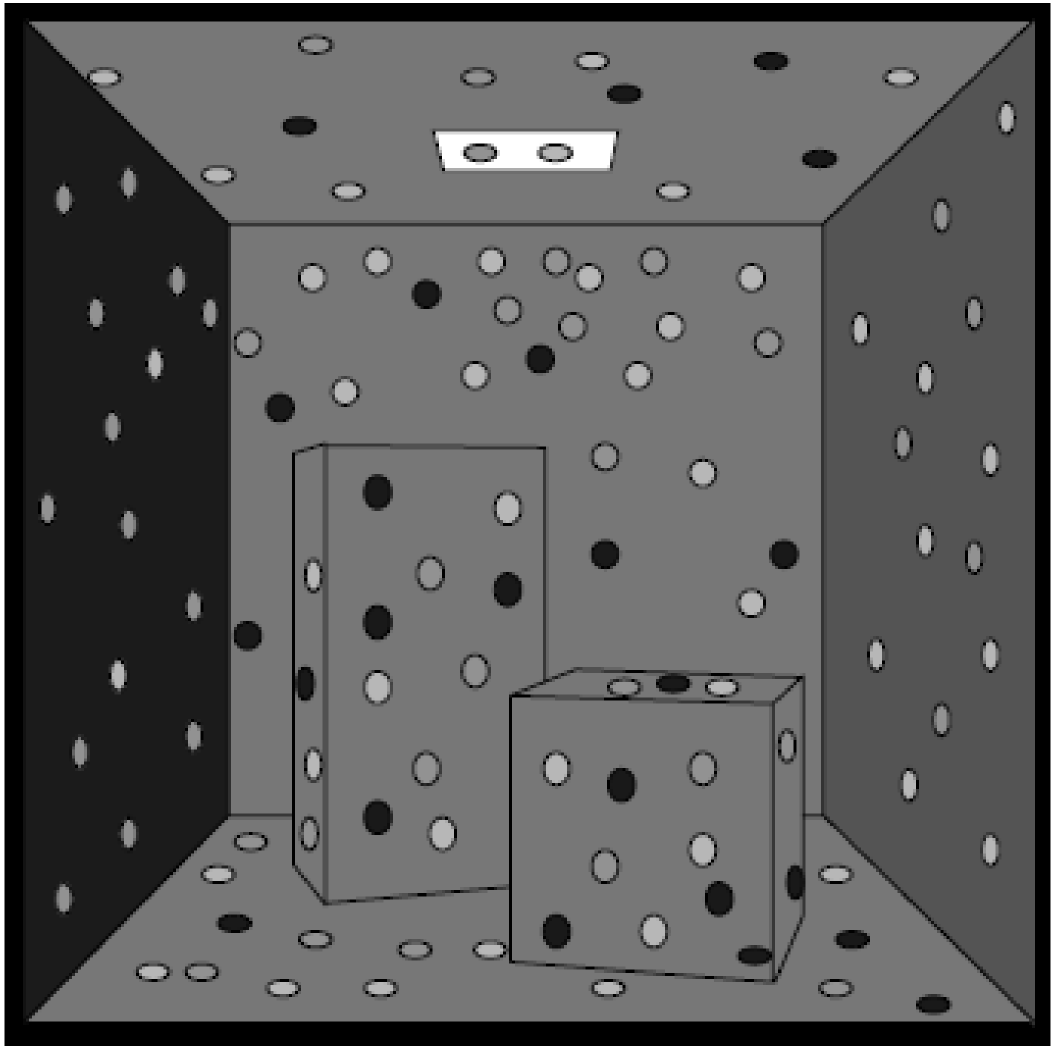
- Light path generated using MC techniques and Russian Roulette
- Store:
  - position
  - incoming direction
  - color
  - ...

# Pass 1: shoot photons



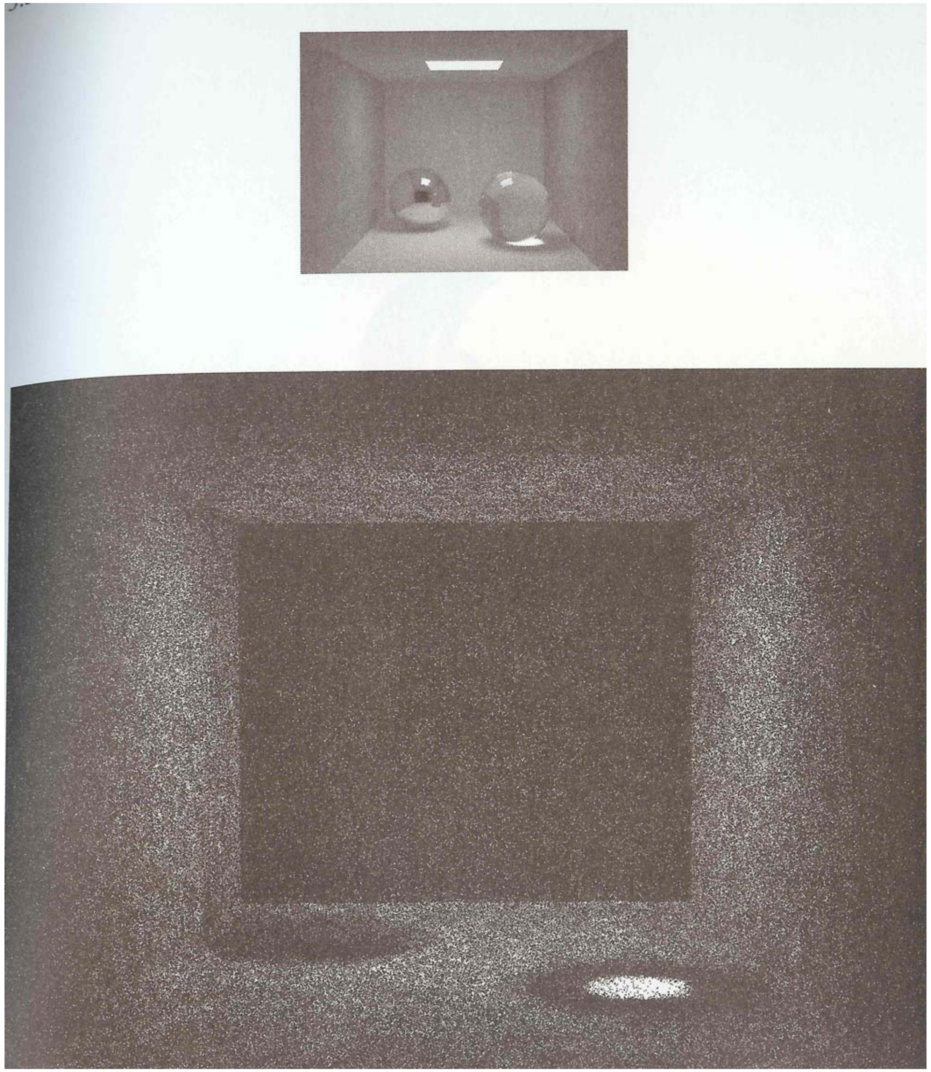
- Light path generated using MC techniques and Russian Roulette
- Store: **Flux for each photon**
  - position
  - incoming direction
  - color
  - ...

