Progressive Photon Mapping Basics

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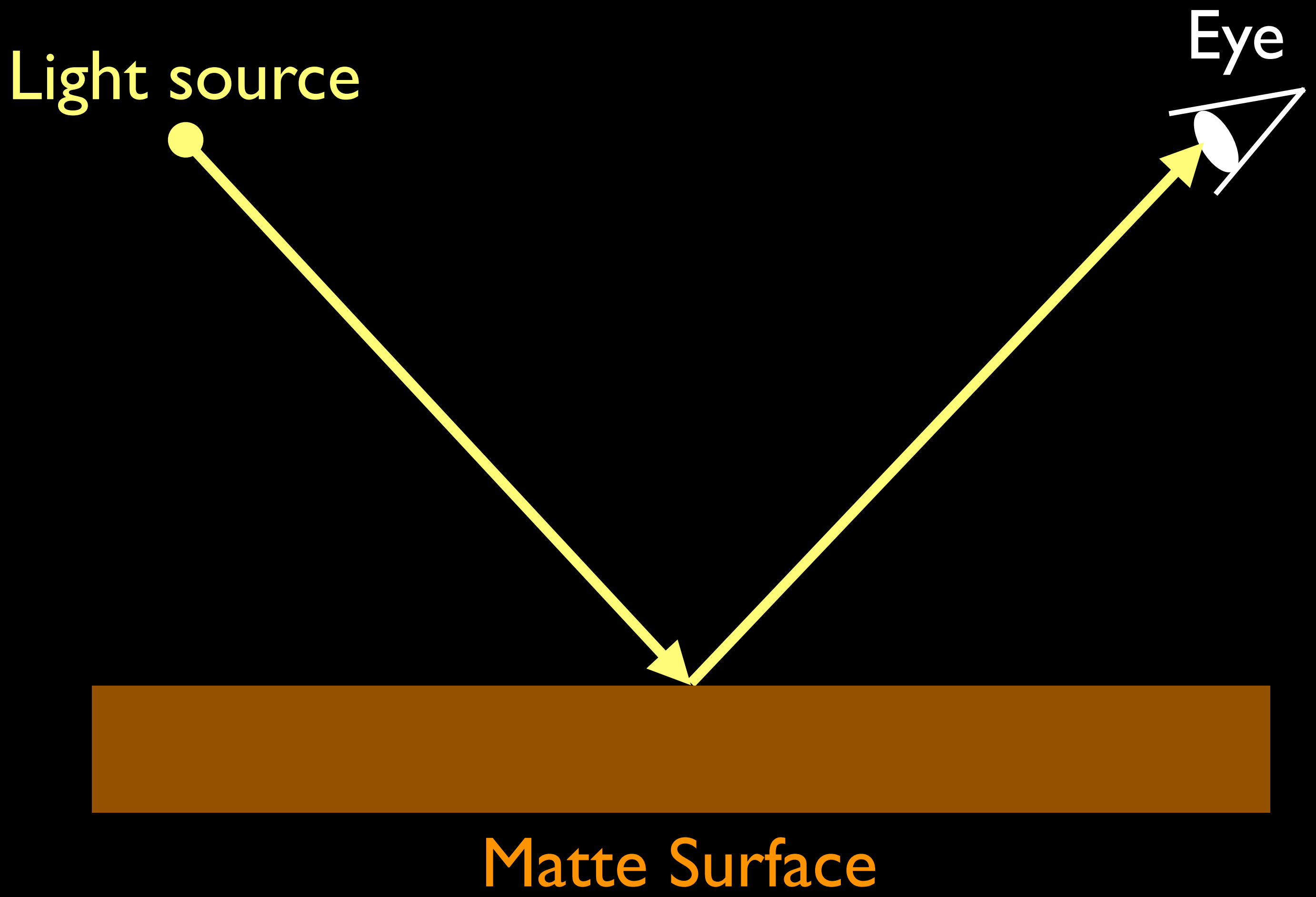
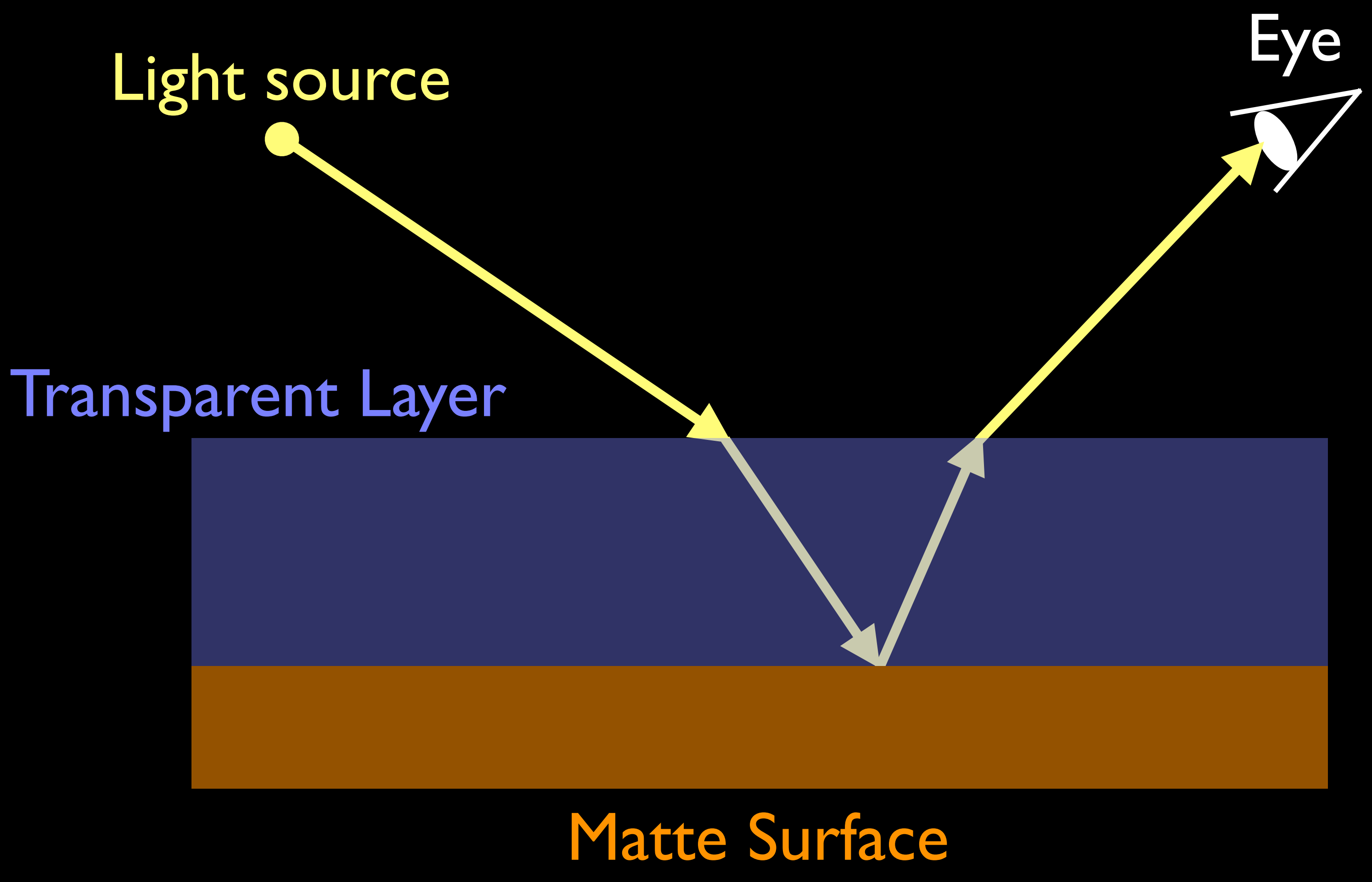
State of the Art in Photon Density Estimation

Light Transport Simulation Algorithms

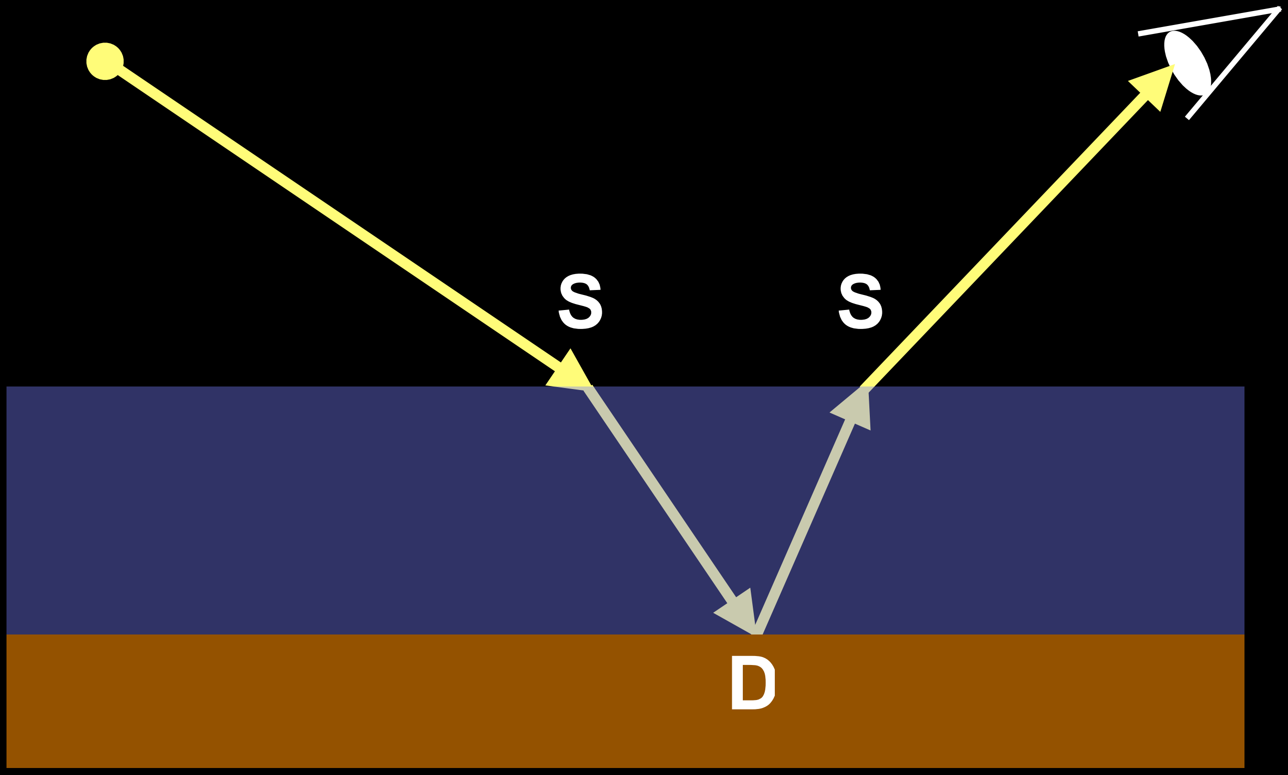
- Path Tracing [Kajiya 86]
- Light Tracing [Arvo 86][Dutré 93]
- Bidirectional Path Tracing [Lafortune 93][Veach 95]
- Photon Mapping [Jensen 95]
- Density Estimation [Shirley 95]
- Instant Radiosity [Keller 97]
- Metropolis Light Transport [Veach 97]
- Lightcuts [Walter 05]
- Energy Redistribution Path Tracing [Cline 05]
- ...

