State of the Art in Photon Density Estimation

Photon Mapping Basics

Wojciech Jarosz

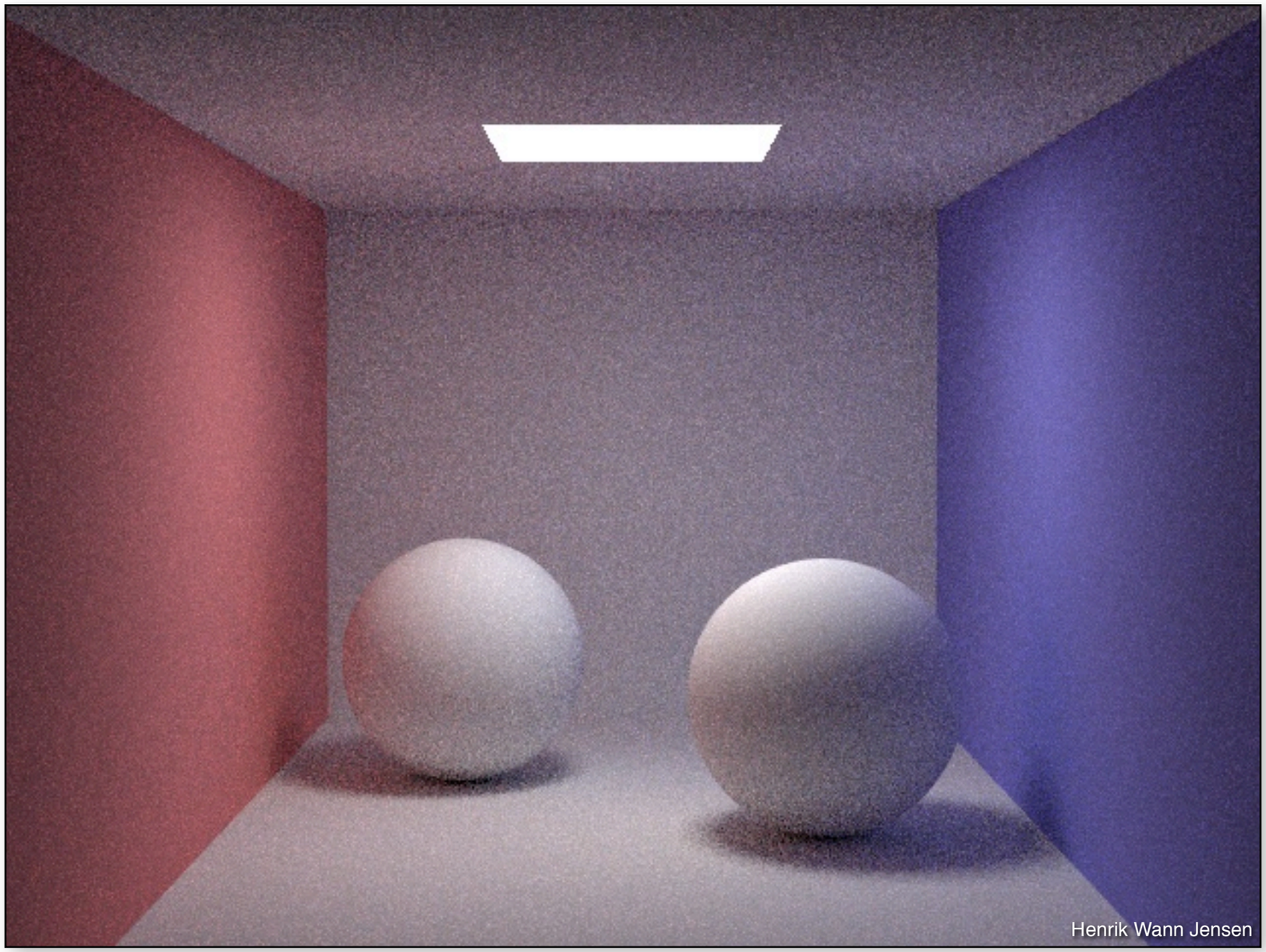
Motivation - Global Illumination

Motivation - Direct Illumination

Motivation - Before photon mapping

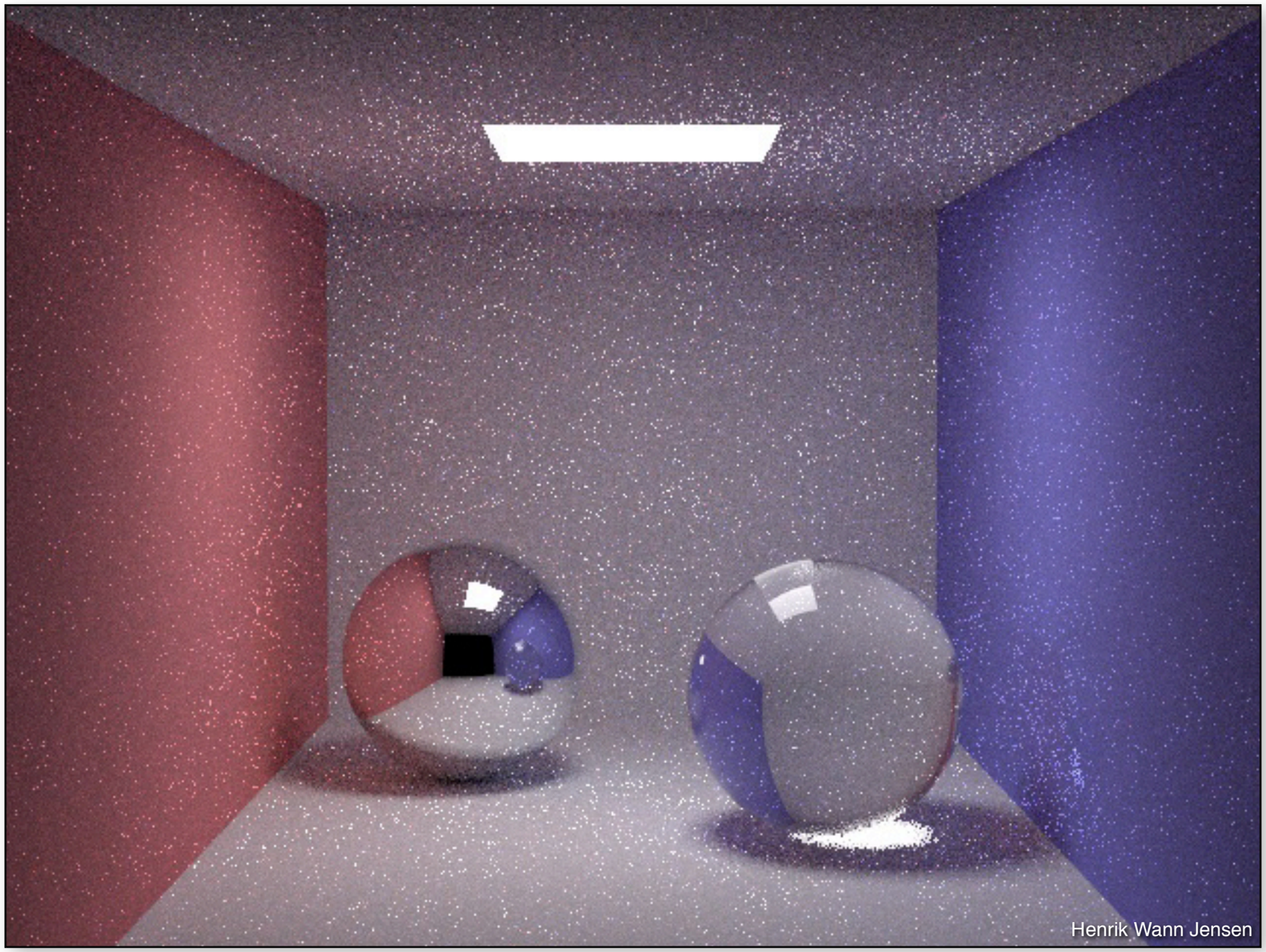
- Radiosity
  - ✘ Mostly diffuse
  - ✘ Mesh based lighting representation
- Monte Carlo path tracing
  - ✓ Very general
  - ✘ Noisy
  - ✘ Computation time/slow convergence