# Pass 1: shoot photons



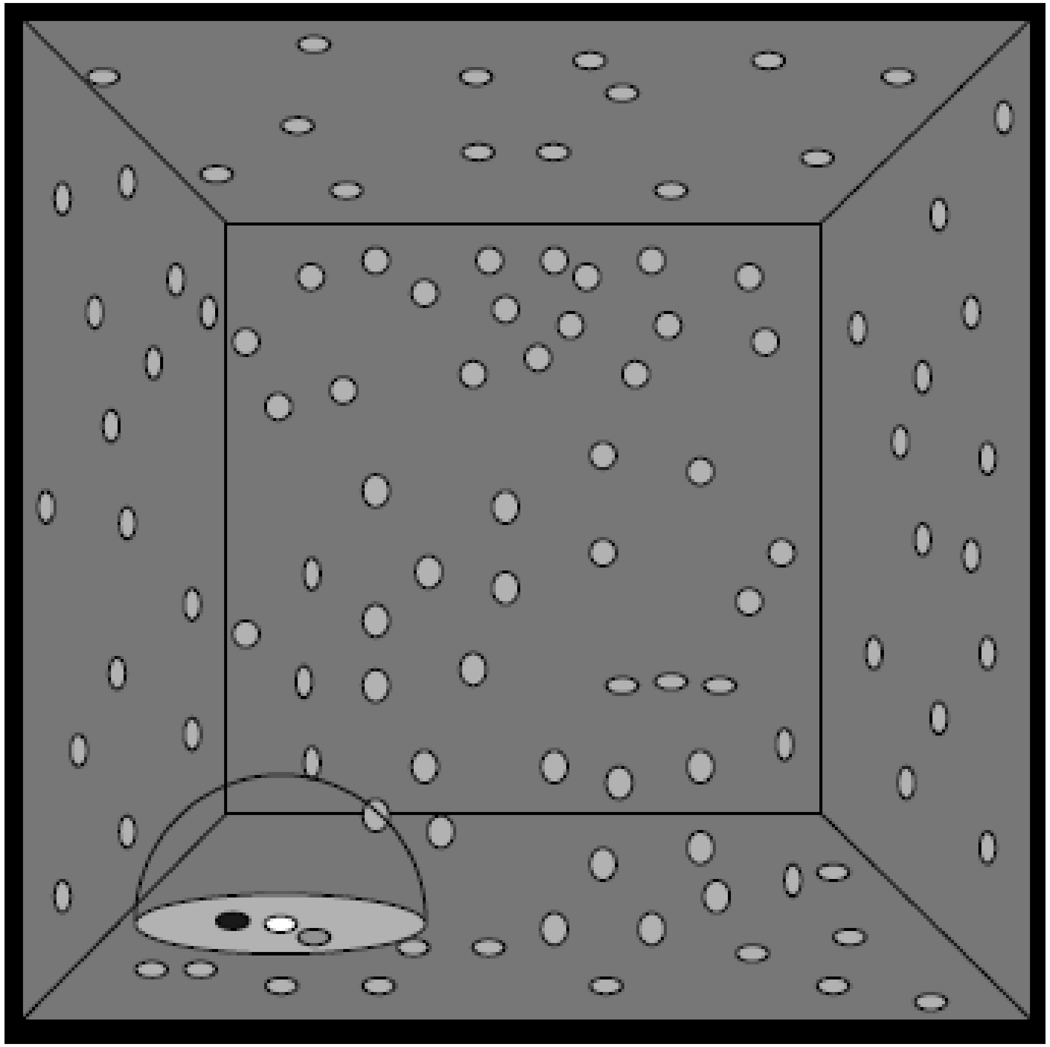
- Light path generated using MC techniques and Russian Roulette
- Store: **for diffuse materials**
  - position
  - incoming direction
  - color
  - …