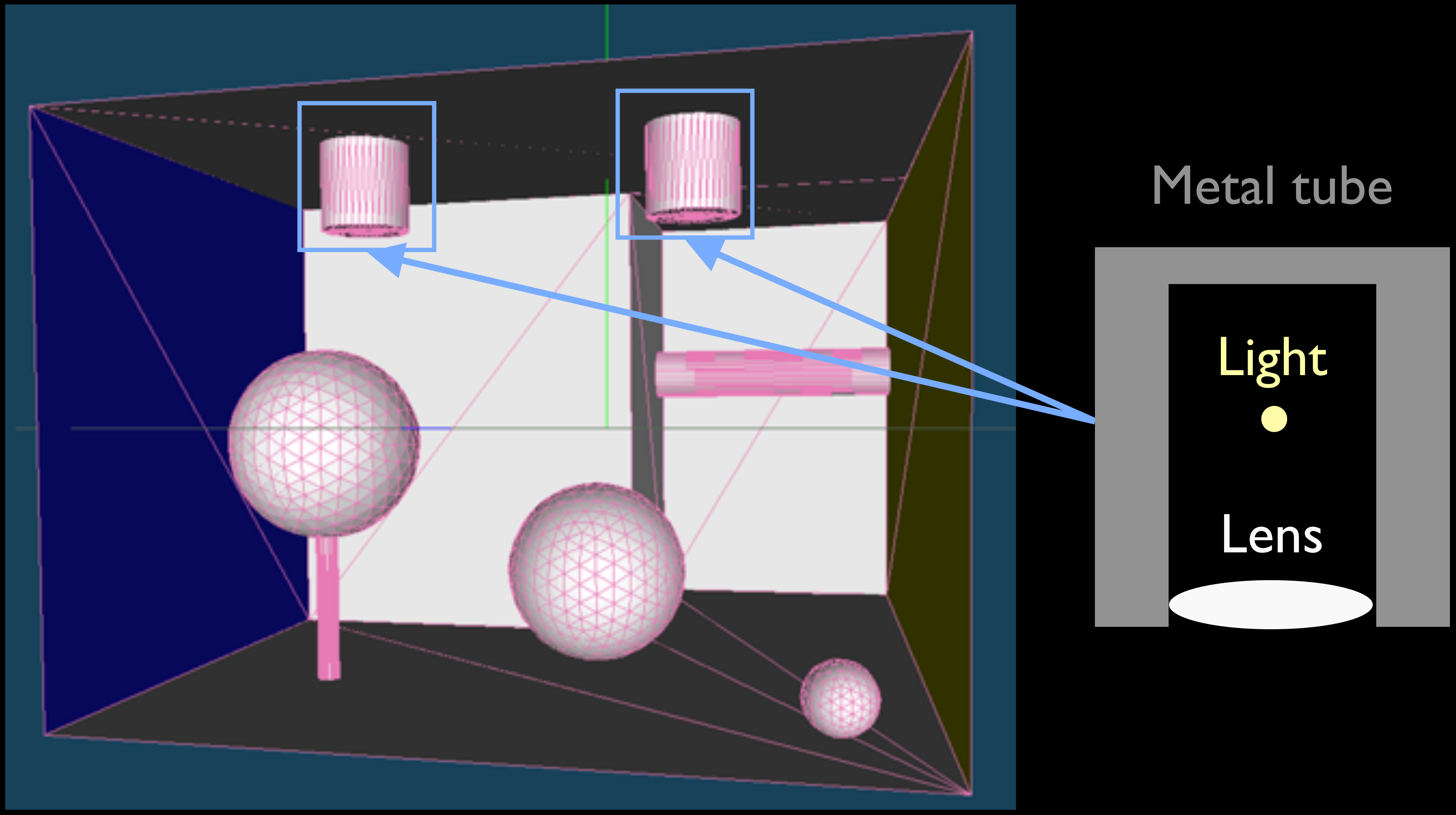

(c)Y. Kimura


Light source
Eye
Matte Surface

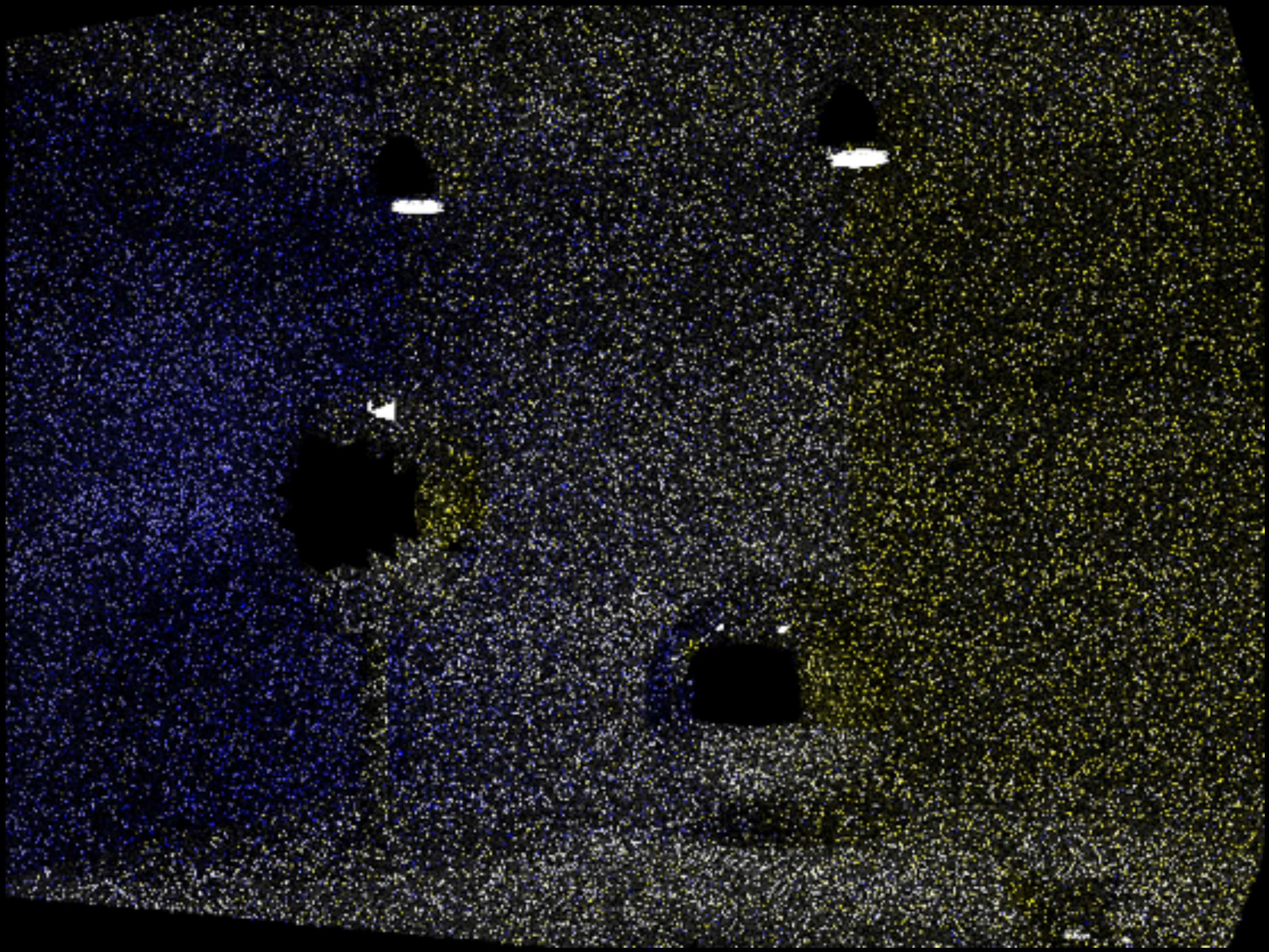

Eye
Light source
Transparent Layer
Matte Surface

Specular-Diffuse-Specular (SDS) paths

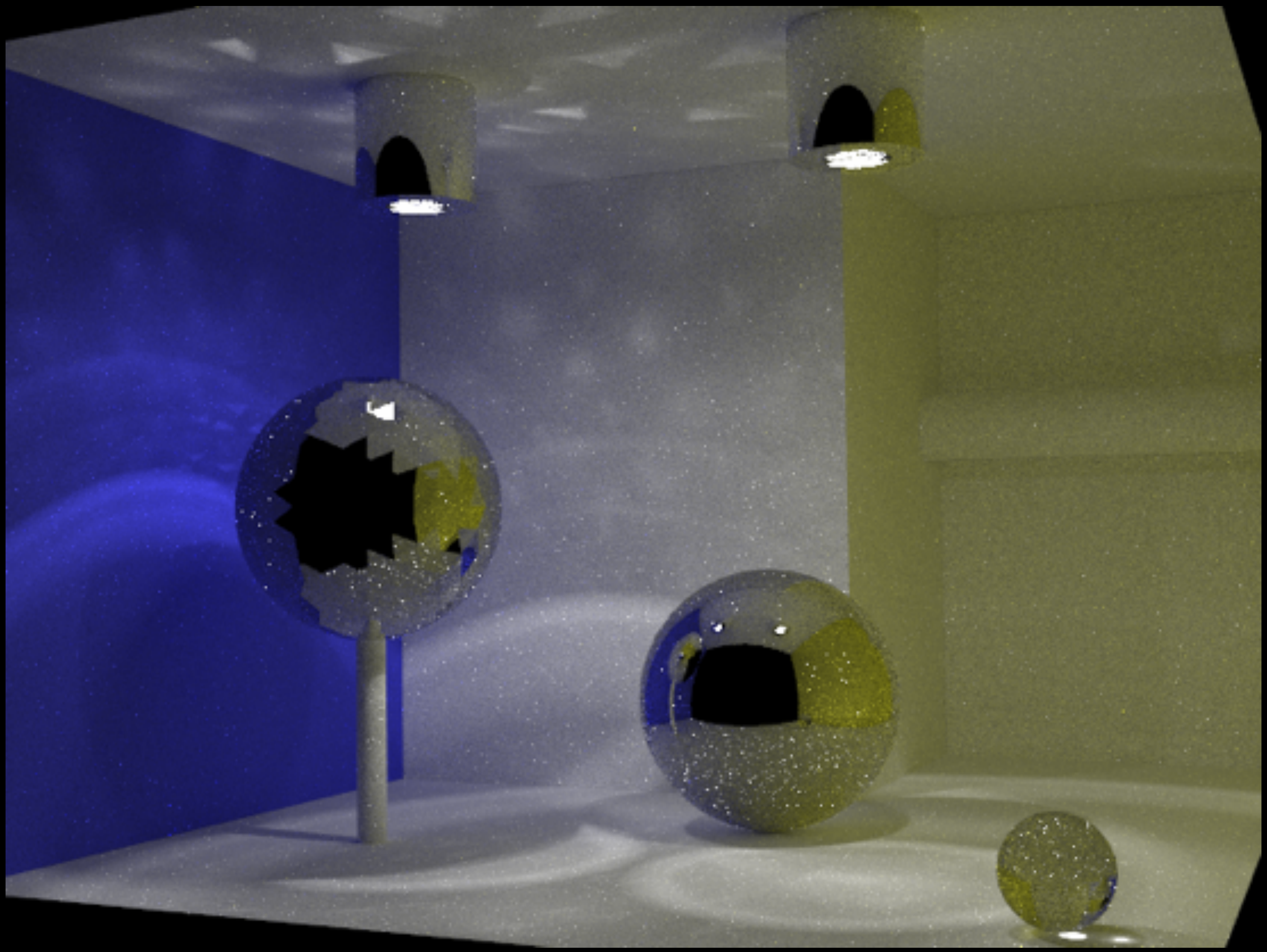



Metal tube
Light
Lens

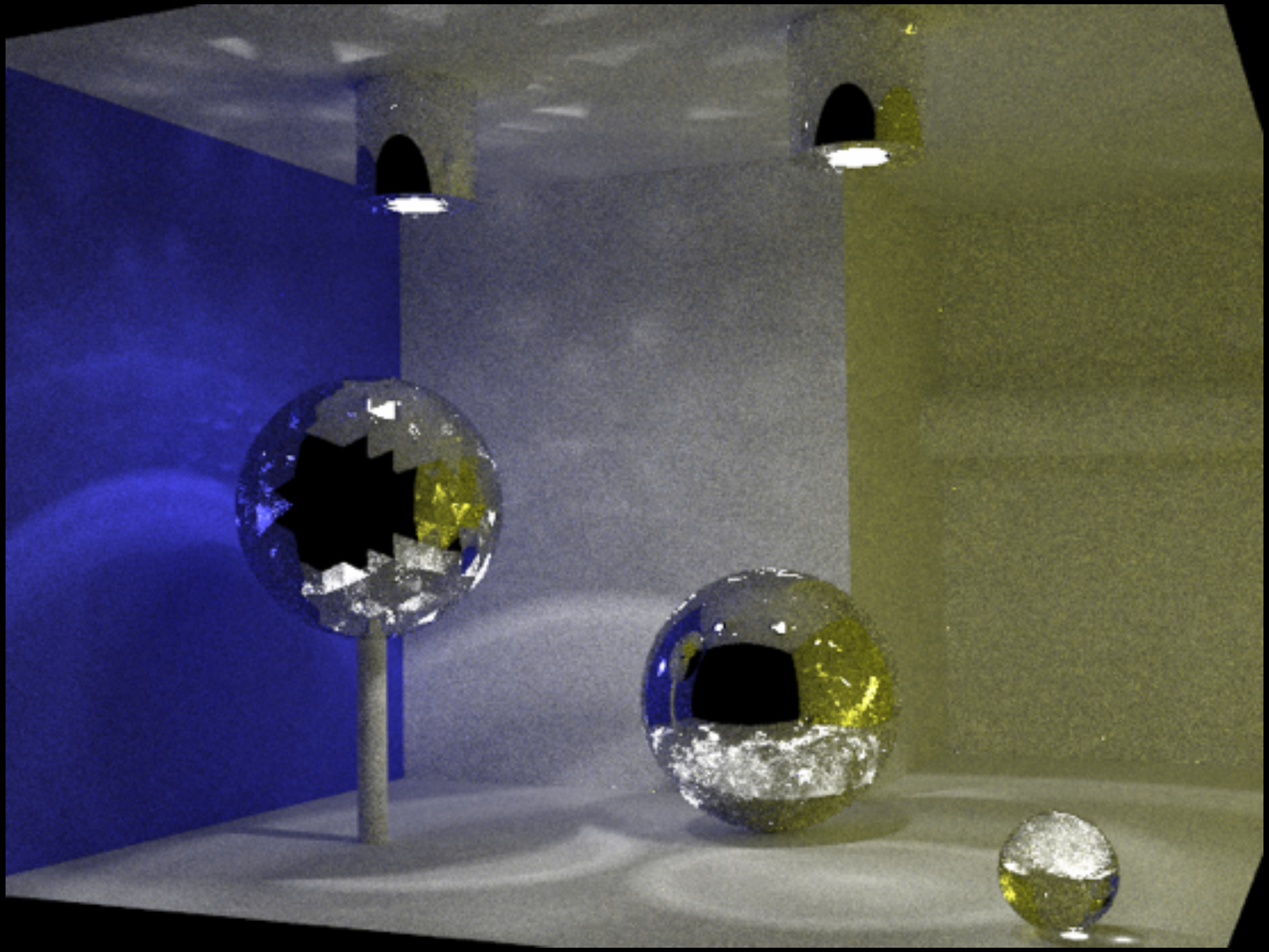
Path Tracing



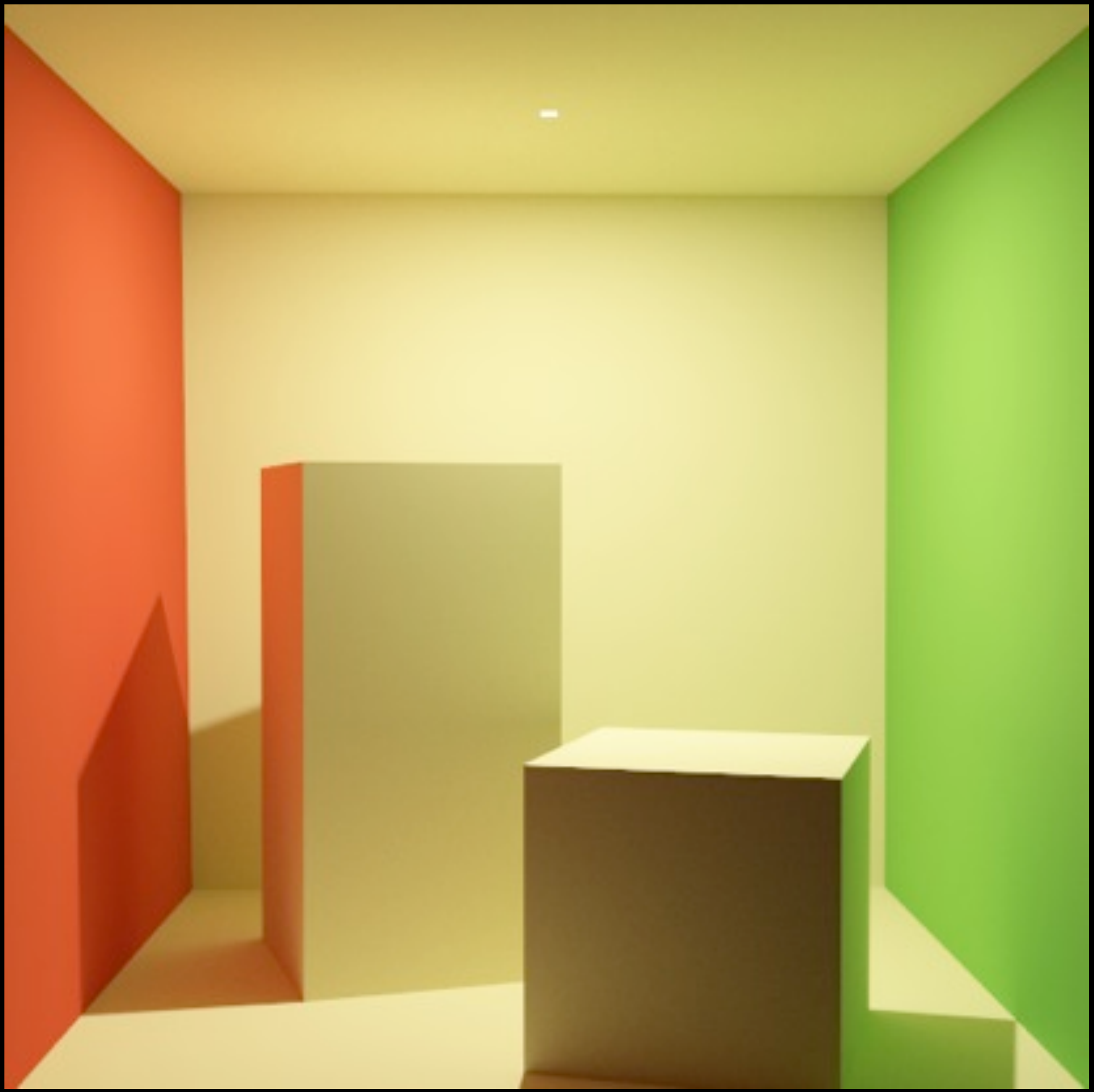
Bidirectional Path Tracing



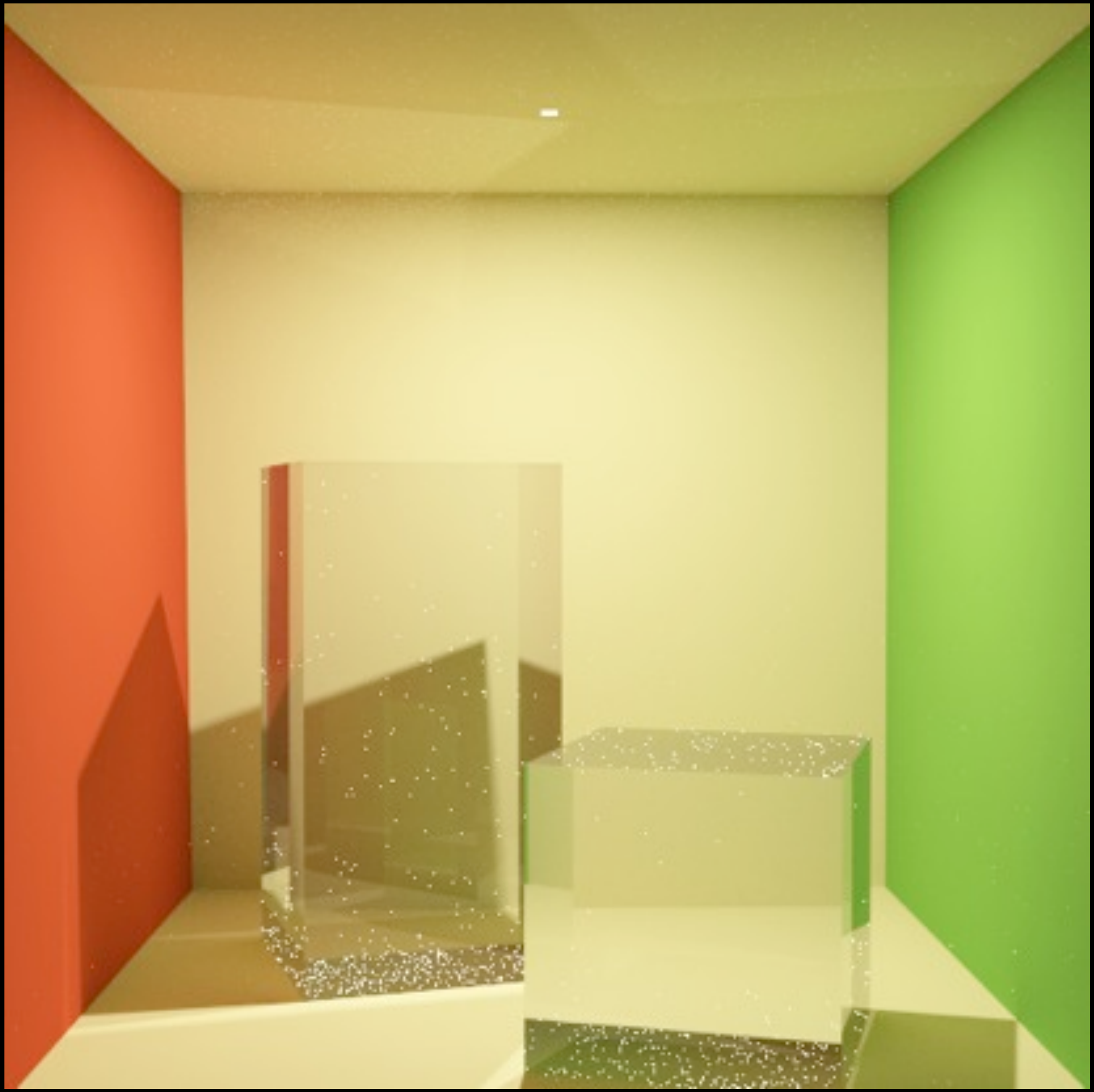
Metropolis Light Transport

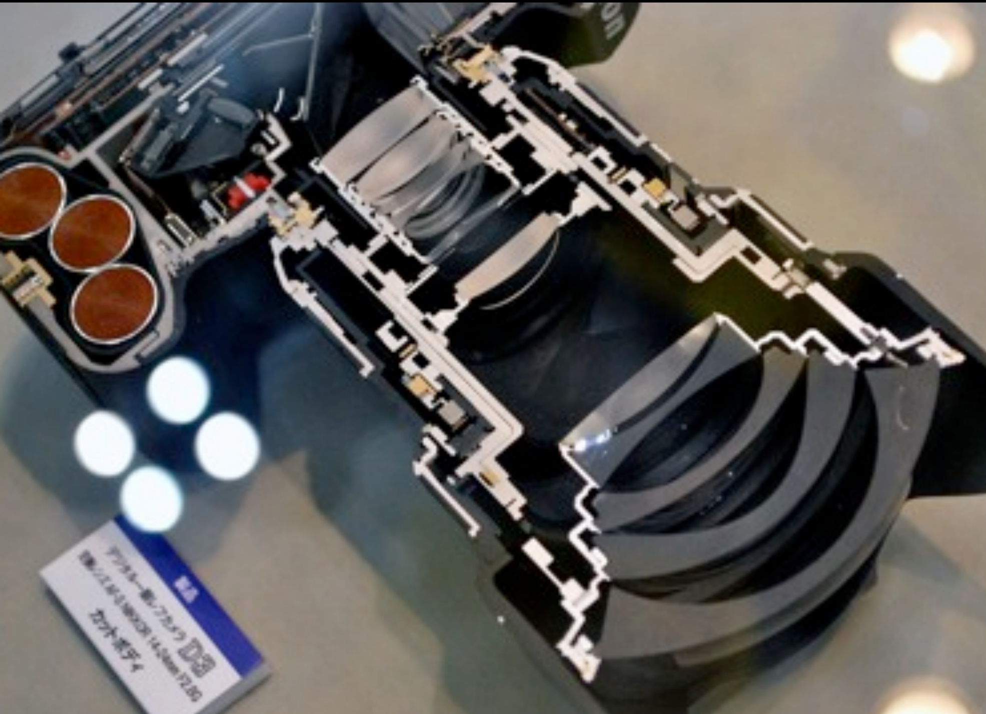


Bidirectional Path Tracing



Bidirectional Path Tracing






Specular-Diffuse-Specular Paths

- Existing methods are not robust for SDS paths