Path Tracing



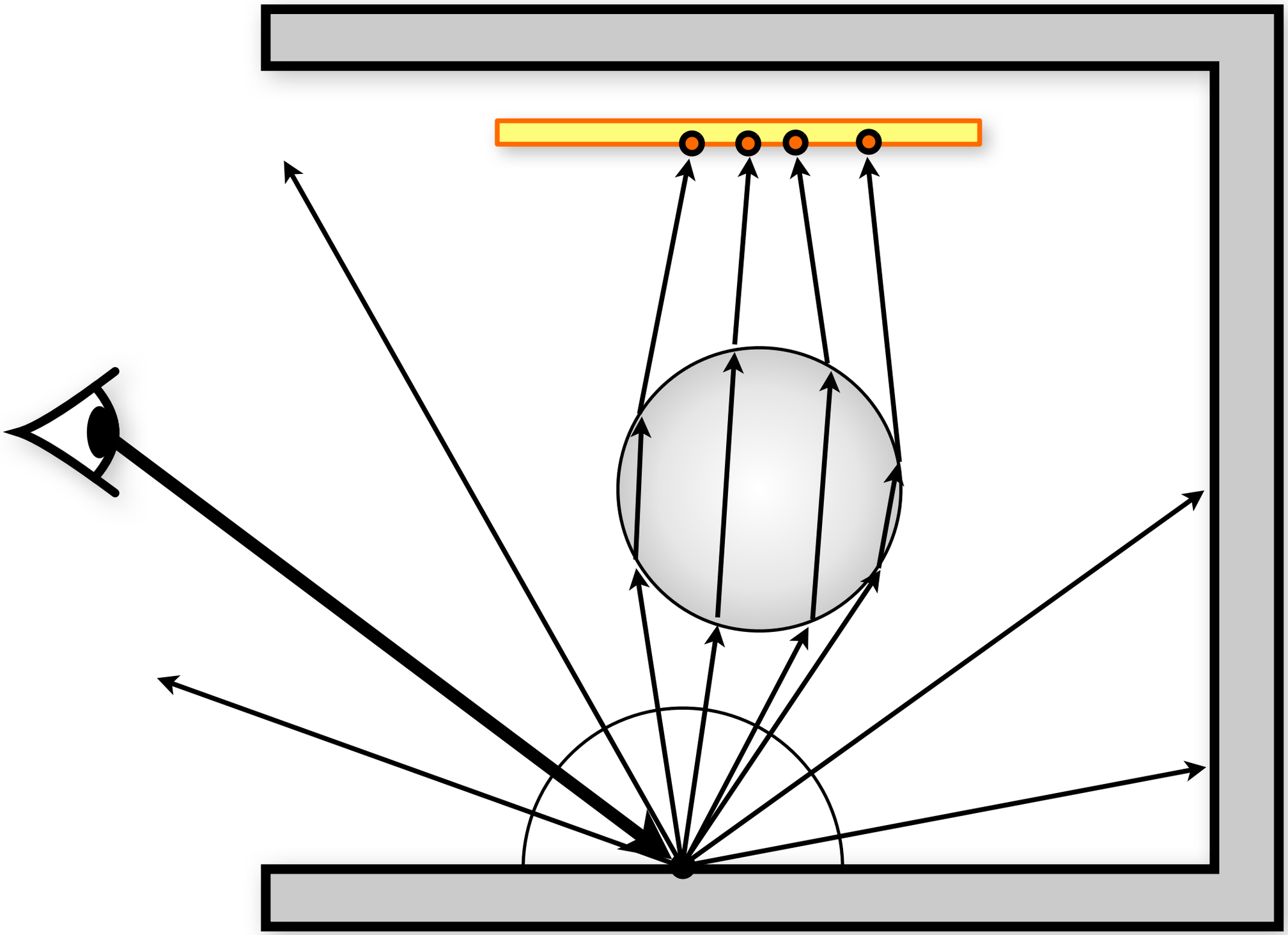
10 paths/pixel

Path Tracing Caustics

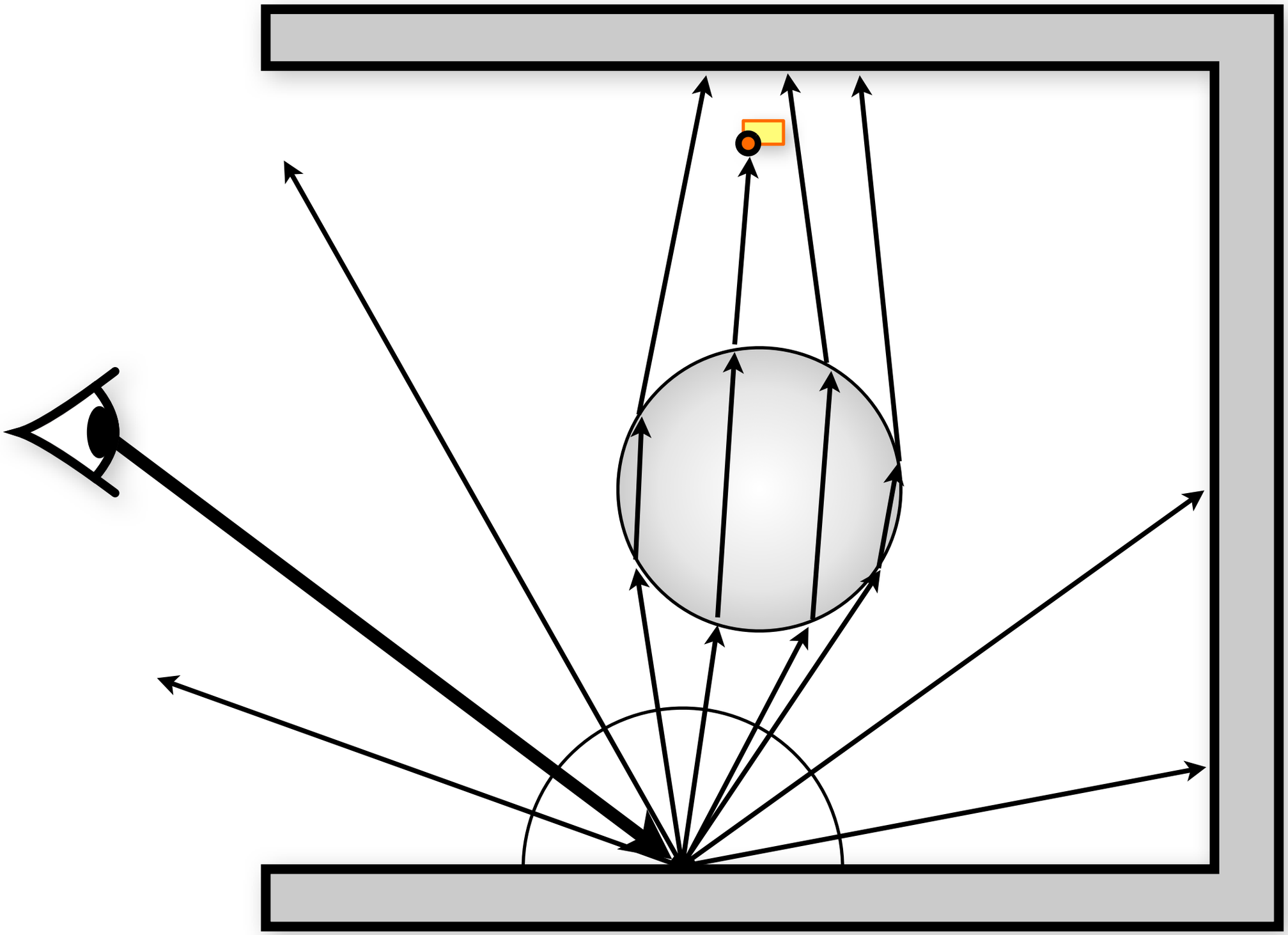


10 paths/pixel

Path Tracing Caustics



Path Tracing Caustics



Path Tracing Caustics

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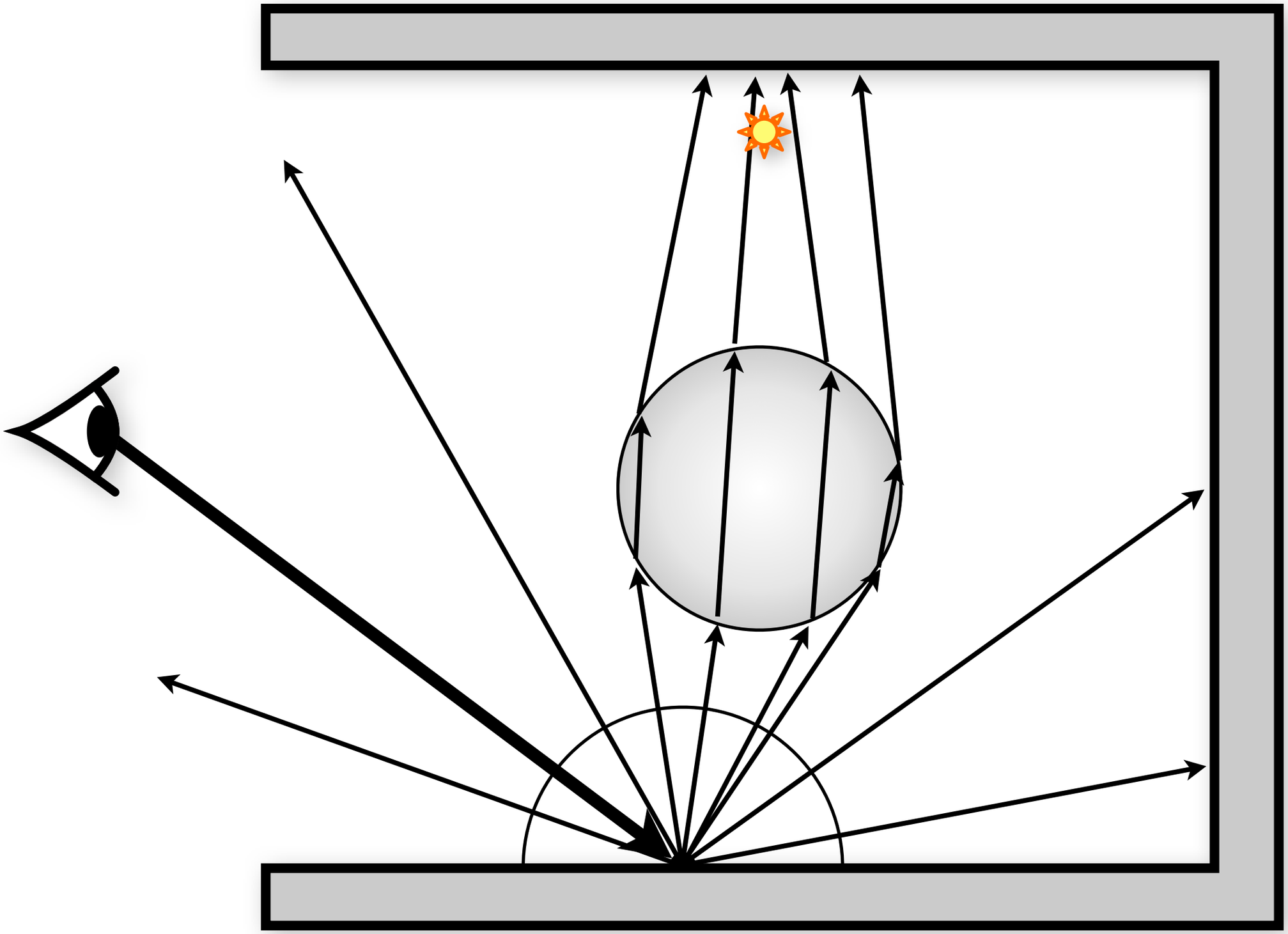

Density Estimation

- Light tracing / “Backward ray tracing”
- James Arvo. In *Developments in Ray Tracing*, SIGGRAPH ‘**86** Course Notes

Light Tracing ("Backward" Ray Tracing)

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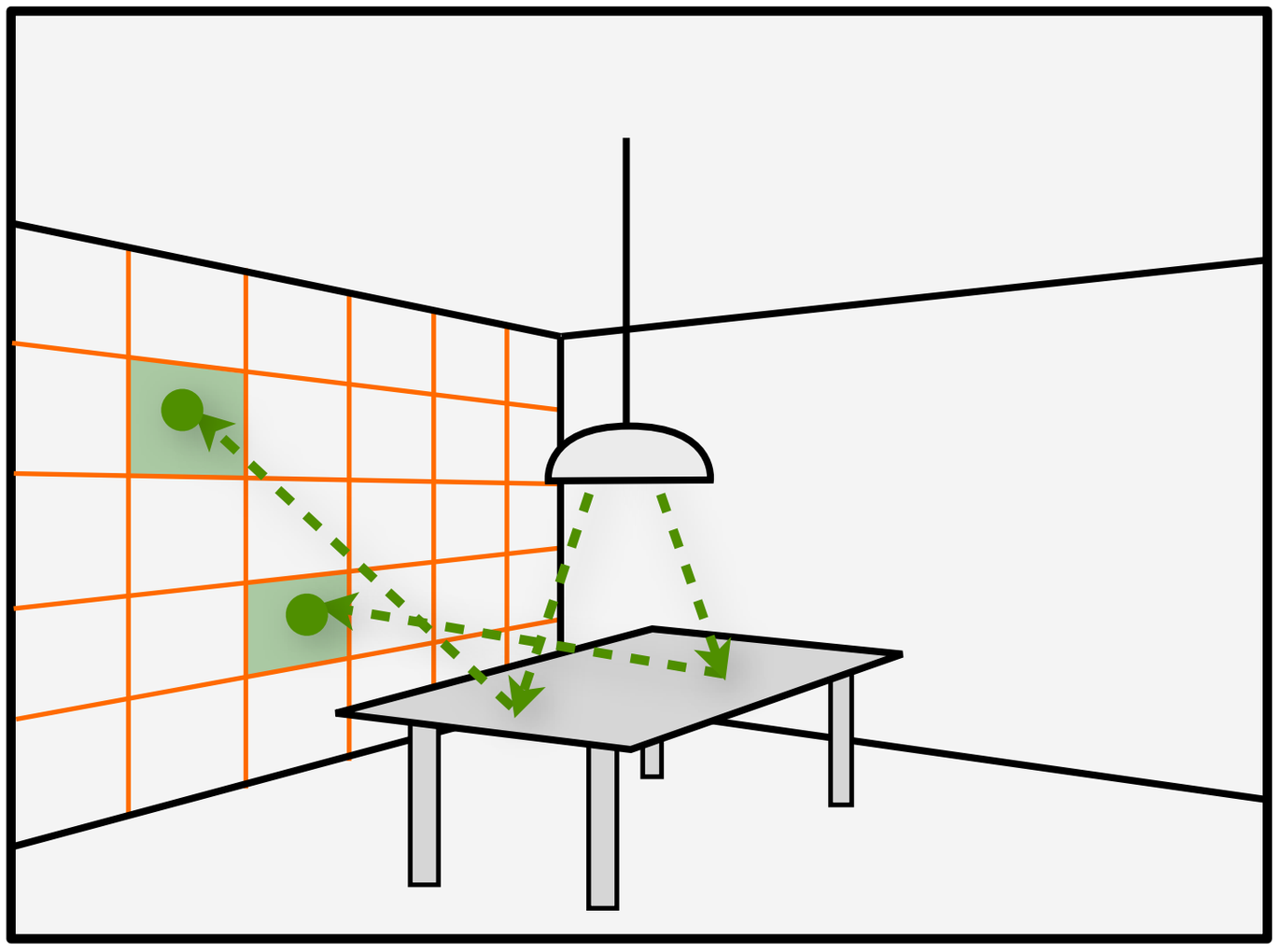
- Preprocess:
  - parametrize surfaces and create "illumination maps"
  - shoot light from light sources
  - deposit photon energy in illumination maps