# Stored Photons



**Generate a few hundreds of thousands of photons**

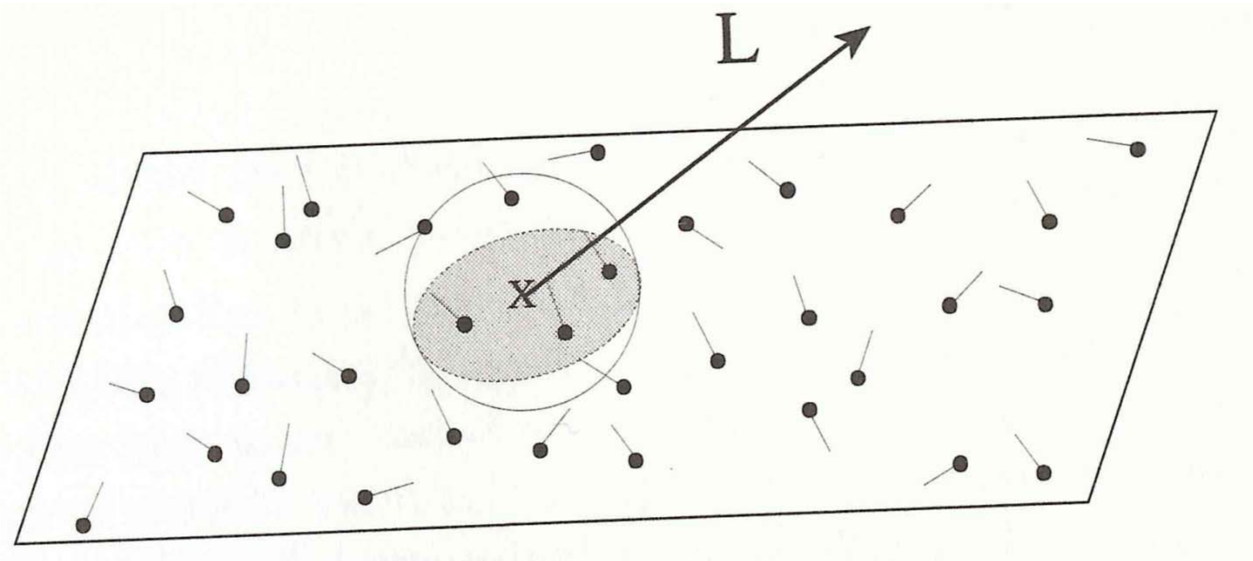
# Pass 2: viewing ray



- Search for N closest photons (+check normal)
- Assume these photons hit the point we're interested in
- Compute average radiance

# Radiance Estimation

- Compute N nearest photons
  - Consider a few hundreds of photons
  - Compute the radiance for each photon to outgoing direction
  - Consider BRDF and
  - Divided by area