  - Path tracing
  - Bidirectional path tracing
  - Metropolis light transport
  - ...name your favorite

Specular-Diffuse-Specular Paths

- Existing methods are not robust for SDS paths
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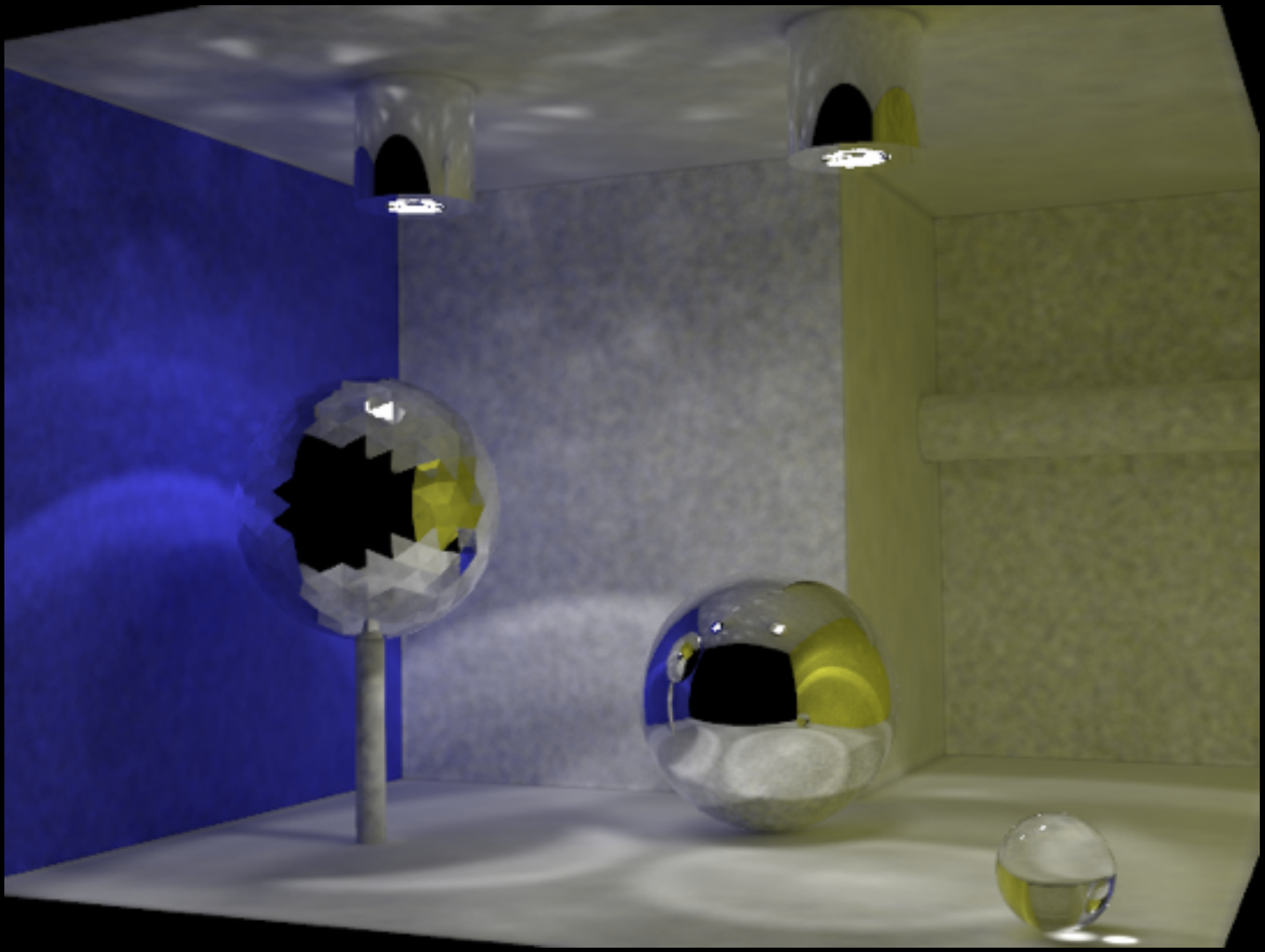
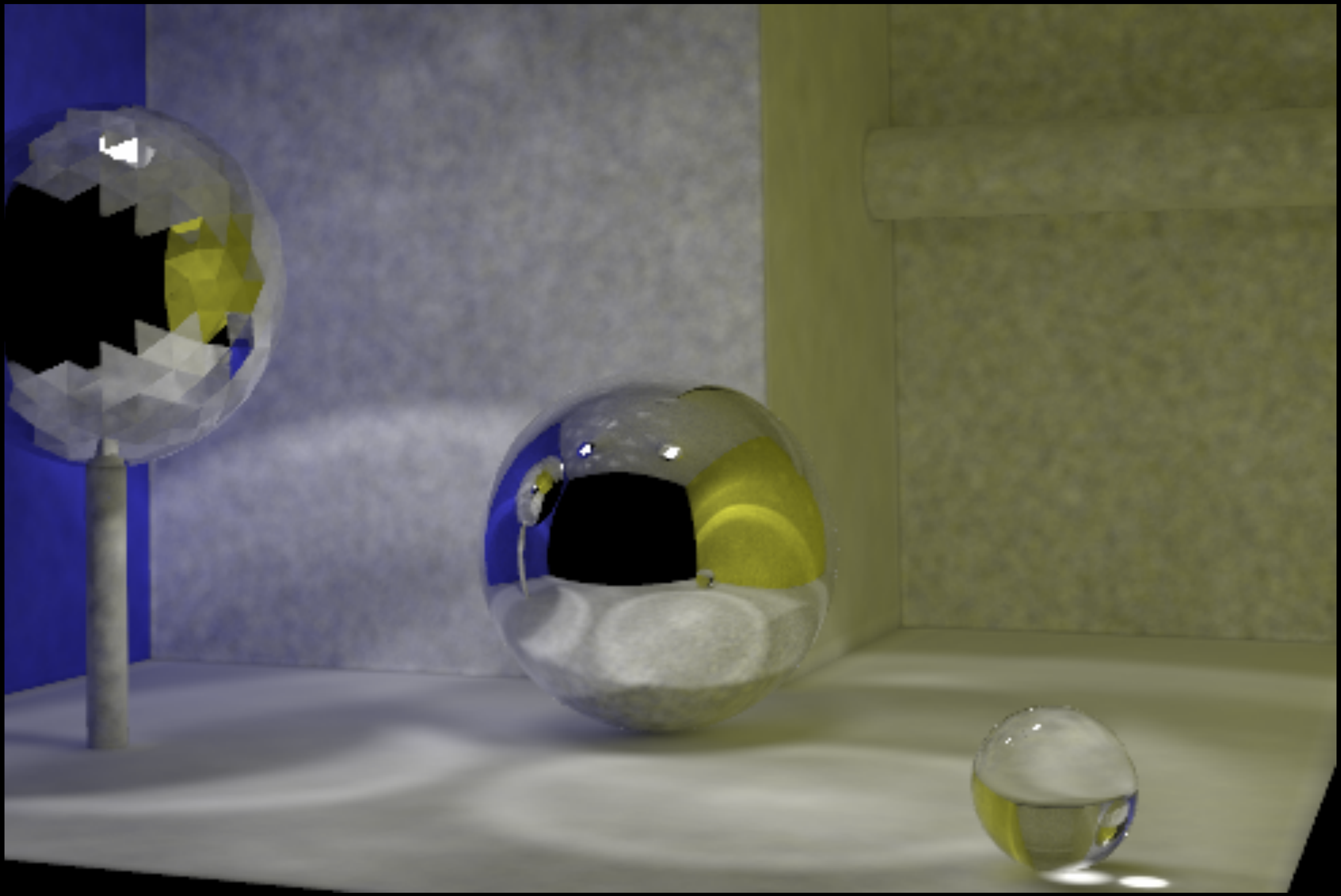
  - ...name your favorite
  - Photon mapping?

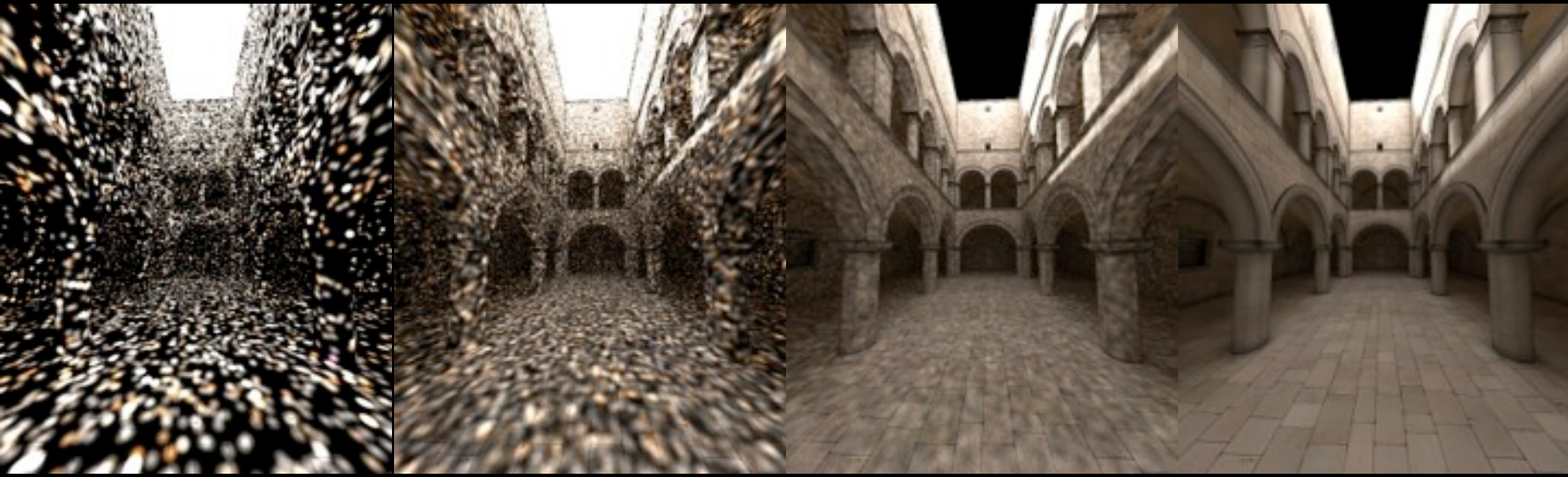
Photon Mapping



Photon Mapping



Convergence of Photon Mapping



More photons →

Convergence of Photon Mapping

$$L(x,\vec{\omega}) = \lim_{N\to\infty} \sum_{p=1}^{N^\beta} \frac{f_r(x,\vec{\omega},\vec{\omega}_p)\phi_p(x_p,\vec{\omega}_p)}{\pi r^2}$$