Rendering

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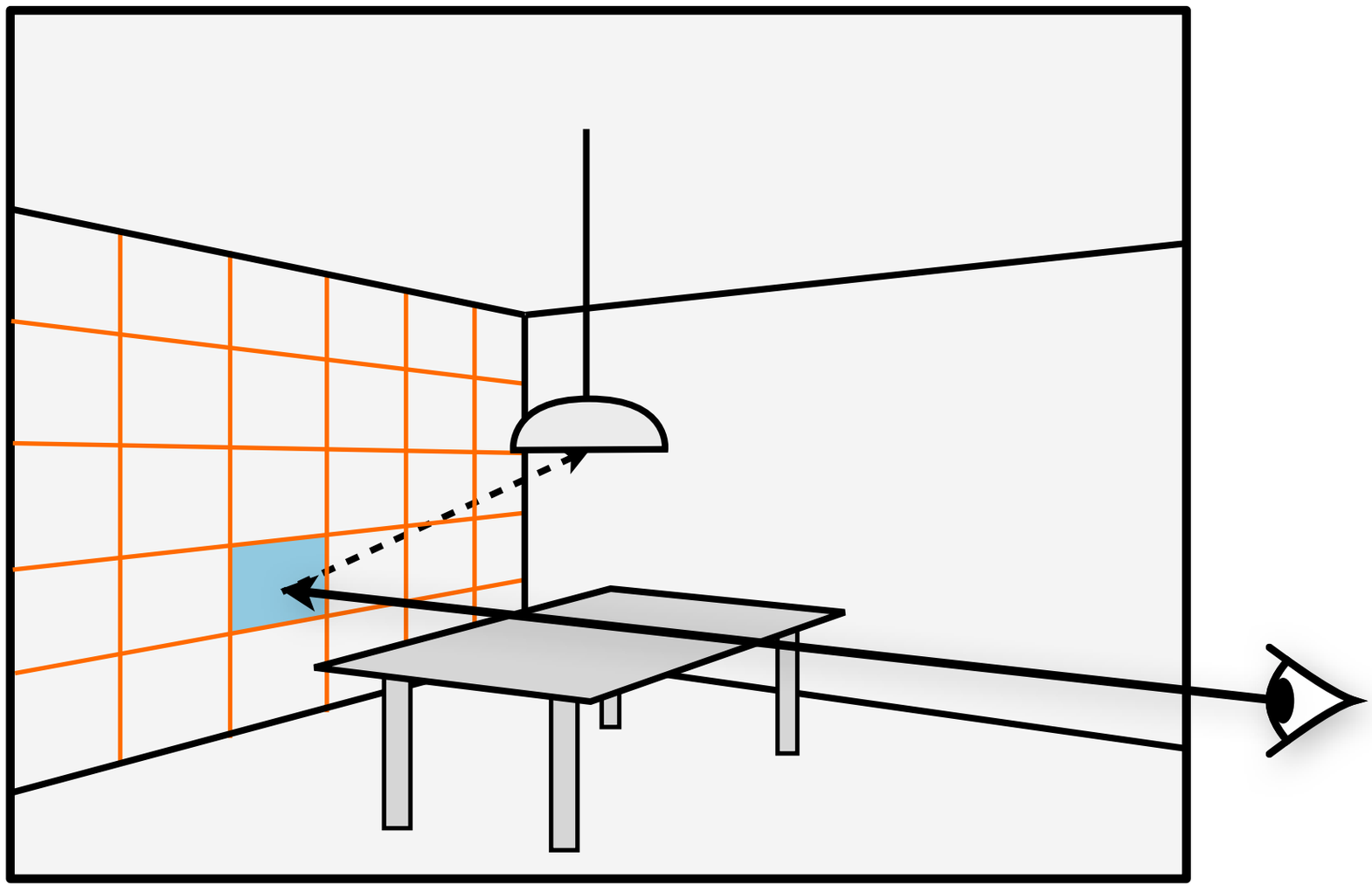
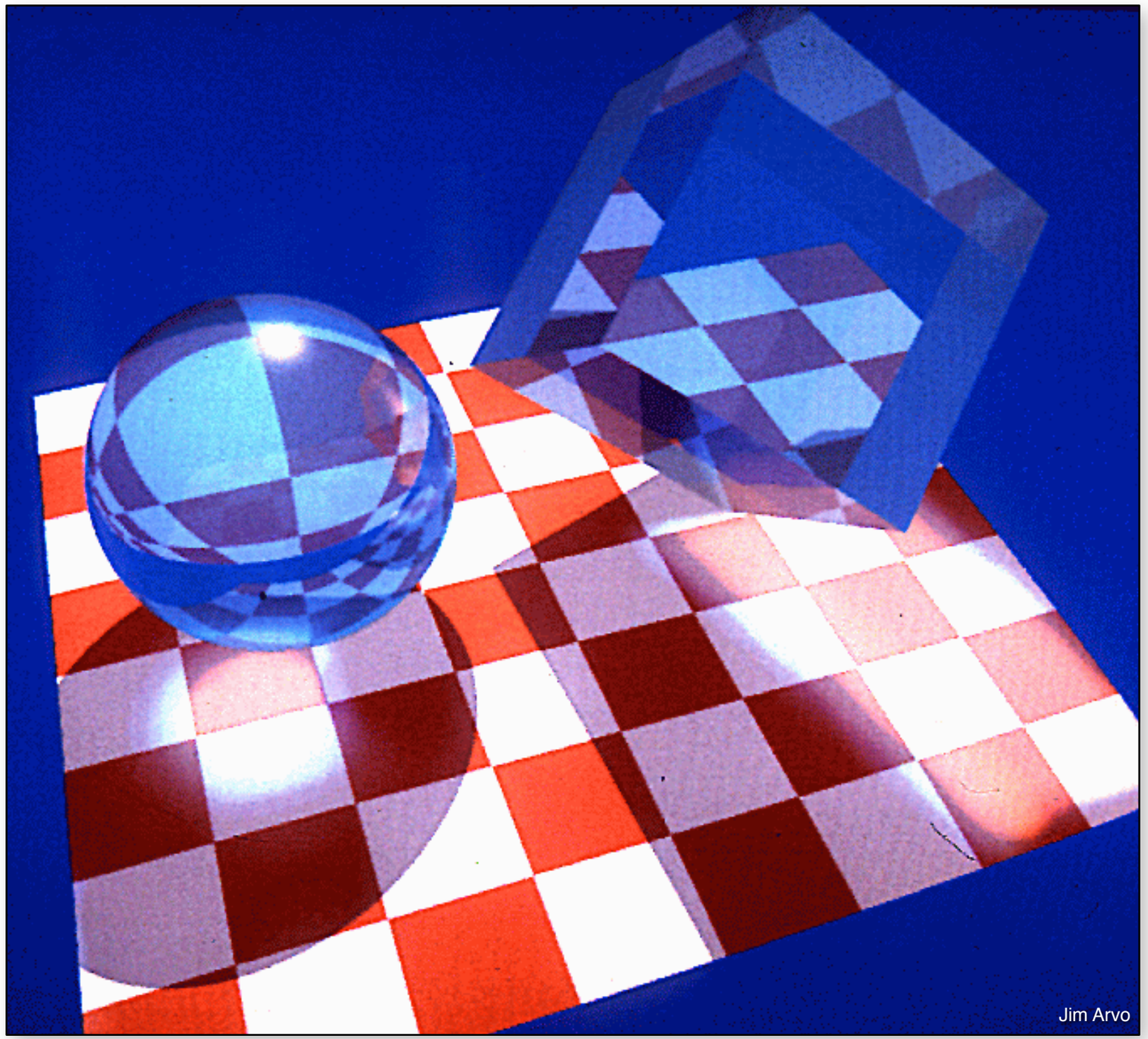
- For each shading point
  - compute direct lighting
  - lookup indirect lighting + caustics from illumination maps



Light Tracing



"Backward Ray Tracing", by James Arvo. In *Developments in Ray Tracing*, SIGGRAPH `86 Course Notes, Volume 12, August 1986.

Light Tracing

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✓ One of first techniques to simulate caustics

✗ Requires parametrizing surface or meshing

- Complex/procedural geometry difficult to handle

✗ Illumination map resolution difficult to choose

- high resolution/few photons: high-frequency noise
- low resolution/many photons: blurred illumination

Photon Mapping

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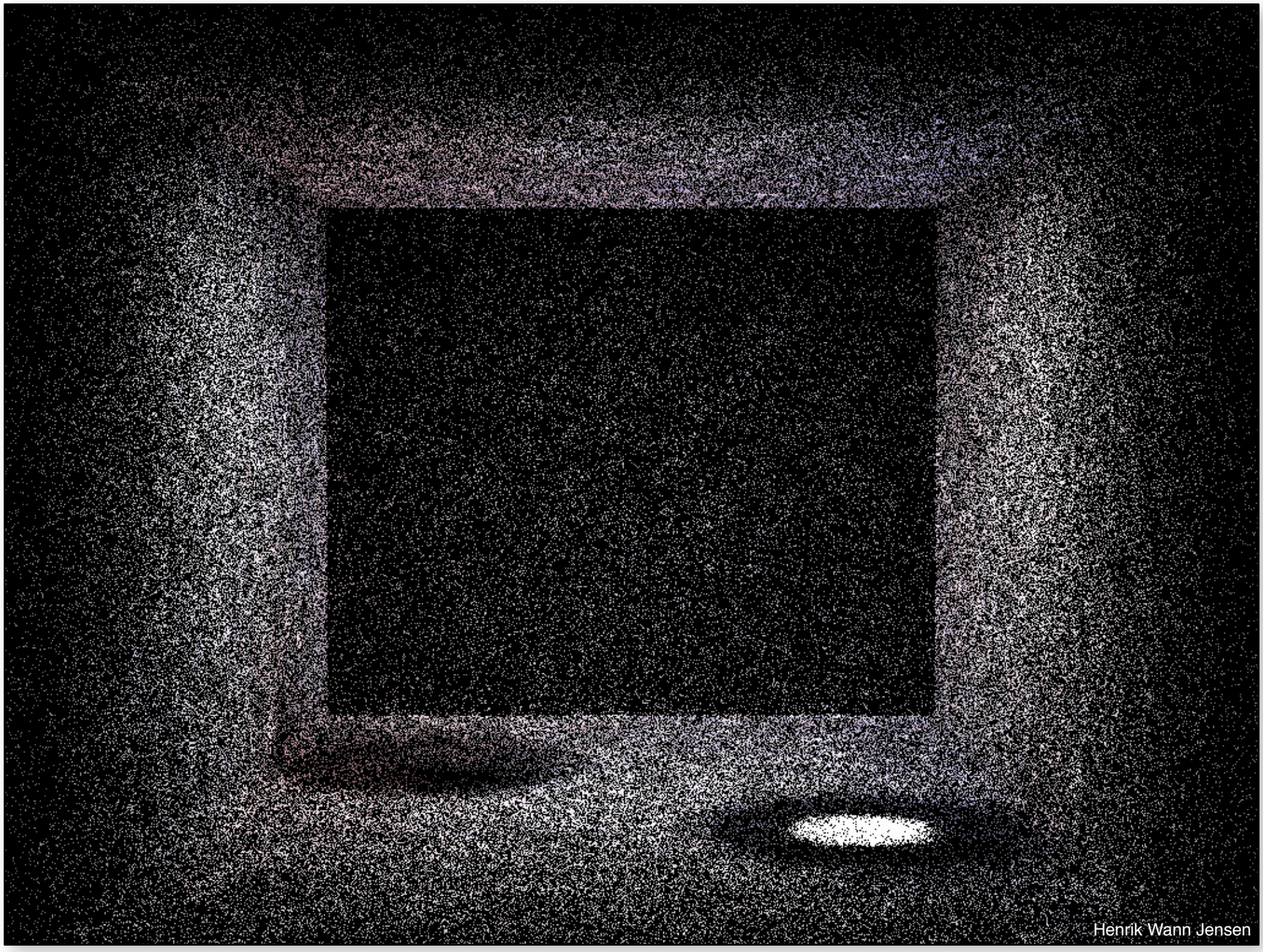
- A two-pass algorithm:
  - Pass 1: Trace virtual photons from the light source, scatter at surfaces, and cache
  - Pass 2: Ray trace the scene and use the photons to compute indirect illumination
- Same as light tracing, but different way of storing/caching photons

The Photon Map



Photon Mapping (Photon Tracing)

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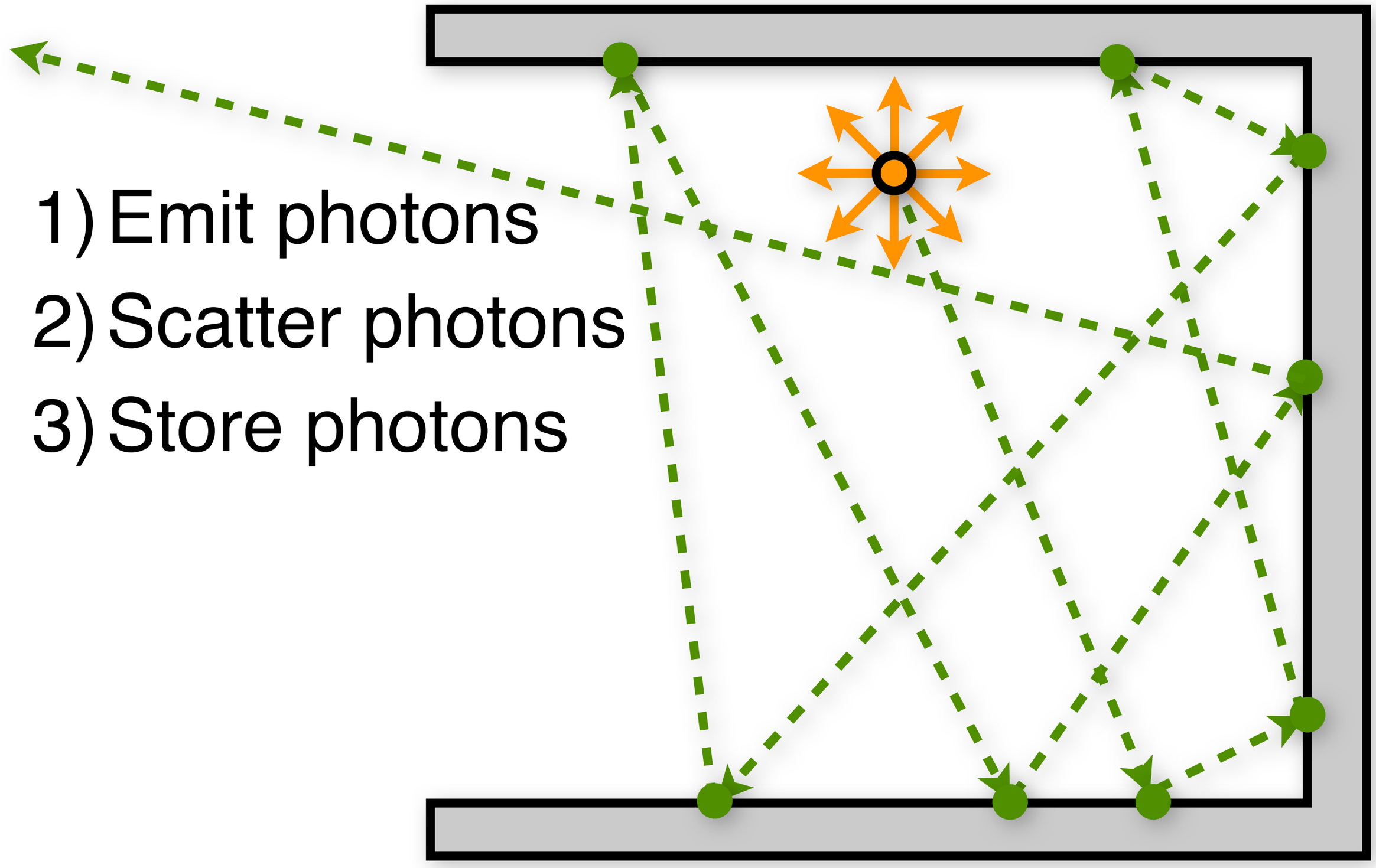
1) Emit photons
2) Scatter photons
3) Store photons