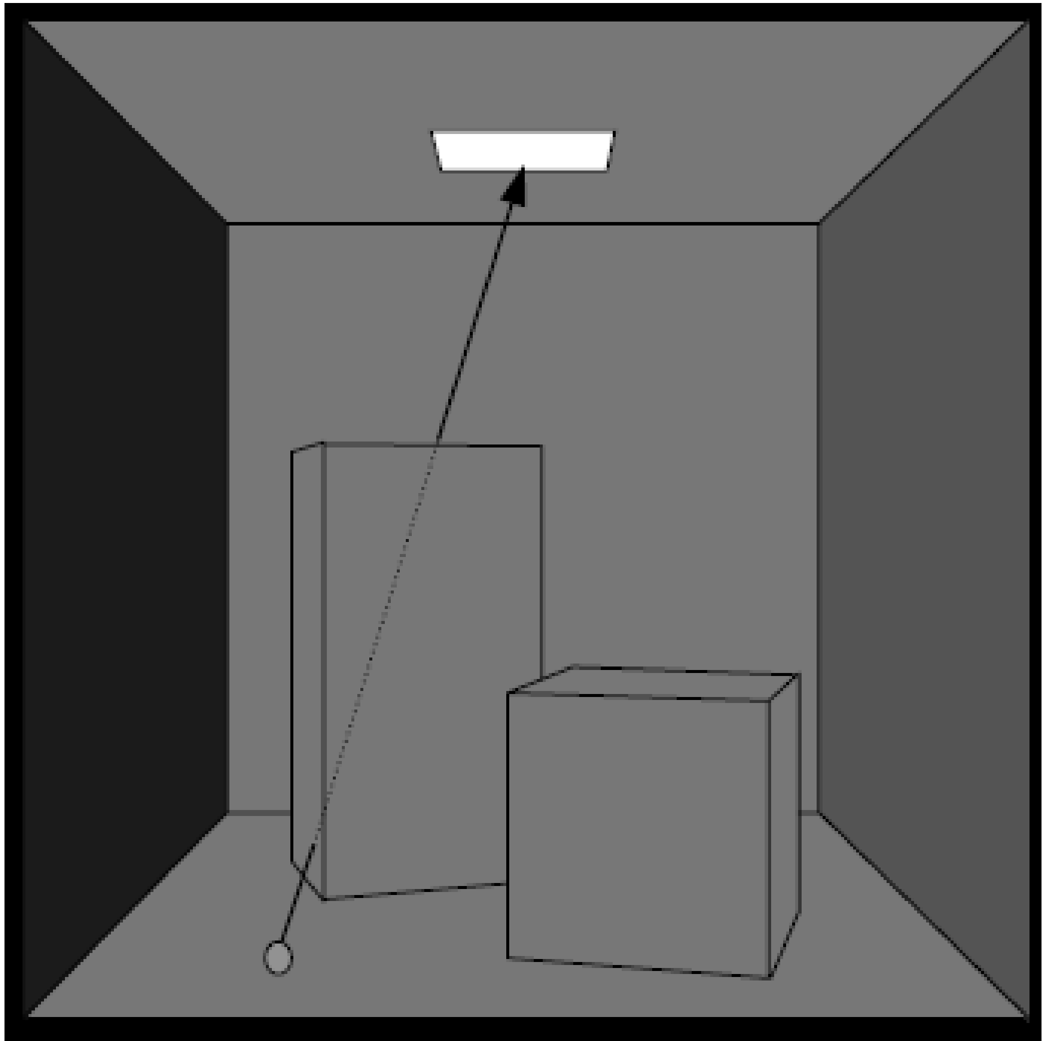


# Efficiency

- **Want k nearest photons**
  - **Use kd-tree**

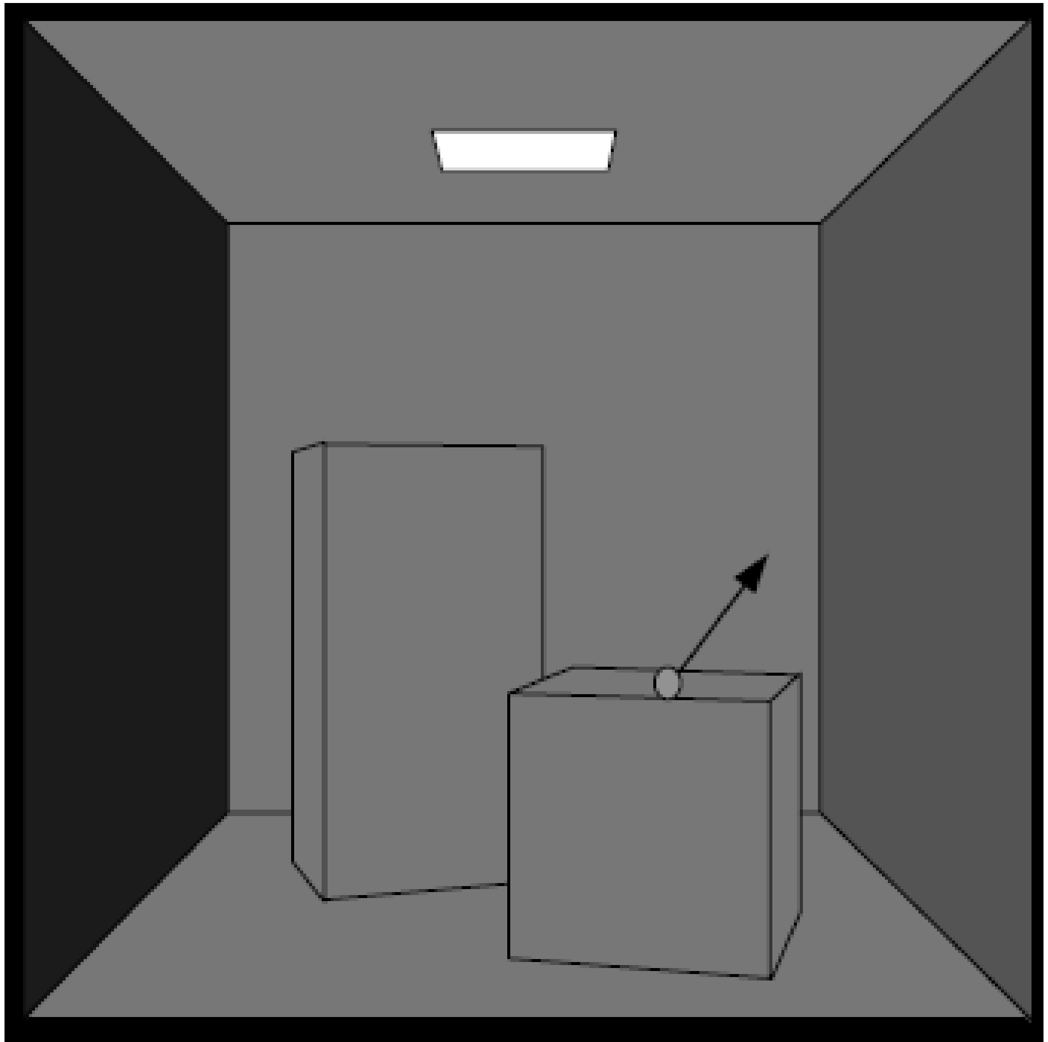
- **Using photon maps as it create noisy images**
  - **Need extremely large amount of photons**