- Infinite number of nearby photons ($N^\beta \to \infty$)
- Infinitely small radius ($r \to 0$)

Convergence of Photon Mapping

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Infinite storage & photon tracing

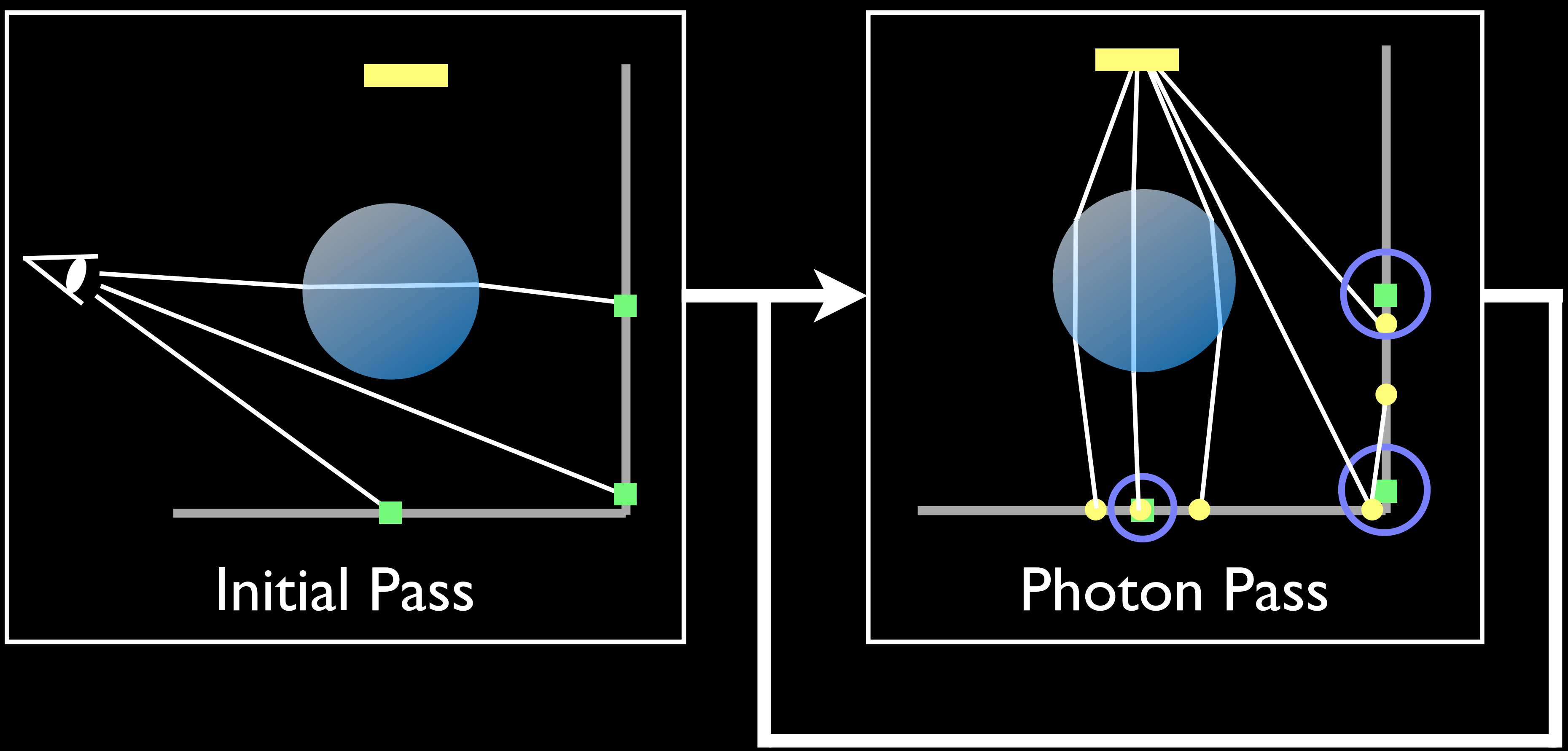
- Infinite number of nearby photons ($N^{\beta}\to\infty$)
- Infinitely small radius ($r\to 0$)

Convergence of Photon Mapping

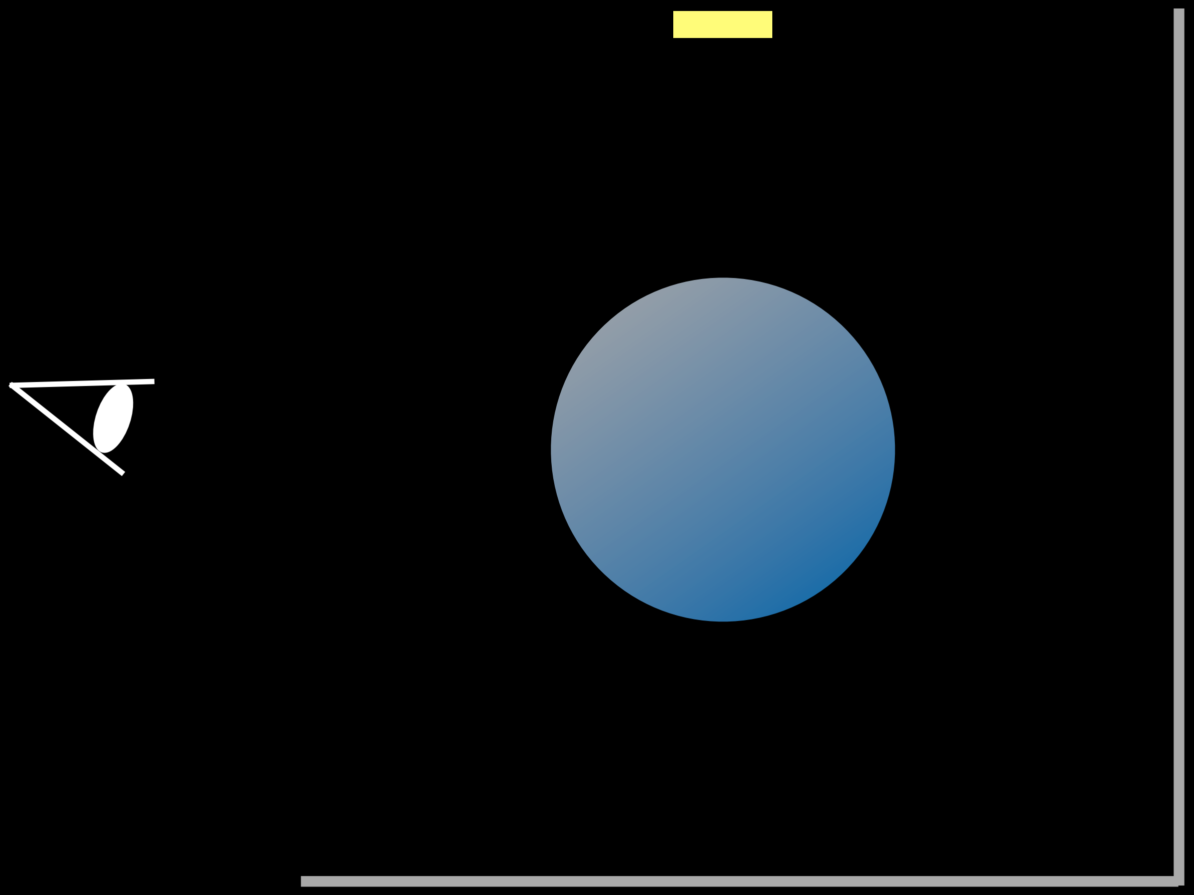
- Conditions of convergence
  - Infinite number of (neighboring) photons
  - Infinitely small radius
- In practice...
  - More memory
  - Longer waiting time to the image
  - Rerun the process with different parameters