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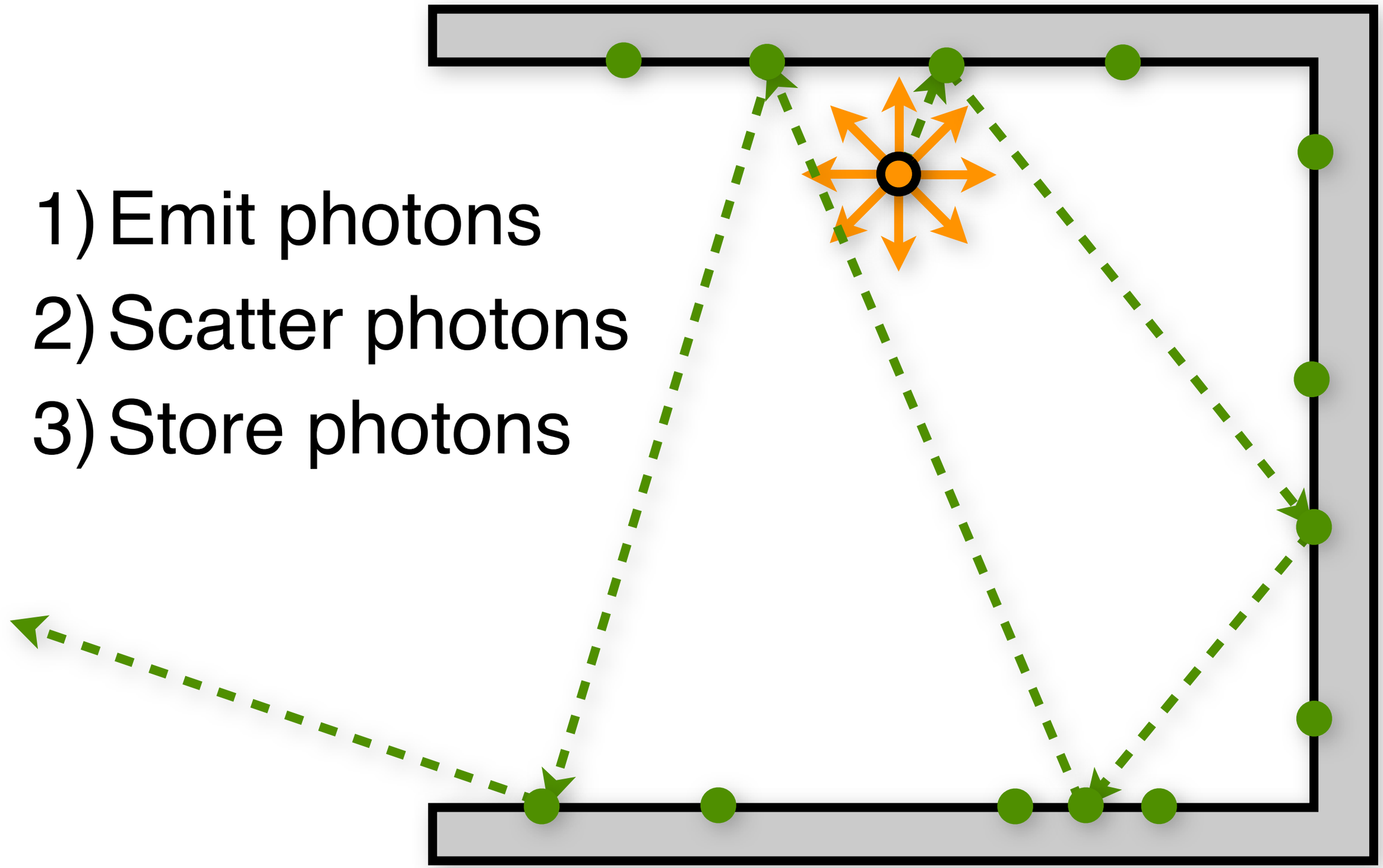

Photon Mapping (Photon Tracing)

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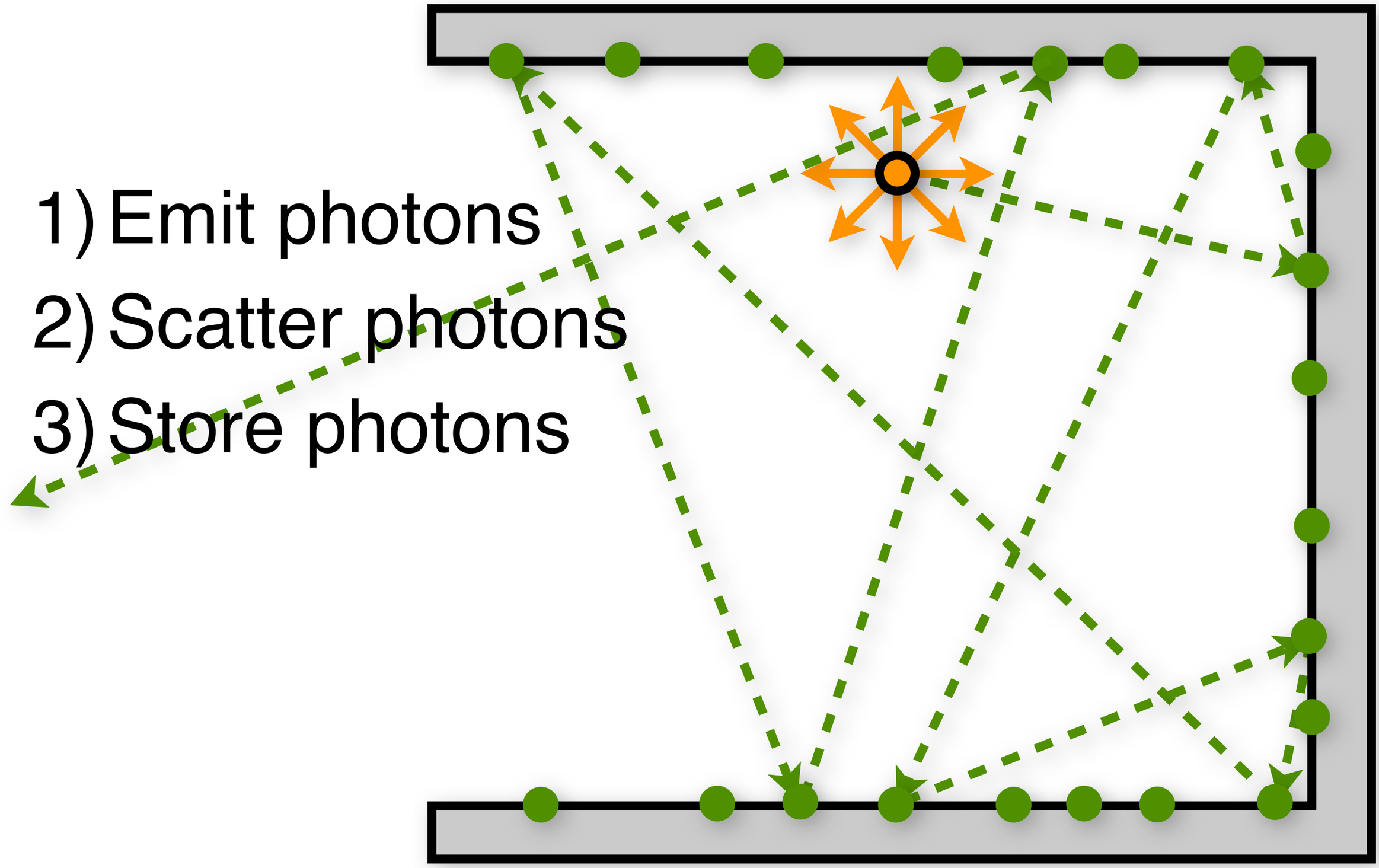

Photon emission

- Define initial:
  - x_p : position
  - ω_p : direction
  - Φ_p : photon power
- Recipe:
  - Sample position on surface area of light $x_p \sim pdf(x_p)$
  - Sample direction $\omega_p \sim pdf(\omega_p)$
  - $\Phi p = L_e(x_p, \omega_p) / pdf(x_p) / pdf(\omega_p)$

Photon emission examples

- Isotropic point light:
  - Generate uniform random direction over sphere
- Spotlight:
  - Generate uniform random direction within spherical cap
- Diffuse square light
  - Generate uniform random location on square
  - Generate cosine-weighted direction over hemisphere

Pseudocode

```
void generatePhotonMap()
    repeat:
        (l, Prob_l) = chooseRandomLight()
        (x, ω, Φ) = emitPhotonFromLight(l)
        tracePhoton(x, ω, Φ / Prob_l)
    until we have enough photons;
    divide all photon powers by number of emitted photons
```

Photon Tracing

```
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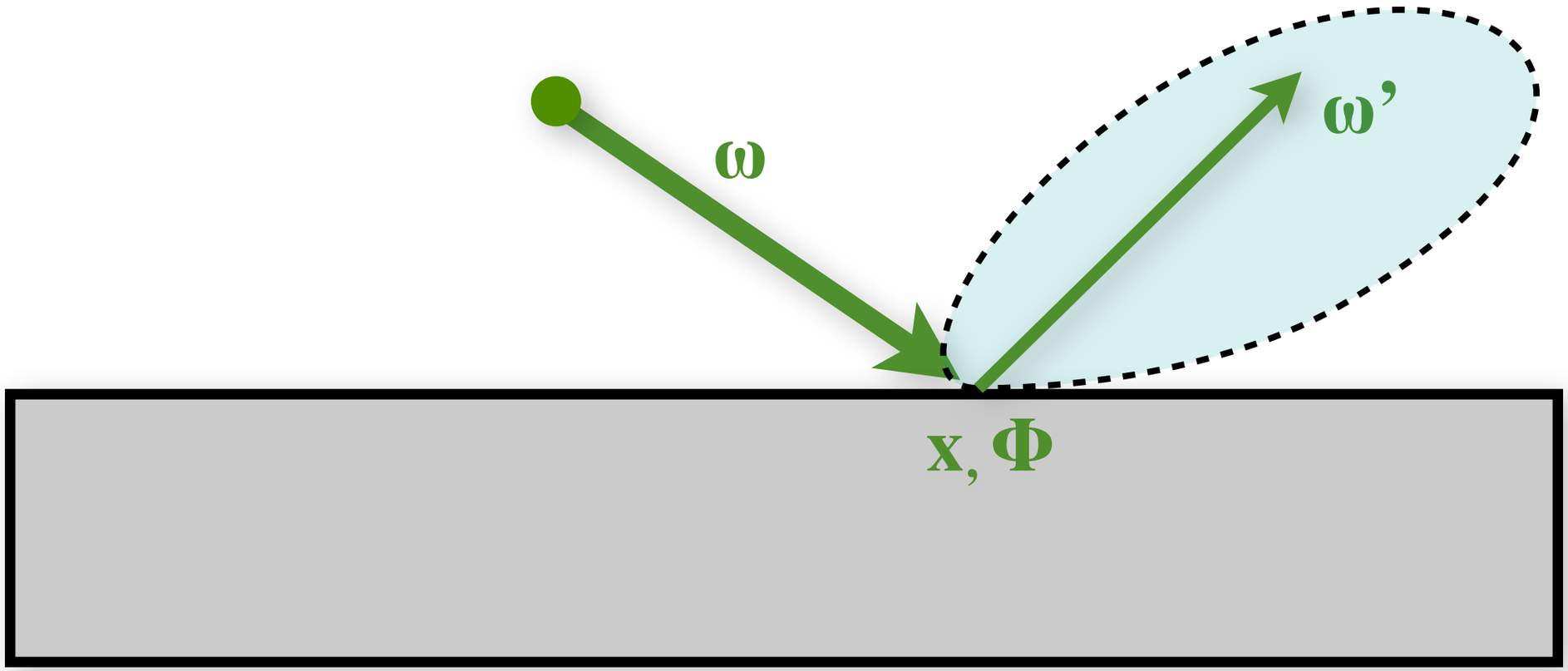
Photon Tracing




