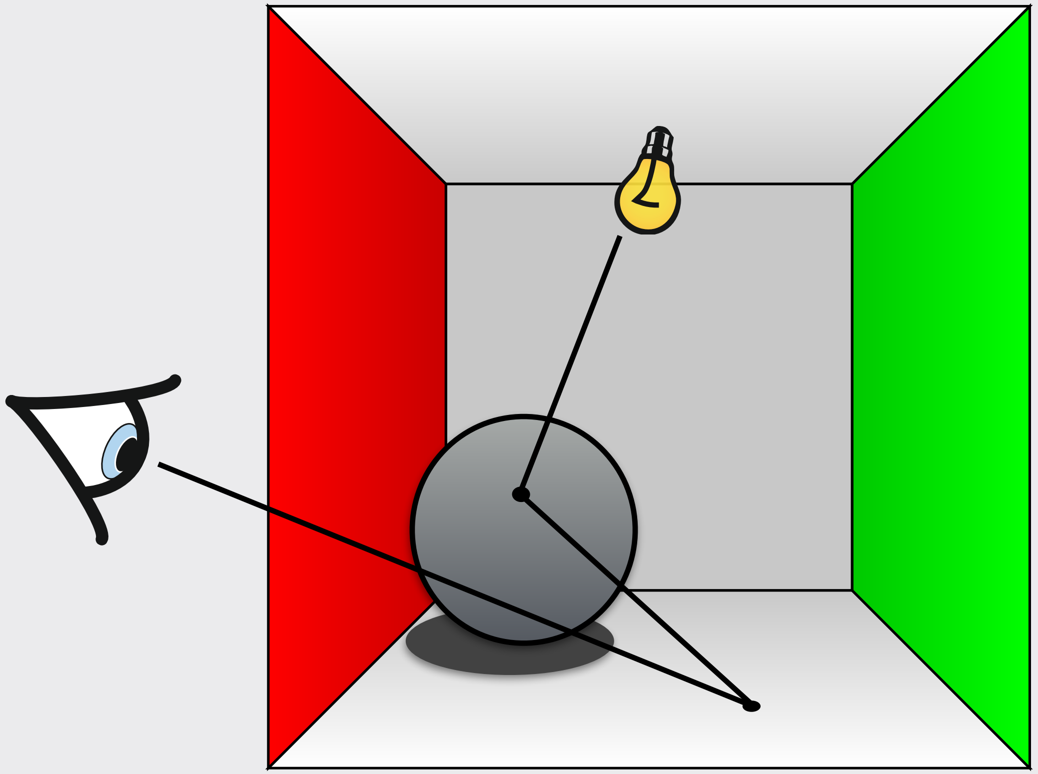
Eurographics 2015
The 36th Annual Conference of the
European Association for Computer Graphics

Rich-VPLs for Improving the Versatility of Many-Light Methods

F. Simon, J. Hanika, C. Dachsbacher
Karlsruhe Institute of Technology

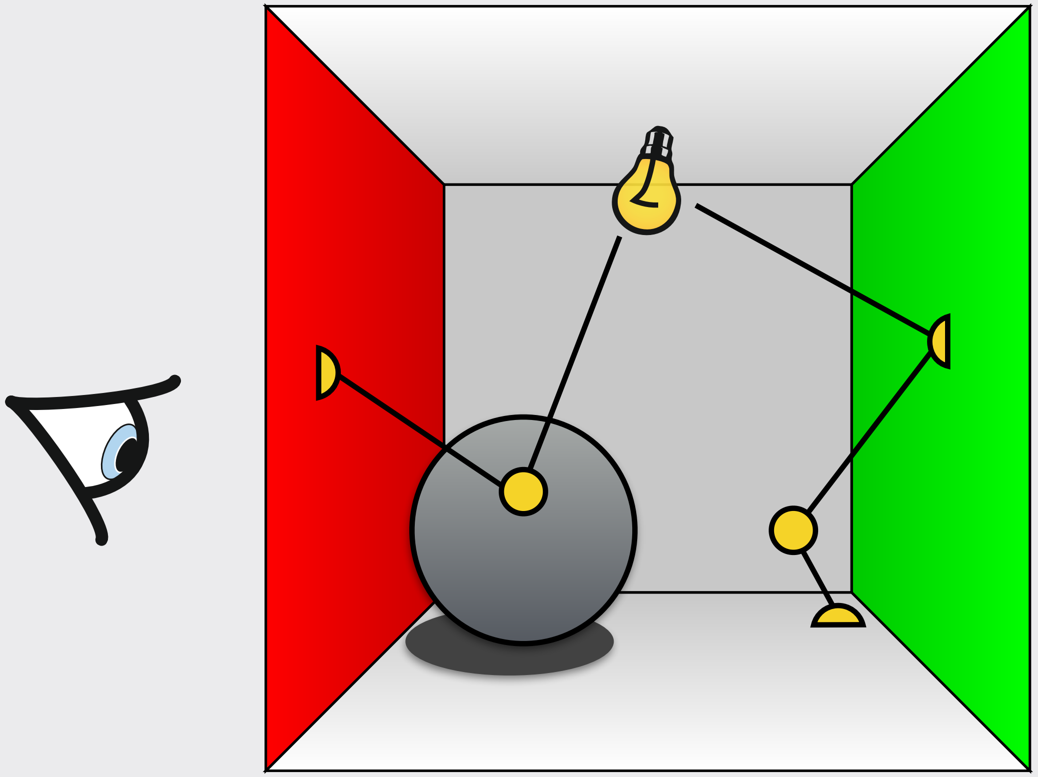
Photorealistic Rendering

- Based on Monte Carlo Methods
- Stochastically sample light carrying paths

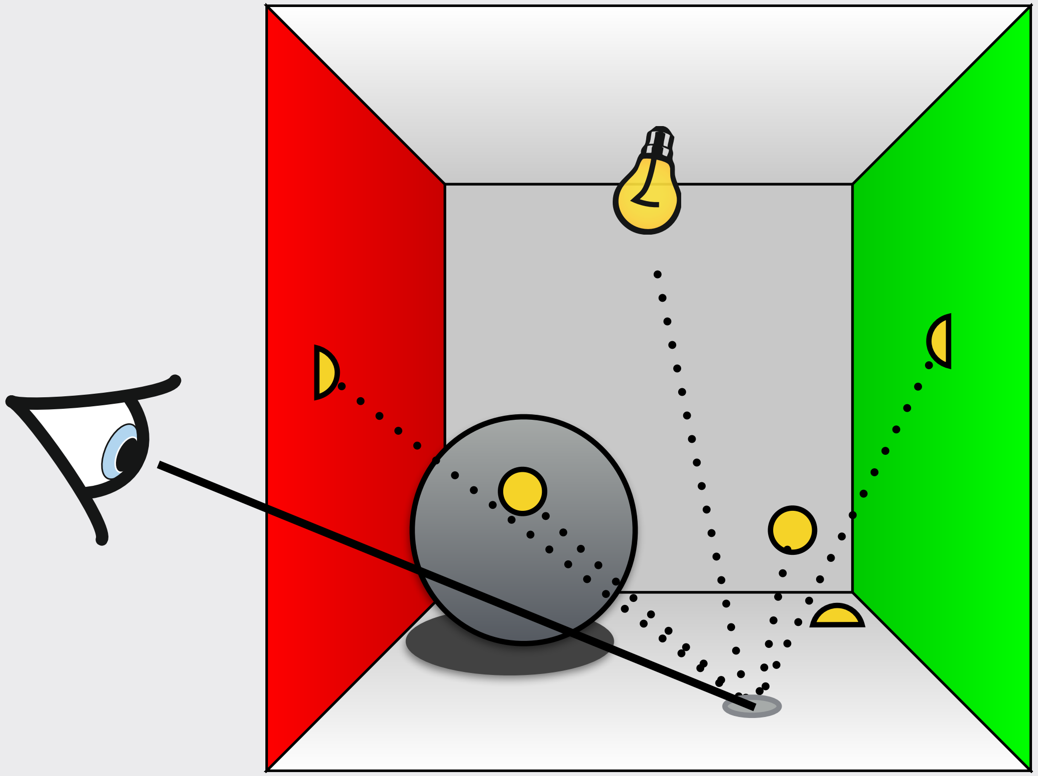


Many-Light Rendering

- Low-Noise Monte Carlo rendering technique



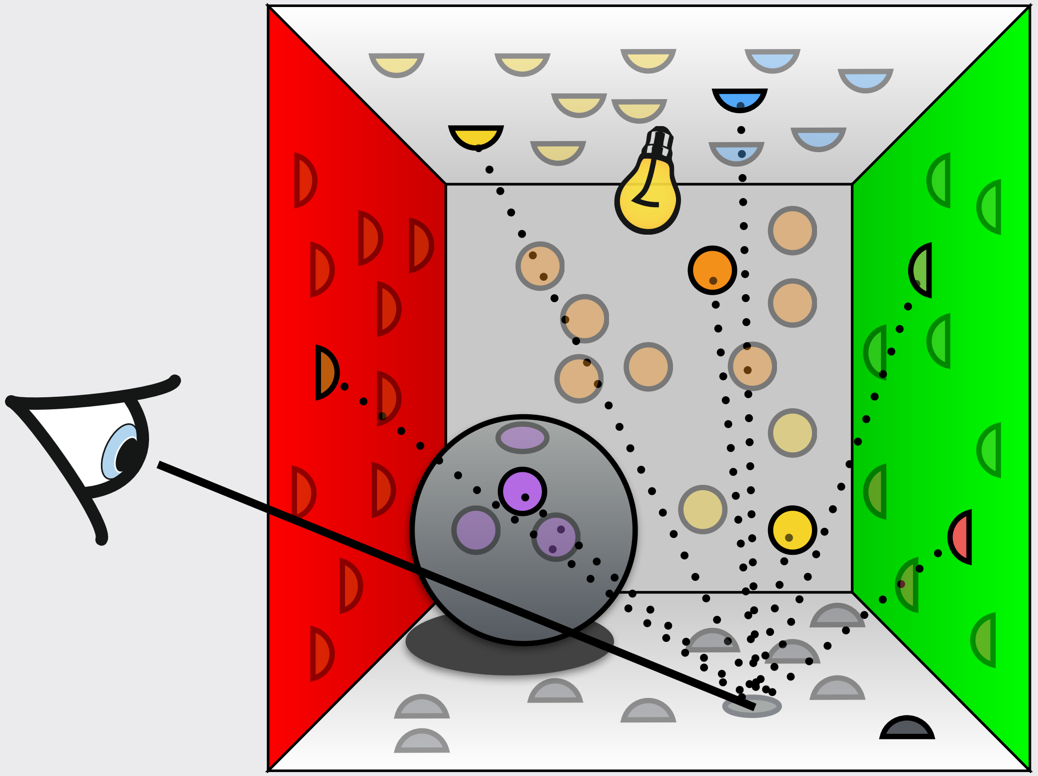
Step 1: VPL creation



Step 2: Shading

Many-Light Rendering

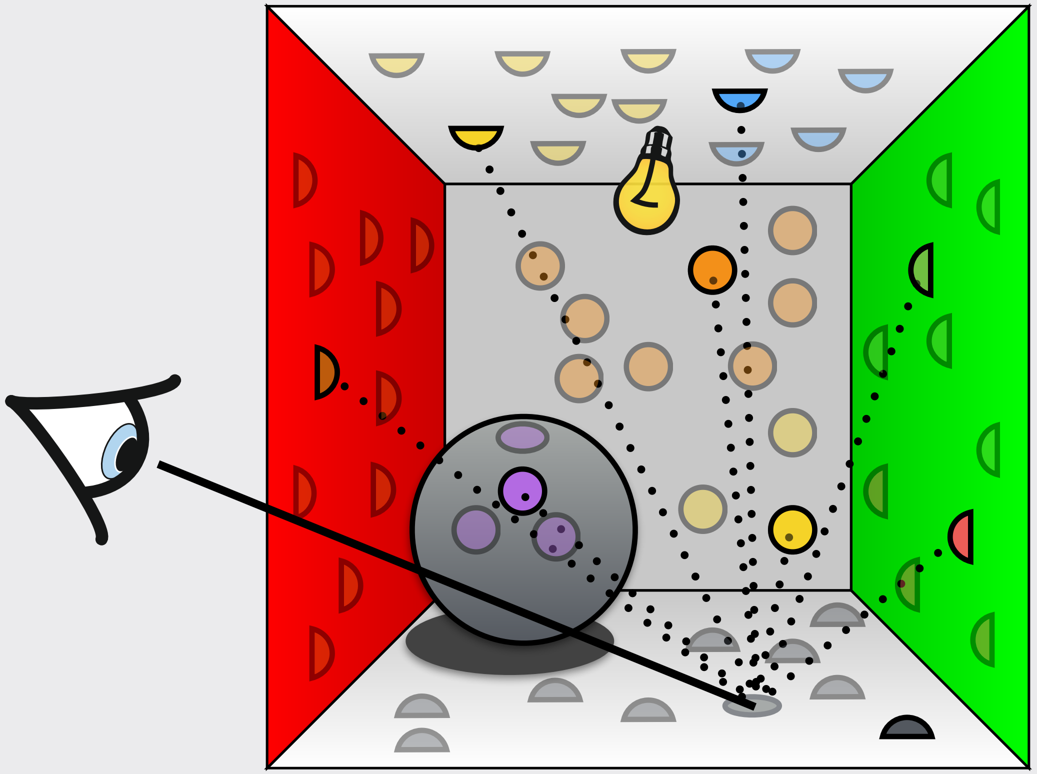
- Complex scenes and illumination effects require **many** lights



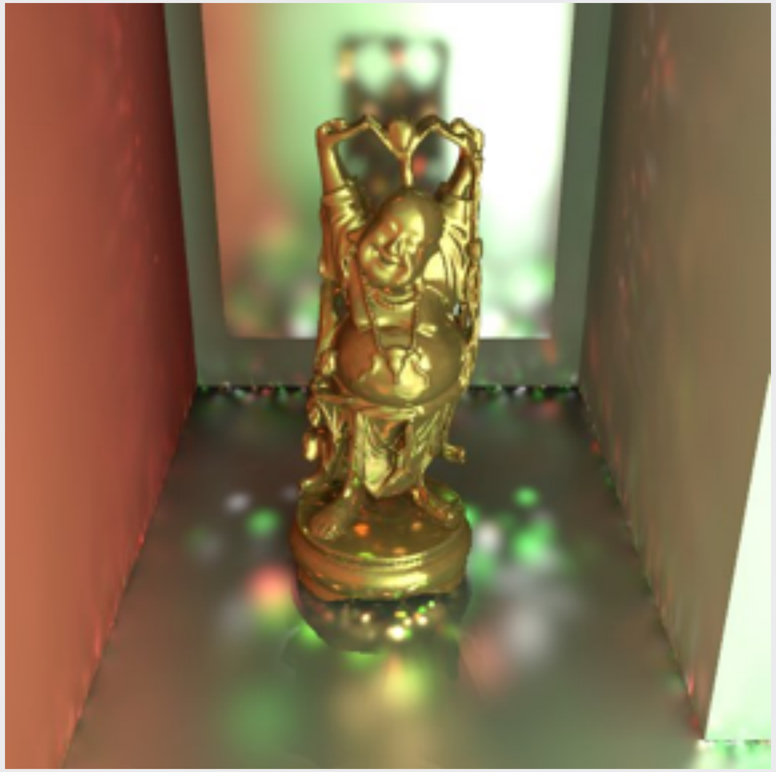
Adaptive clustering of VPLs (Lightcuts)

Many-Light Rendering

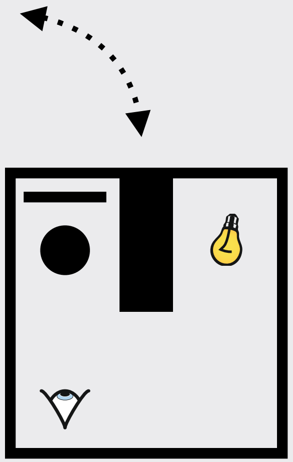
- For highly glossy materials many might not be enough



Adaptive clustering of VPLs (Lightcuts)