Solution:
Progressive Photon Mapping

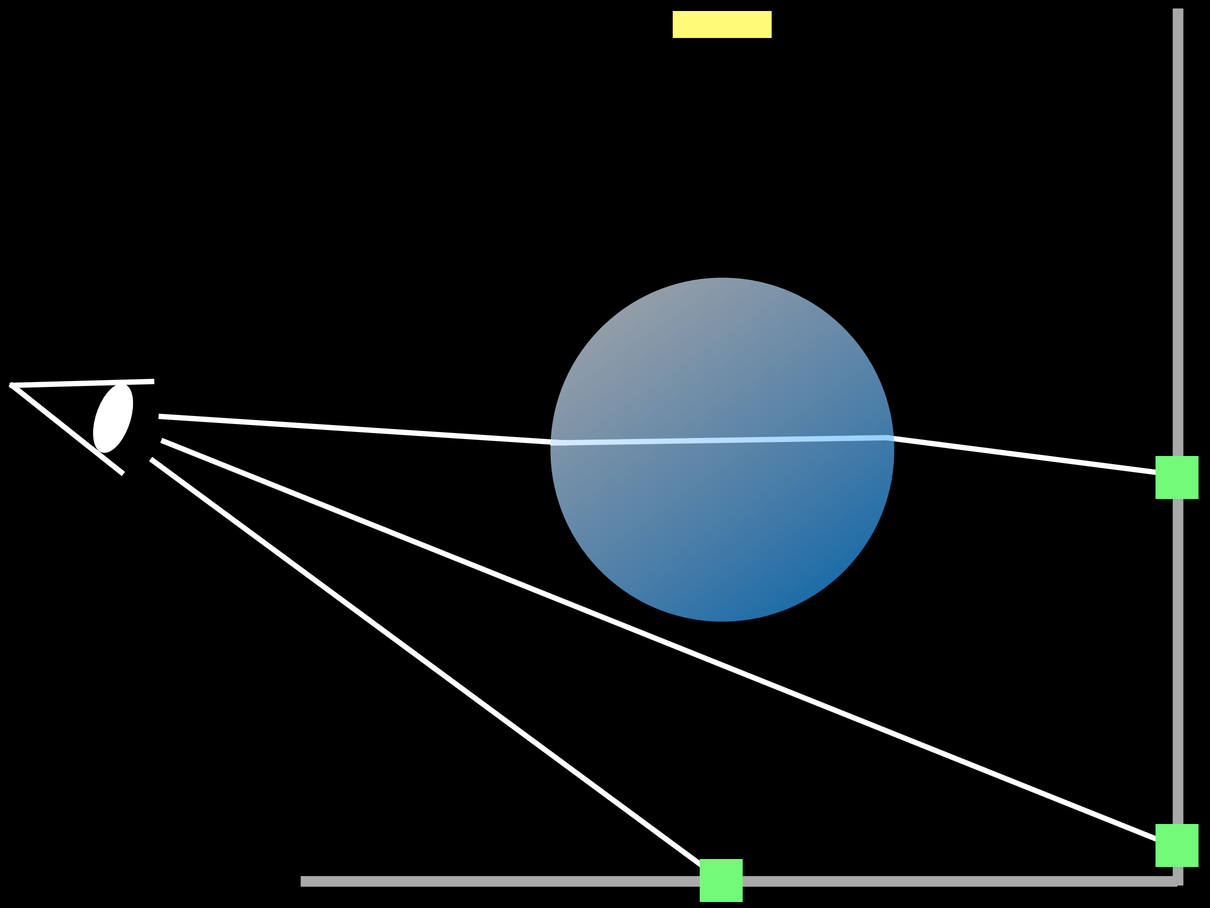
Overview



Scene

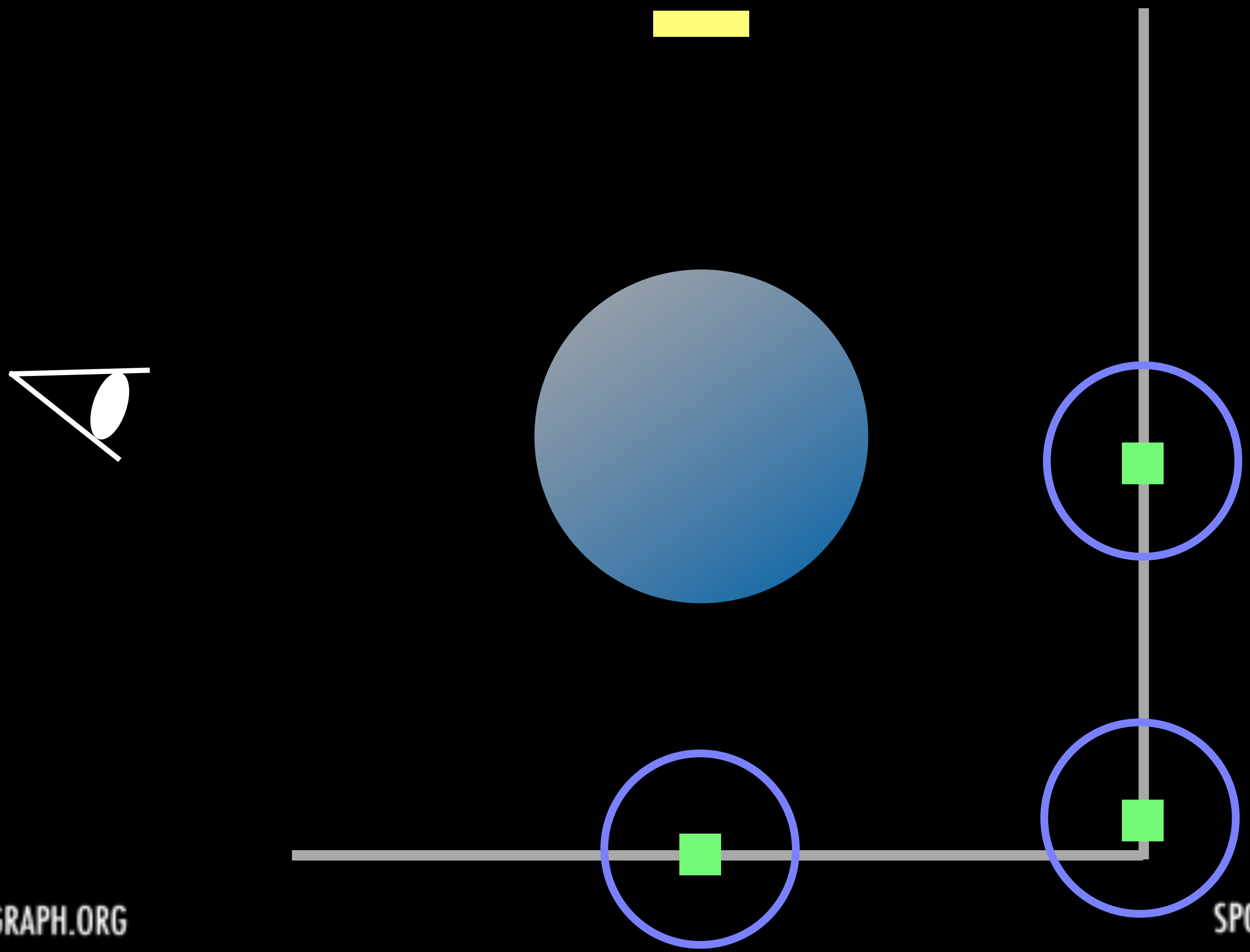


Initial Pass



Initial Pass

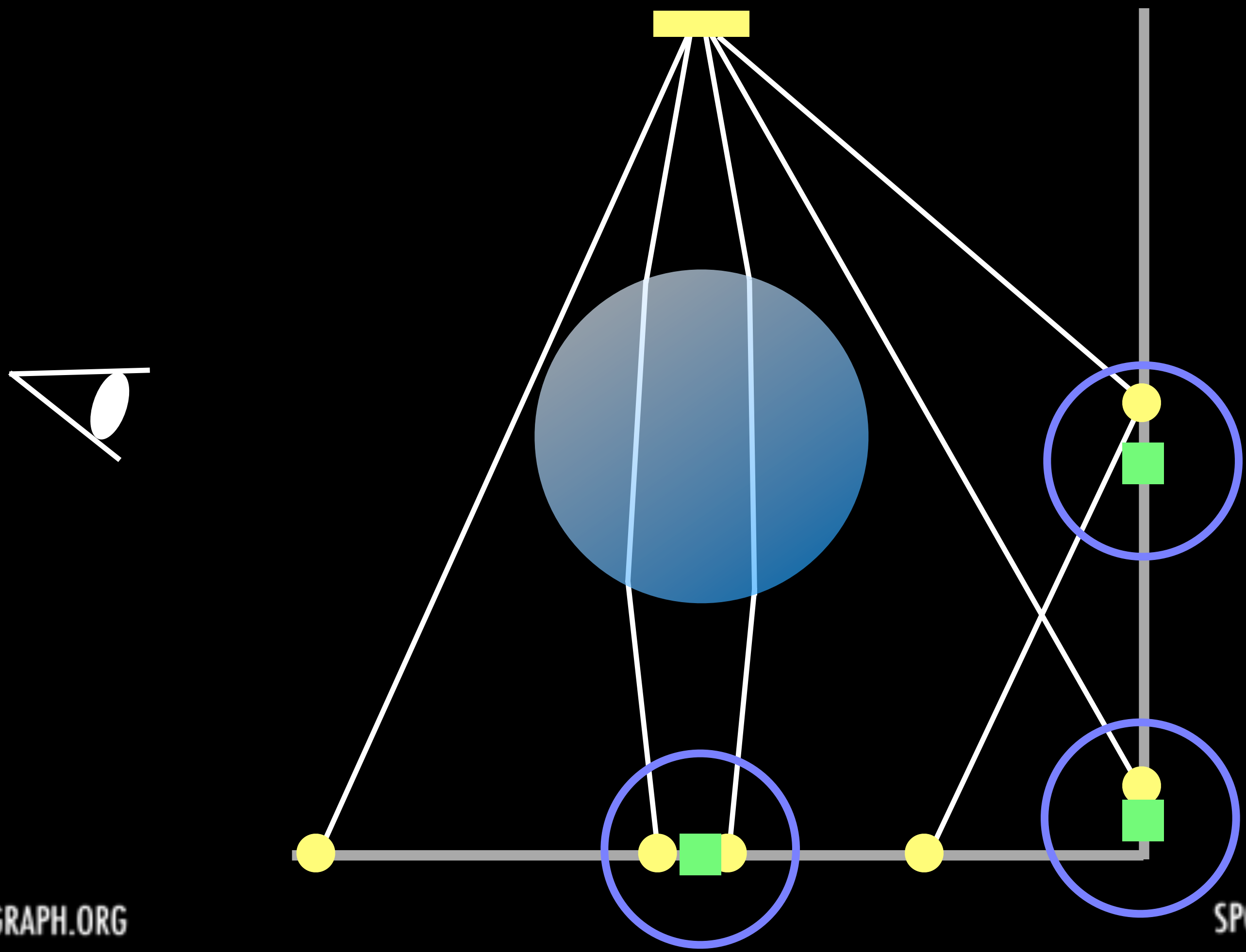
* Similar to Havran et al. 2008



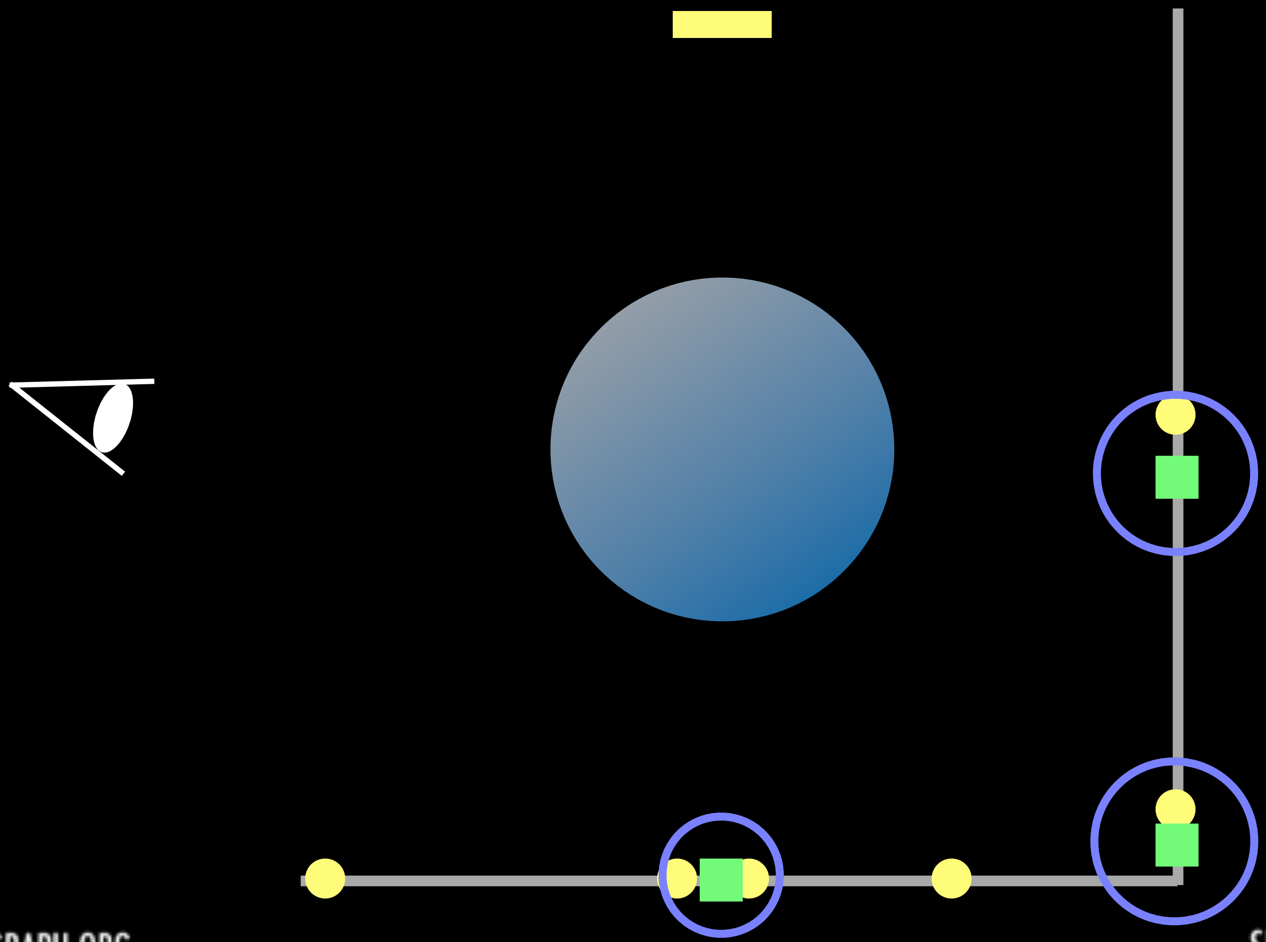
Photon Statistics

- Each measurement point:
  - Accumulated flux times BRDF $\tau_i\left(x, \vec{\omega}\right)$
  - Search radius $R_i\left(x\right)$
  - Local photon count $N_i(x)$
- Global:
  - Emitted photon count $N_e(i)$