```
void tracePhoton(x, ω, Φ)
    s = nearestSurfaceHit(x, ω)
    x += s*ω        // propagate photon
    possiblyStorePhoton(x, ω, Φ)
    (ω’, pdf) = sampleBxDF(x, ω)
    return tracePhoton(o, ω’, Φ * BxDF(x,ω,ω’) / pdf)
```

Use Russian roulette!

Photon Mapping

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- A two-pass algorithm:
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Photon Mapping (Rendering)

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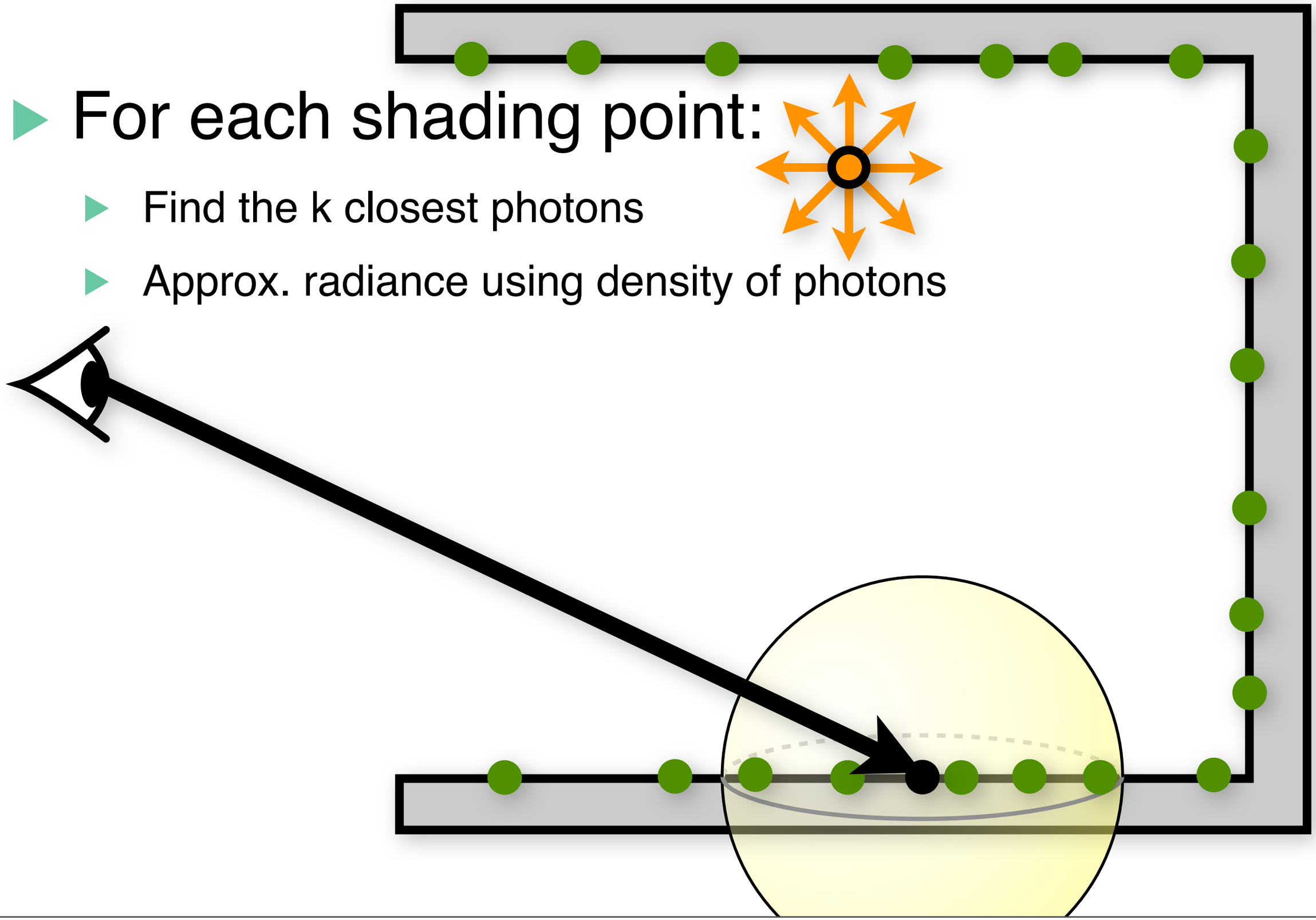
- For each shading point:
  - Find the k closest photons
  - Approx. radiance using density of photons



Photon Mapping (Rendering)