# Pass 2: Direct Illumination




**Perform direct illumination for visible surface using regular MC sampling**

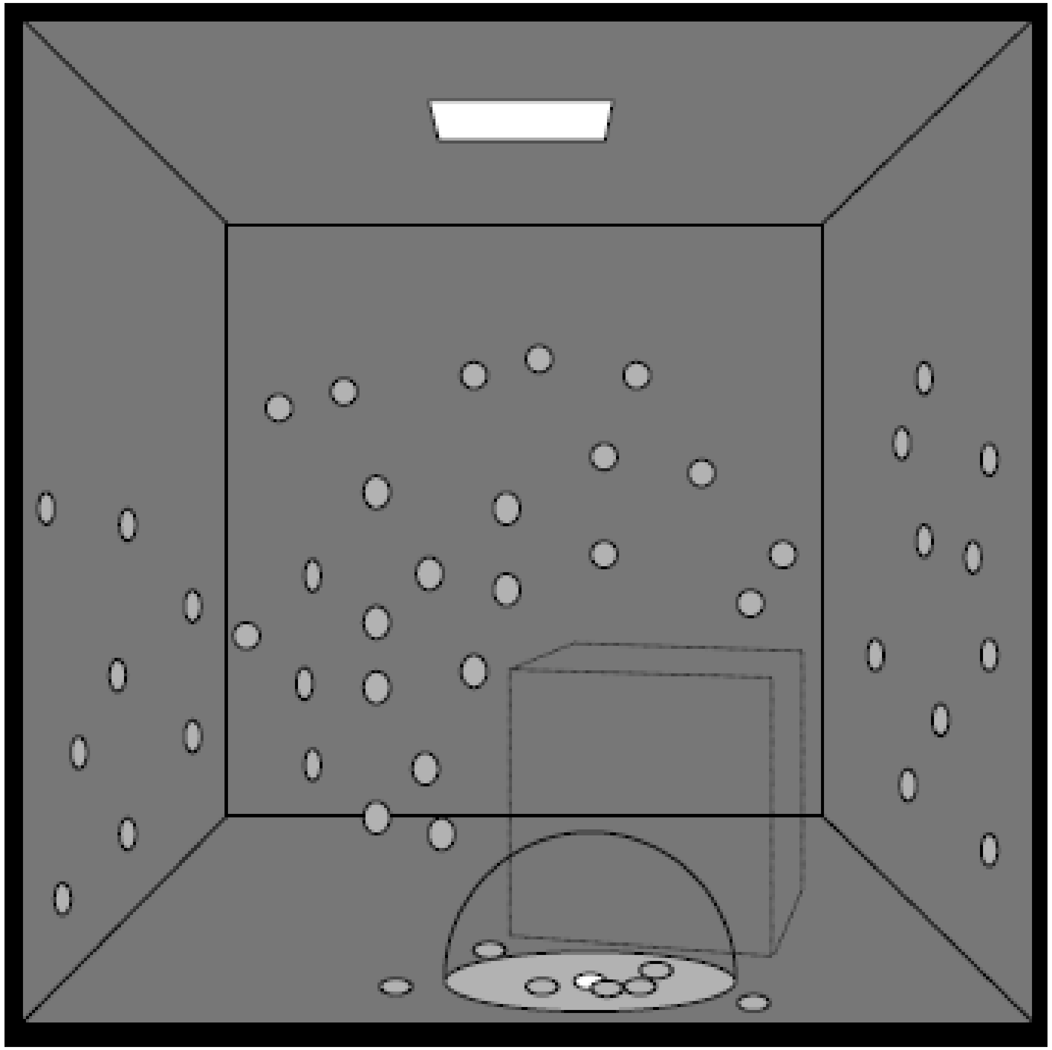
# Pass 2: Specular reflections





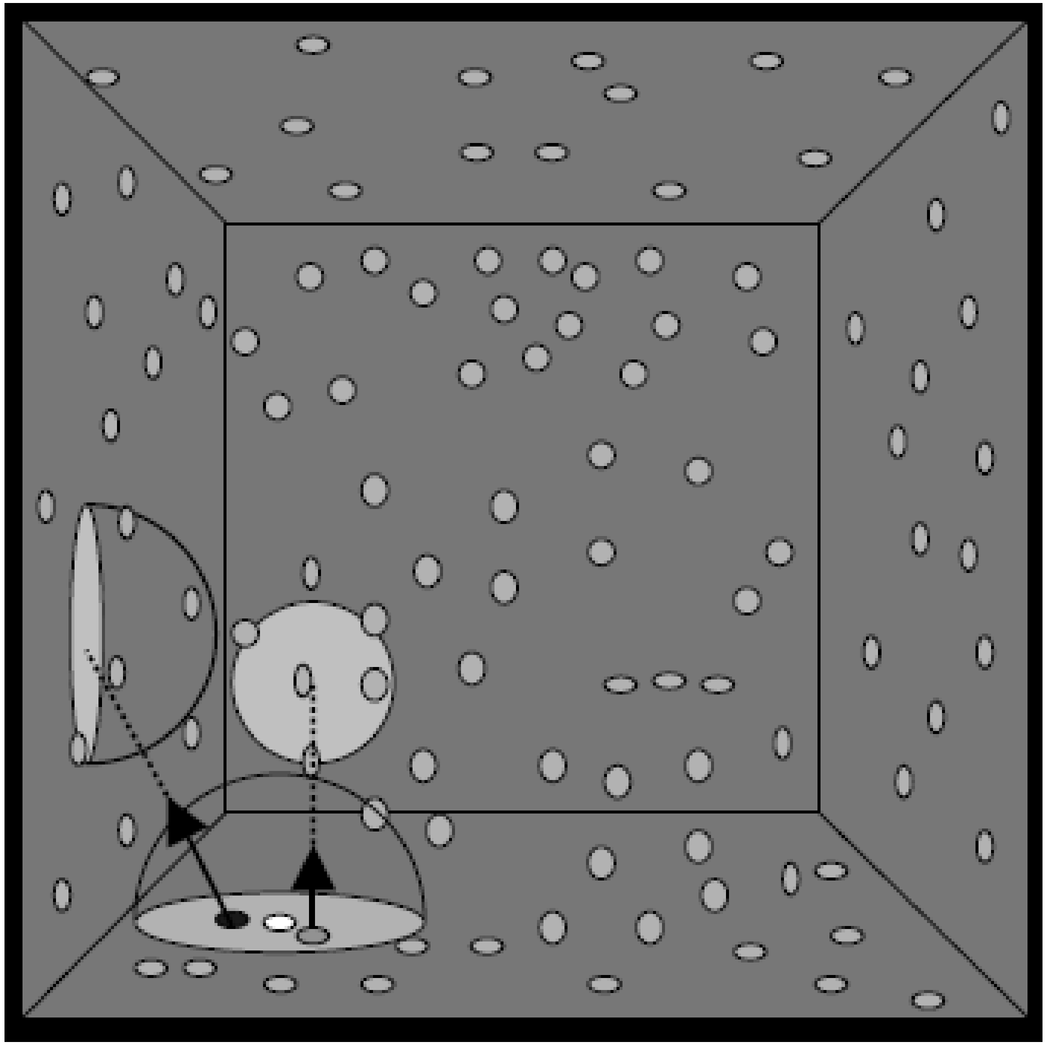
**Specular reflection and transmission are ray traced**

# Pass 2: Caustics



- Direct use of "caustic" maps
- The "caustic" map is similar to a photon map but treats LS*D path
- Density of photons in caustic map usually high enough to use as is

# Pass 2:Indirect Diffuse



- Search for N closest photons
- Assume these photons hit the point
- Compute average radiance by importance sampling of hemisphere

# Result


**350K photons for the caustic map**

# Progressive Photon Mapping [Hachisuka et al., SIG. A. 08]

- Photon mapping
  - A consistent algorithm and good at caustics and SDS paths
  - Requires huge # of photons to avoid noises