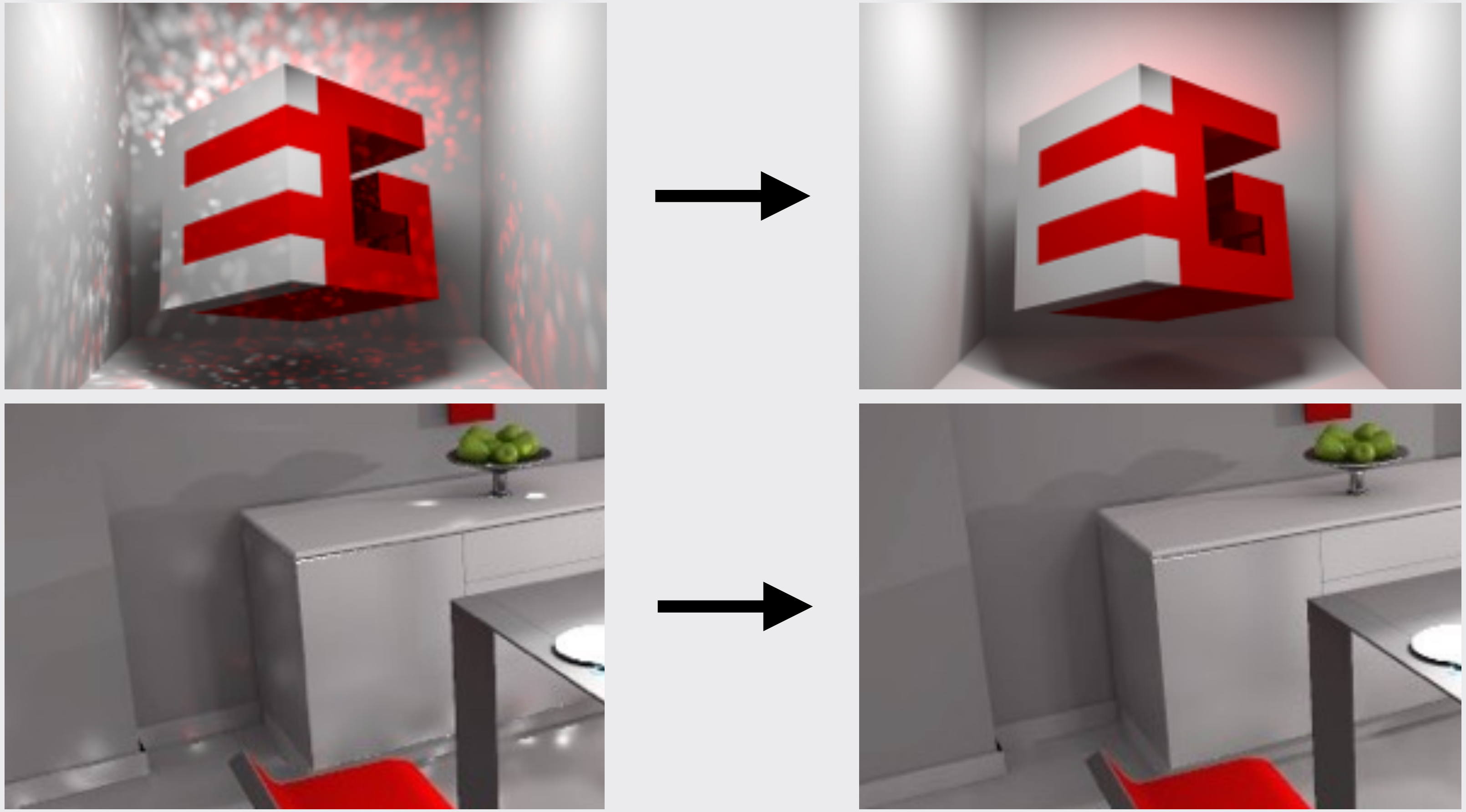


1.4 million VPLs

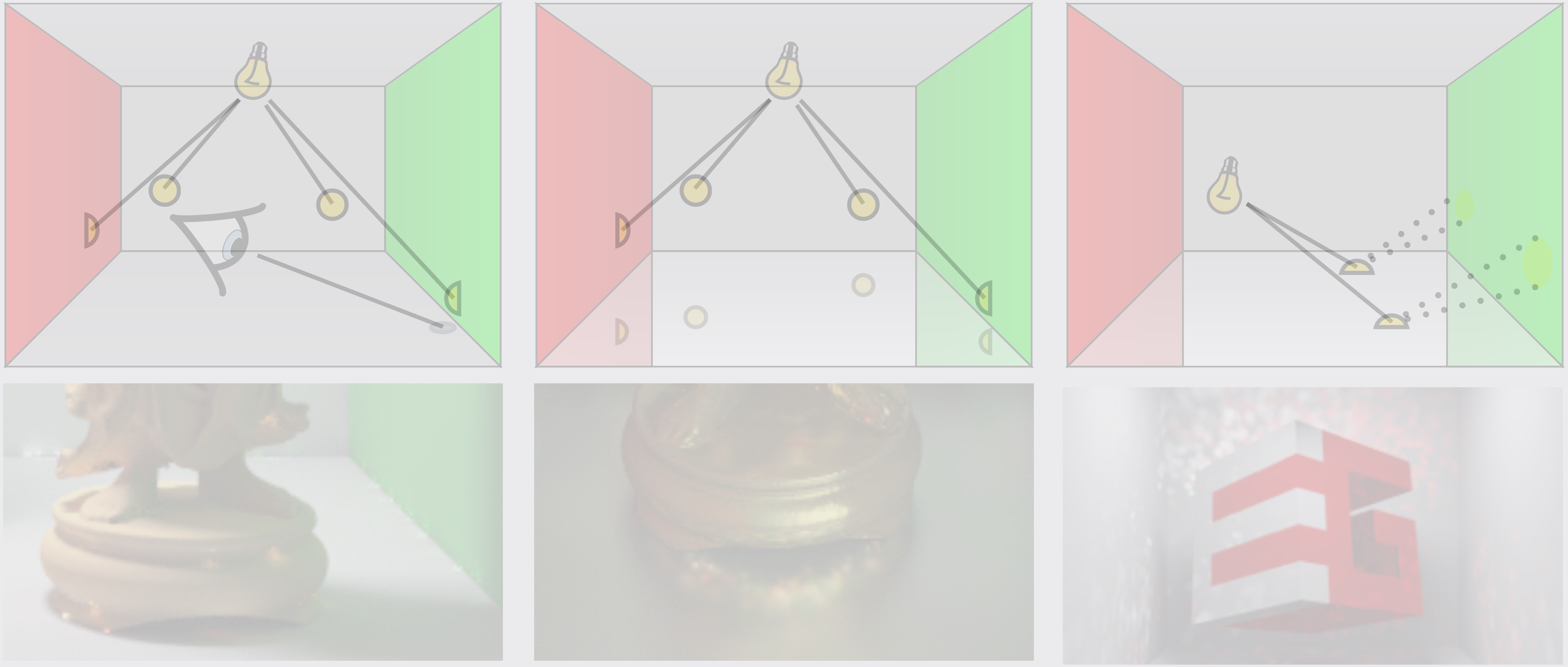


Many-Light Rendering

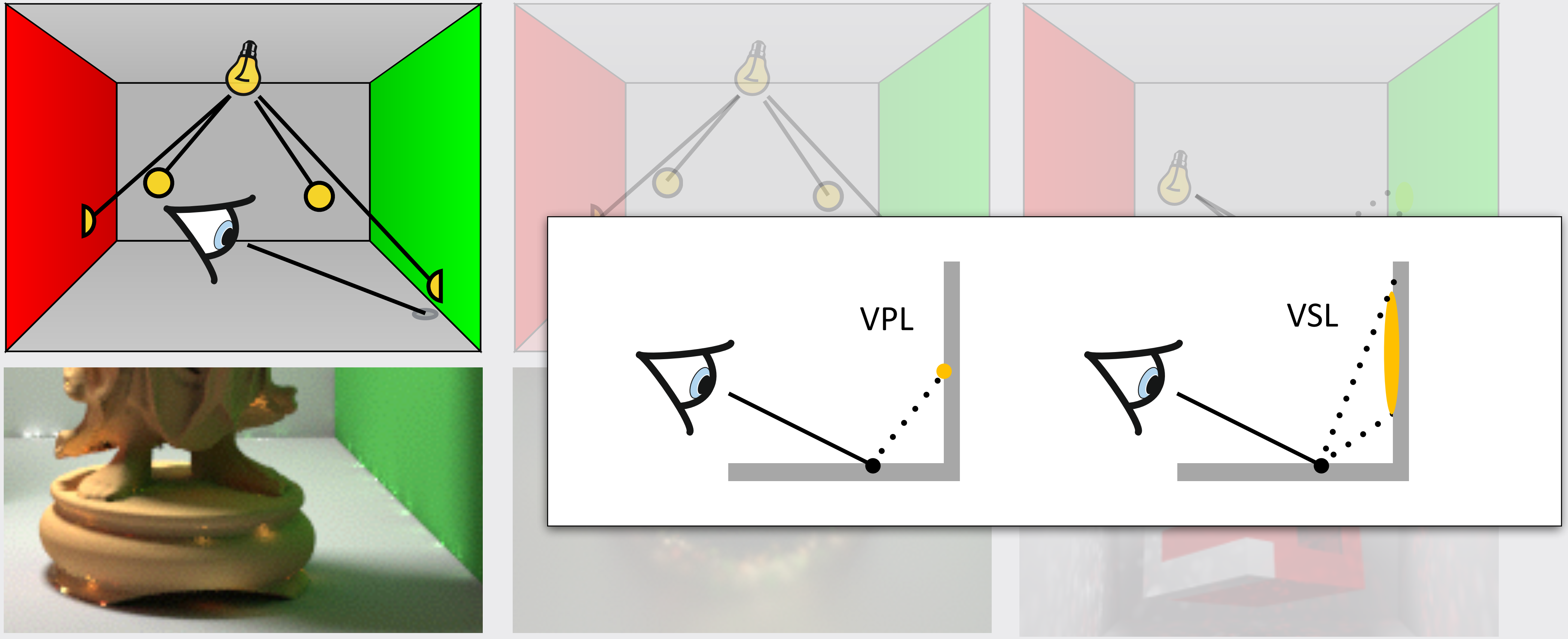
- Goal: Improve many-light efficiency for highly glossy materials



Problems: Correlation & Singularities

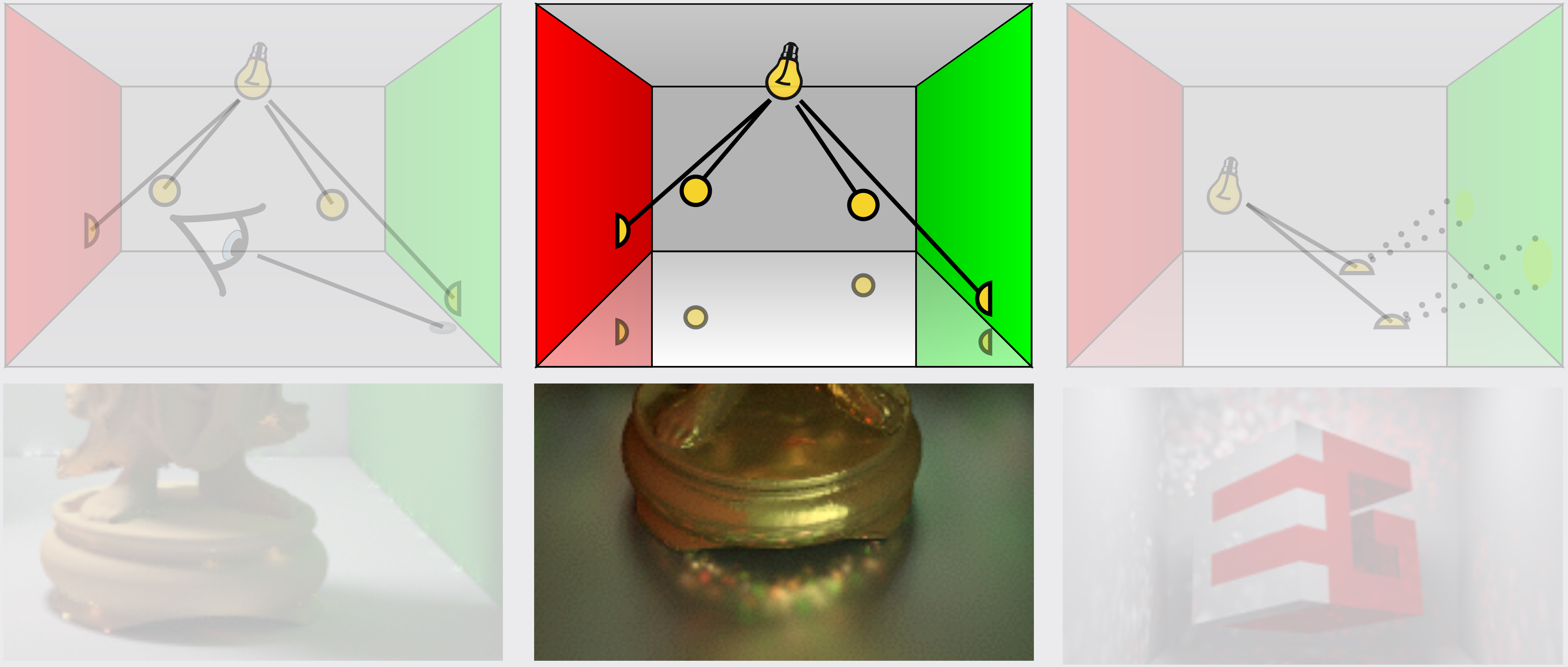


Problems: Correlation & Singularities



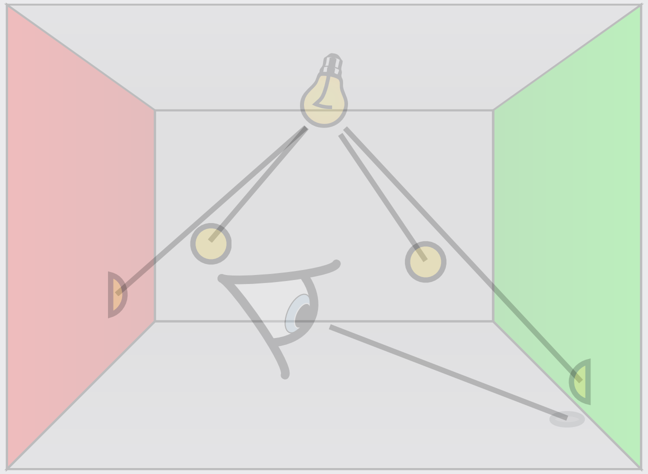
Clamping and Bias Compensation (Kollig & Keller 2004),
VSLs (Hašan et al. 2009)

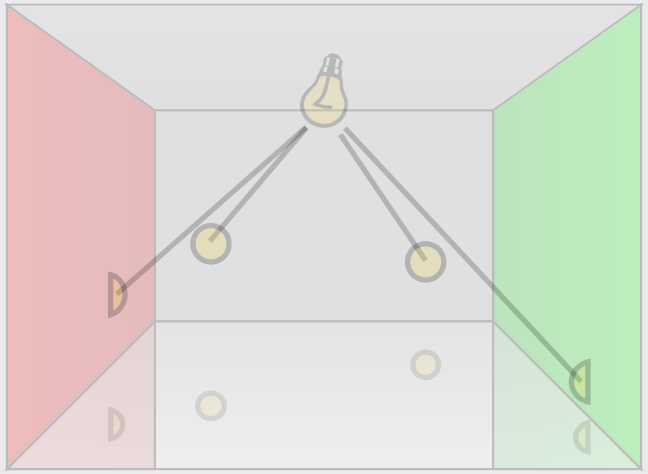
Problems: Correlation & Singularities

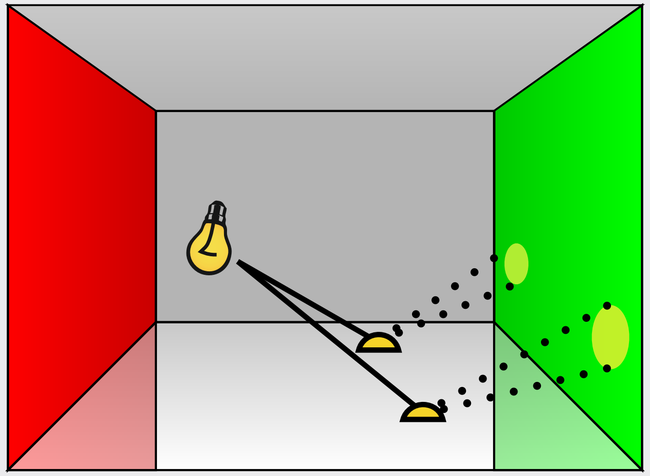


VSLs, Bidirectional Lightcuts (Walter et al. 2012)

Problems: Correlation & Singularities

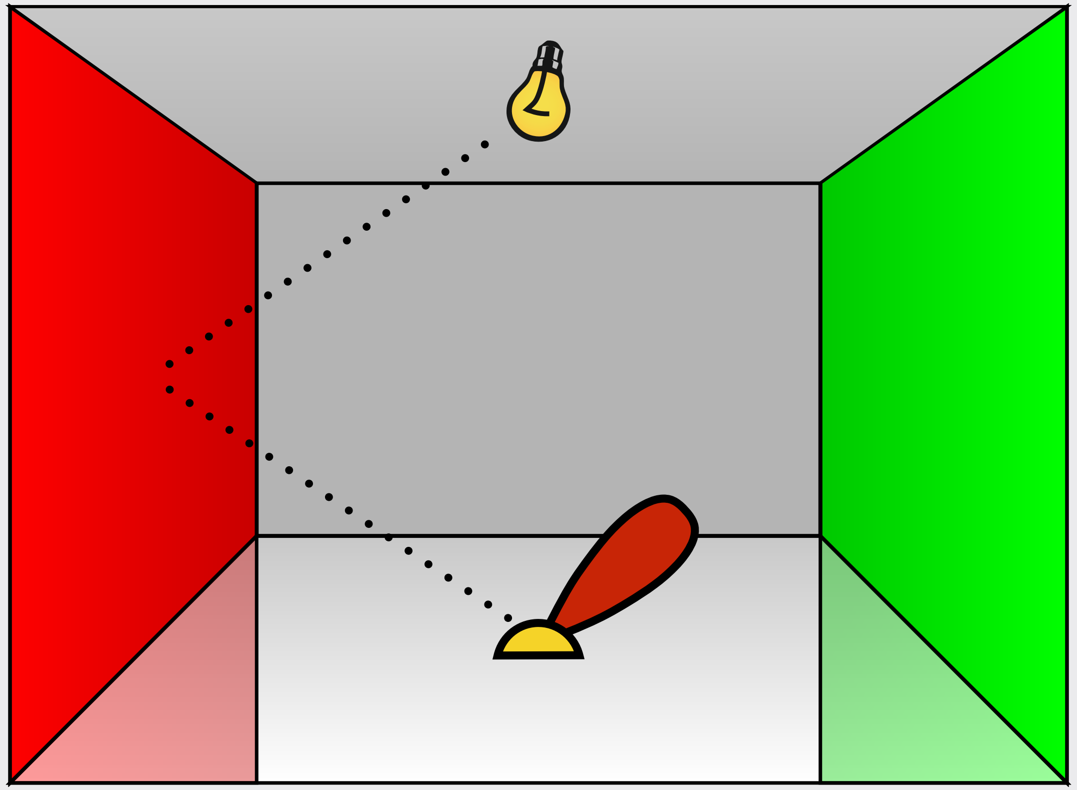






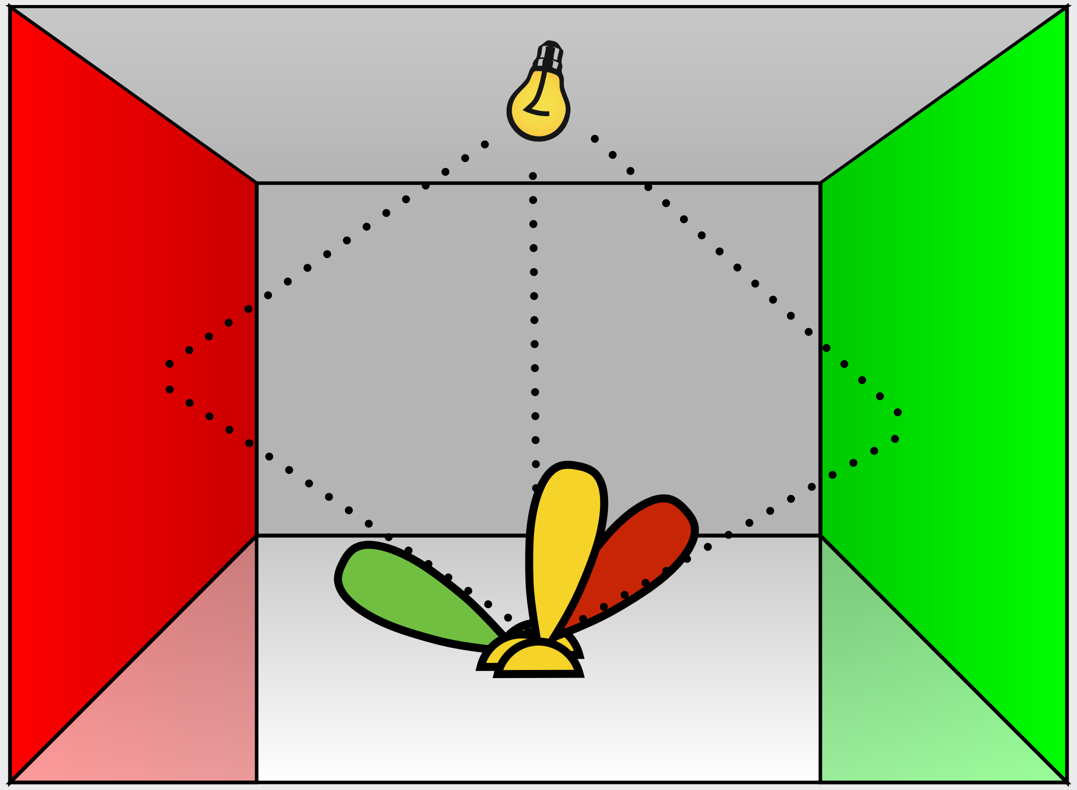
VPLs on glossy surfaces

- On glossy surfaces most energy is emitted in a small cone of directions



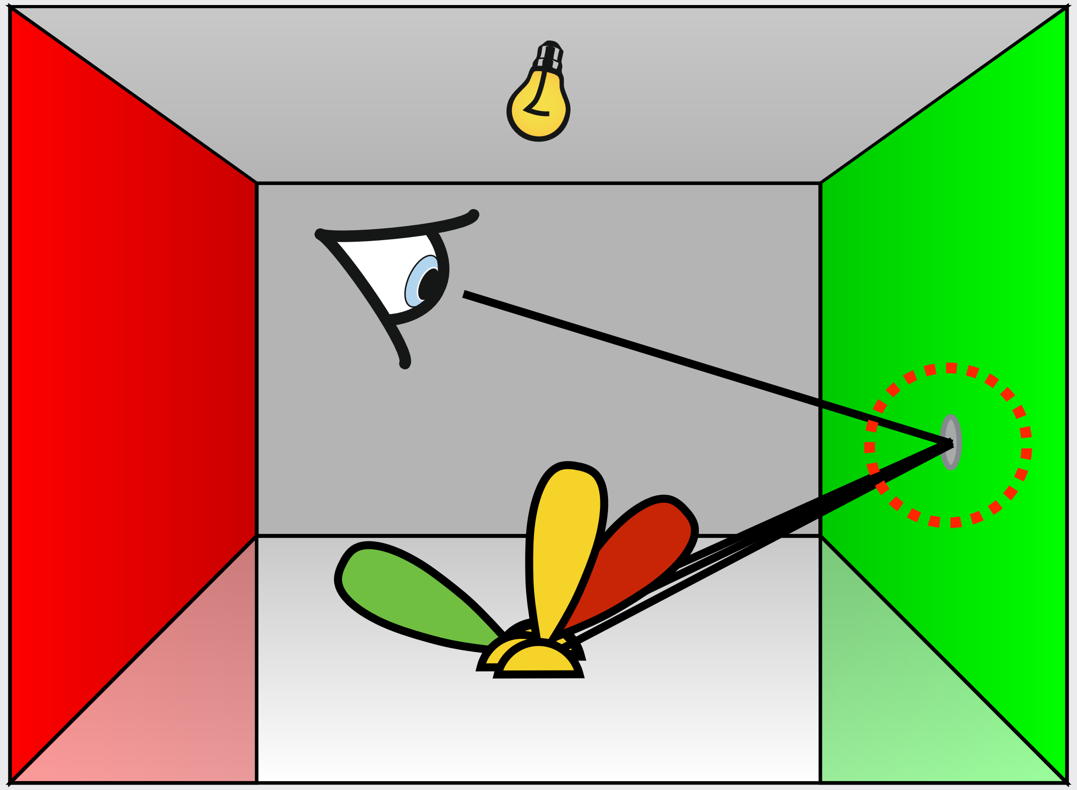
VPLs on glossy surfaces

- Estimating the light leaving a surface point in all directions requires a lot of light paths