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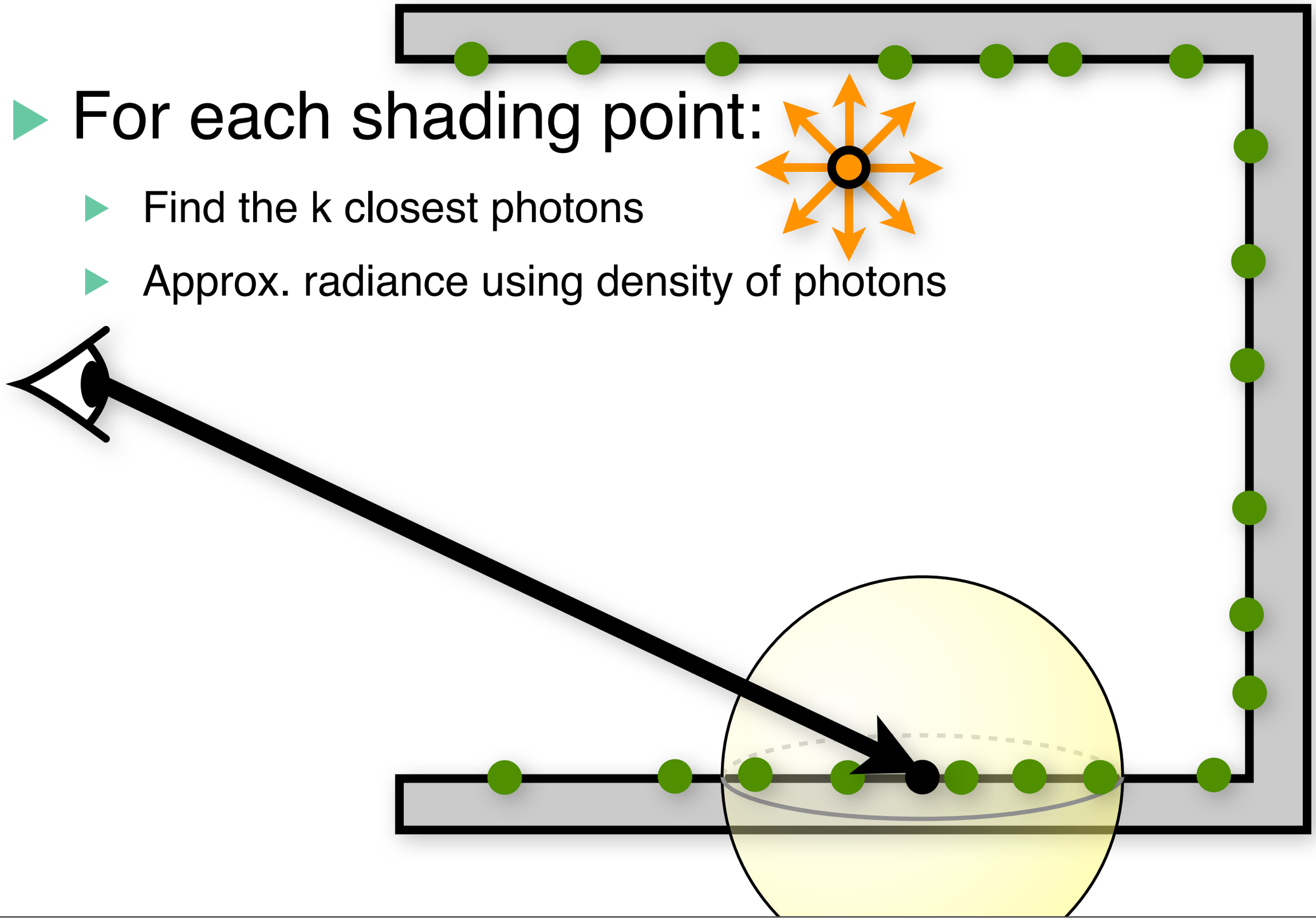
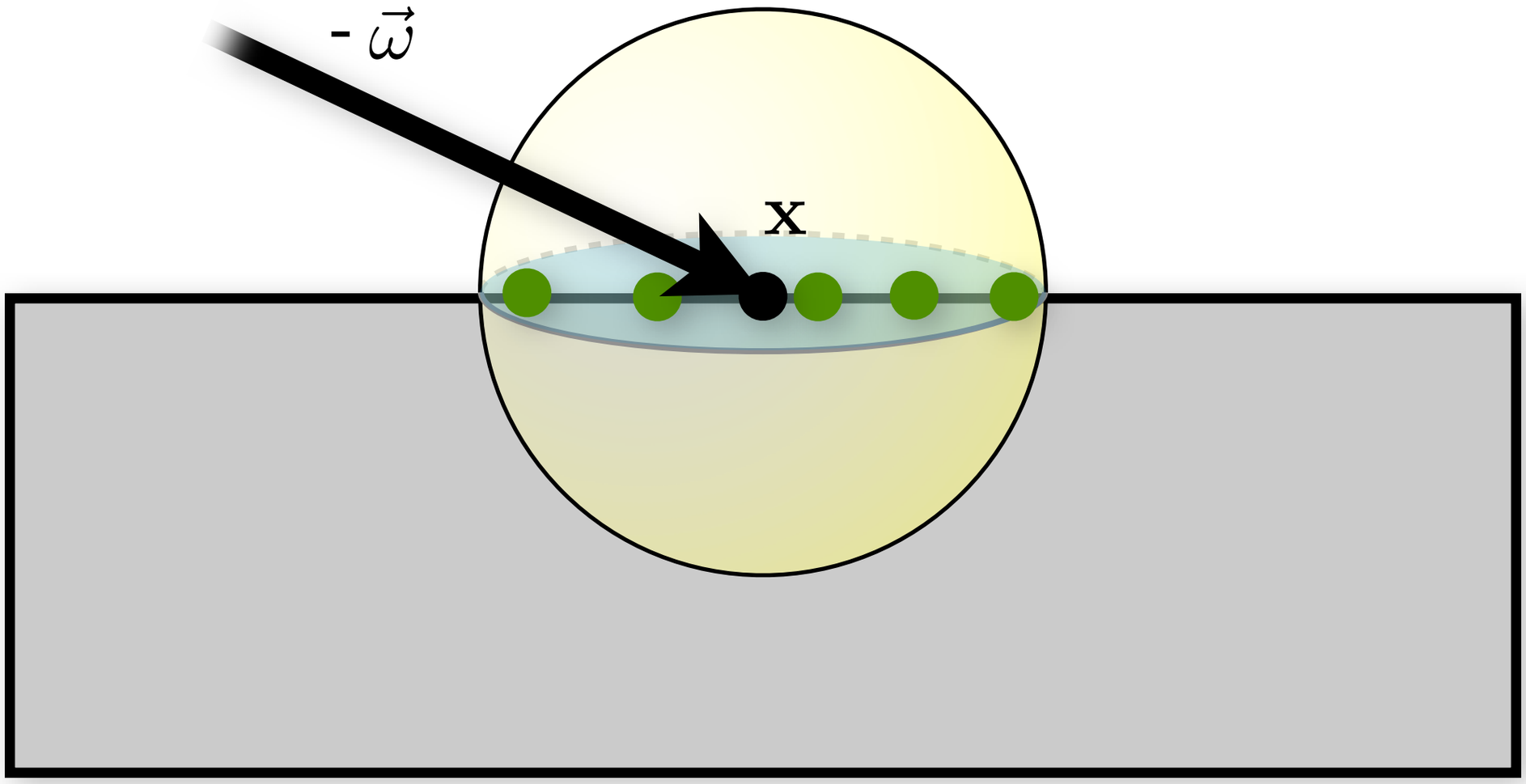


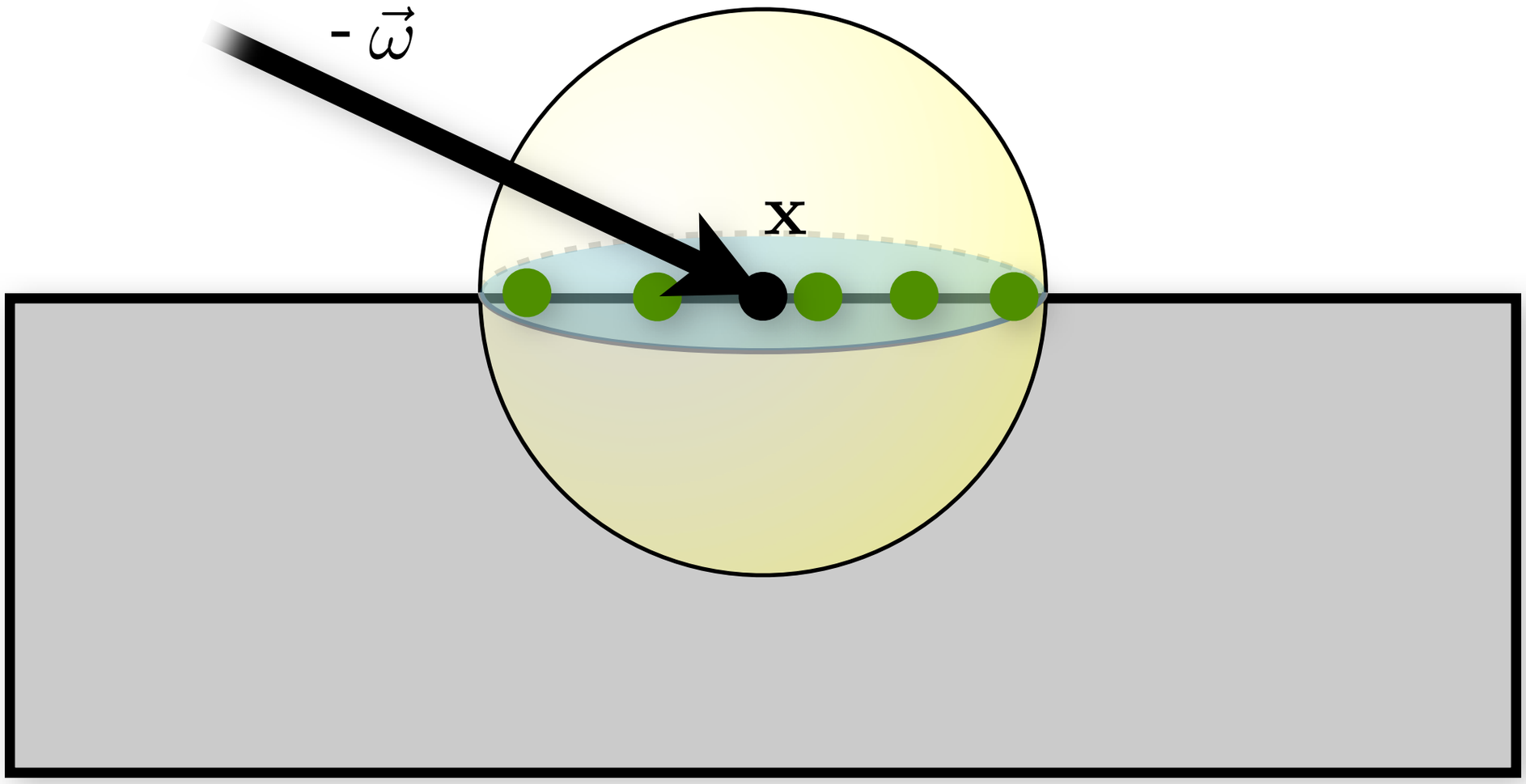
The Radiance Estimate

$$L_r(\mathbf{x}, \vec{\omega}) \approx \sum_{p=1}^{k-1} f_r(\mathbf{x}, \vec{\omega}_p, \vec{\omega}) \frac{\Phi_p}{A_k}$$



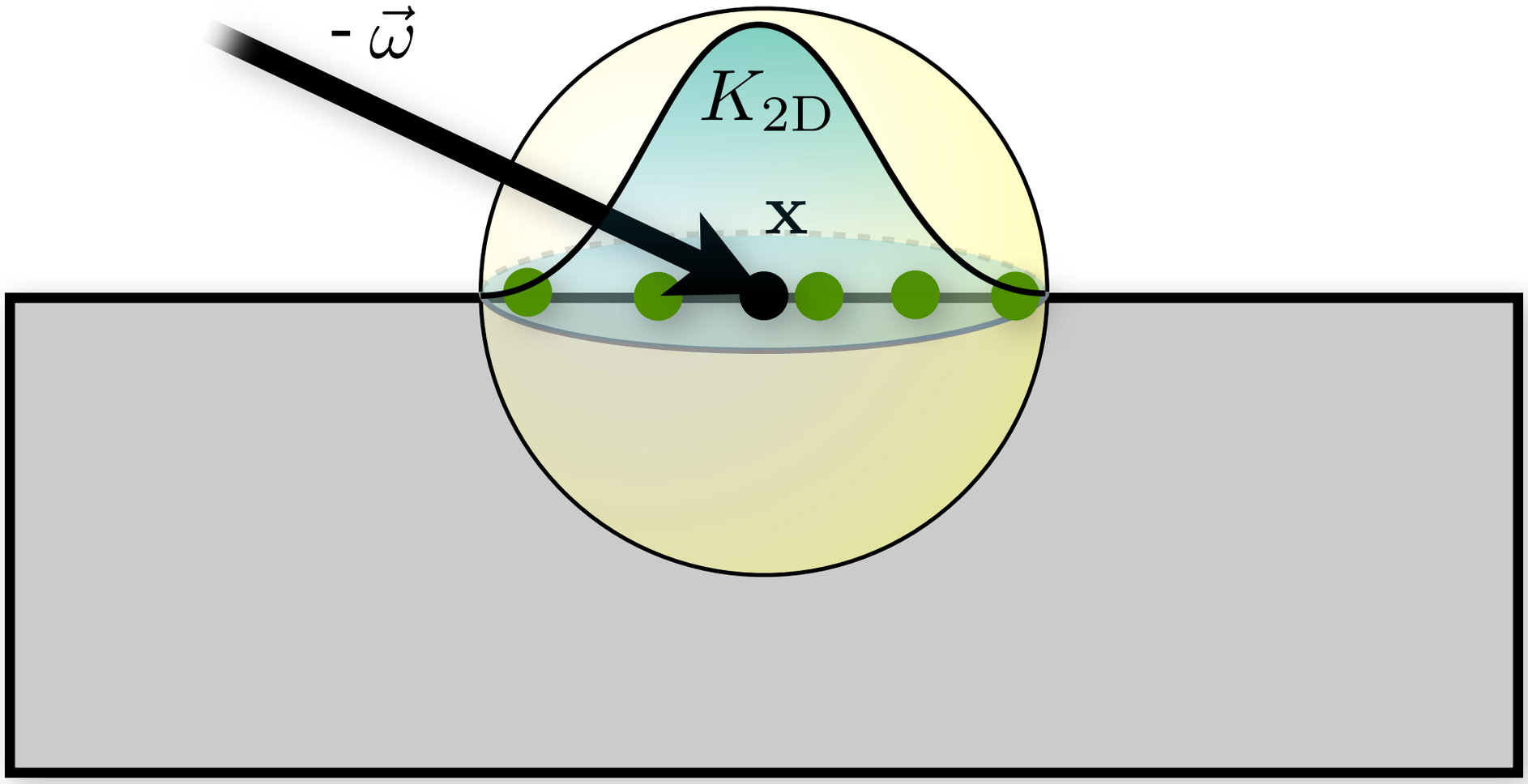
The Radiance Estimate

$$L_r(\mathbf{x}, \vec{\omega}) \approx \sum_{p=1}^{k-1} f_r(\mathbf{x}, \vec{\omega}_p, \vec{\omega}) \frac{\Phi_p}{\pi r_k^2}$$



The Radiance Estimate

$$L_r(\mathbf{x}, \vec{\omega}) \approx \sum_{p=1}^{k-1} f_r(\mathbf{x}, \vec{\omega}_p, \vec{\omega}) \Phi_p K_{2\mathrm{D}}(r_p, r_k)$$



The Photon Map Data Structure