Img.blog.yahoo.co.kr/ybi

# Progressive Photon Mapping [Hachisuka et al., SIG. A. 08]

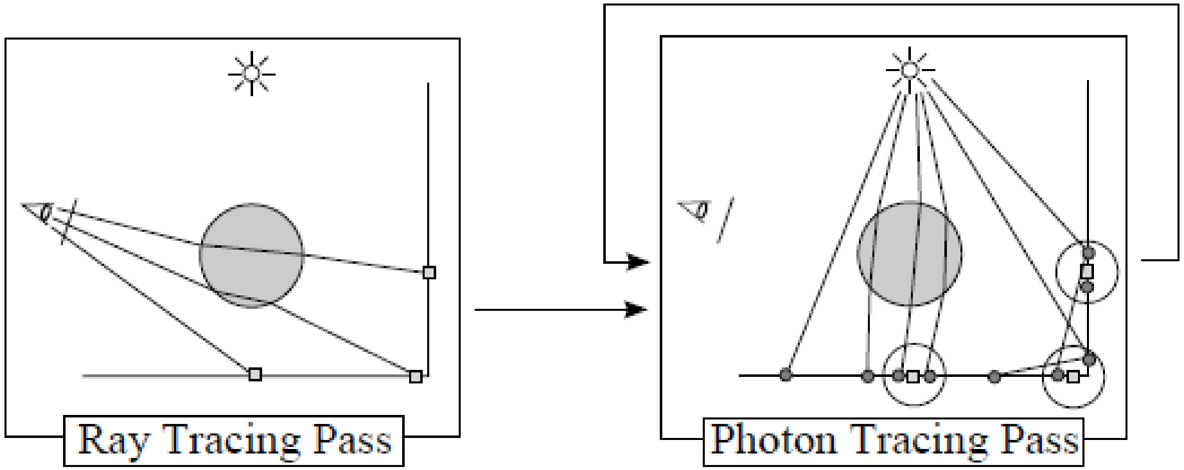
- Photon mapping
  - Requires huge # of photons to avoid noises
    - Its quality is limited by the available memory

Path tracing | Bidirectional path tracing | Metropolis light transport | Photon mapping | Progressive photon mapping

22 hours | 20M photons | 165M photons

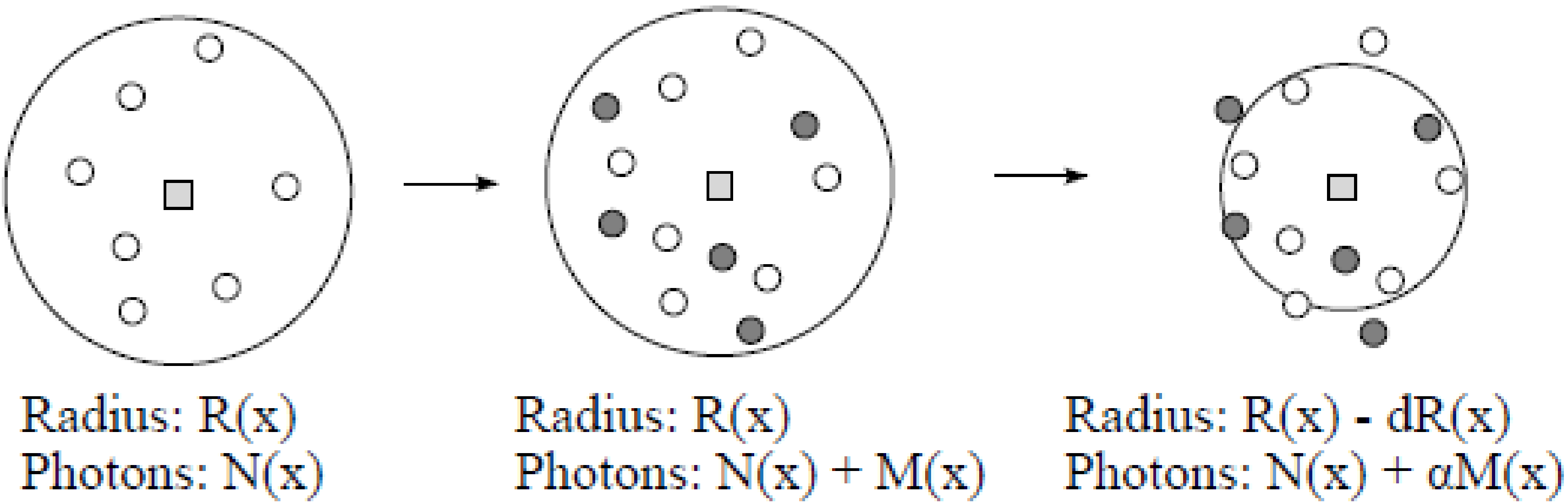
# Overall Framework

- Achieve arbitrary accuracy without requiring infinite memory
- Uses multiple phases