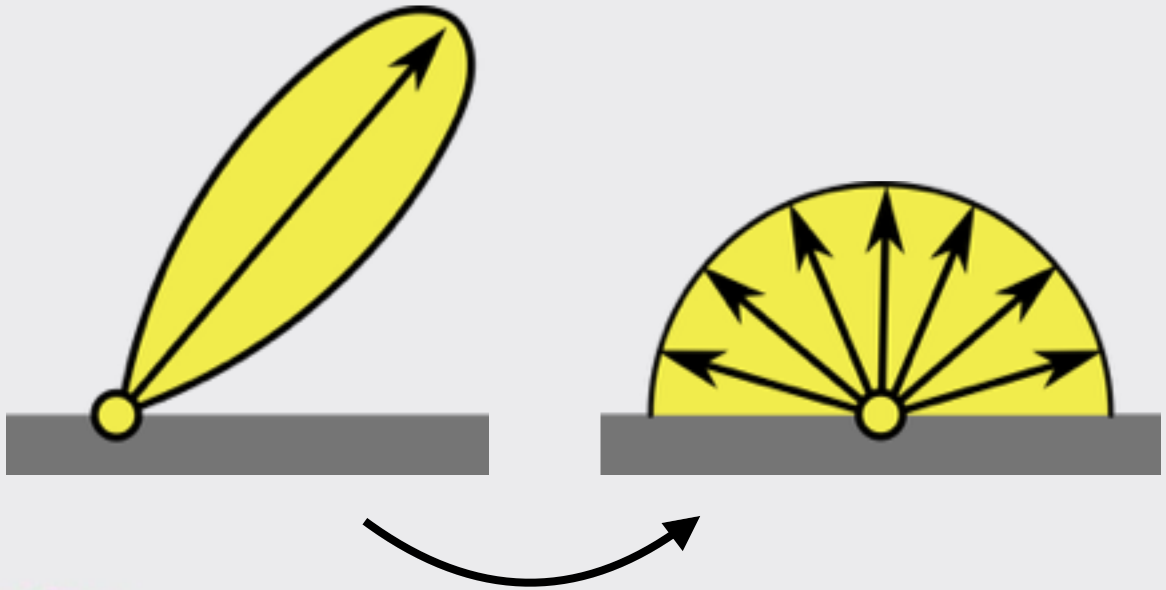
VPLs on glossy surfaces

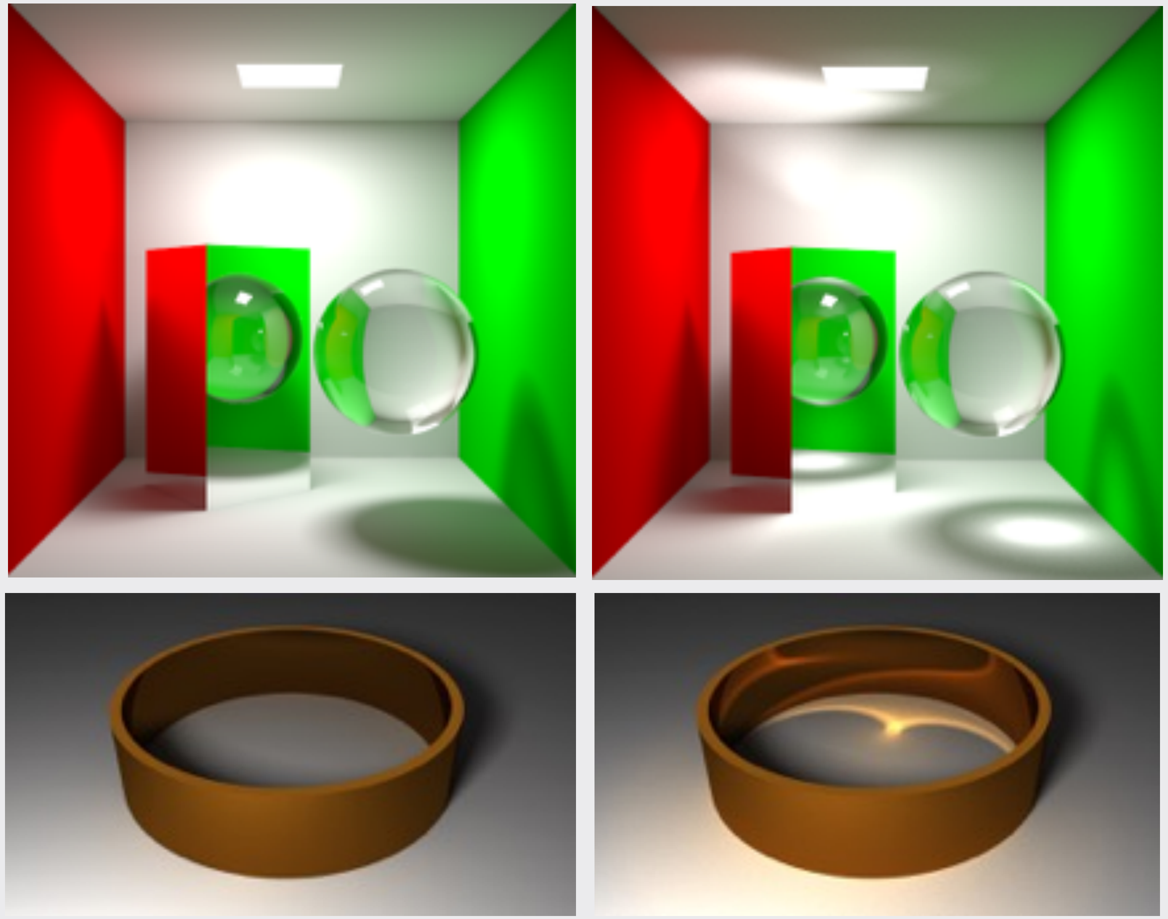
- Oversampling of the spatial and undersampling of the angular domain



VPLs on glossy surfaces

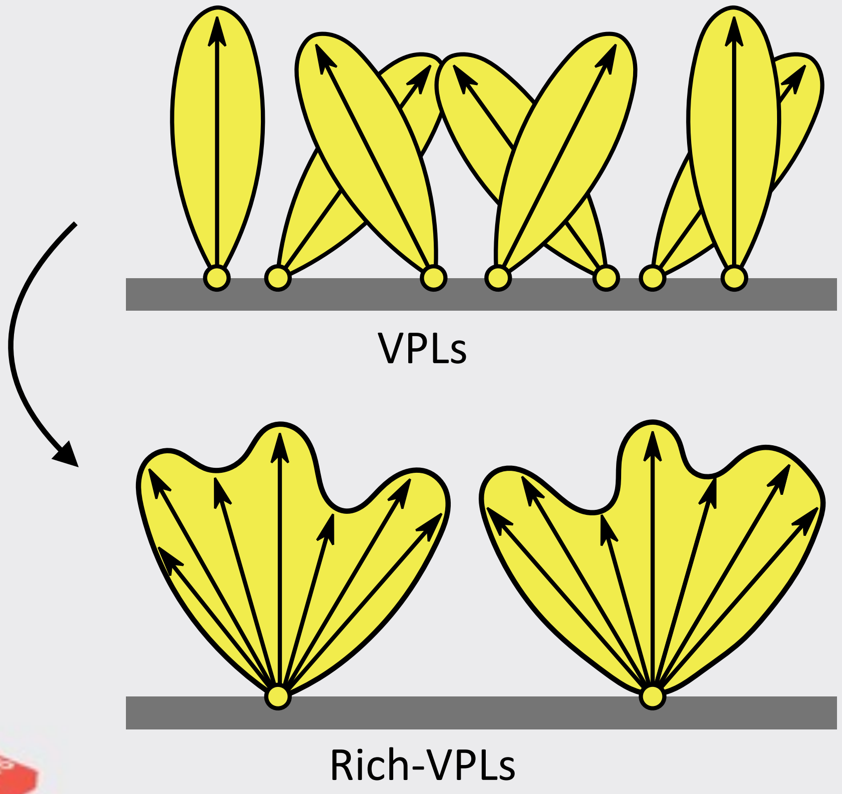
- Popular assumption: diffuse VPLs
  - energy is emitted equally in all directions

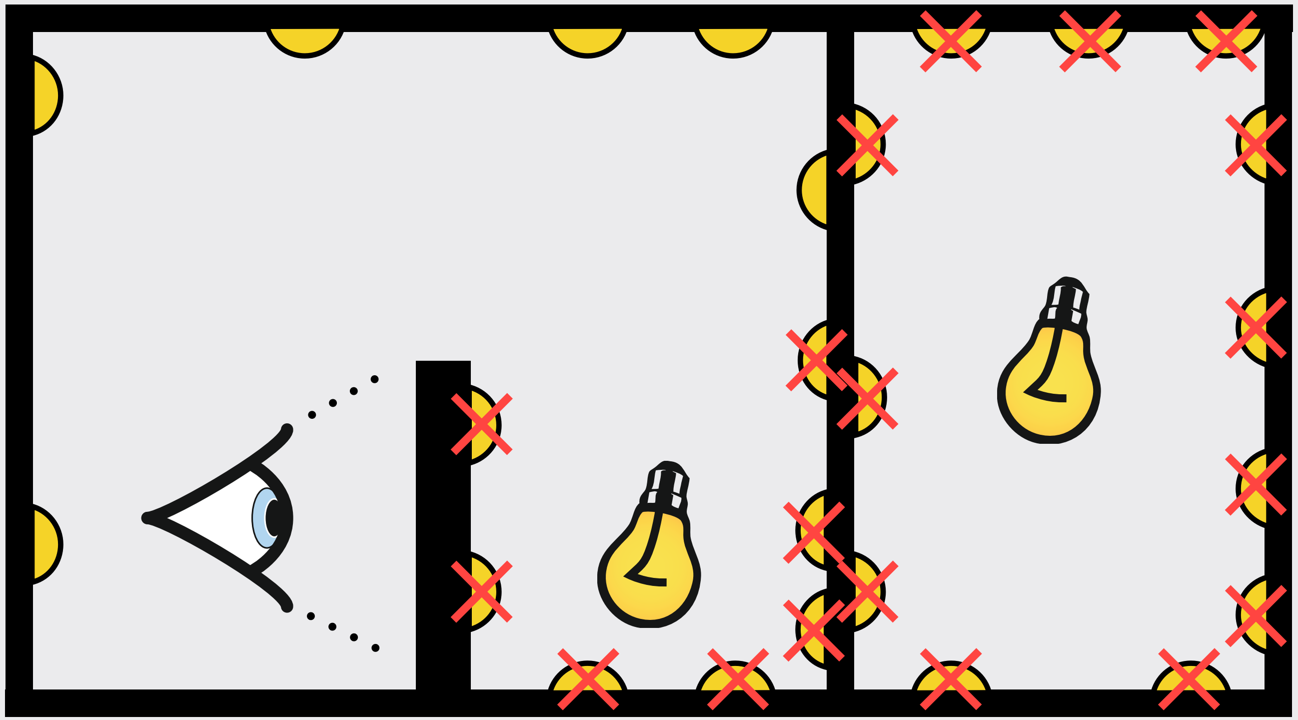




Contributions

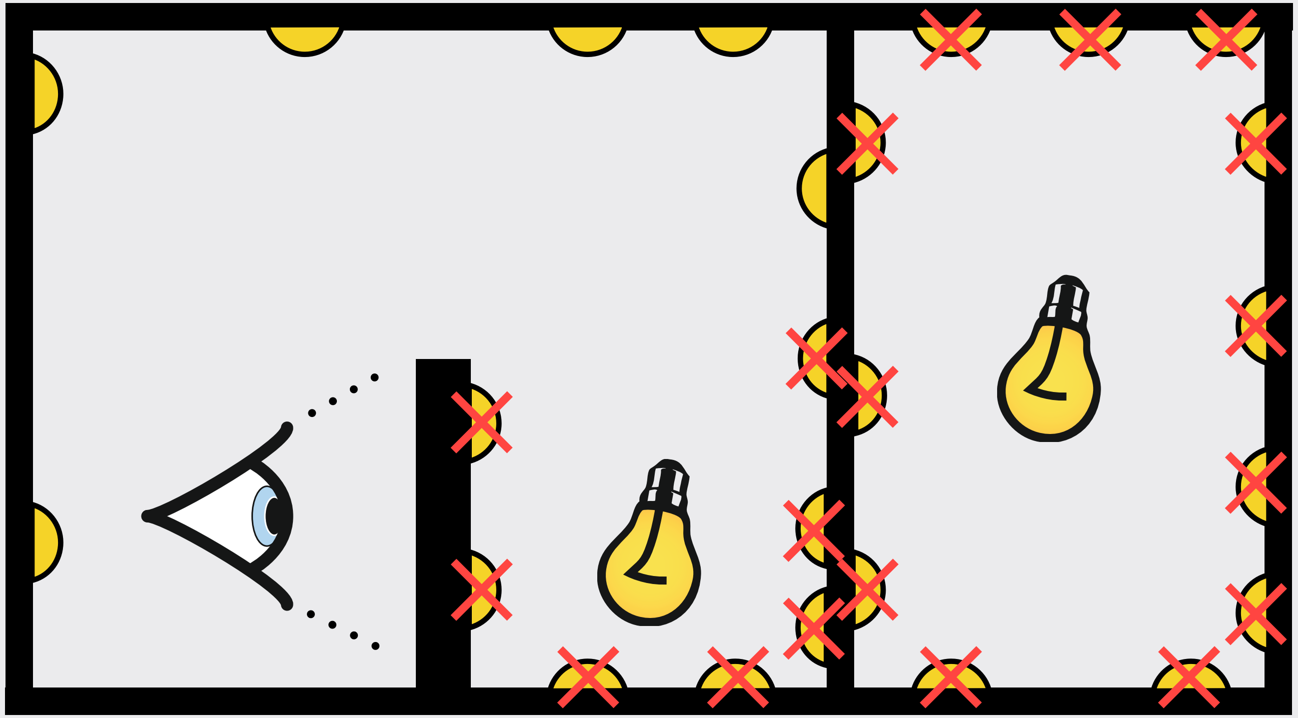
- Rich-VPLs: Account for many light path at once
- Importance Sampling: Make sure Rich-VPLs are well placed



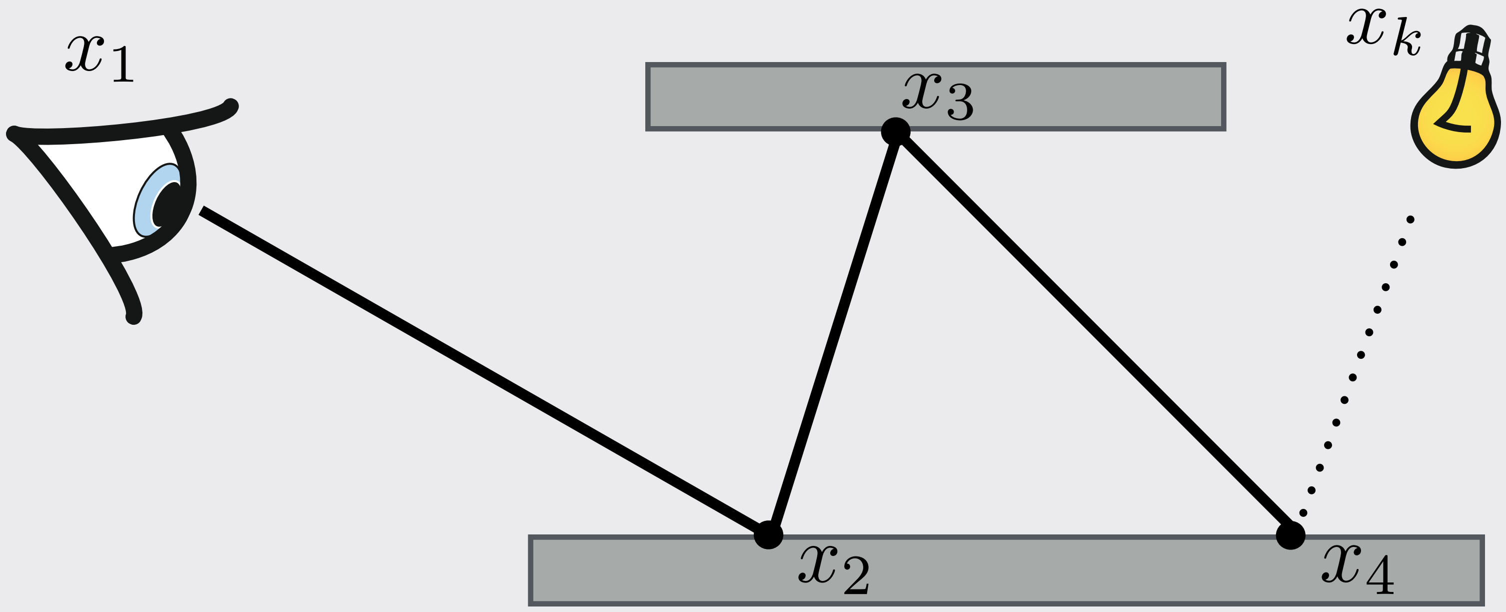


Importance Sampling

- Intuitively VPLs should only be placed where (Georgiev & Slusallek 2010, Segovia et al. 2006)
  - there is a lot of energy and
  - they contribute to the image



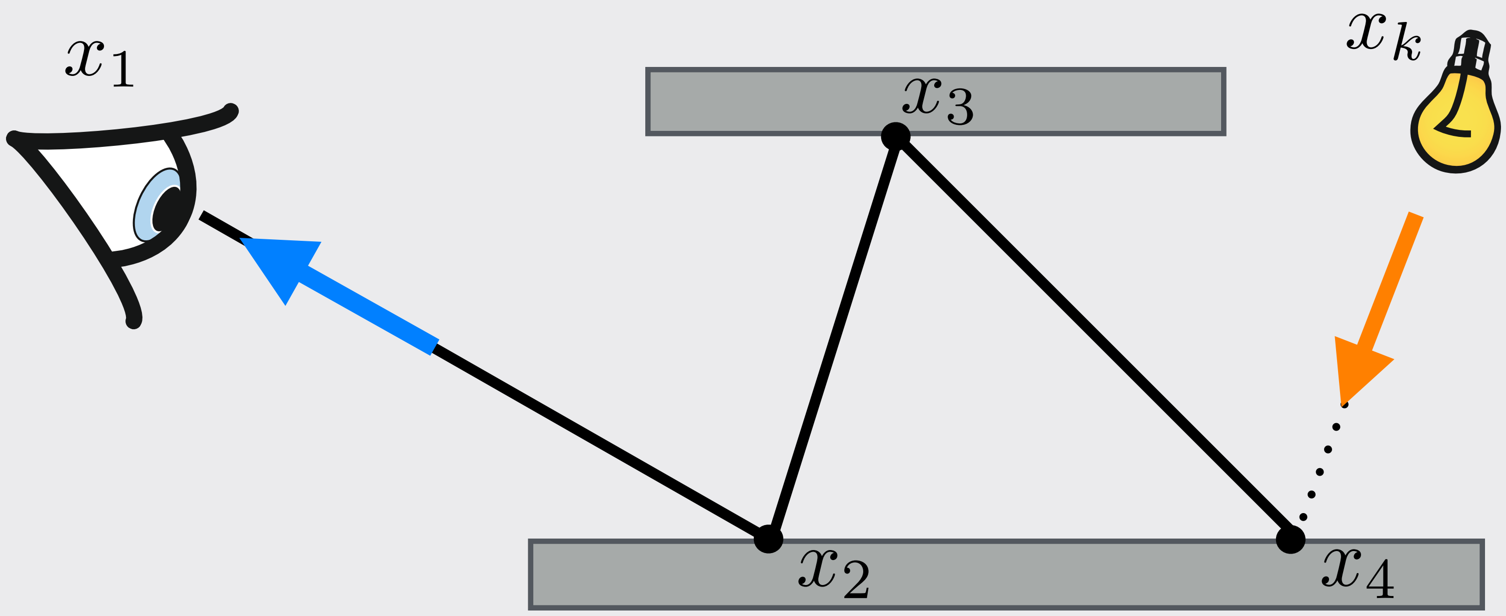
Measurement Contribution



$$f(X) = W_e(x_2 \to x_1) \left(\prod_{i=1}^{k-1} G_{x_i \leftrightarrow x_{i+1}} \right) \left(\prod_{i=2}^{k-1} f_r(x_i) \right) L_e(x_k \to x_{k-1})$$