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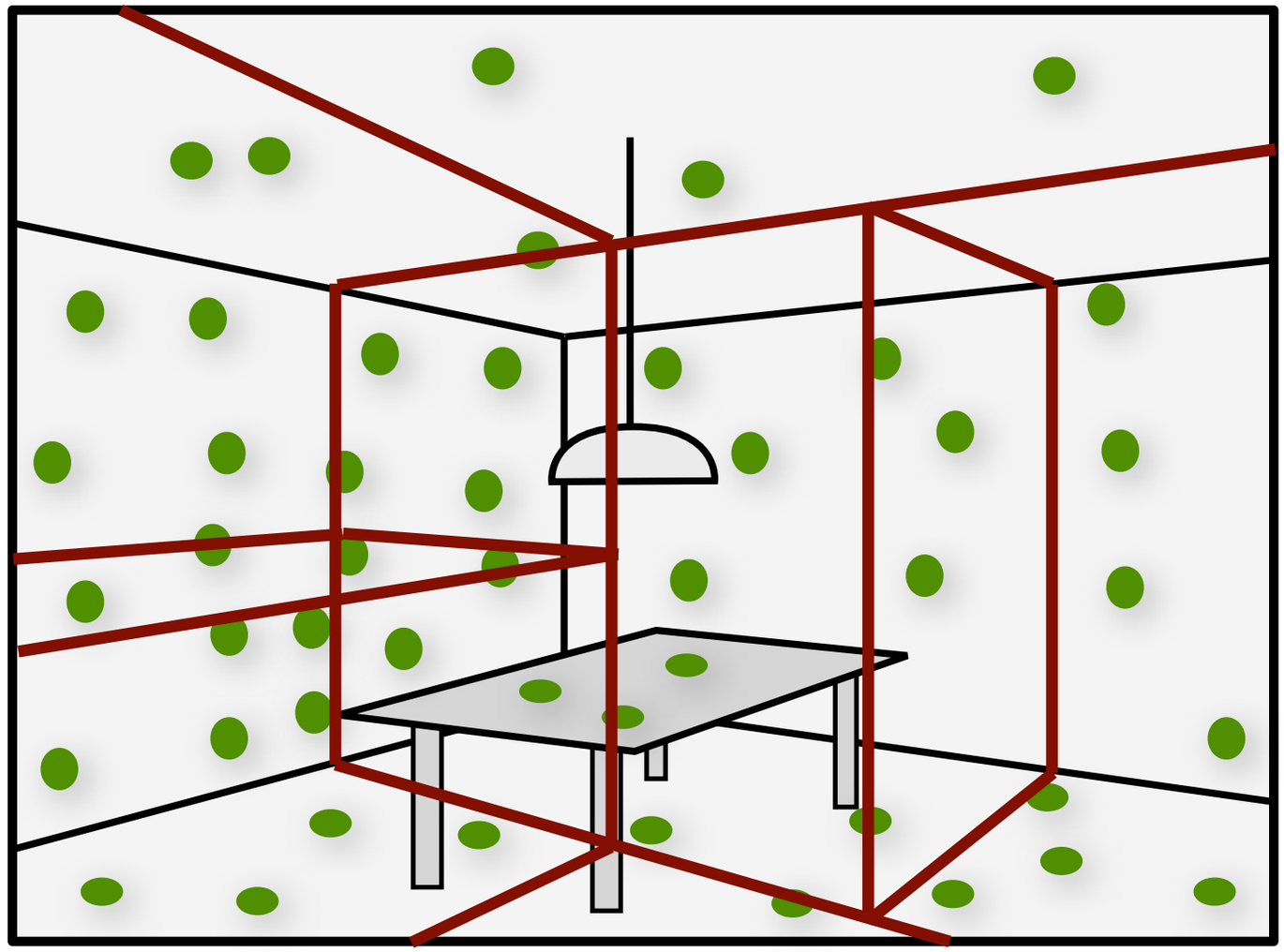
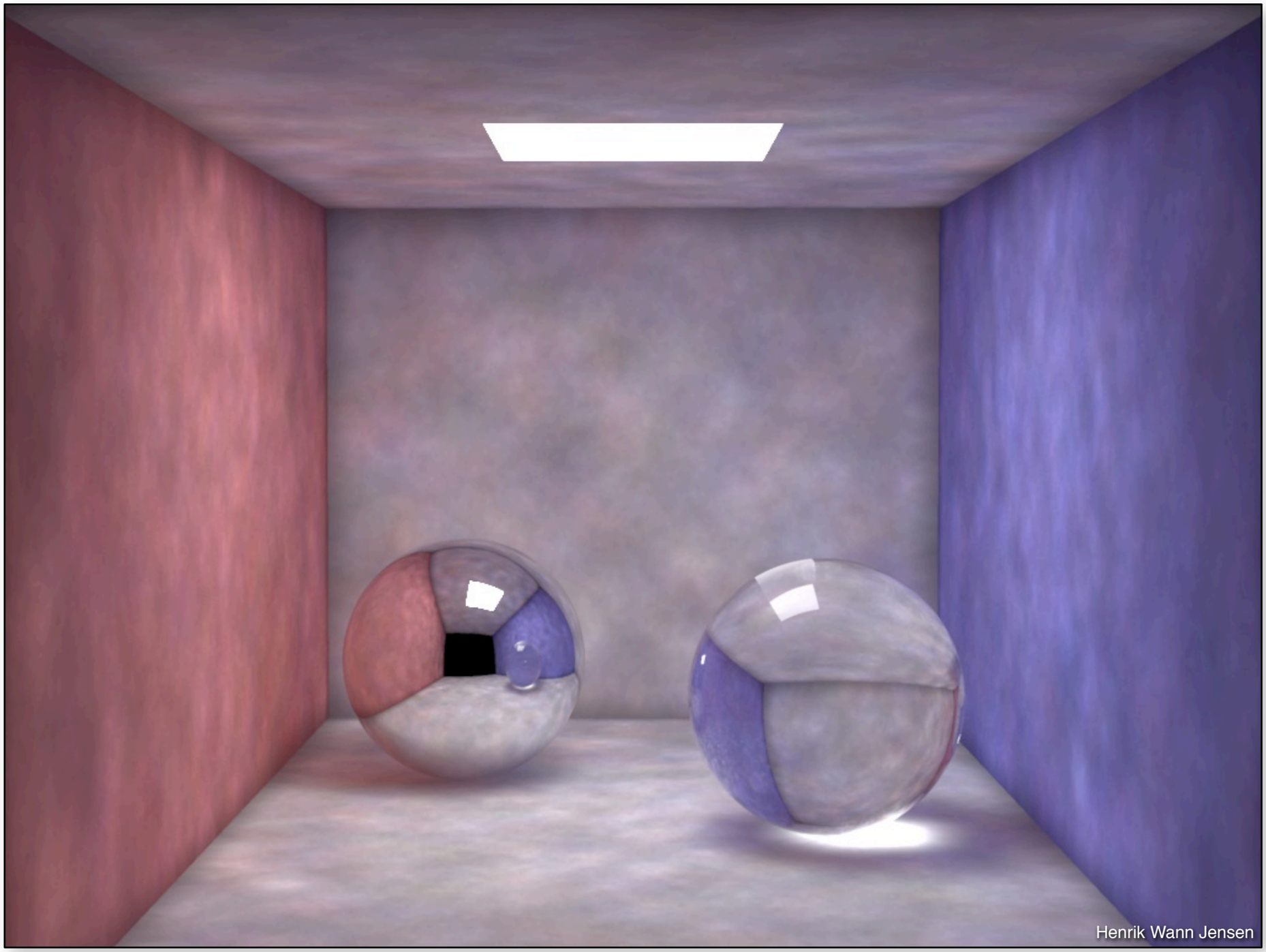
- Requirements:
  - Compact (we want many photons)
  - Fast nearest neighbor search
- KD-tree

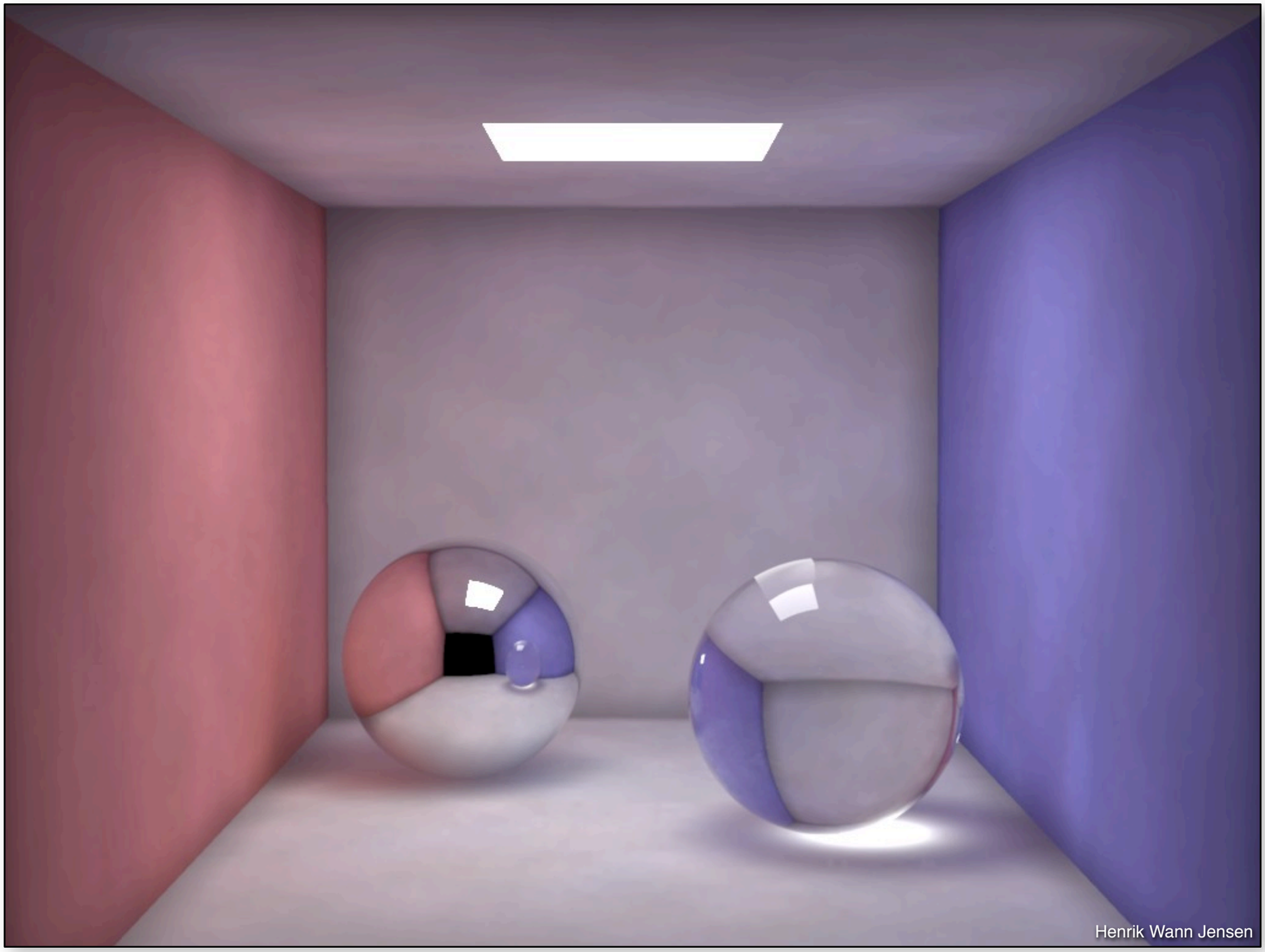


Global Illumination



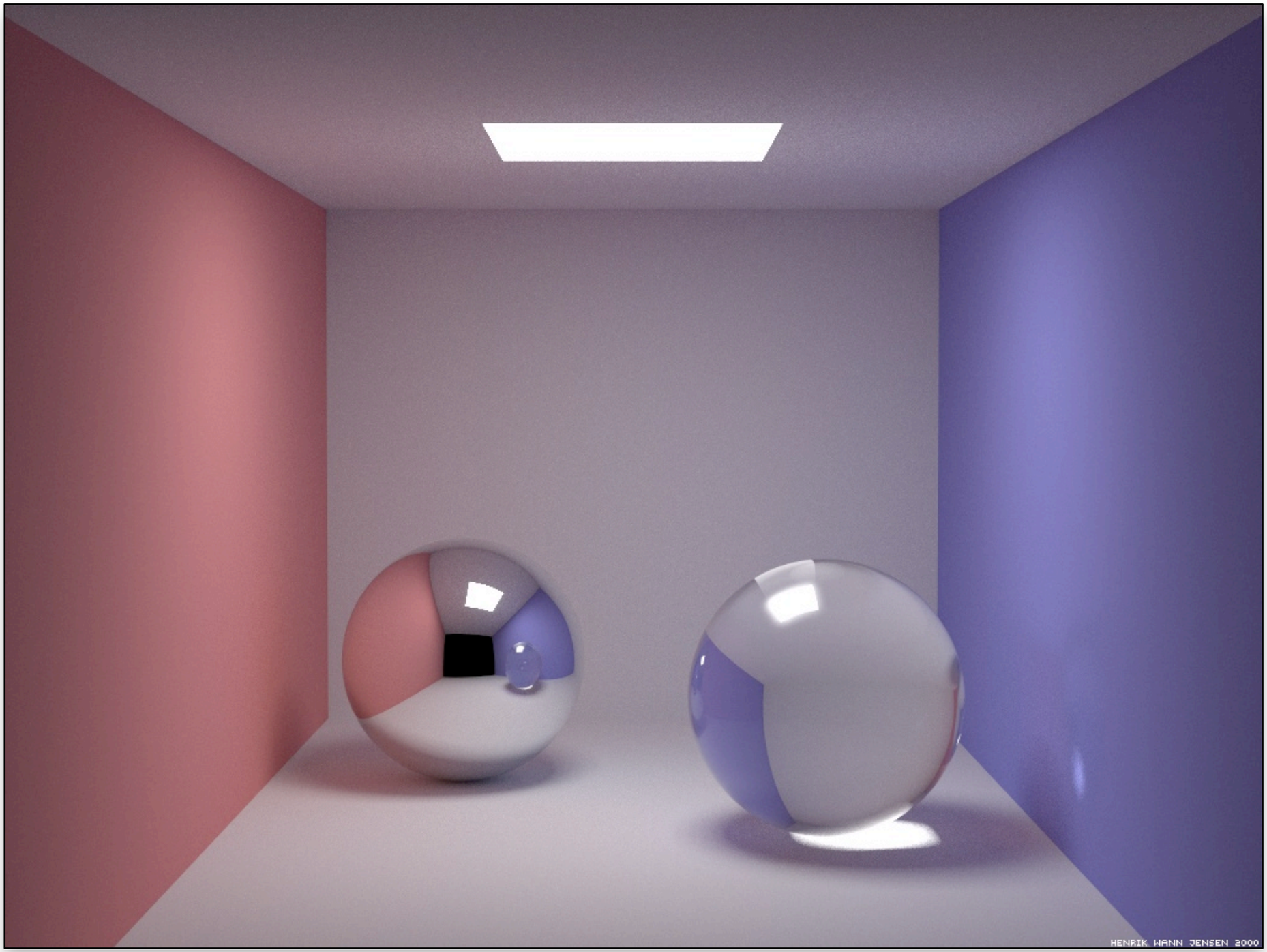
100000 photons / 50 photons in radiance estimate

Global Illumination



500000 photons / 500 photons in radiance estimate

Path Tracing



Practical Photon Mapping

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- Split illumination

Caustics

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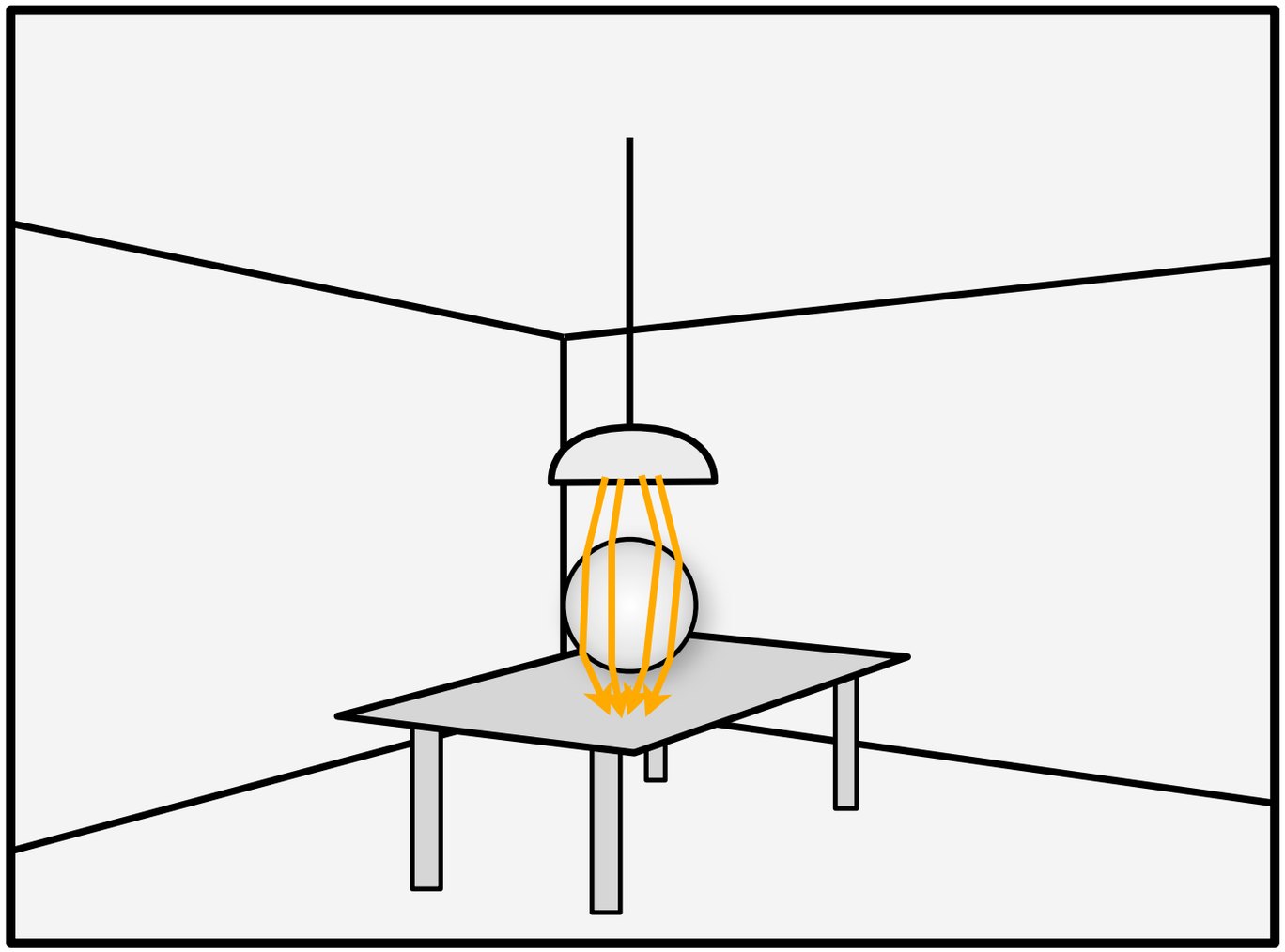