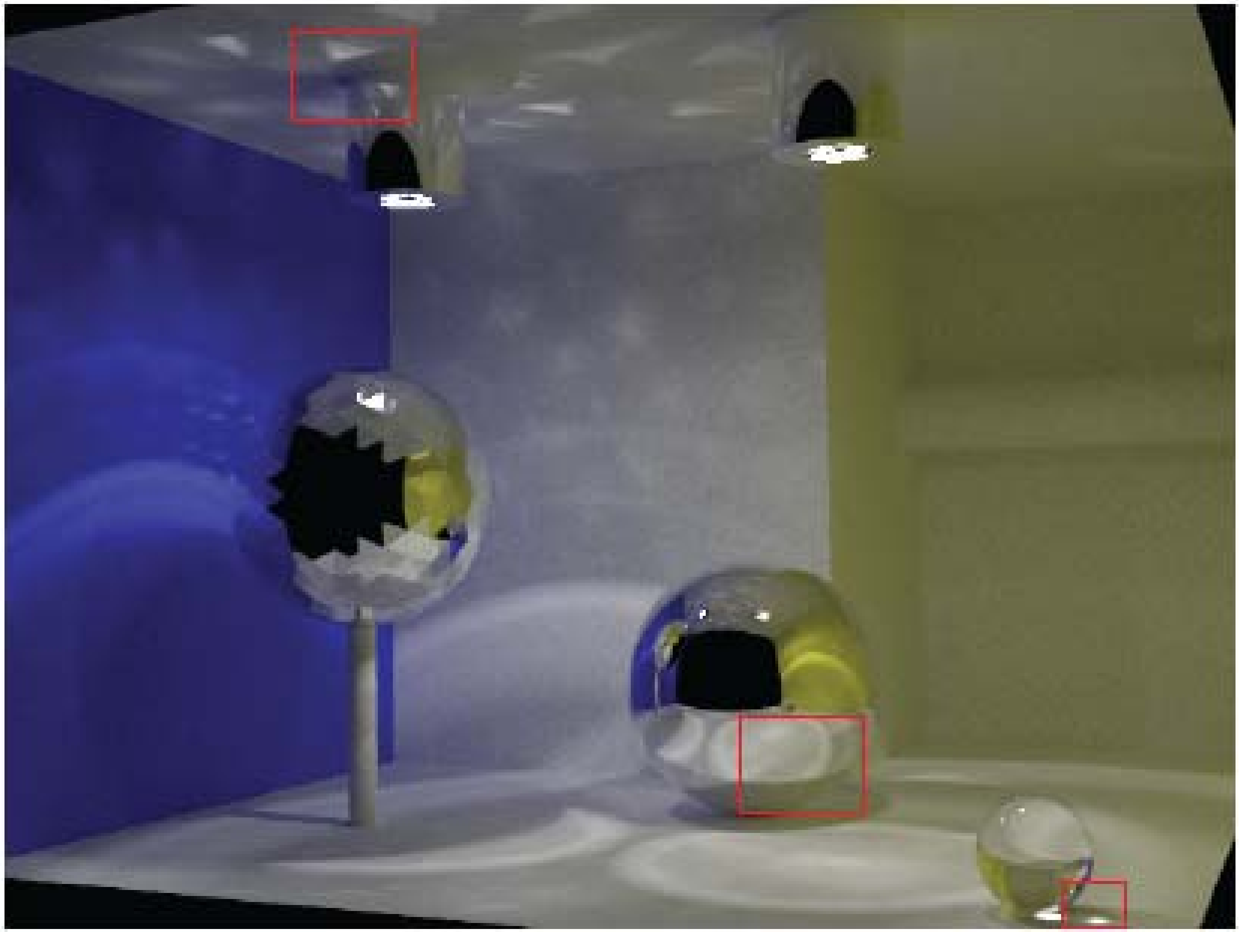

- Store extra information for all the hit points along all the  ray paths
  - E.g., accumulated # of photons, flux, and current radius

# Key Idea




- **We want to increase # of photons and reduce radius while keeping photon density**
- **Key assumption:**
  - **Uniform photon density and illumination within each radius**