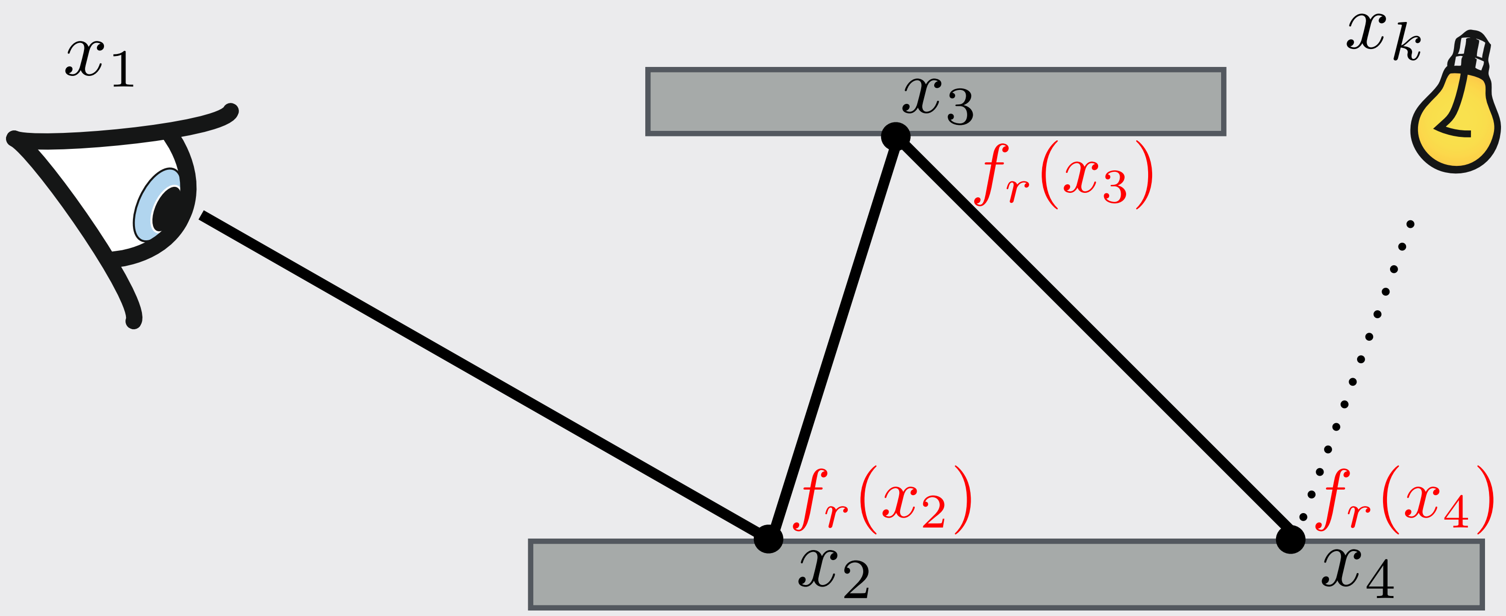
Measurement Contribution

- L_e : emitted radiance
- W_e: sensor importance



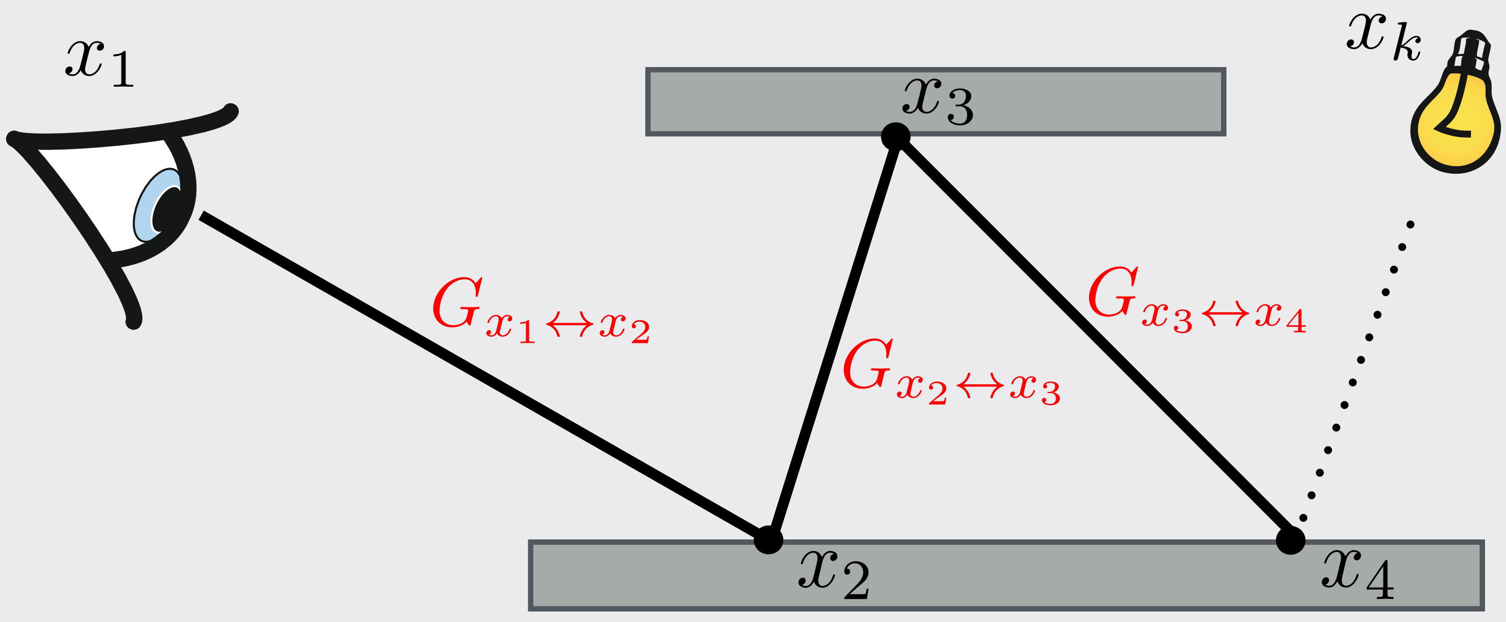
$$f(X) = W_e(x_2 \to x_1) \left(\prod_{i=1}^{k-1} G_{x_i \leftrightarrow x_{i+1}} \right) \left(\prod_{i=2}^{k-1} f_r(x_i) \right) L_e(x_k \to x_{k-1})$$

Measurement Contribution



$$f(X) = W_e(x_2 \to x_1) \left(\prod_{i=1}^{k-1} G_{x_i \leftrightarrow x_{i+1}} \right) \left(\prod_{i=2}^{k-1} f_r(x_i) \right) L_e(x_k \to x_{k-1})$$

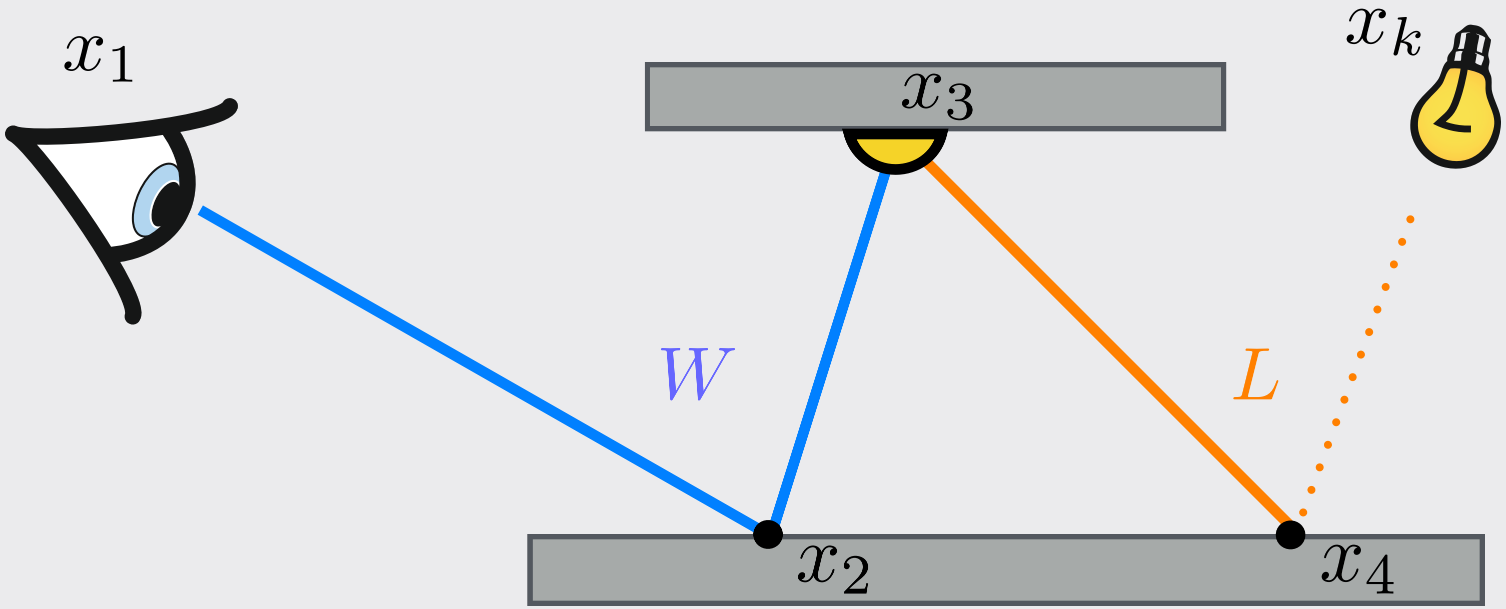
Measurement Contribution



$$f(X) = W_e(x_2 \to x_1) \left(\prod_{i=1}^{k-1} G_{x_i \leftrightarrow x_{i+1}} \right) \left(\prod_{i=2}^{k-1} f_r(x_i) \right) L_e(x_k \to x_{k-1})$$

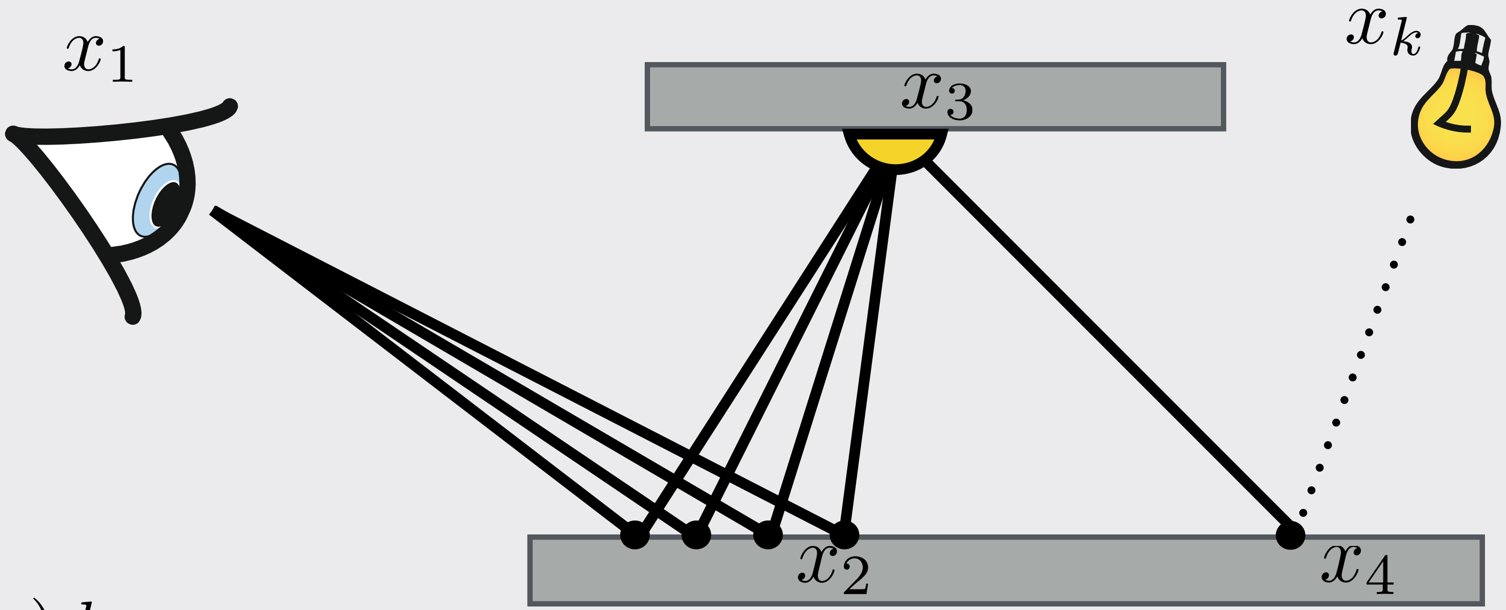
Importance Sampling

- $W(x_1, x_2, x_3)$: importance of VPL at x_3 for one pixel



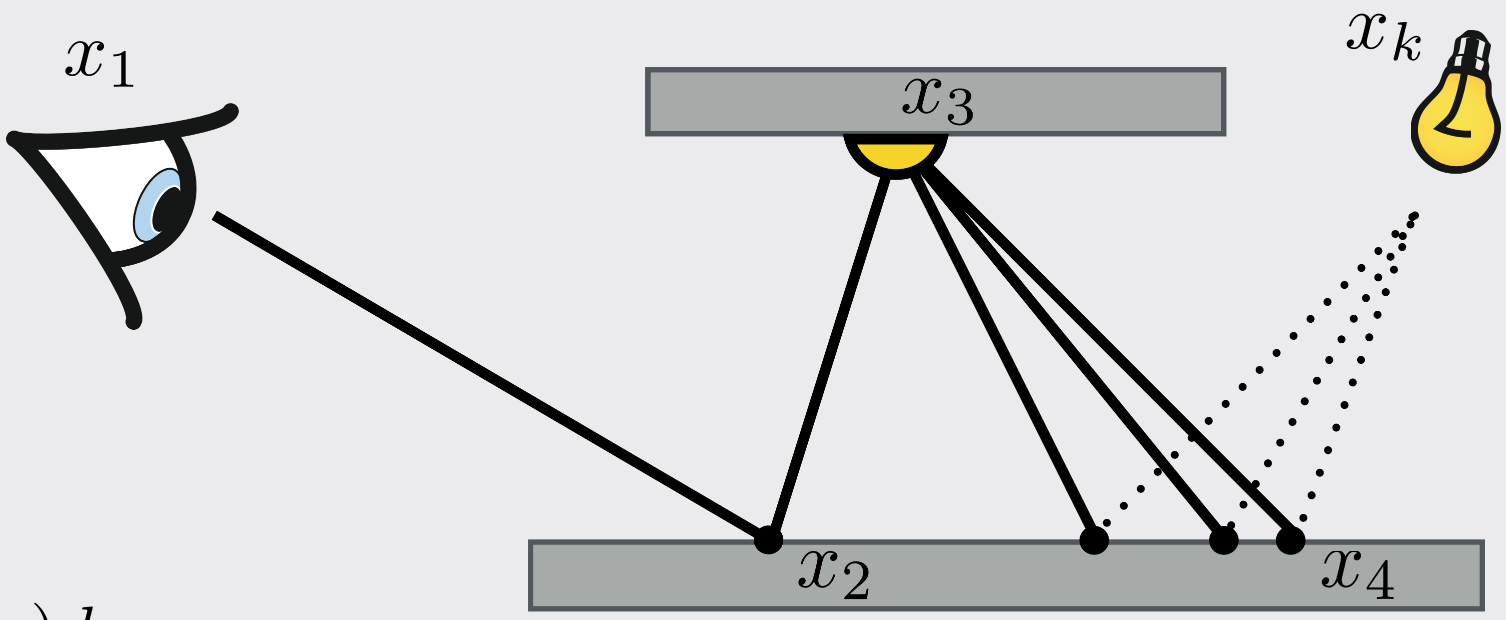
$$f(X) = W(x_1, x_2, x_3)\ f_r(x_3)\ L(x_3, ..., x_k)$$