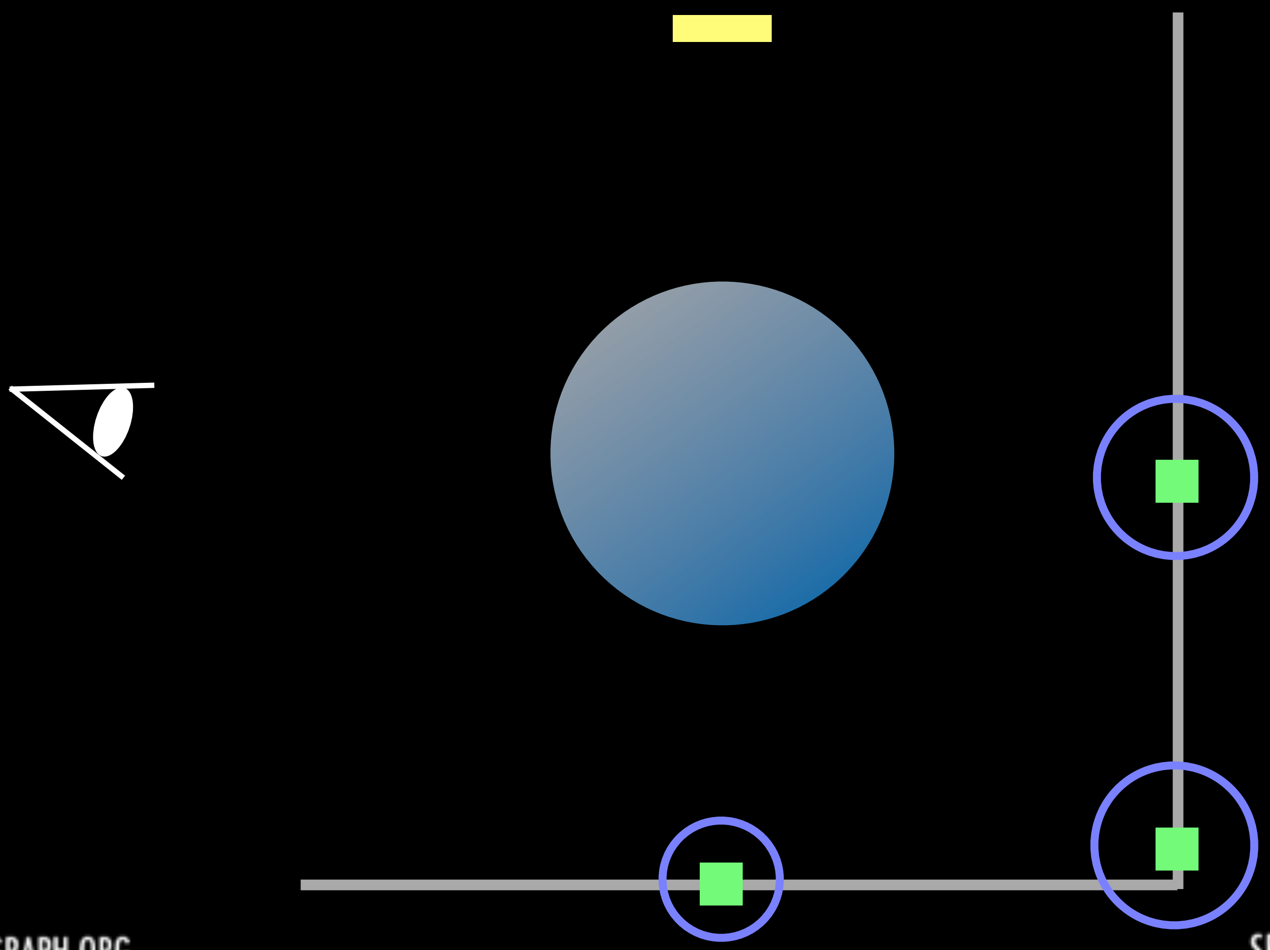
Photon Pass



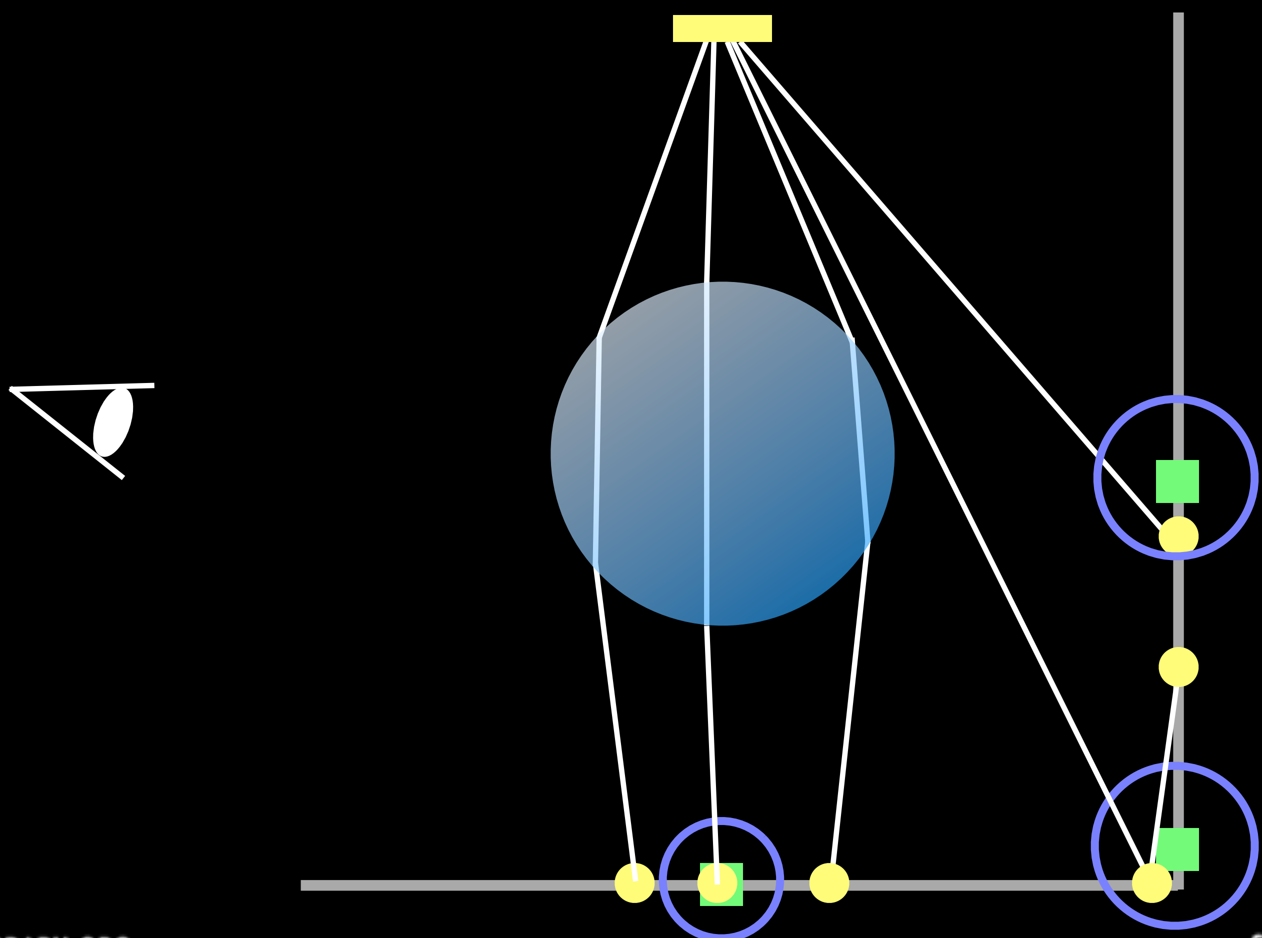
Photon Pass



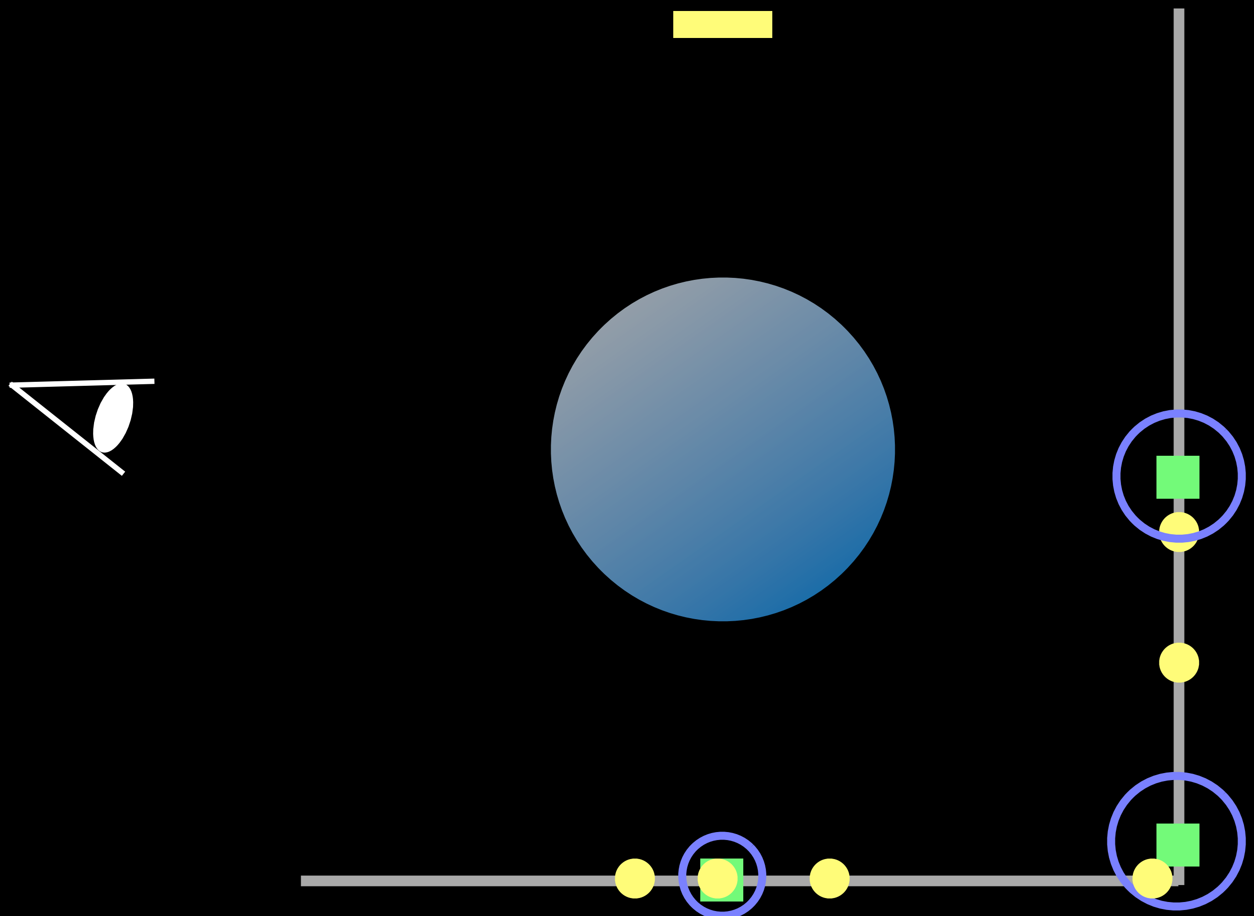
Photon Pass



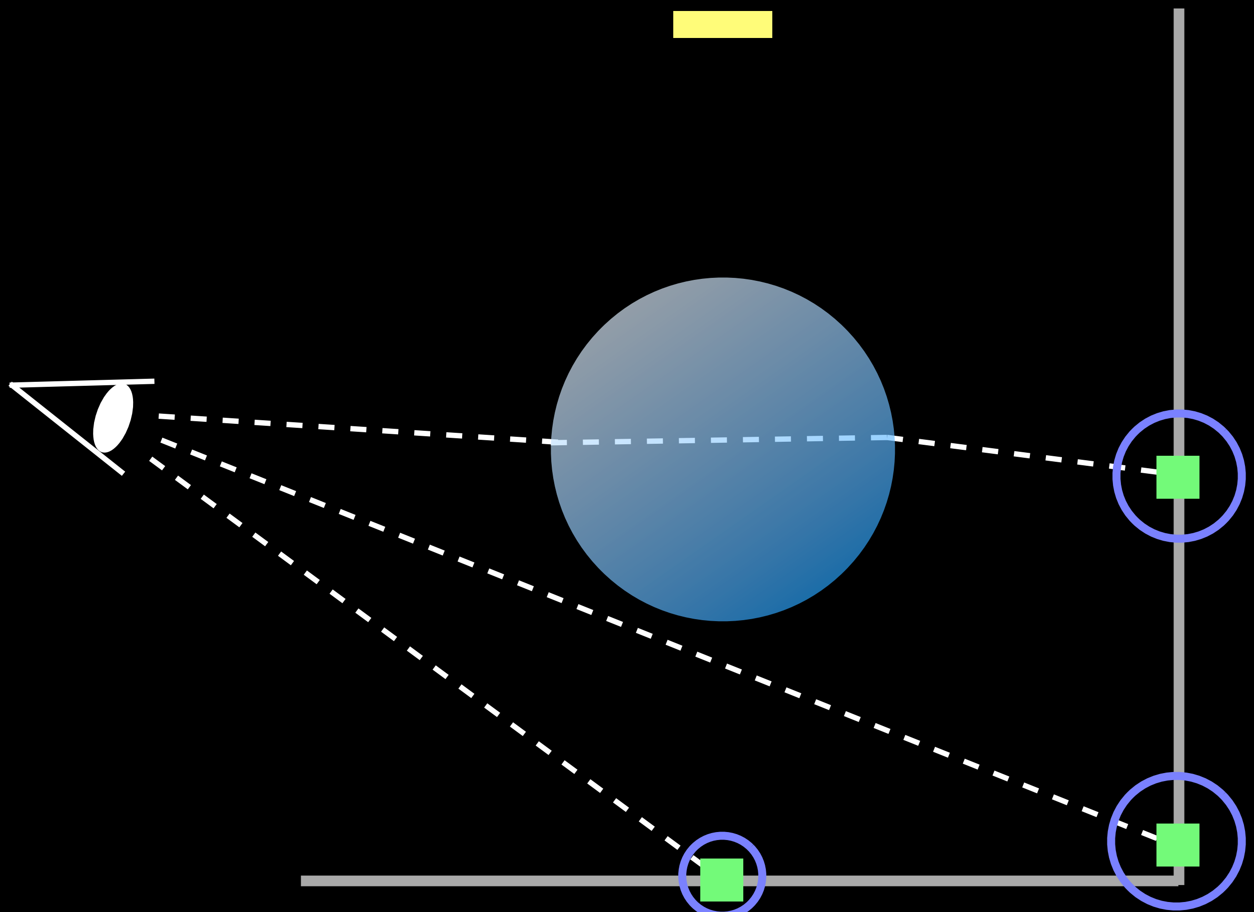
Next Photon Pass



Next Photon Pass



Rendering



Progressive Density Estimation

$$L_i(\vec{\omega}) = \sum_{p=1}^{N_i} \frac{f_r(\vec{\omega}, \vec{\omega}_p)\, \phi_p(\vec{\omega}_p)}{\pi R_i^2}$$

- Converges to the correct solution
  - Infinite number of photons
  - Infinitely small radius

Progressive Density Estimation

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  - $\lim_{i \to \infty} N_i(R_i) = \infty$
  - $\lim_{i \to \infty} R_i(N_i) = 0$

Progressive Density Estimation

SIGGRAPHASIA2013

$$L_i(\vec{\omega}) = \sum_{p=1}^{N_i} \frac{f_r(\vec{\omega}, \vec{\omega}_p)\, \phi_p(\vec{\omega}_p)}{\pi R_i^2}$$

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Recursive density estimation using sample statistics

Progressive Density Estimation

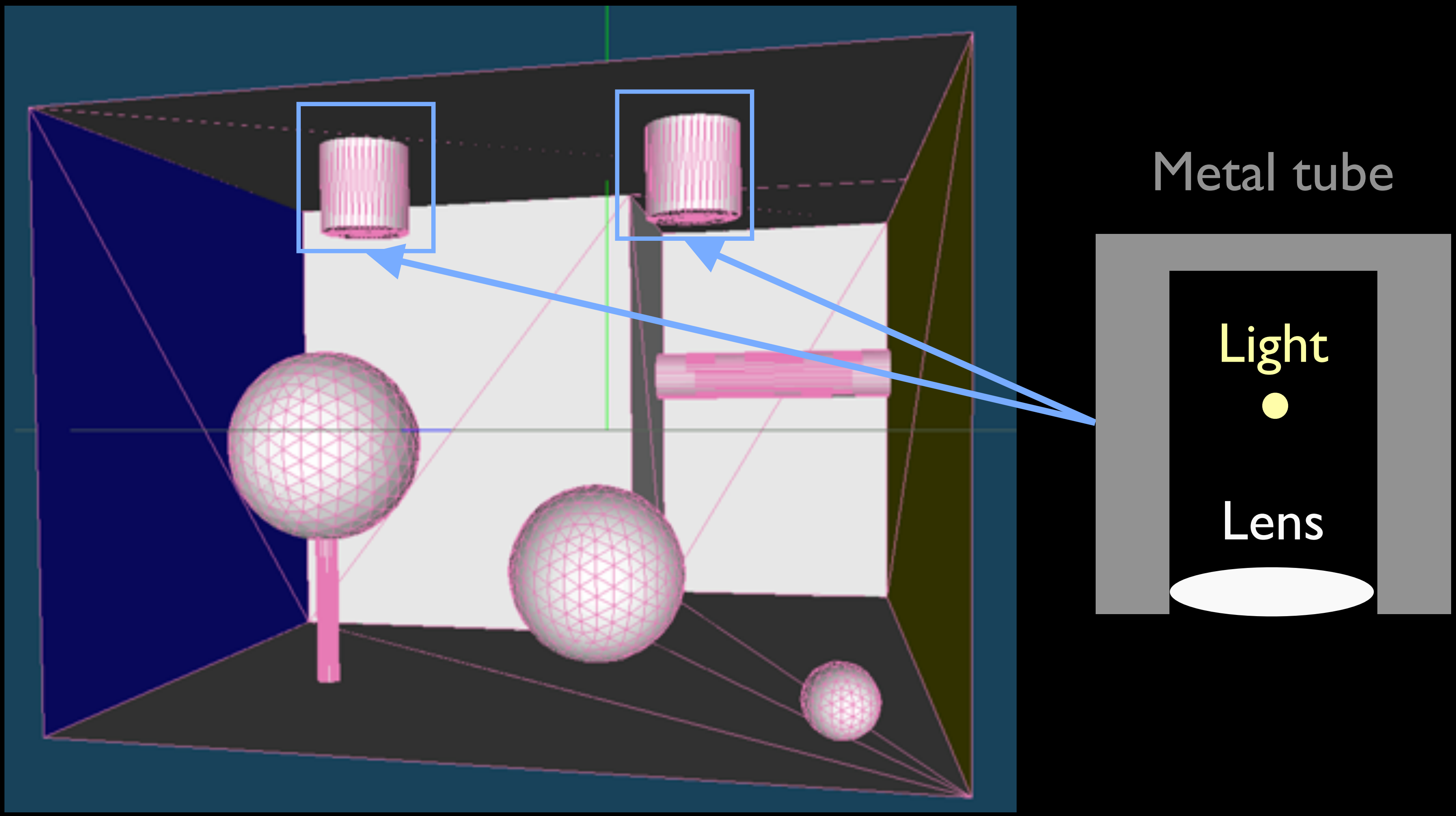
Number of photons $$N_{i+1} = N_i + \alpha M_i$$

Radius $$R_{i+1} = R_i \sqrt{\frac{N_i + \alpha M_i}{N_i + M_i}}$$

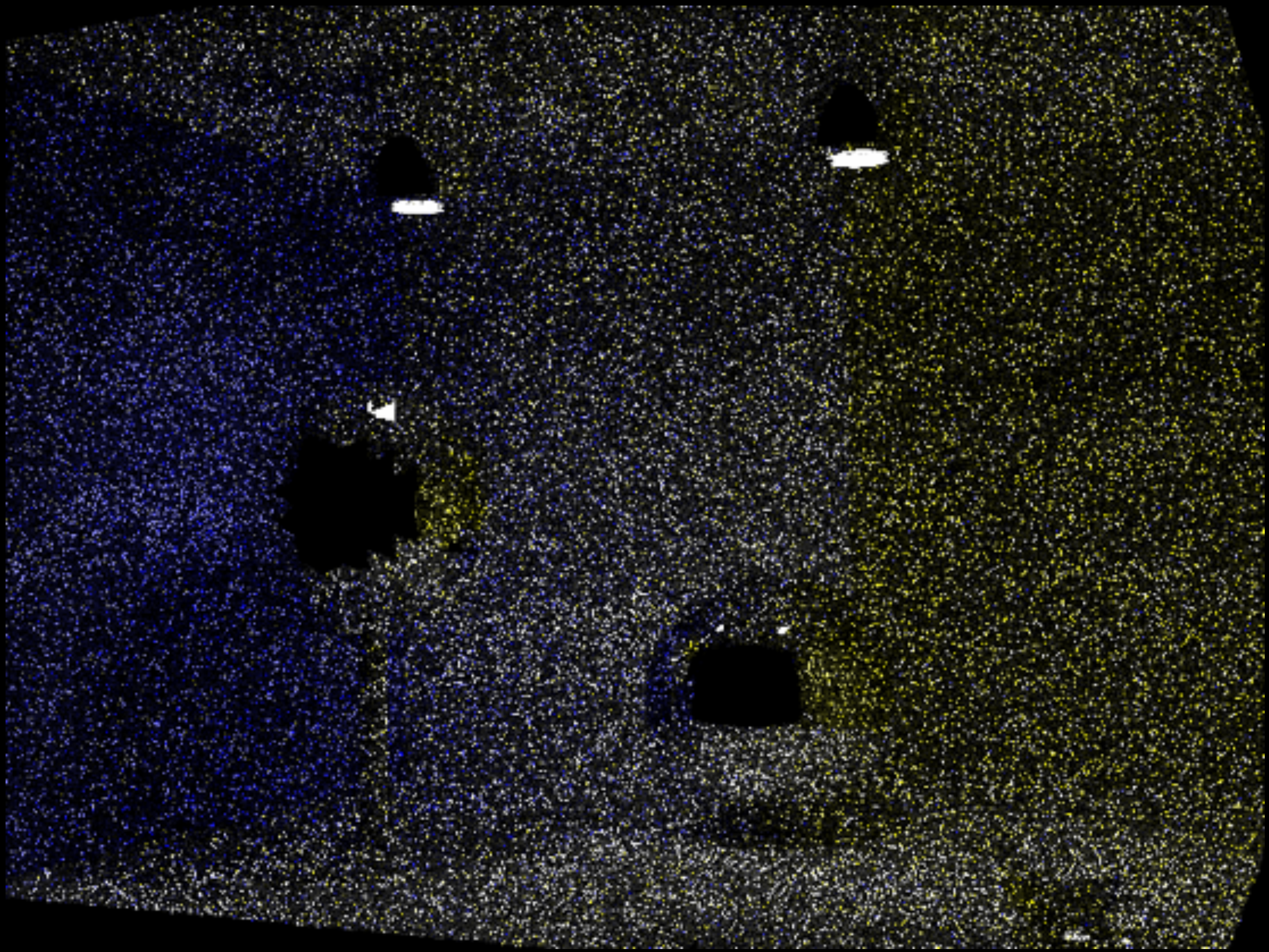
Accumulated flux $$\tau_{i+1} = \tau_i \frac{N_i + \alpha M_i}{N_i + M_i}$$

Radiance $$L_i = \frac{\tau_i}{\pi {R_i}^2} = \frac{\sum_{p=1}^{N_i} f_r \phi_p}{\pi {R_i}^2}$$