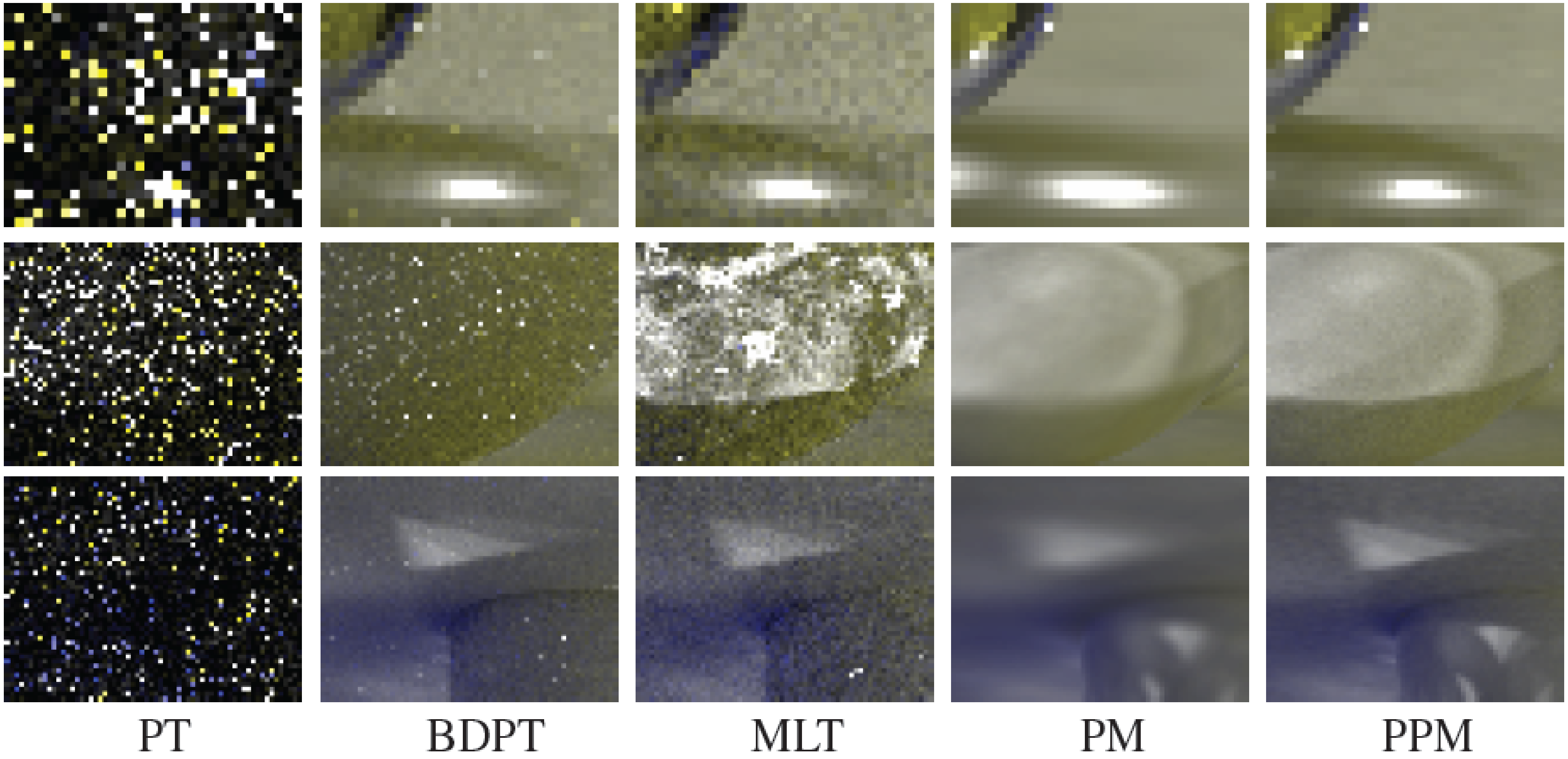
# Results



Progressive photon mapping

213M photons

# Comparison



# Future Work

- Stopping criteria and error estimate
  - How many photons do we need?

- Adaptive photon tracing
  - We know how many photons are used in each hit point in the PPM framework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# Class Objectives were:

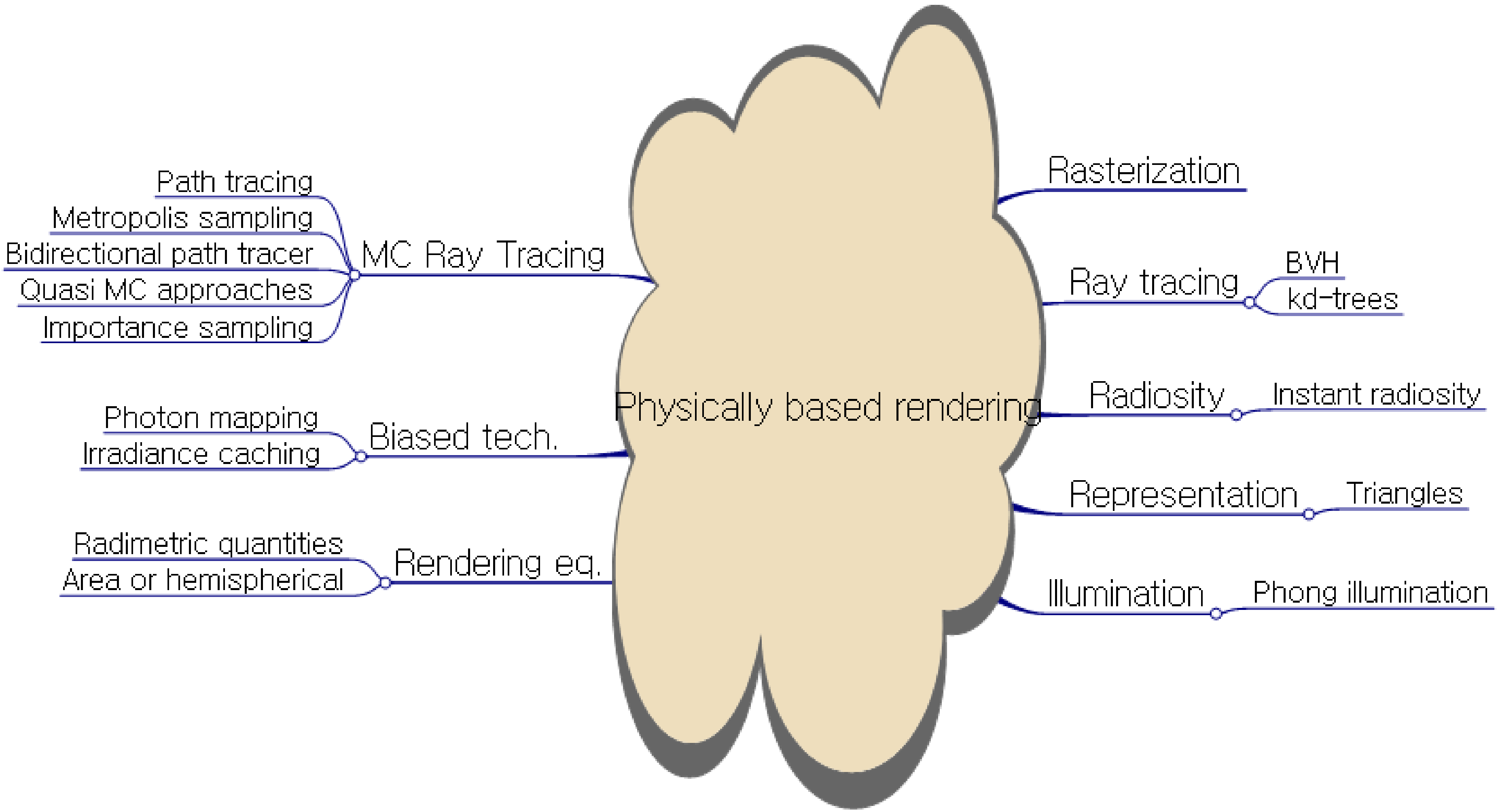
- Extensions to the basic MC path tracer
  - Bidirectional path tracer
  - Metropolis sampling

- Biased techniques
  - Irradiance caching
  - Photon mapping

# Summary

- Two basic building blocks
- Radiometry
- Rendering equation
- MC integration
- MC ray tracing
  - Unbiased methods
  - Biased methods

# Summary


Physically based rendering
MC Ray Tracing
Path tracing
Metropolis sampling
Bidirectional path tracer
Quasi MC approaches
Importance sampling
Biased tech.
Photon mapping
Irradiance caching
Rendering eq.
Radimetric quantities
Area or hemispherical
Rasterization
Ray tracing
BVH
kd-trees
Radiosity
Instant radiosity
Representation
Triangles
Illumination
Phong illumination