Importance Sampling - Total Incident Importance



$$\hat{W}(x_3) = \int_{x_2} W(x_1, x_2, x_3)\,dx_2$$

Importance Sampling - Total Incident Radiance

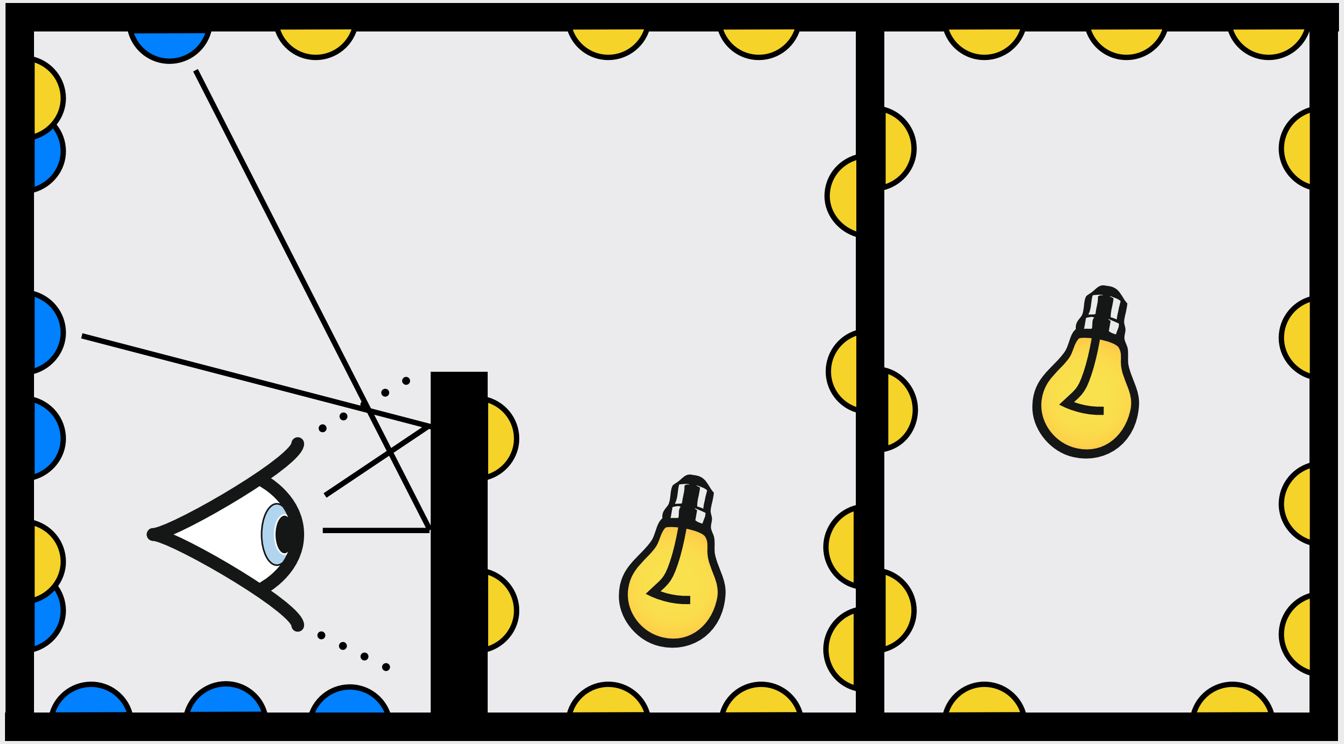


$$\hat{W}(x_3) = \int_{x_2} W(x_1, x_2, x_3) dx_2$$

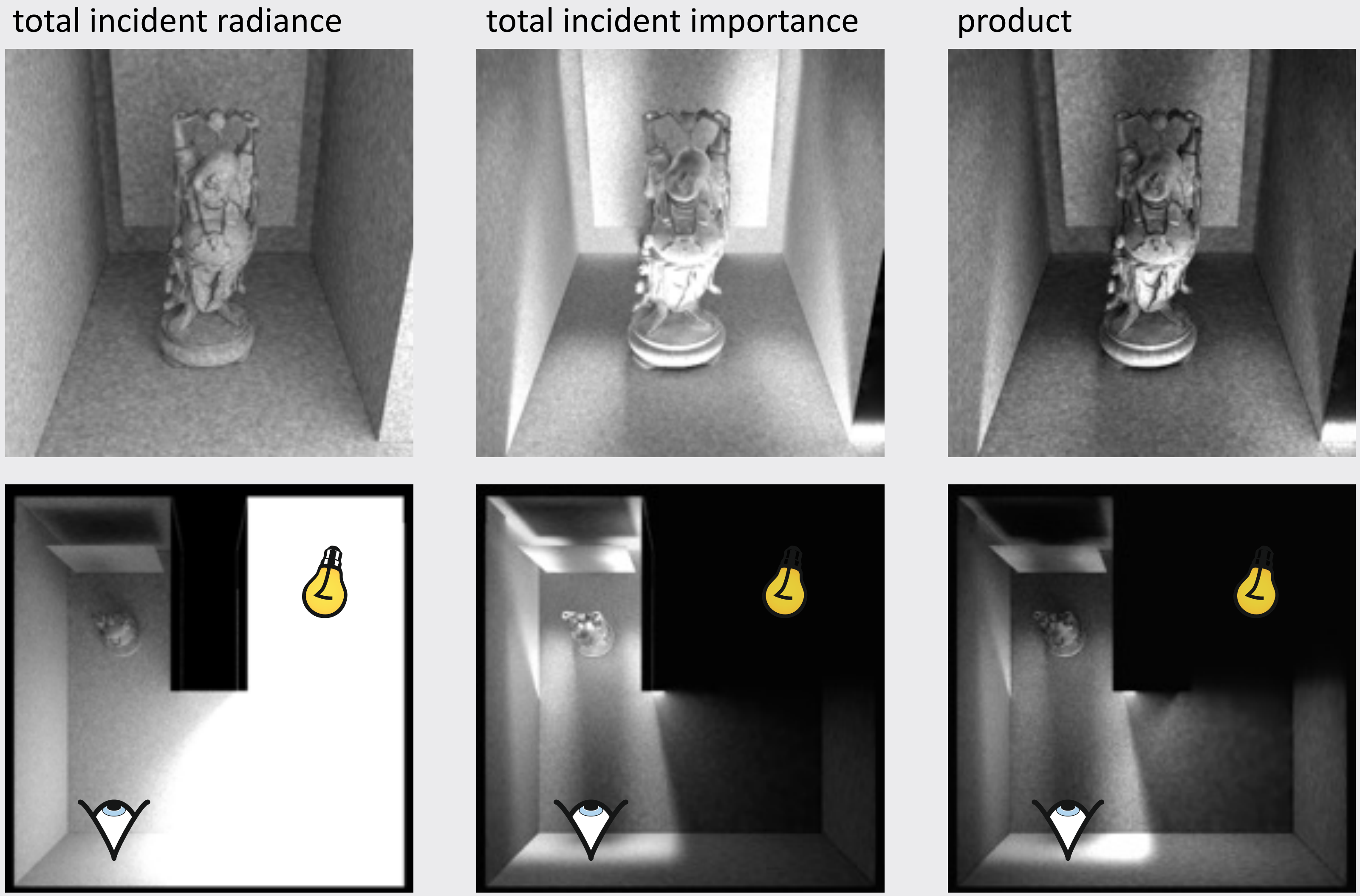
$$\hat{L}(x_3) = \int_{x_3,\ldots,x_k} L(x_3, \ldots, x_k) d(x_3, \ldots, x_k)$$

Importance Sampling

- Goal: VPL distribution $\sim \hat{W}\hat{L}$
- Create photon map to estimate $\hat{L}$
- Create importon map to estimate $\hat{W}$
- Implementation: Rejection sample photons according to importance

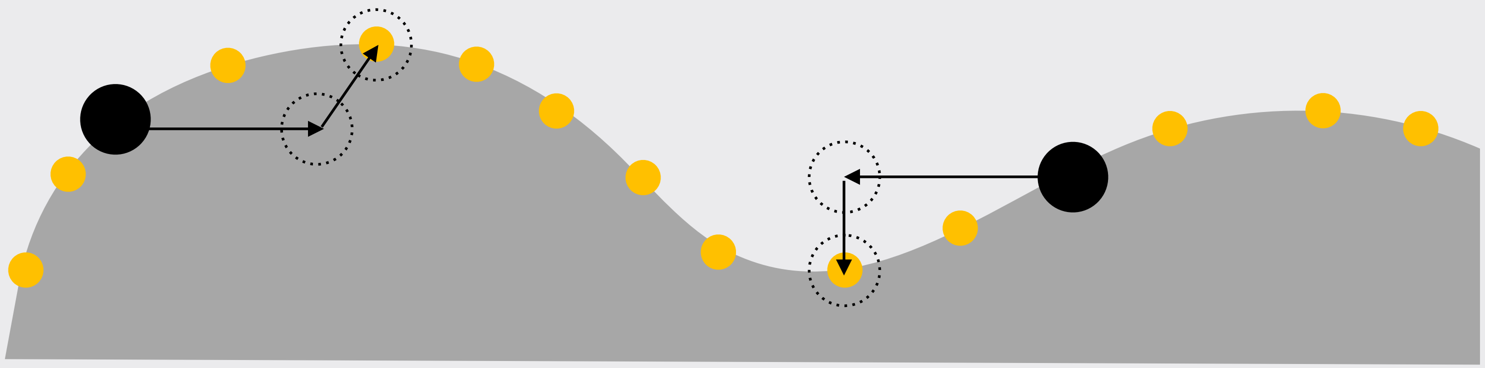


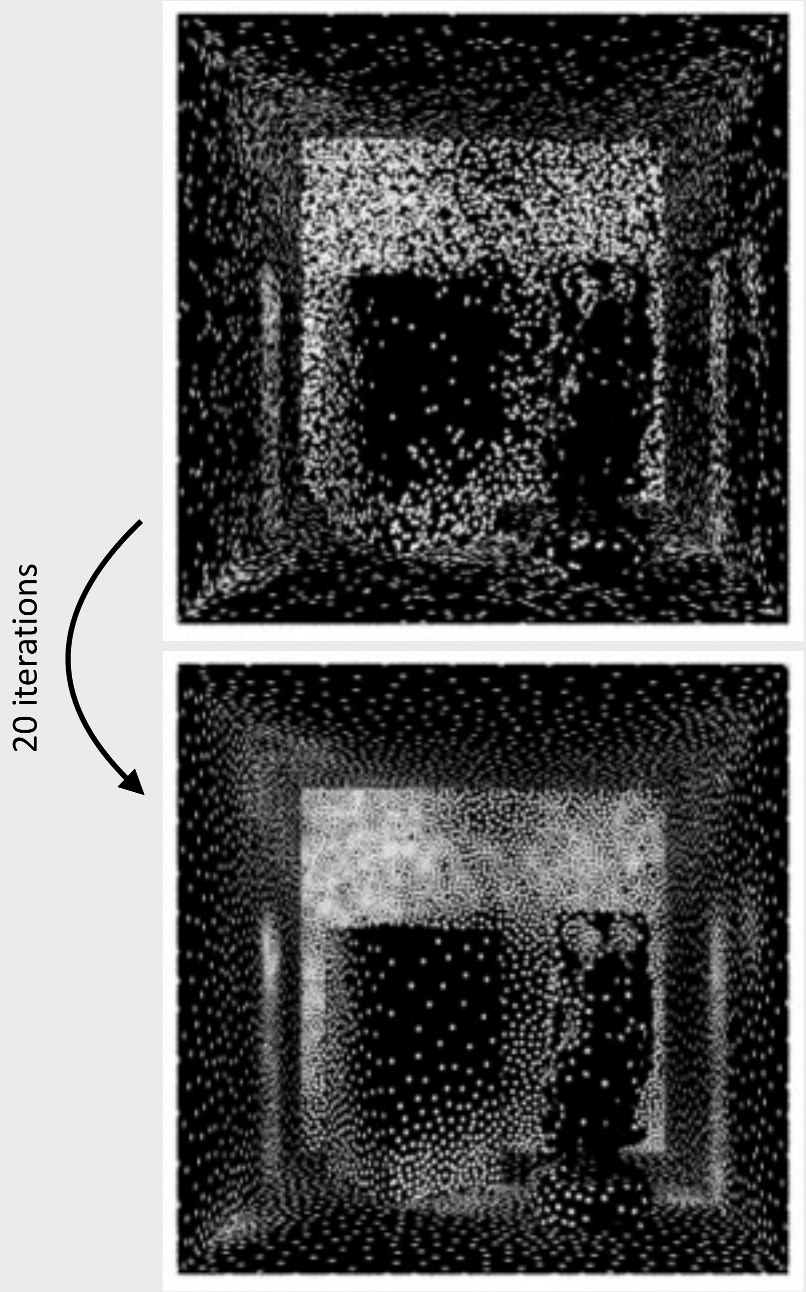
Product Distribution



Optional: Iterative Relaxation

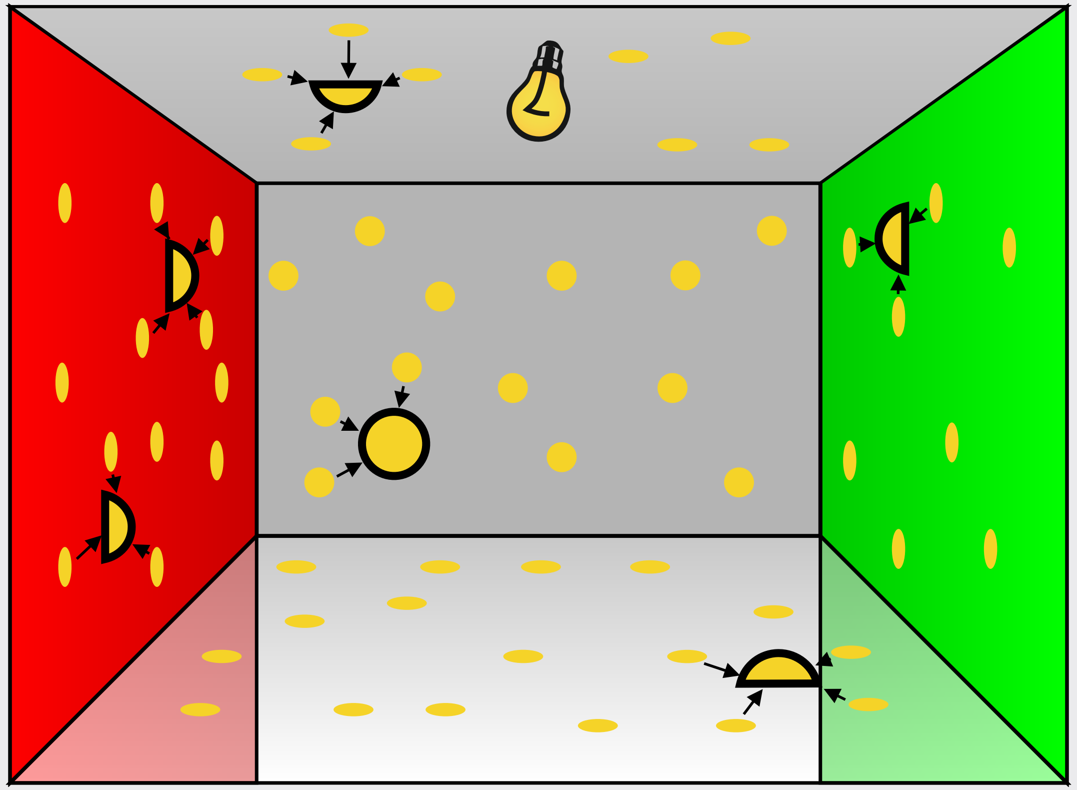
- Improves the distribution of Rich-VPLs
- Simple distance based point repulsion (Spencer et al. 2013)
- Snap to nearest photon





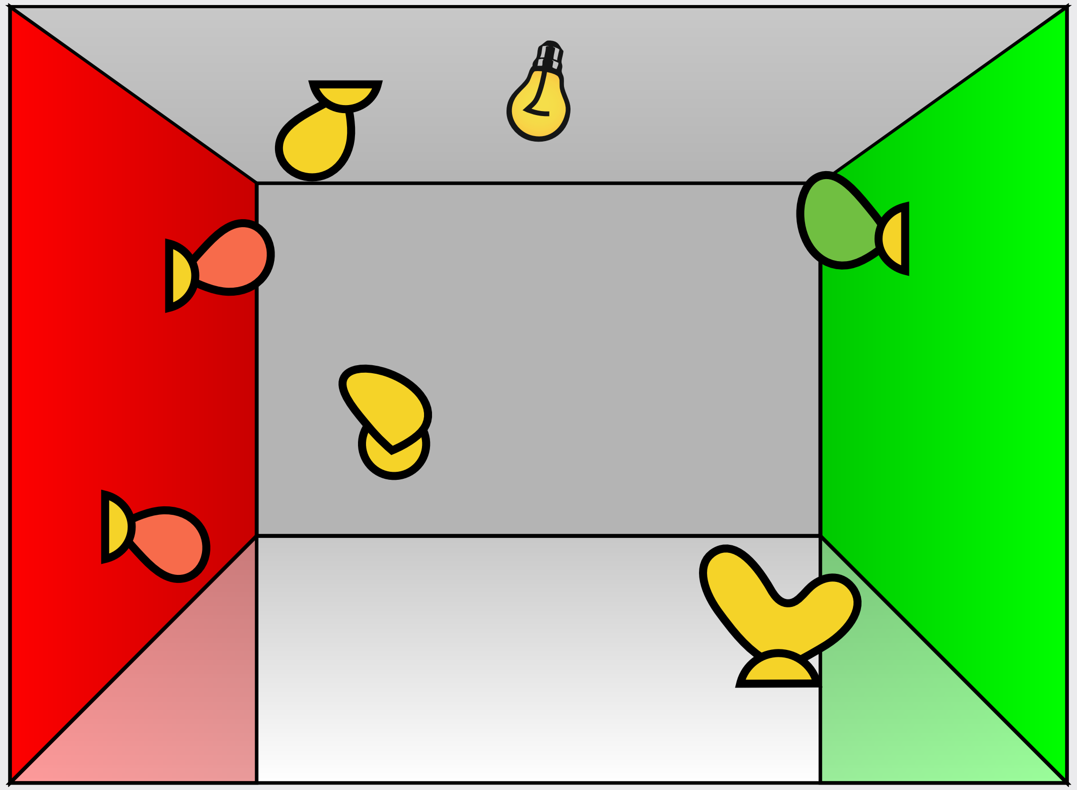
Rich-VPL Creation

- Collect nearby photons to get information about the local illumination



Rich-VPL Creation

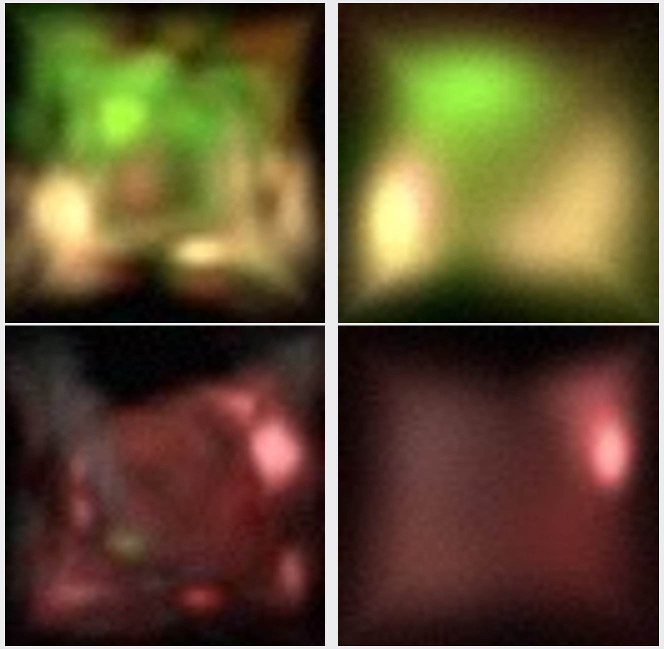
- Compute outgoing radiance distribution from the photons



Storing Outgoing Radiance

- Default: Tabulation with 32x32 discrete directions
- Alternative: Fit of Mises-Fisher lobes