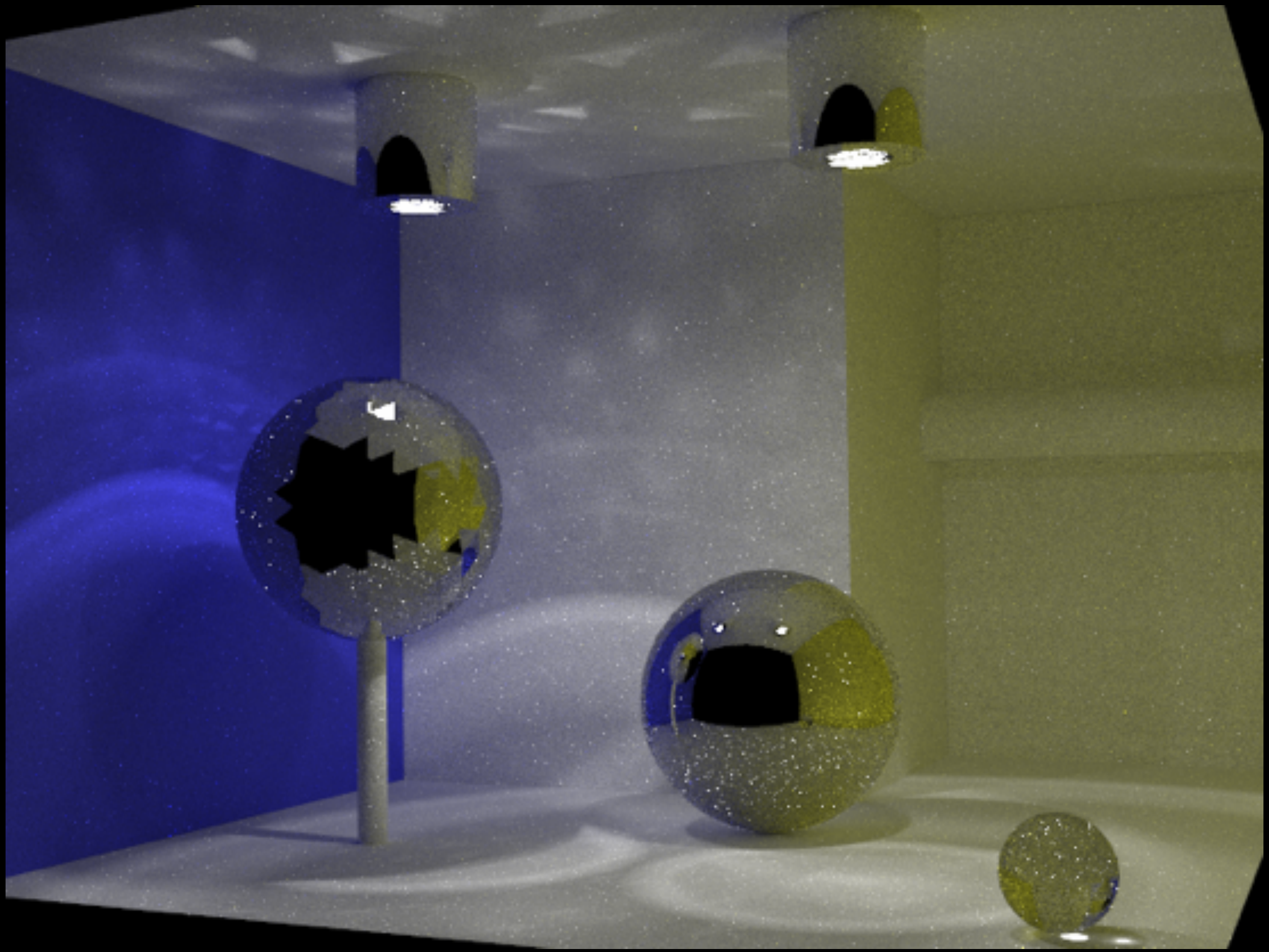
Equal-time Comparisons



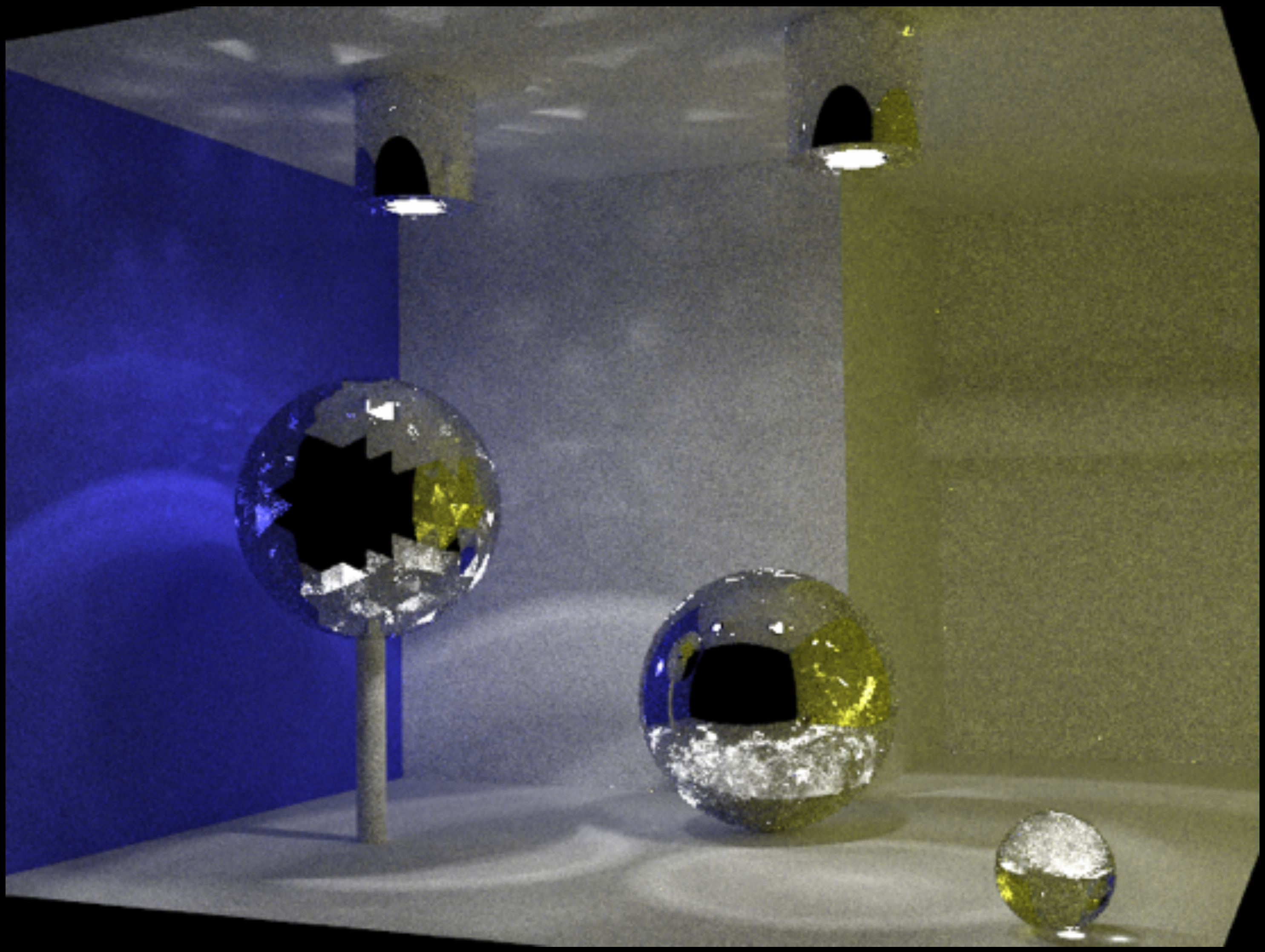
Path Tracing



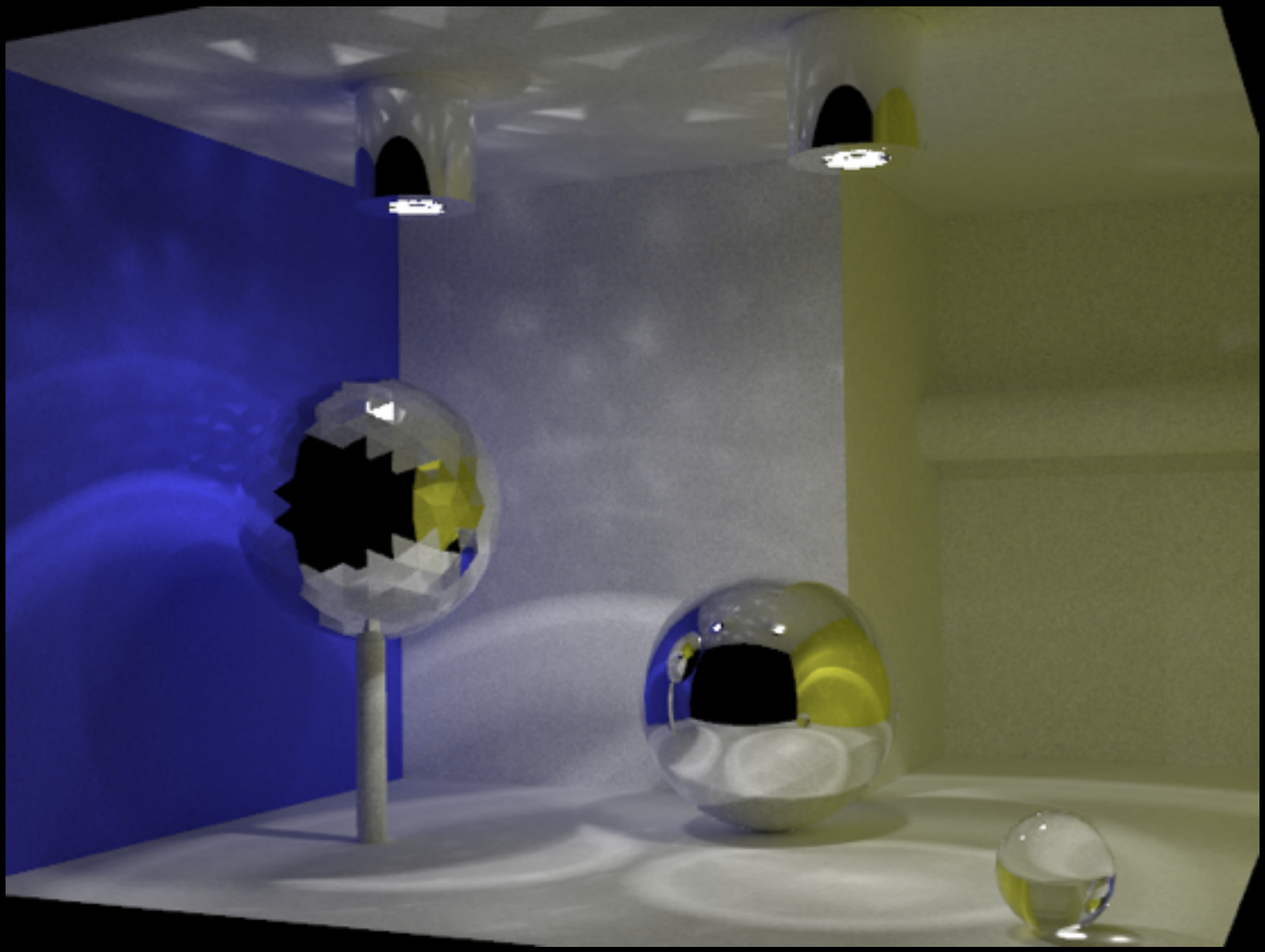
Bidirectional Path Tracing



Metropolis Light Transport



Progressive Photon Mapping



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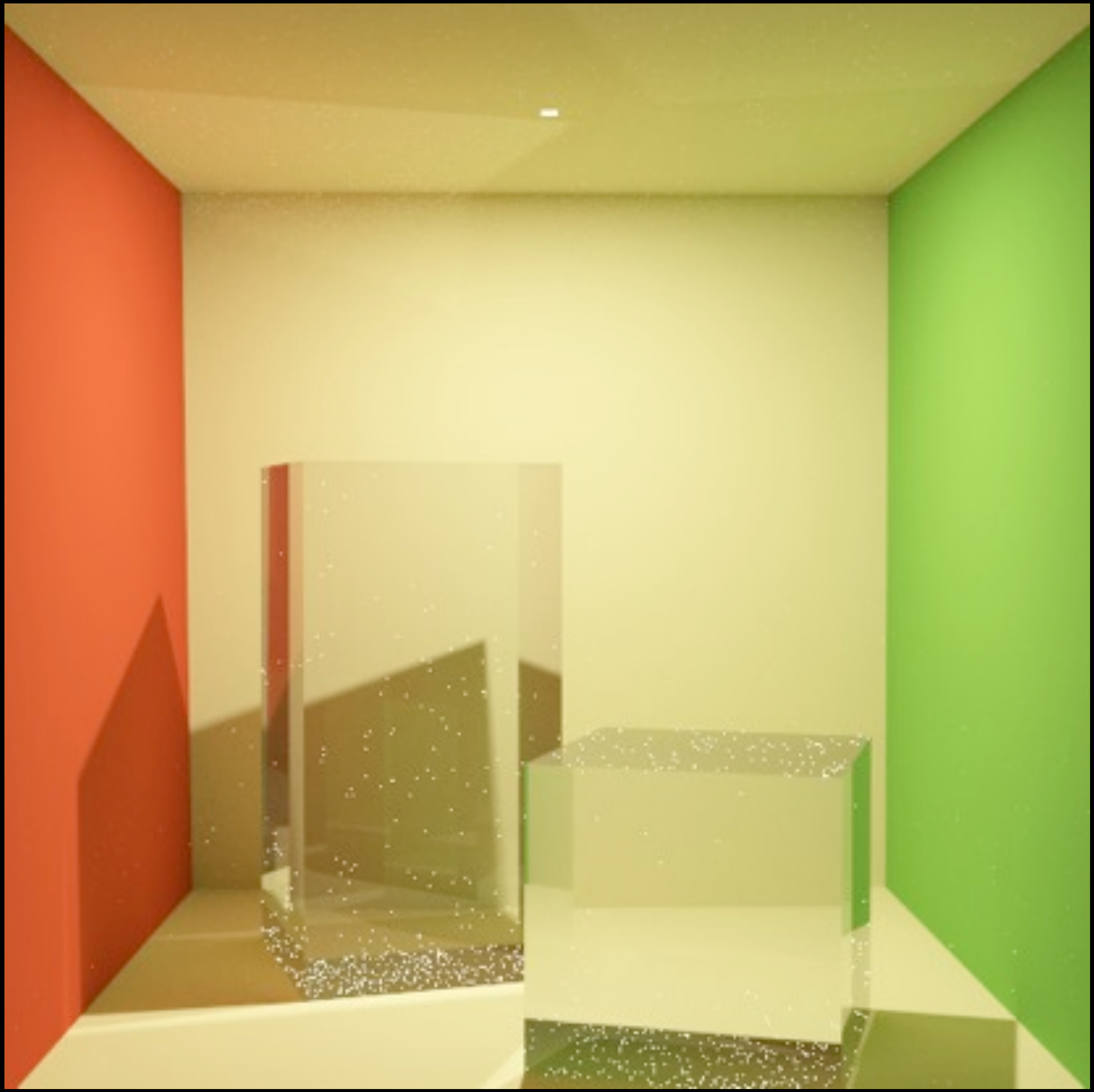