- Separate, higher quality photon map for caustics
  - Only stores LS^+D paths
  - Many photons shot directly at specular objects



Diffuse Indirect

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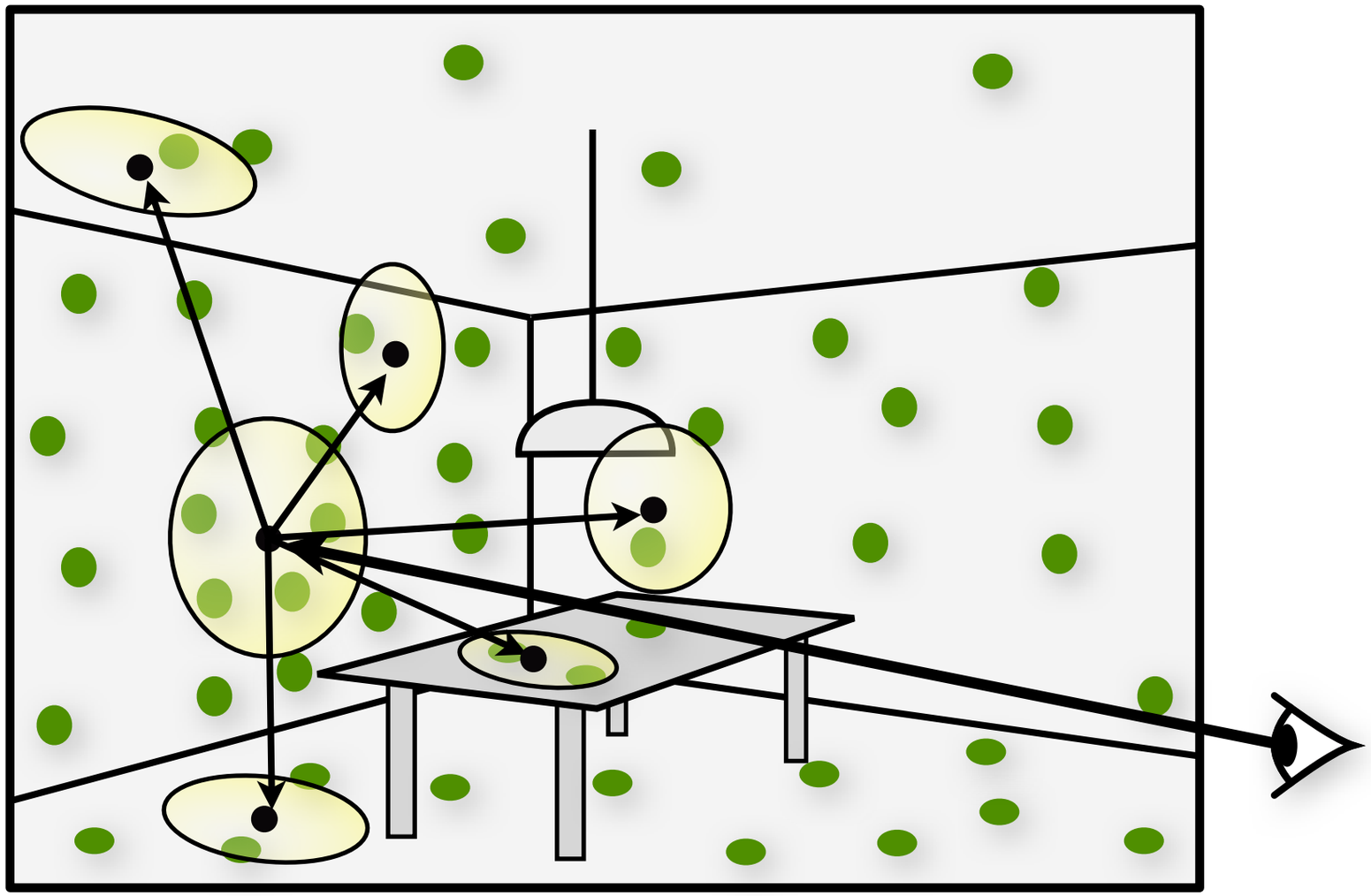
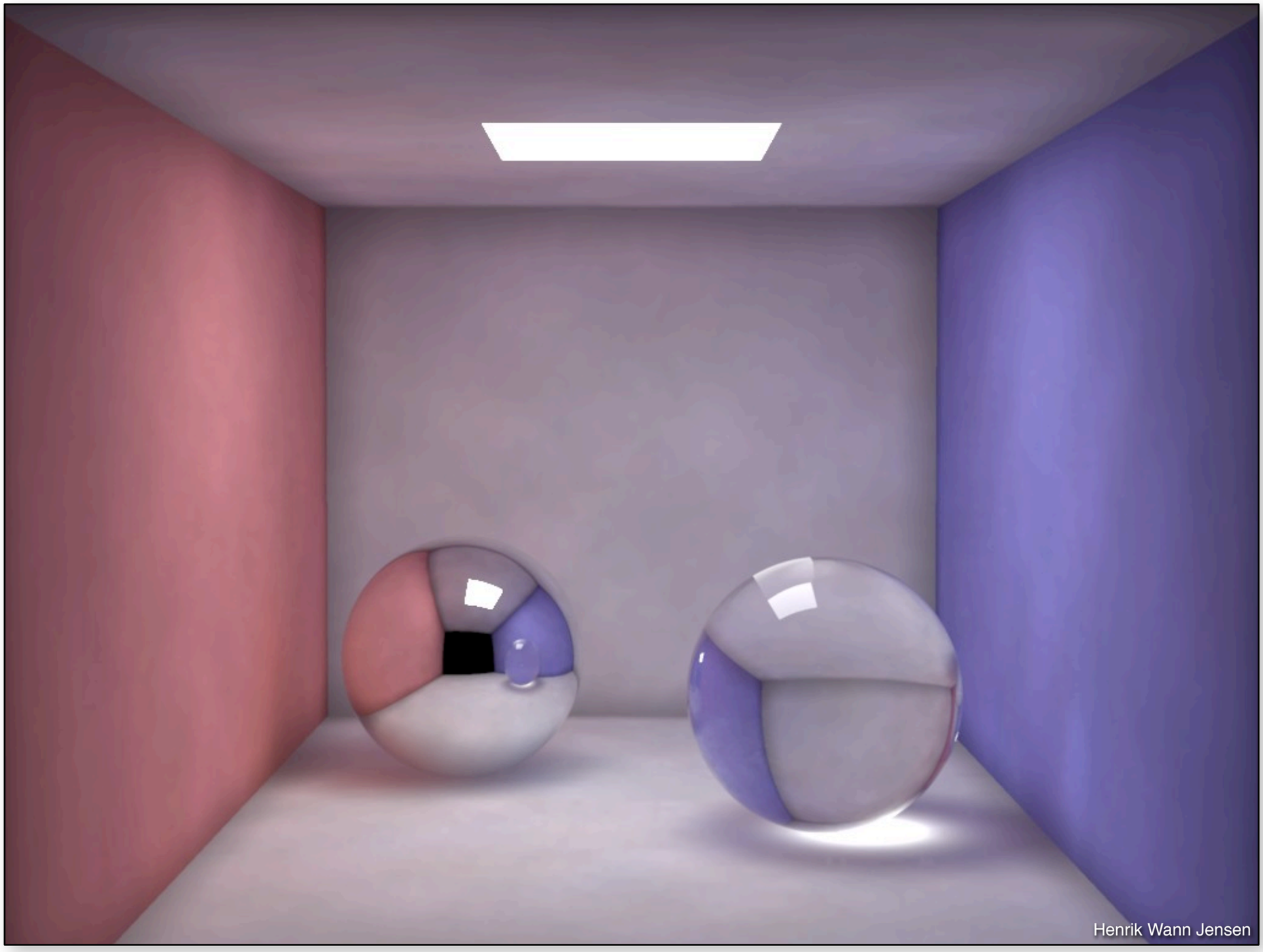
✘ Density estimation is blotchy

✓ Use final gather

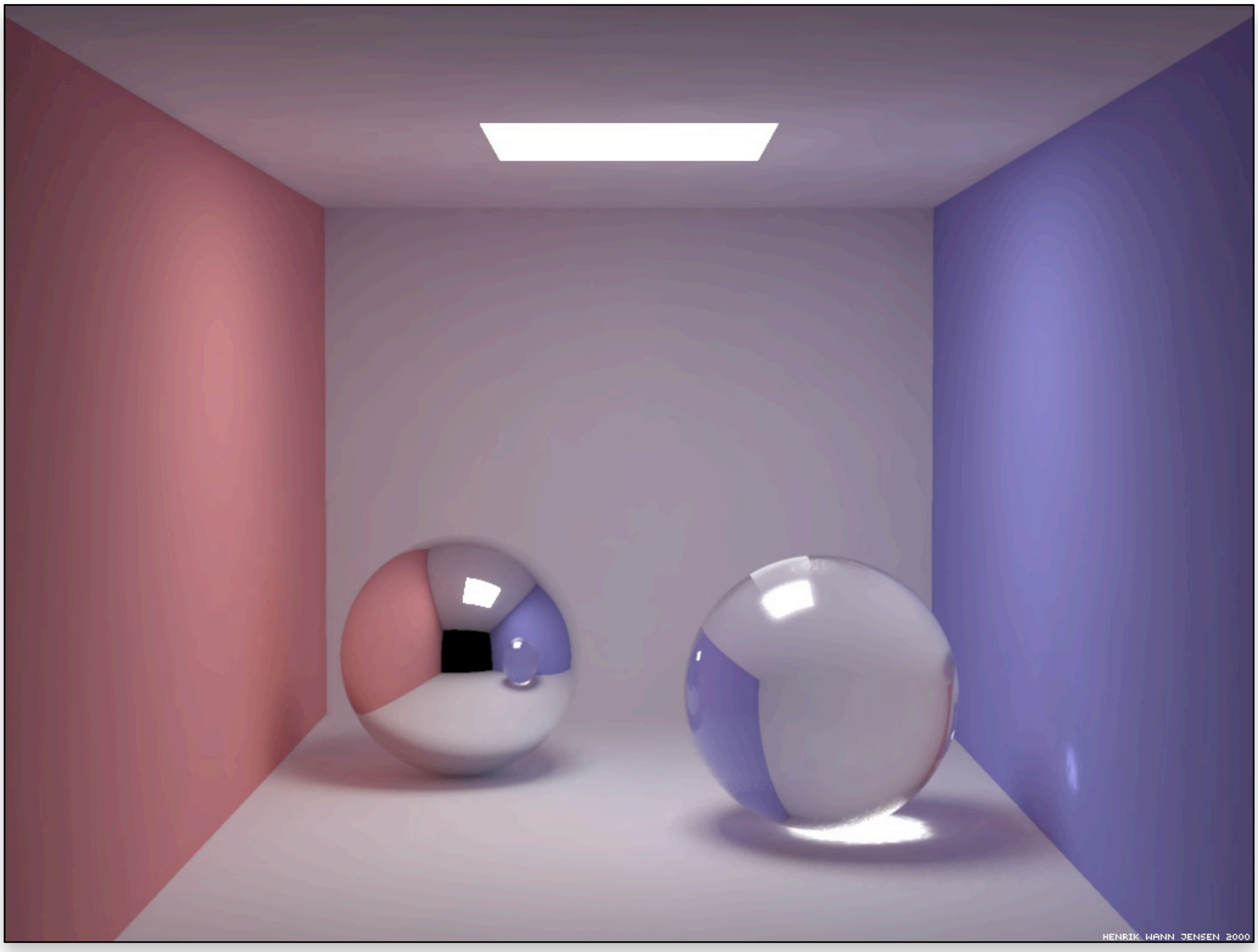


Global Illumination



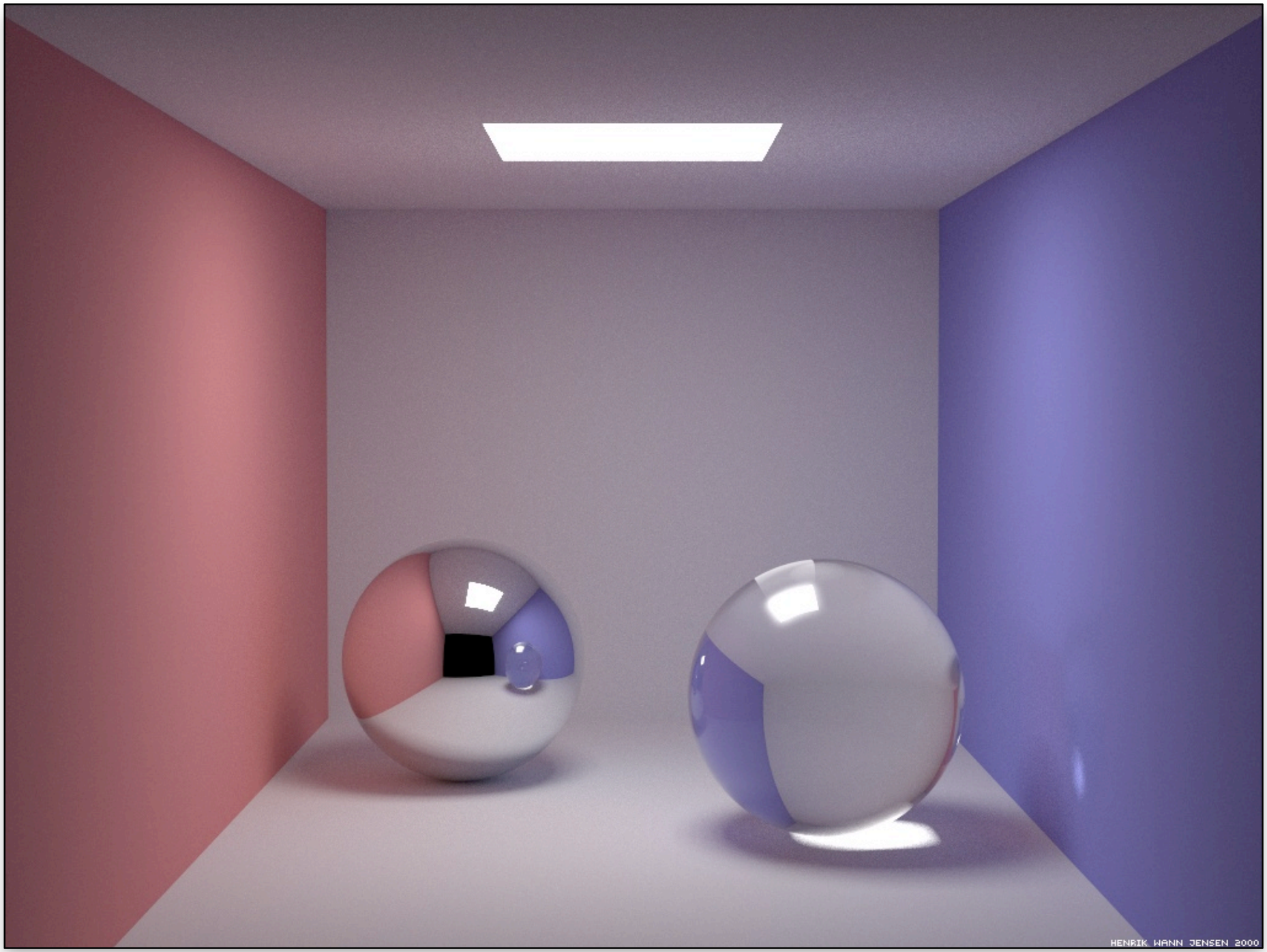
500000 photons / 500 photons in radiance estimate

Improved Photon Mapping



final gather + global photon map (200000) + caustic photon map (50000)

Path Tracing



Next...

- Improve / extend / generalize
- Progressive Photon Mapping