tabulated | 5 lobe vMF fit



32x32 tabulation

≈ 1GB per 100k Rich-VPLs

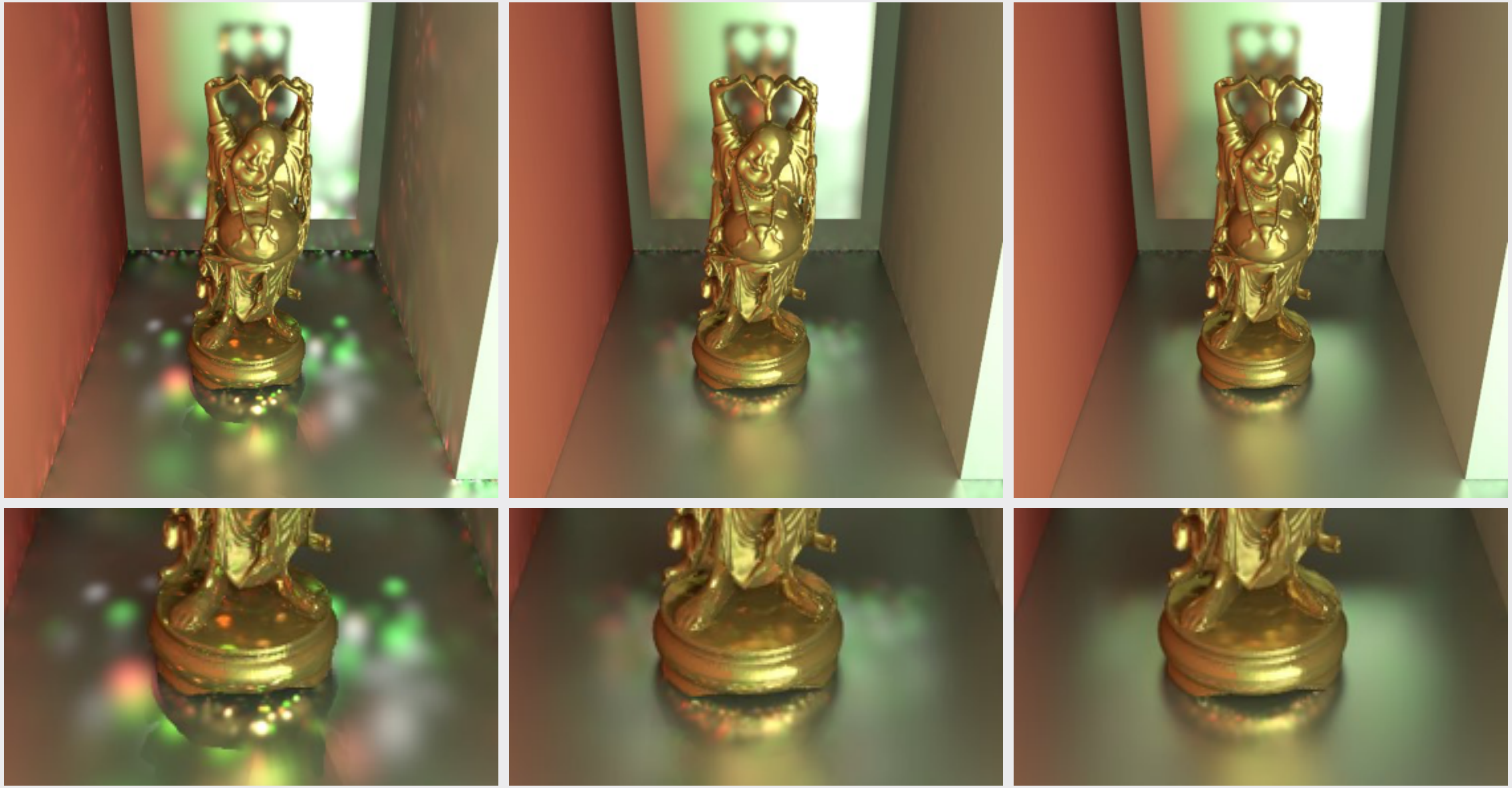
5 lobe vMF fit

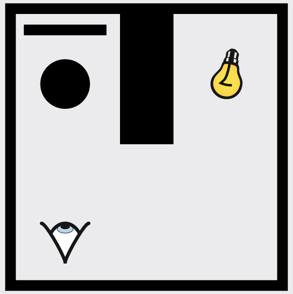
≈ 10MB per 100k Rich-VPLs

Results

Results - 1.4M (Rich-)VPLs

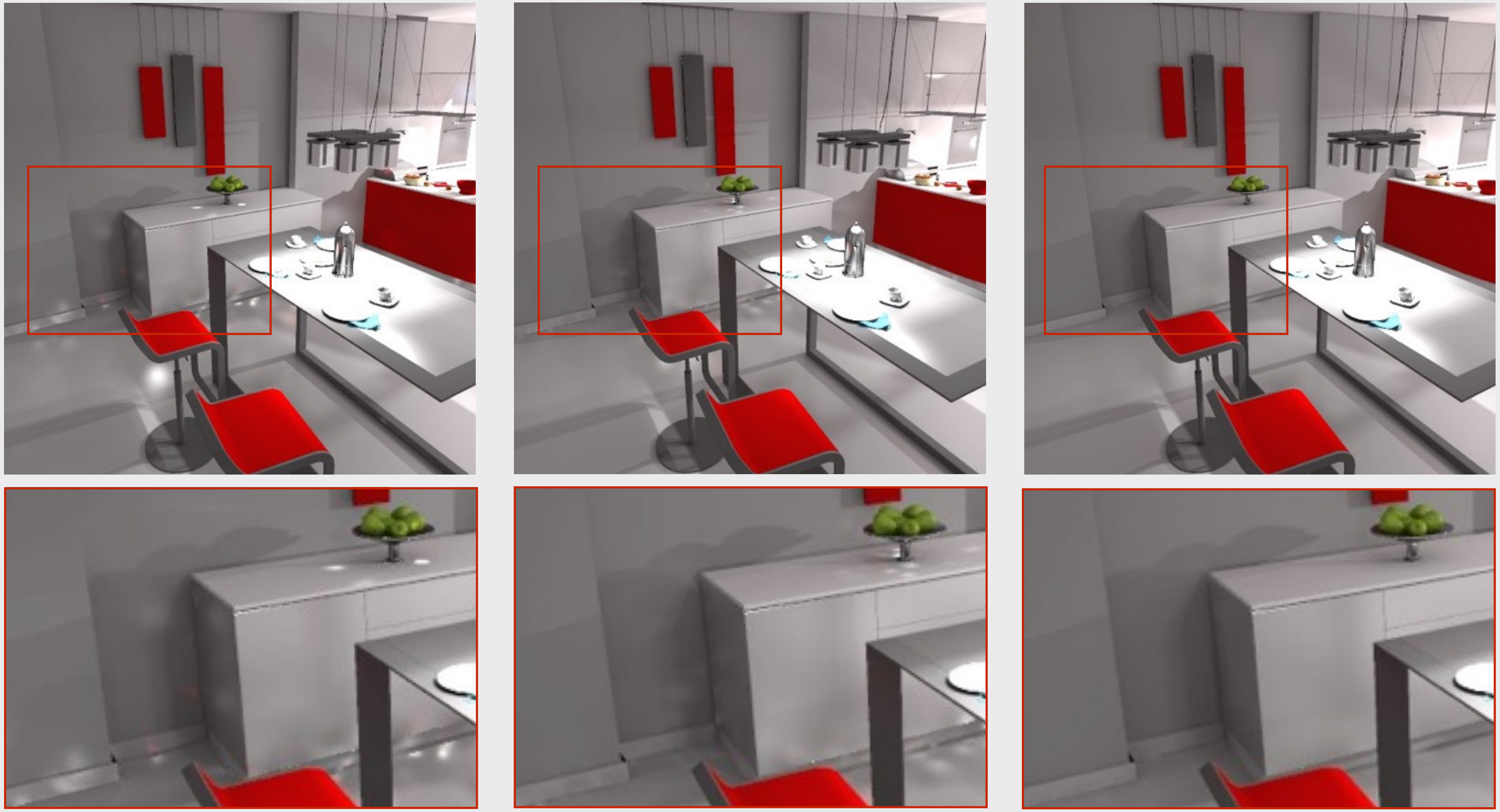
VPLs | VPLs & Importance Sampling | Rich-VPLs & Importance Sampling



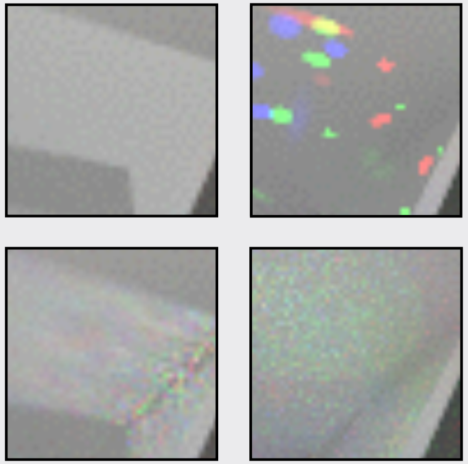


Results - 42k (Rich-)VPLs - Equal Time (14min)

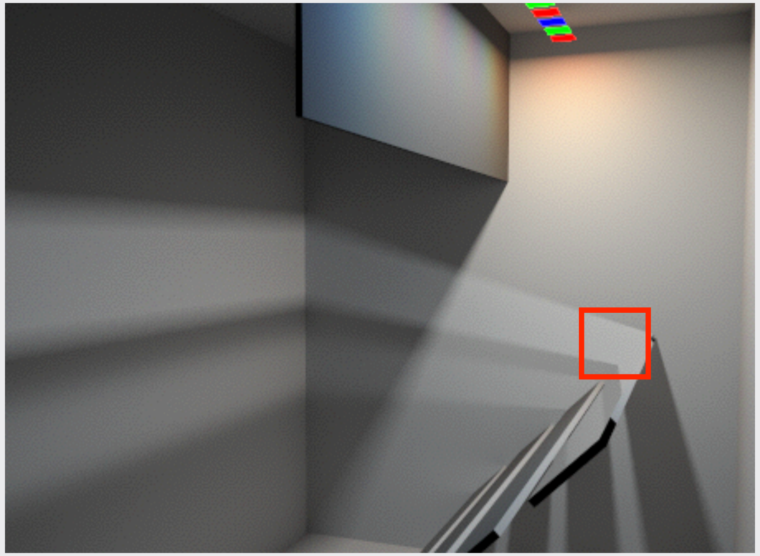
VPLs | VPLs & Importance Sampling | Rich-VPLs & Importance Sampling



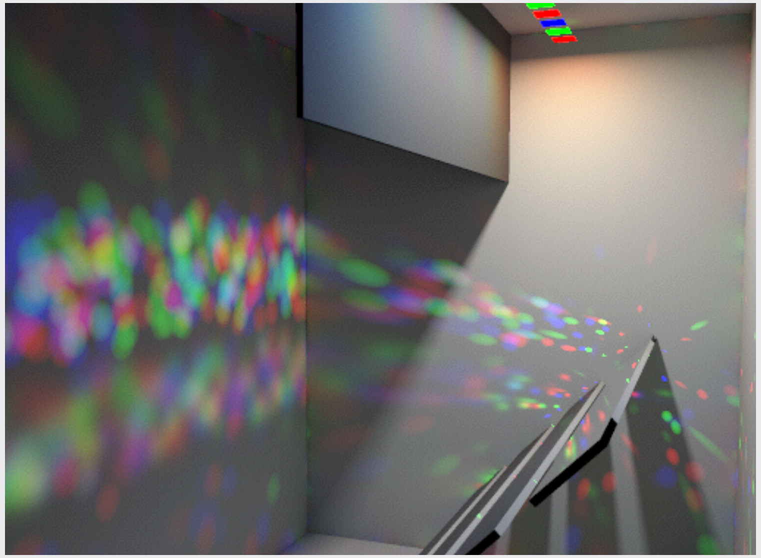
Results

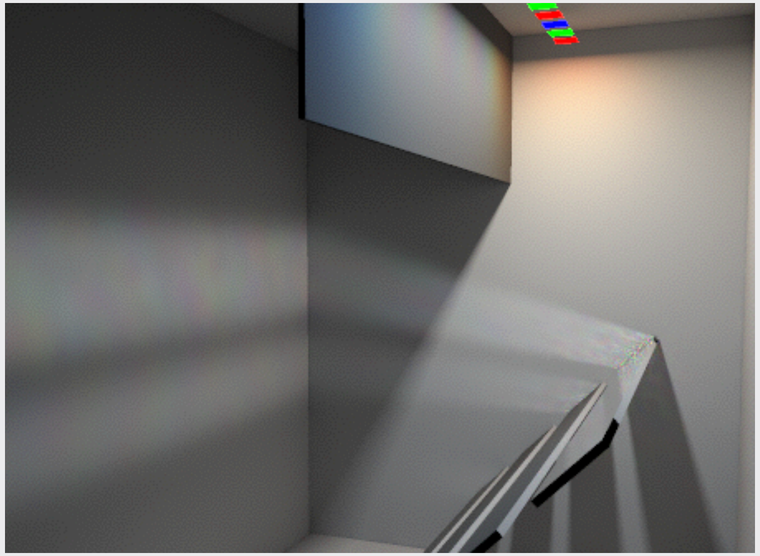


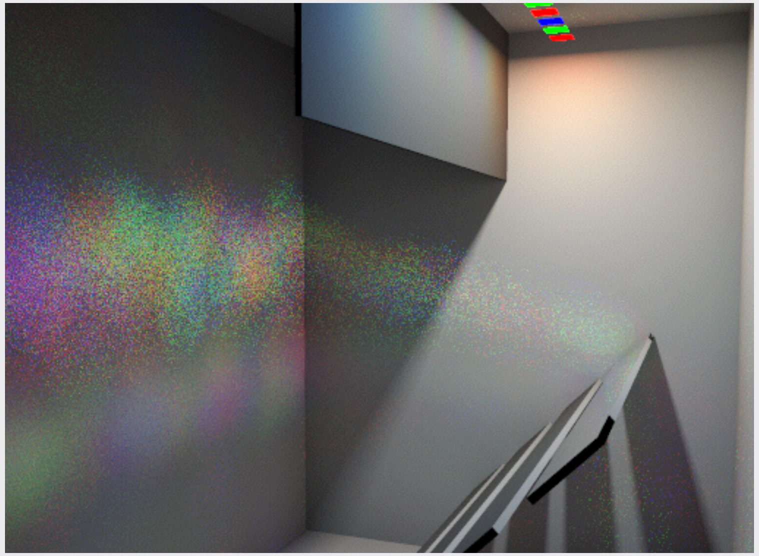
PT reference



VPL (25k)







Rich-VPL (25k)

VSL (25k)

Timings - Brute Force VPL Shading

Scene	#Lights	Importance sampling	Rich-VPL creation	Shade	Total
CBox	25k	11s	11s	567s	589s
U-Shape	35k	13s	8s	533s	554s
Kitchen	42k	12s	10s	808s	830s

Discussion: Lightcuts

- Tabulation allows simple and fast clustering
- Highly glossy materials result in large cuts

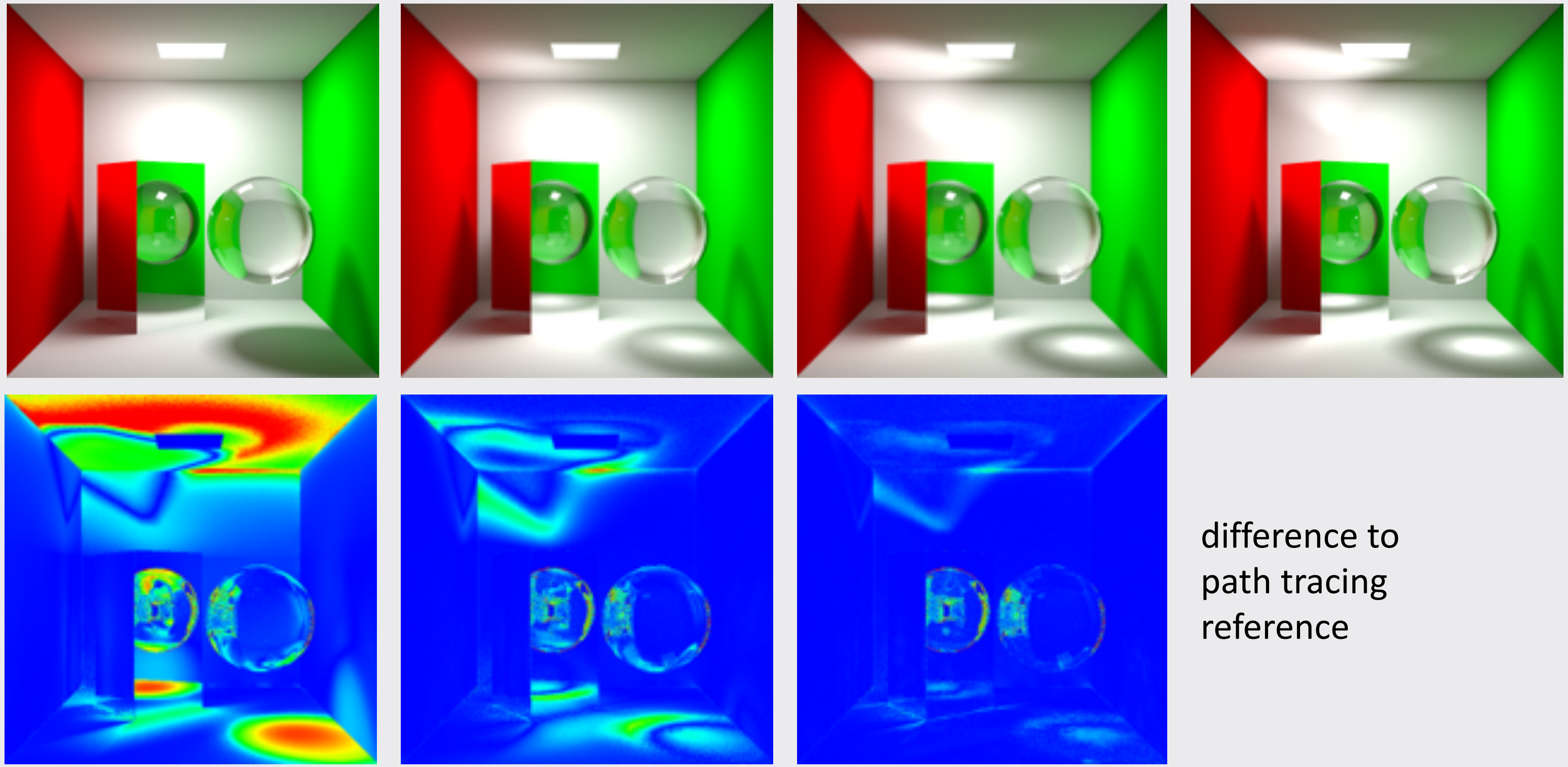
Shading Times:

Scene	*#Lights*	*Brute Force*	*Lightcuts*
CBox	*42k*	*13min*	*3min*
Kitchen	*150k*	*30min*	*15min*
Garage	*250k*	*100min*	*80min*

Discussion: Bias

unit: MSE to path tracing

- Angular discretisation of tabulation
- Rich-VPL creation



Conclusion

- Improved many-light efficiency for highly glossy surfaces by using Rich-VPLs and Importance Sampling.
- Orthogonal to other Many-Light techniques like Lightcuts and VSLs.
- Memory footprint $\longleftrightarrow$ Bias
- Still needs clamping for artifact free renderings
  - Rich-VPLs + Bidirectional Lightcuts?

Backup

- Rejection Sampling
  - Rejection ratio (typically 100): q
  - Importance of photon: W
  - Average importance: $\bar{W}$
  - Rejection probability: $p = \min\left(1, \frac{W}{q\bar{W}}\right)$

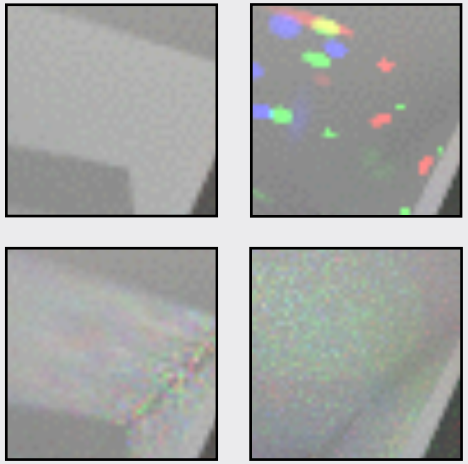
Backup

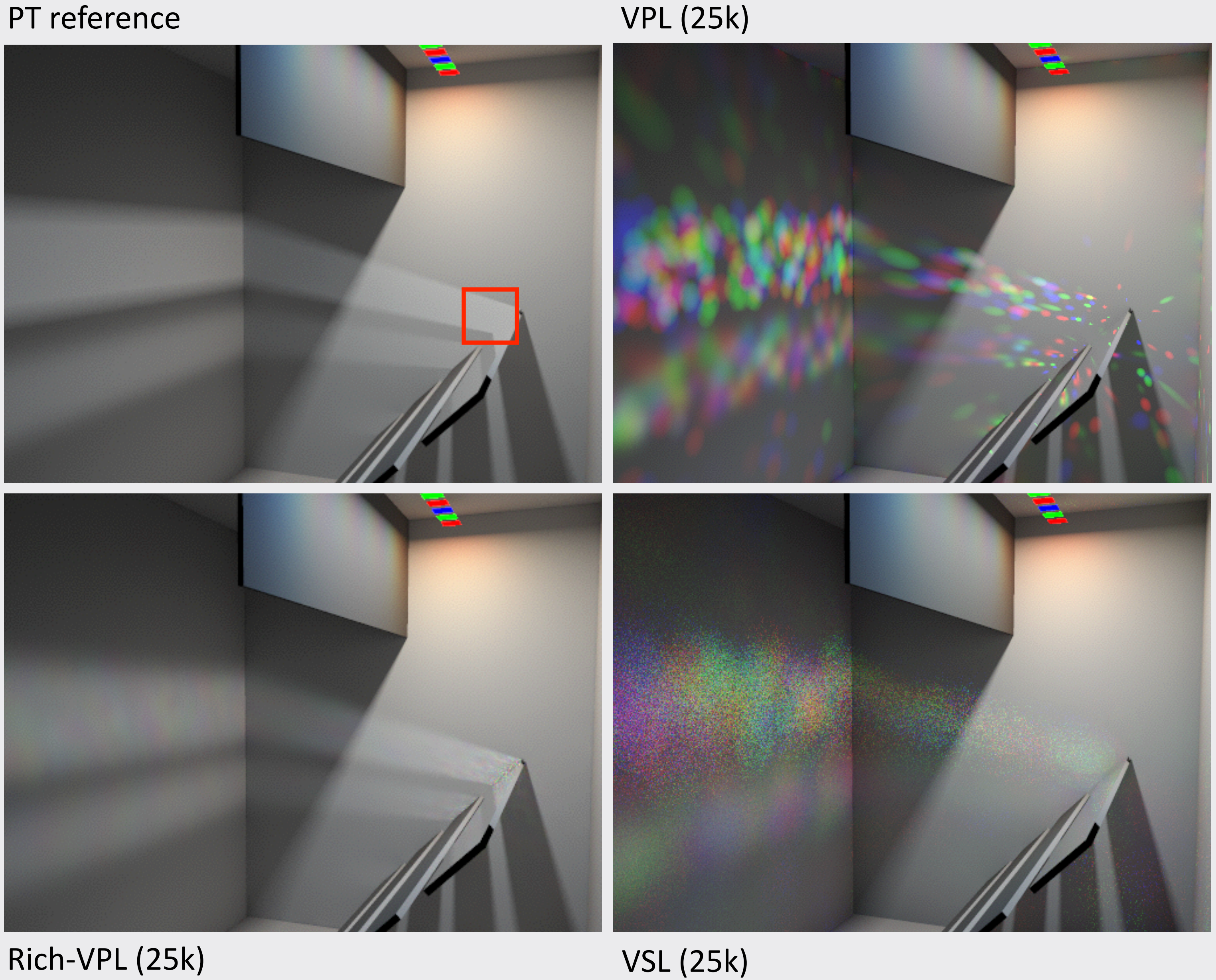
- Estimating $\hat{W}$:
  - K nearest neighbours
  - Density estimation with Epanechnikov kernel:

$$\hat{W}(x) = \frac{2}{\pi d_K^2} \sum_{i=1}^{K} \Psi_i \cdot w_i(x)$$

$$w_i(x) = 1 - \frac{d_i^2}{d_K^2}$$

Results



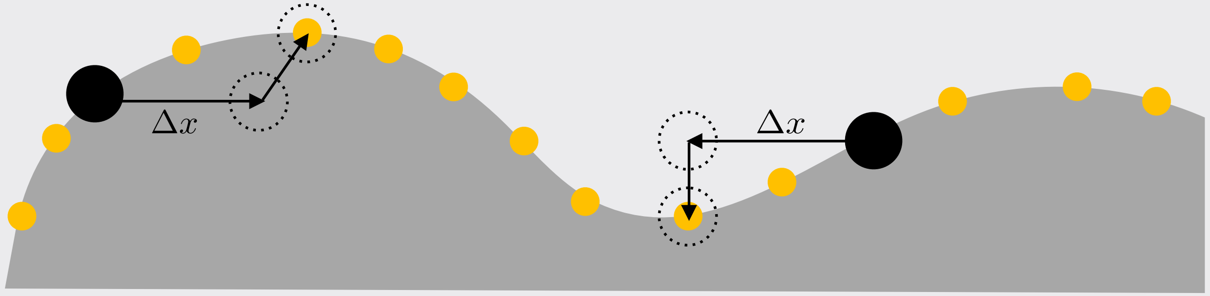


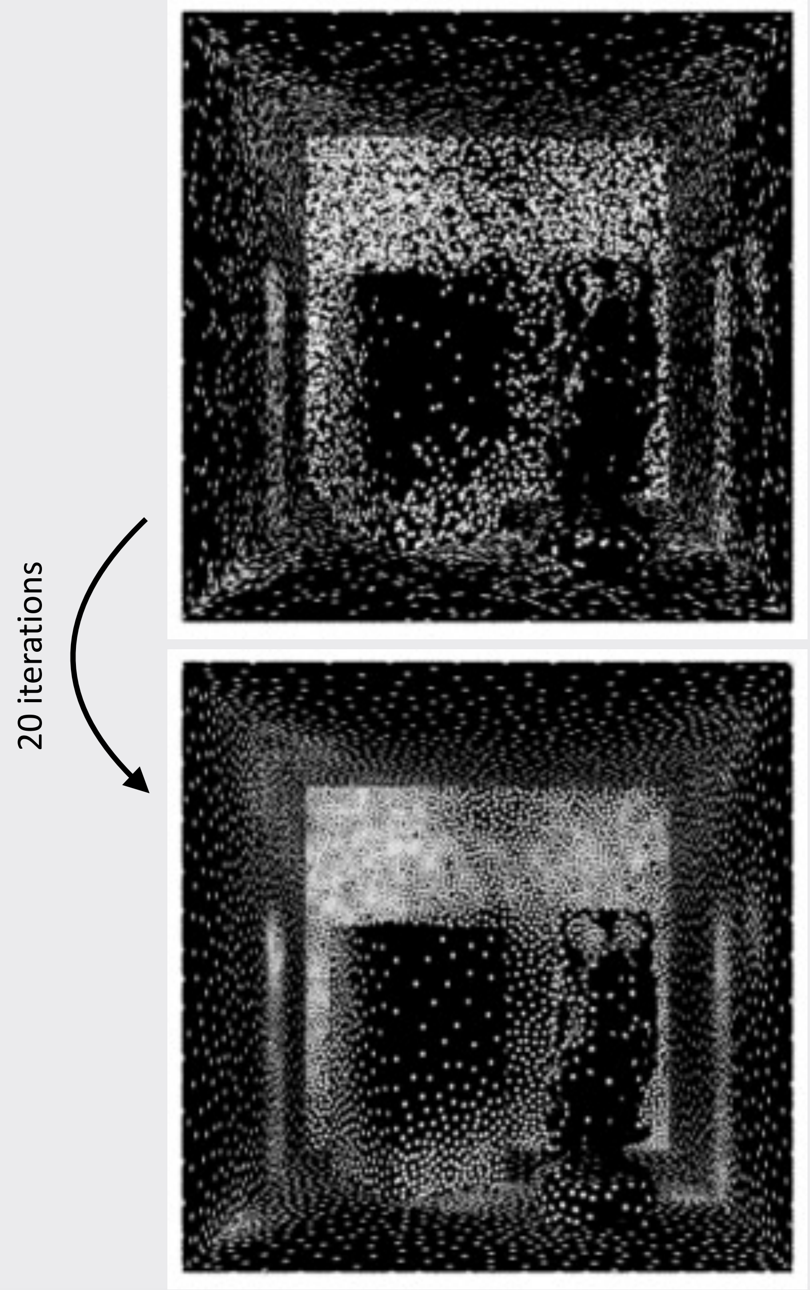
Iterative Relaxation

- Improves the distribution of Rich-VPLs
- Simple point repulsion (Spencer et al. 2013)

$$\Delta x = \frac{1}{K}\sum_{k=1}^{K}(x - x_k)\left(\frac{\|x - x_K\|}{\|x - x_k\| + \epsilon} - 1\right)$$