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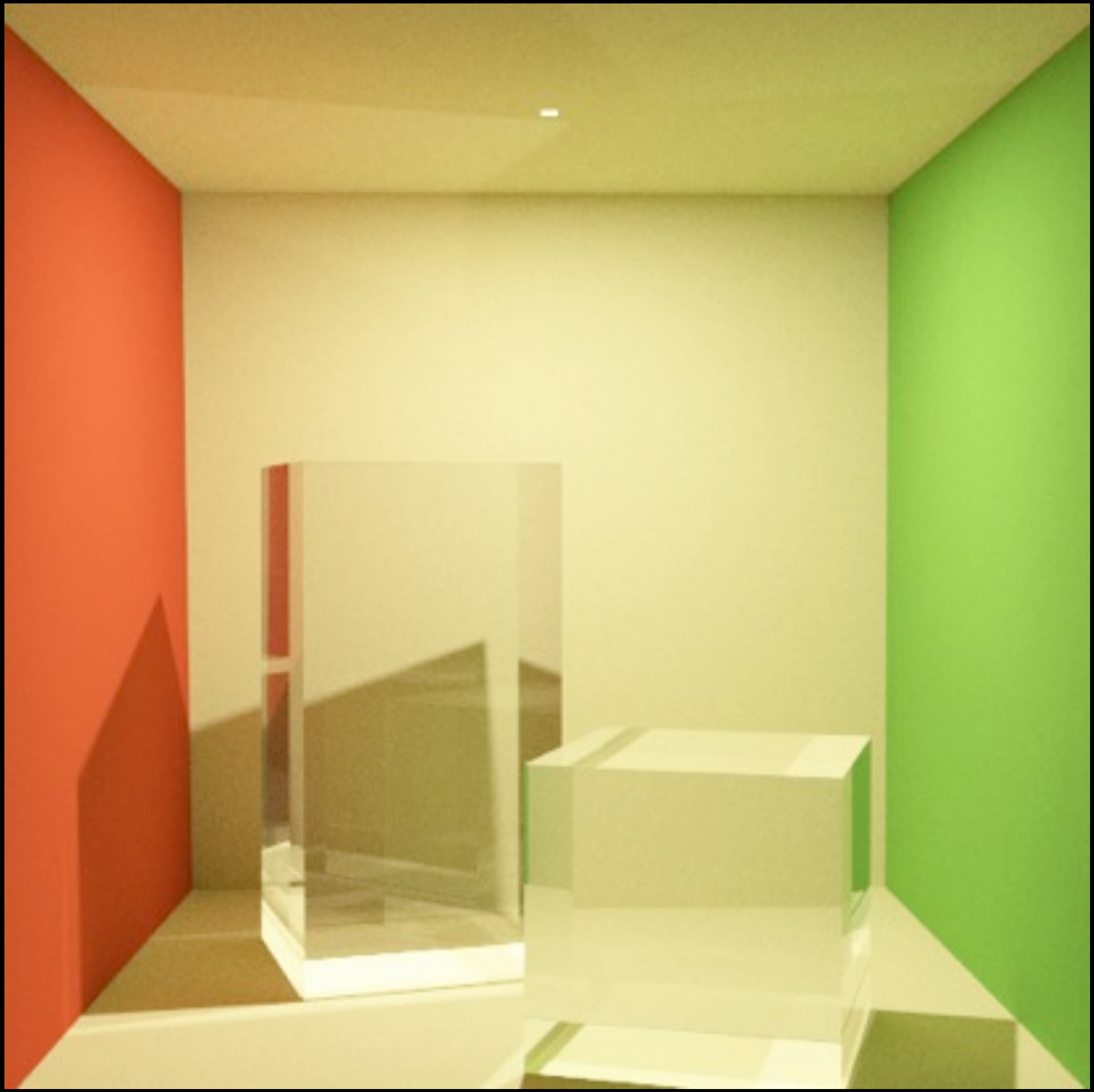


Bidirectional Path Tracing

Progressive Photon Mapping

Metropolis Light Transport

Progressive Photon Mapping

Implementation

- Need an efficient range query of photons (*not* kNN query)
- Be aware of tradeoff
  - Tree is adaptive, but costly to construct
  - Hash is fast to construct, but not adaptive

Parameters

- Important parameters
  - Initial radius
  - Alpha value (= radius reduction rate)
  - Number of photons per pass
- Convergence is guaranteed no matter what (as long as $0 < \alpha < 1$)

Parameters - Initial Radius

- Several options
  - kNN queries on the first photon map
  - Ray differentials
  - Constant
- Avoid using too large radius
  - Few pixels per photons is usually good
- Anton will introduce a better approach

Parameters - Alpha Value

- Use 0.6... = 2/3
  - Theoretical optimal
  - Works well in practice
  - Adaptive alpha is possible

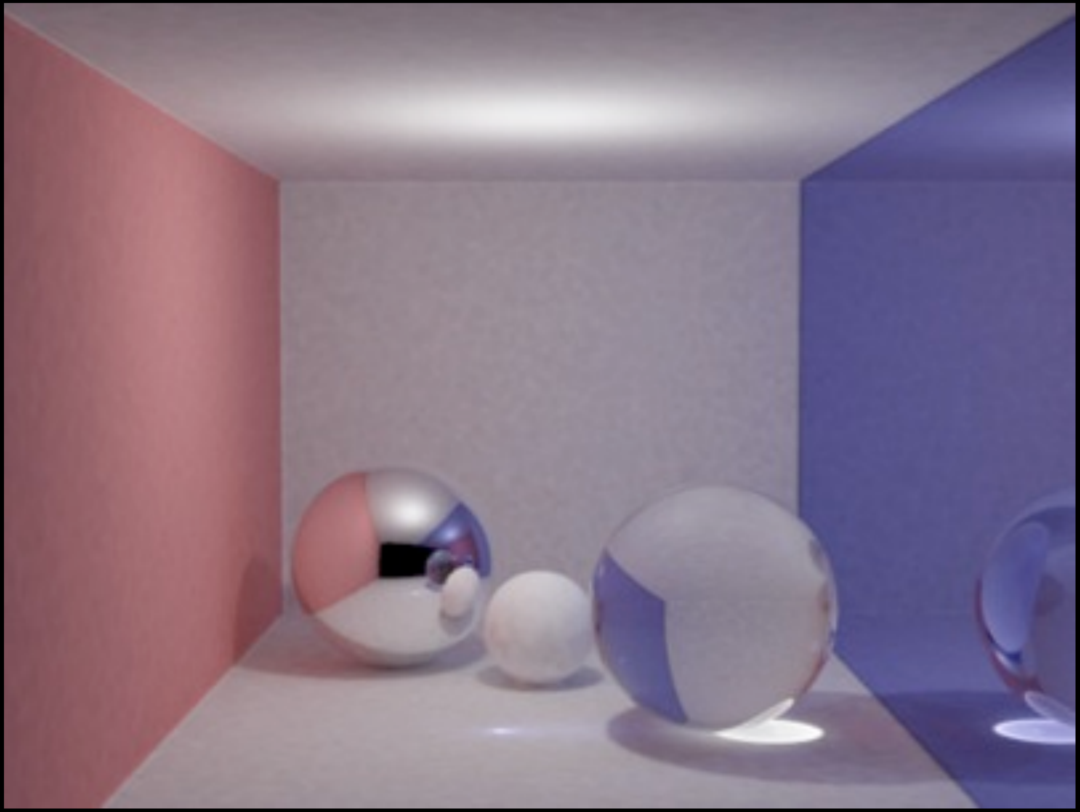
  - Anton will tell you more details

Parameters - # of Photons Per Pass

- Mainly depends on two factors
  - Desired frequency of visual feedback
  - Cost of making a data structure for range query
- Splatting approach can lower this number to one

Sample Code

- smallppm - 128 lines of working PPM code



cs.au.dk/~toshiya/smallppm.cpp

Sample Code

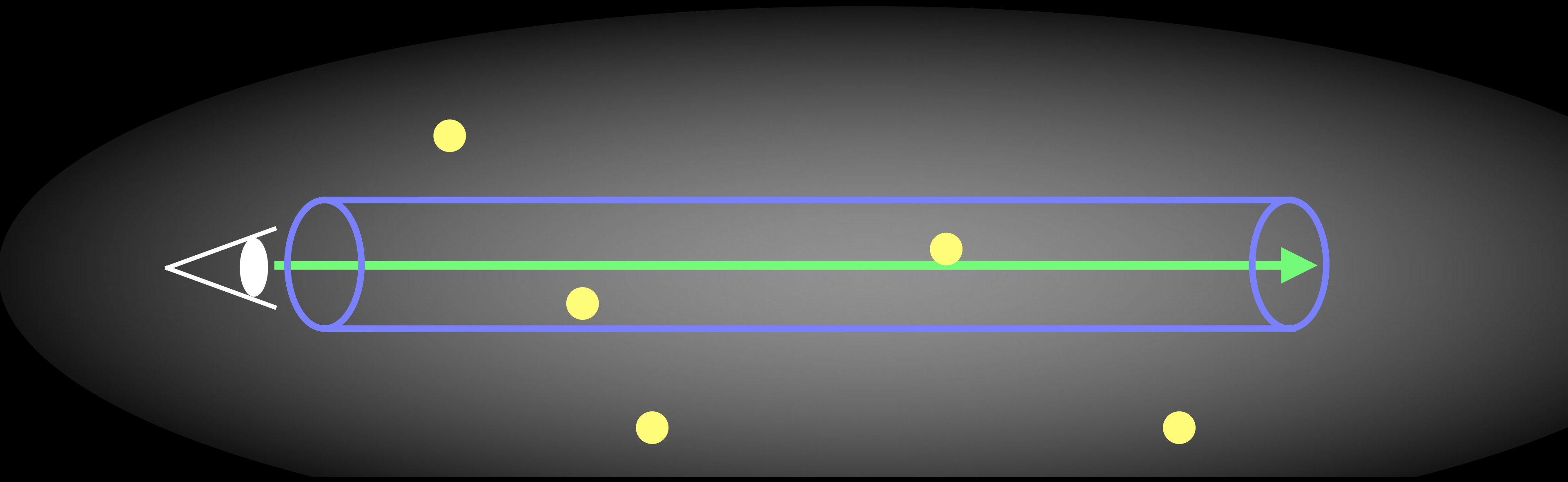
- Based on smallpt by Kevin Beason

- Splatting approach
- Uses spatial hashing for range queries

- Stores αN instead of N for each measurement point
  - Save some multiplications
  - αN is integer while N is not (avoids precision issue)

Participating Media

- Use a cylinder kernel around eye rays
  - Progressive extension of beam radiance estimate [Jarosz et al. 08]
  - Equations for radius reduction stay the same
  - More details in Section 5.6 of my dissertation



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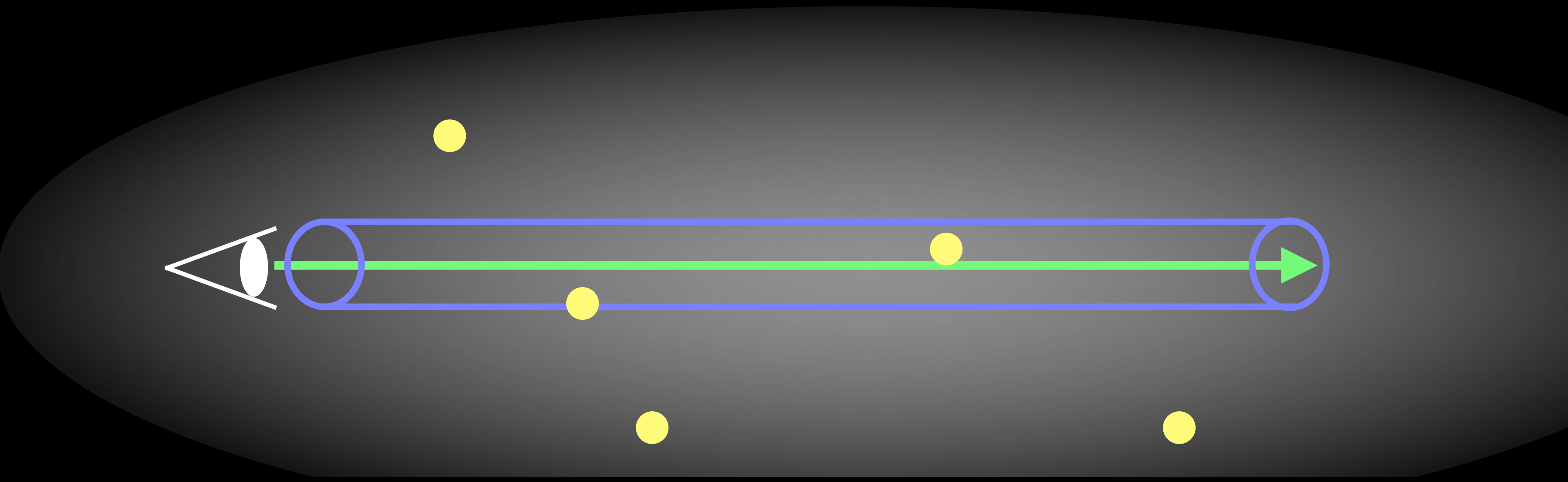

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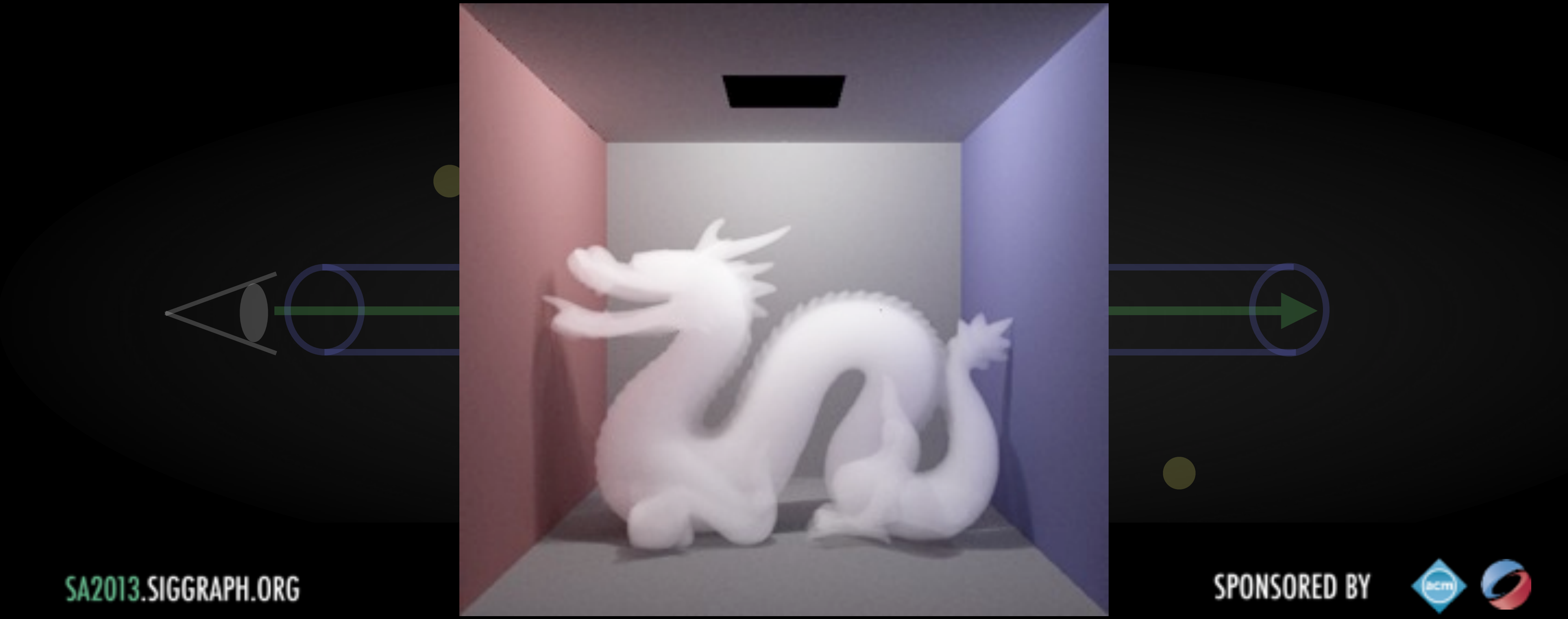

Summary

- Infinite number of photons without storing them
  - “Path tracing”nization of photon mapping

- Robust to specular-diffuse-specular paths
- Converges to the correct solution
- Easy to implement

PPM in the Wild

CHAOSGROUP v-ray

NVIDIA

VRED PROFESSIONAL

YAFARAY

LuxRender GPL PHYSICALLY BASED RENDERER

Next Talk

- Probabilistic formulation of PPM
- “How to turn your PM into PPM in a minute!”