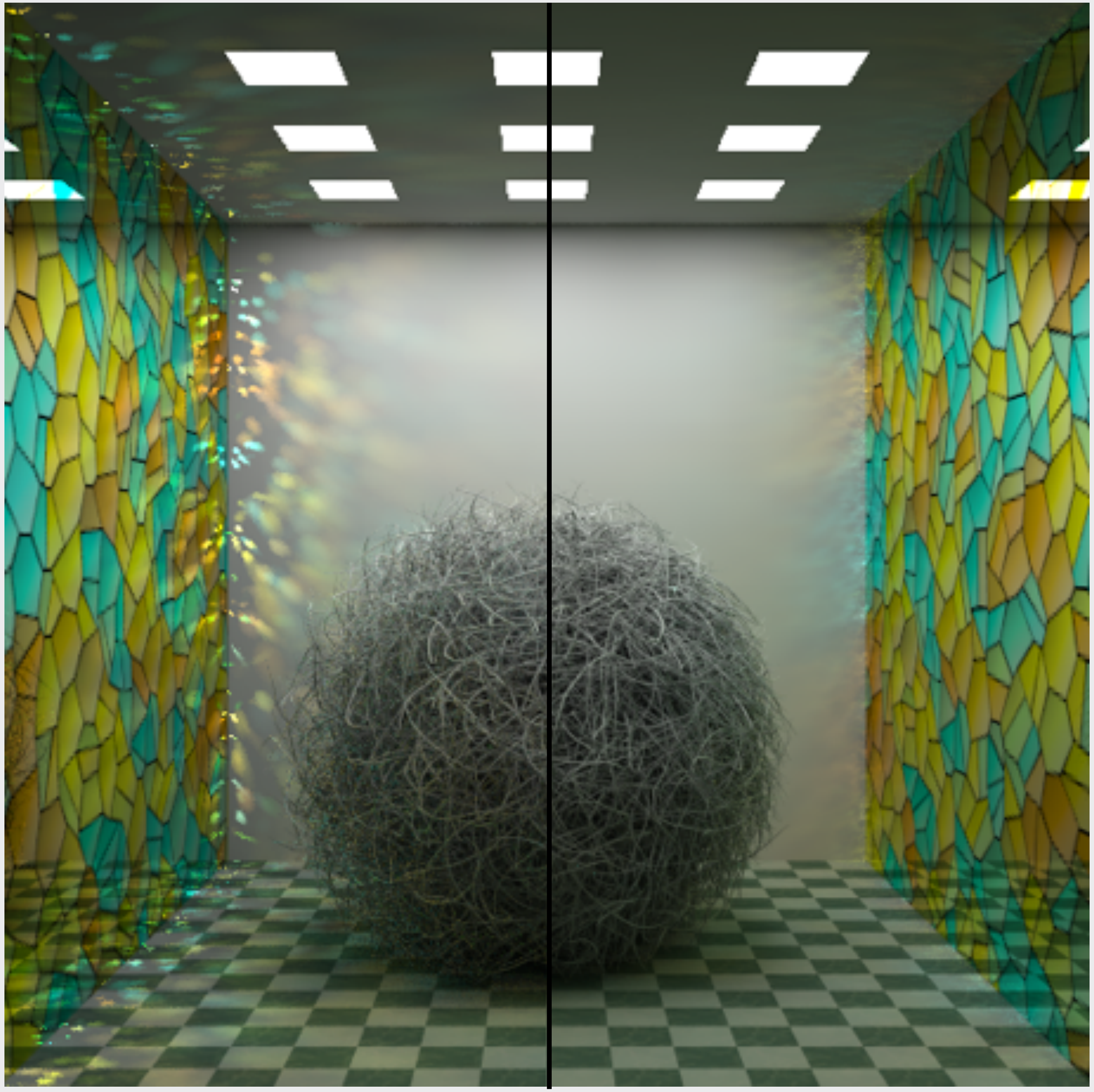
- Snap to nearest photon





Results

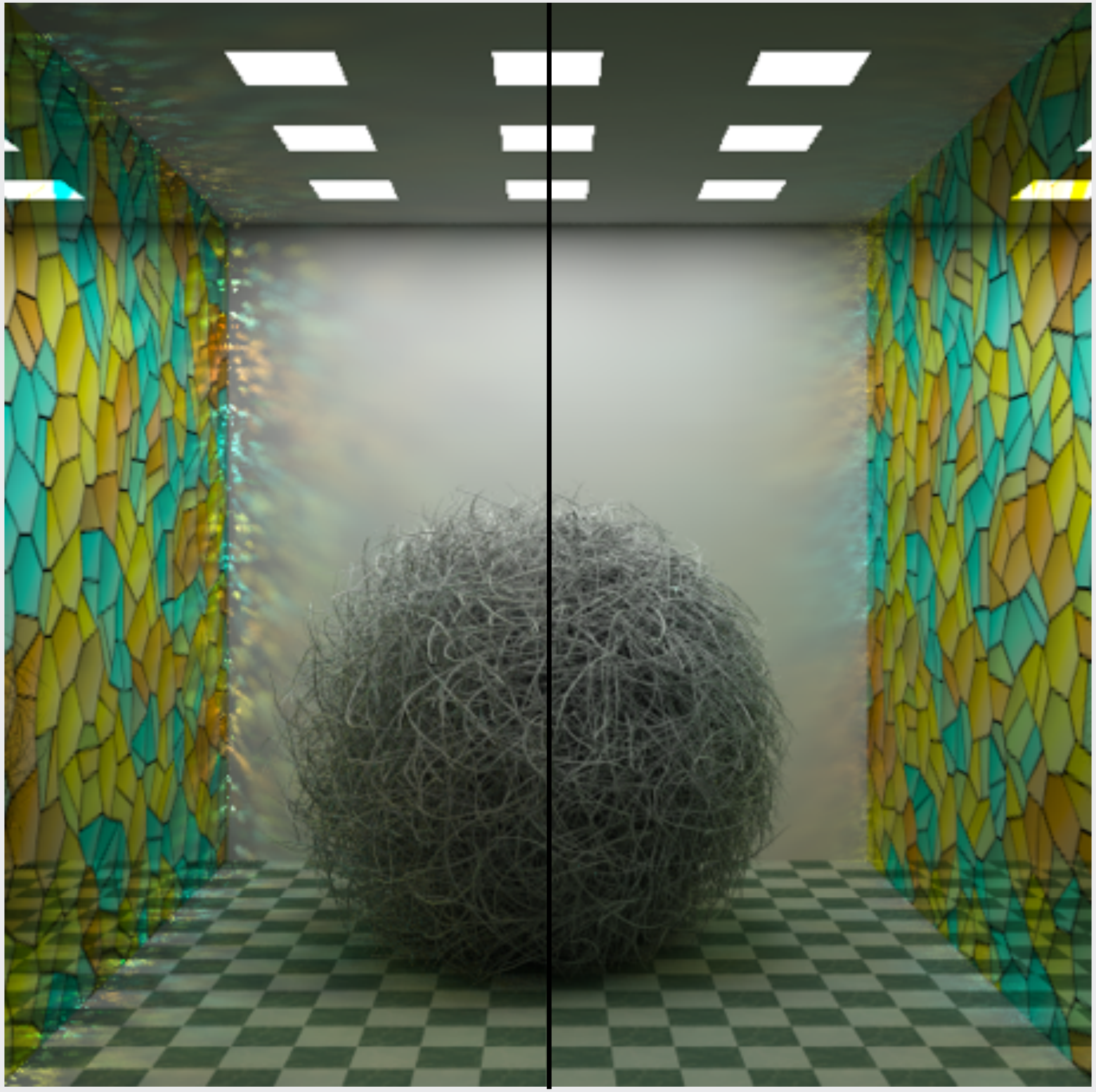
80k VPLs
36min



75k Rich-VPLs
36min

Results

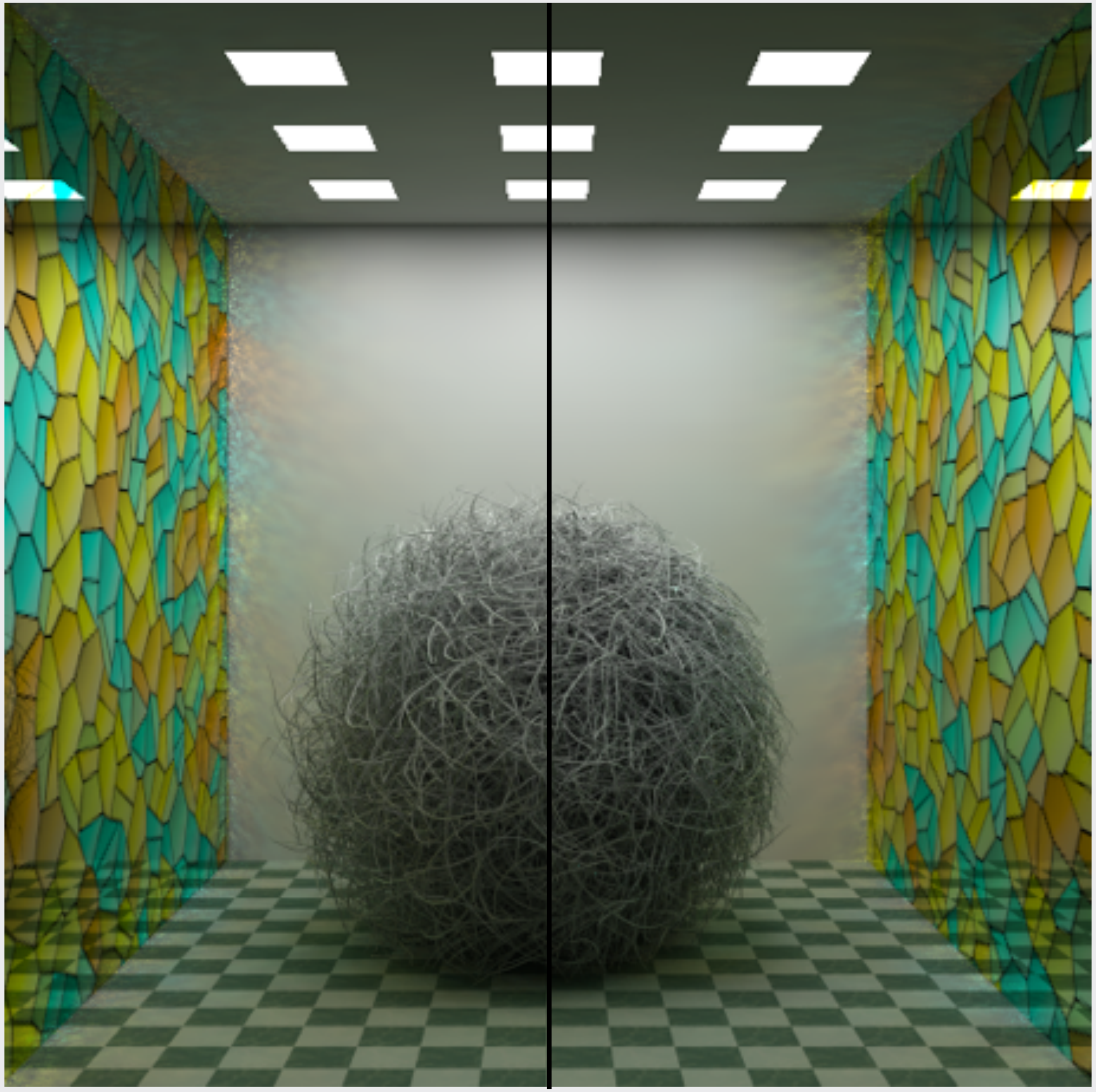
4x80k VPLs
4x36min



75k Rich-VPLs
36min

Results

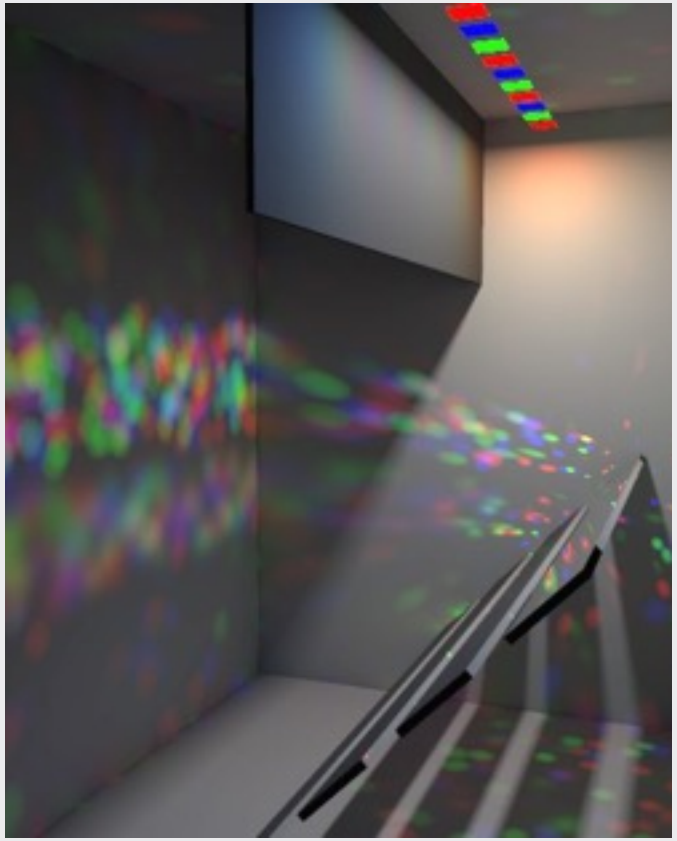
100x80k VPLs
100x36min



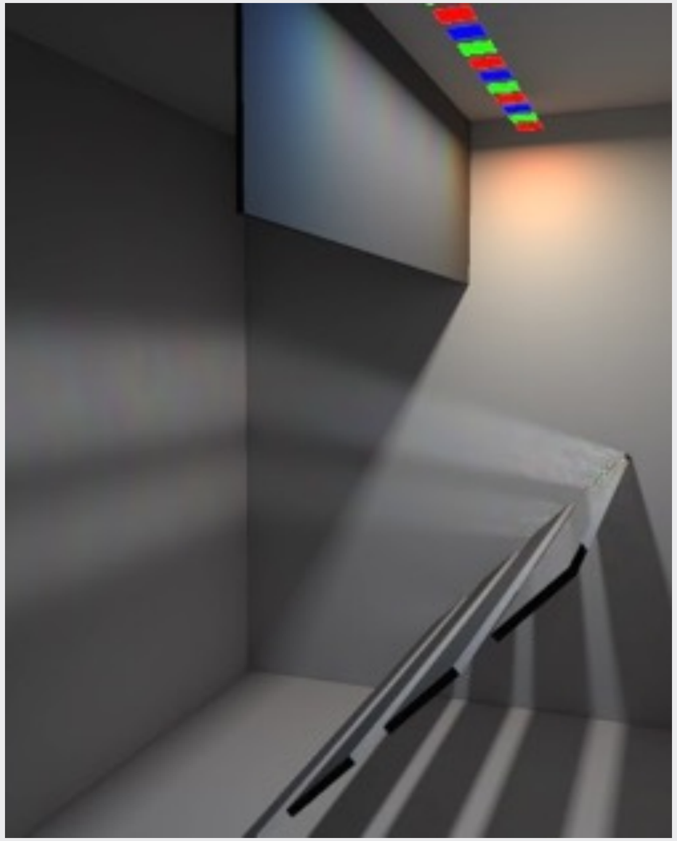
75k Rich-VPLs
36min

Results

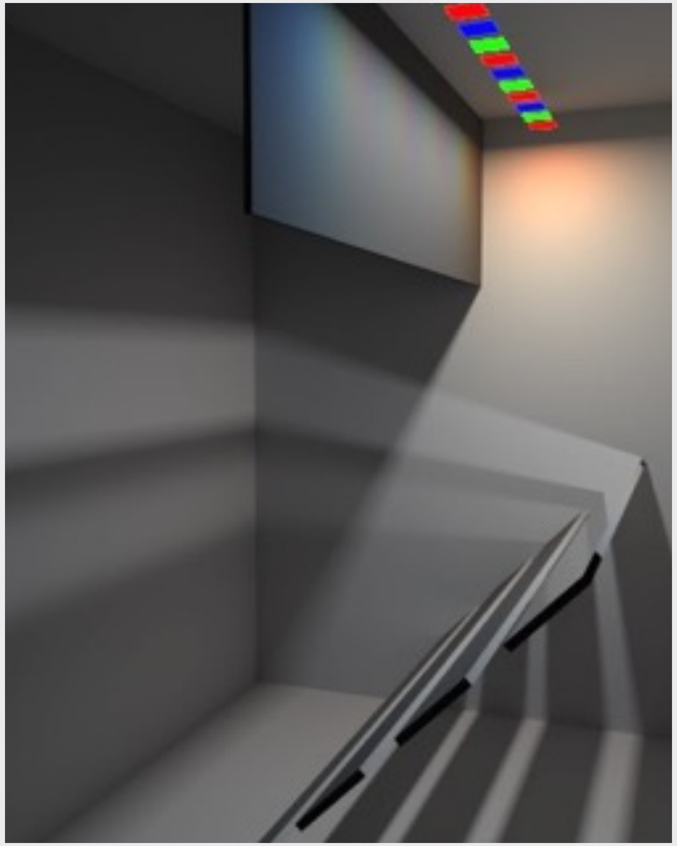
VPL (25k)



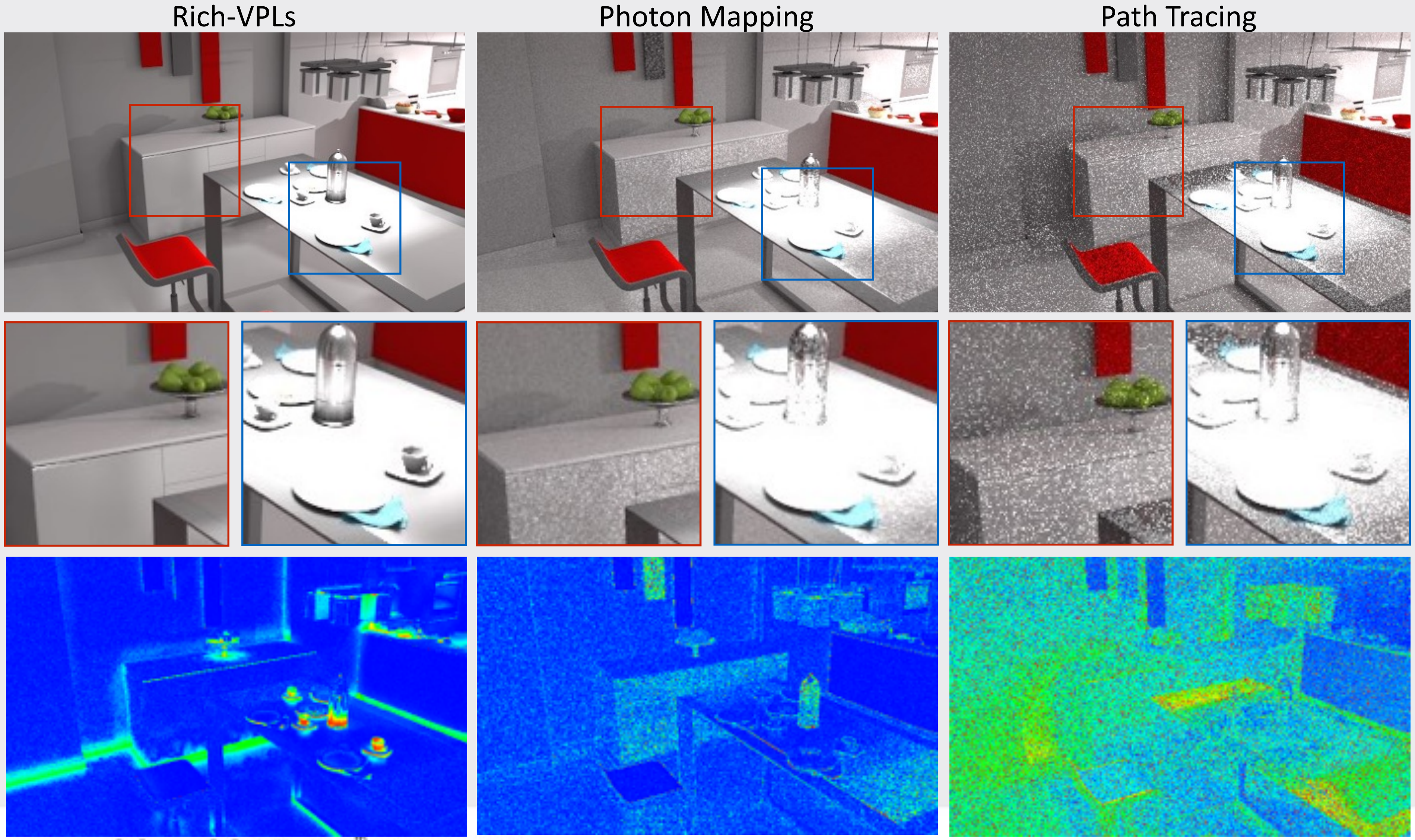
Rich-VPL (25k)



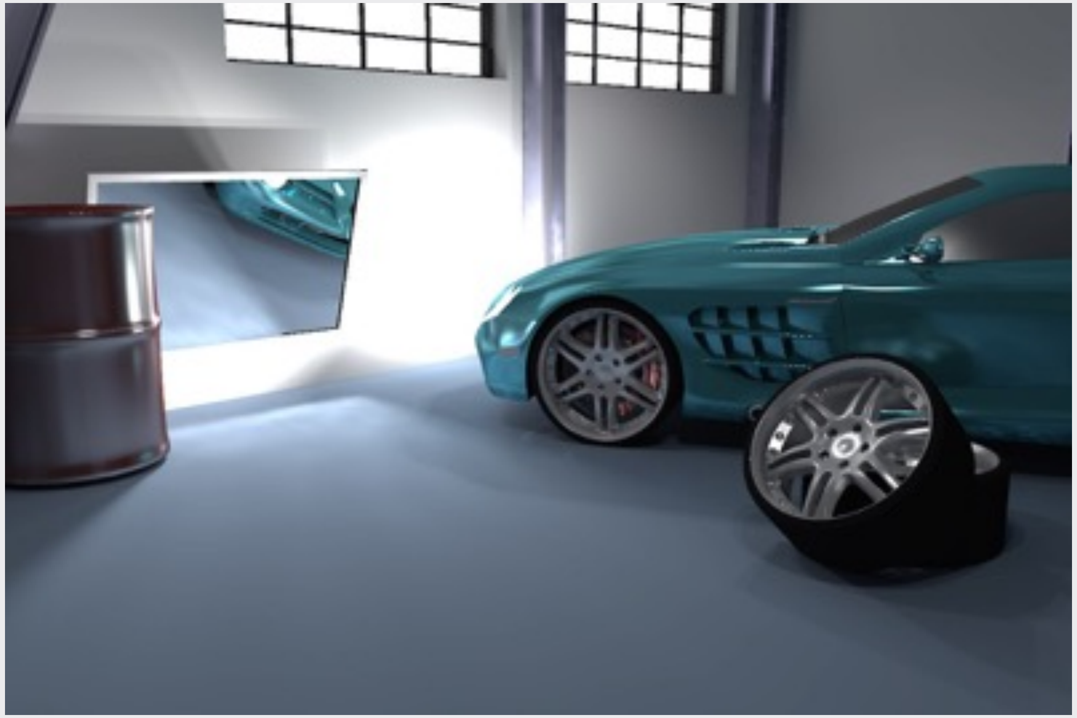
path tracing reference



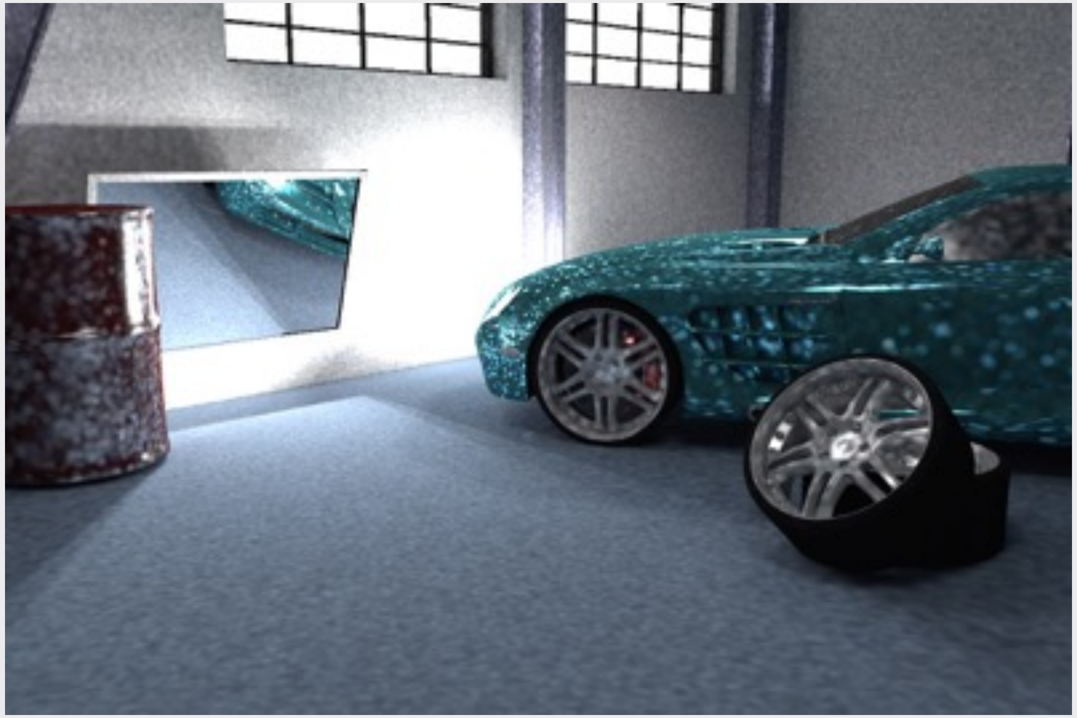
Results - Kitchen 60min



Direct Rendering of the Photon Map



Rich-VPL



Rendering of underlying photon map

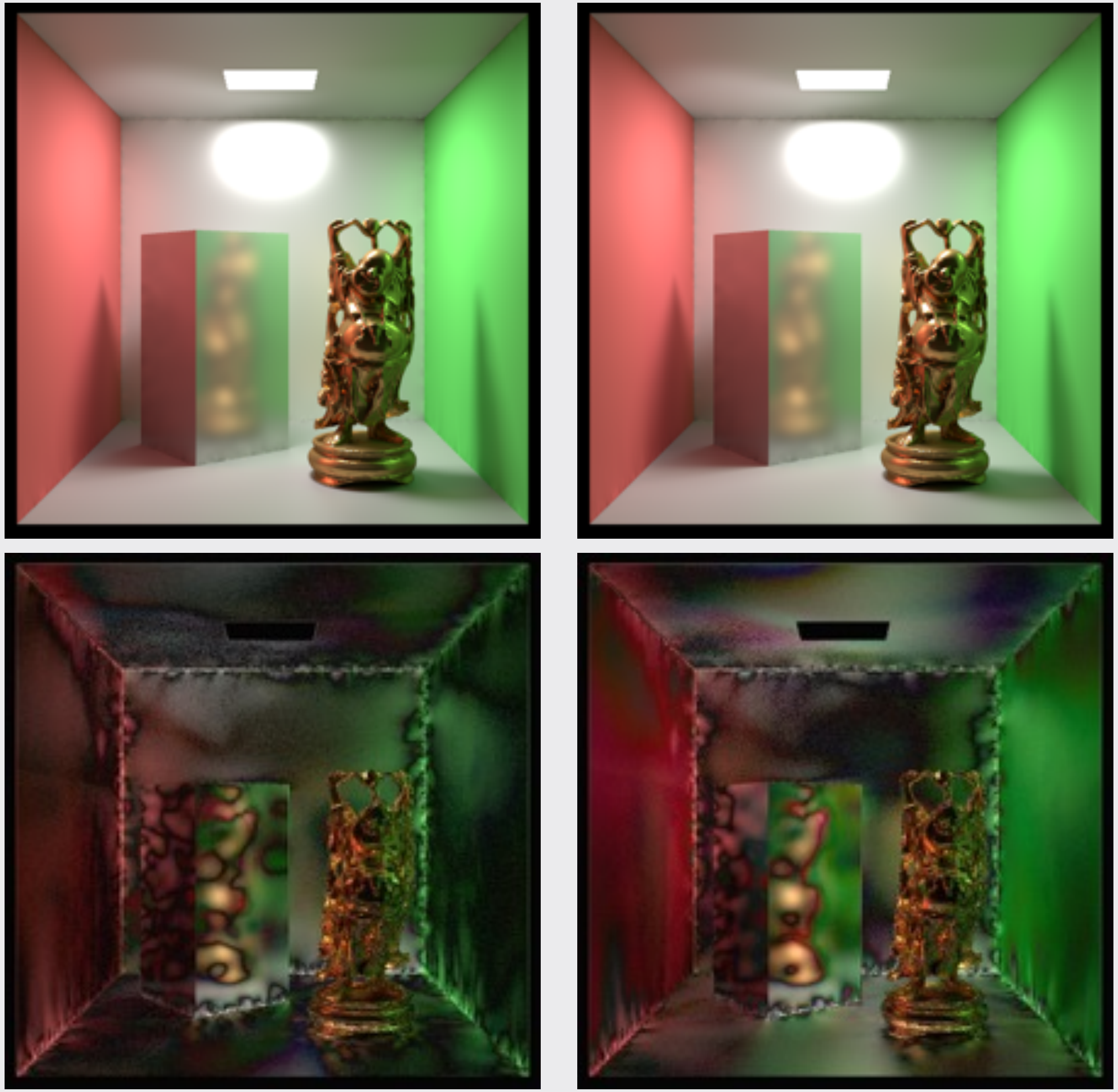
Tabulated
32x32

~1GB
per 100k
Rich-VPLs

Mixture of
5 vMFs

~10MB
per 100k
Rich-VPLs

4x difference to
pathtracing reference



Storing Outgoing Radiance

- Tabulated (Octahedron Environment Map, Engelhardt 2008)
- Usually 32x32 discrete directions ω_o

$$L(x, \omega_o) = \sum_{j=1}^{K} w(d_j, d_K) f_r(x, \omega_j, \omega_o) \Phi_j$$

Discussion: Lightcuts

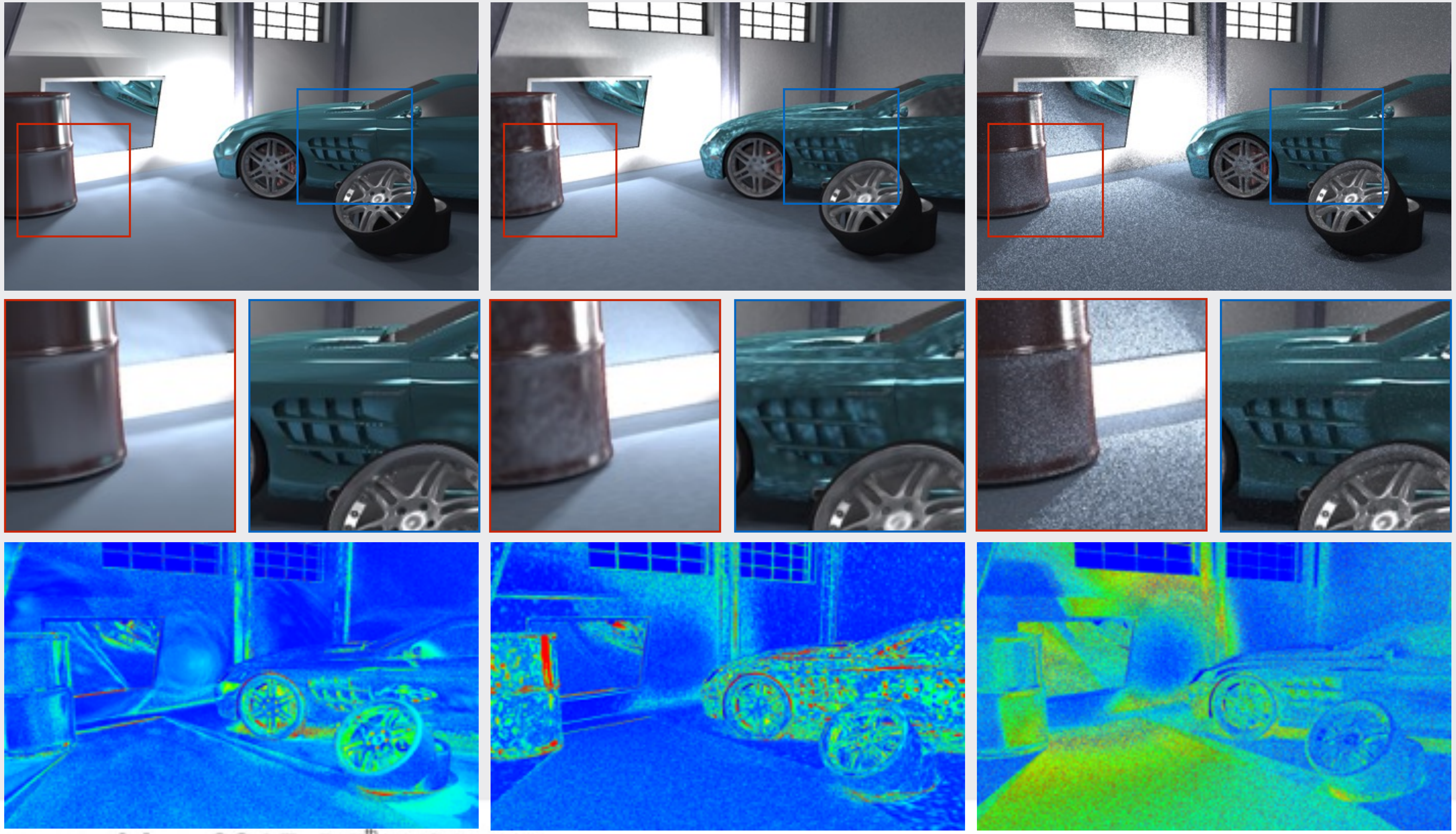
- More refinement (larger cuts) needed for smooth shading results

original refinement

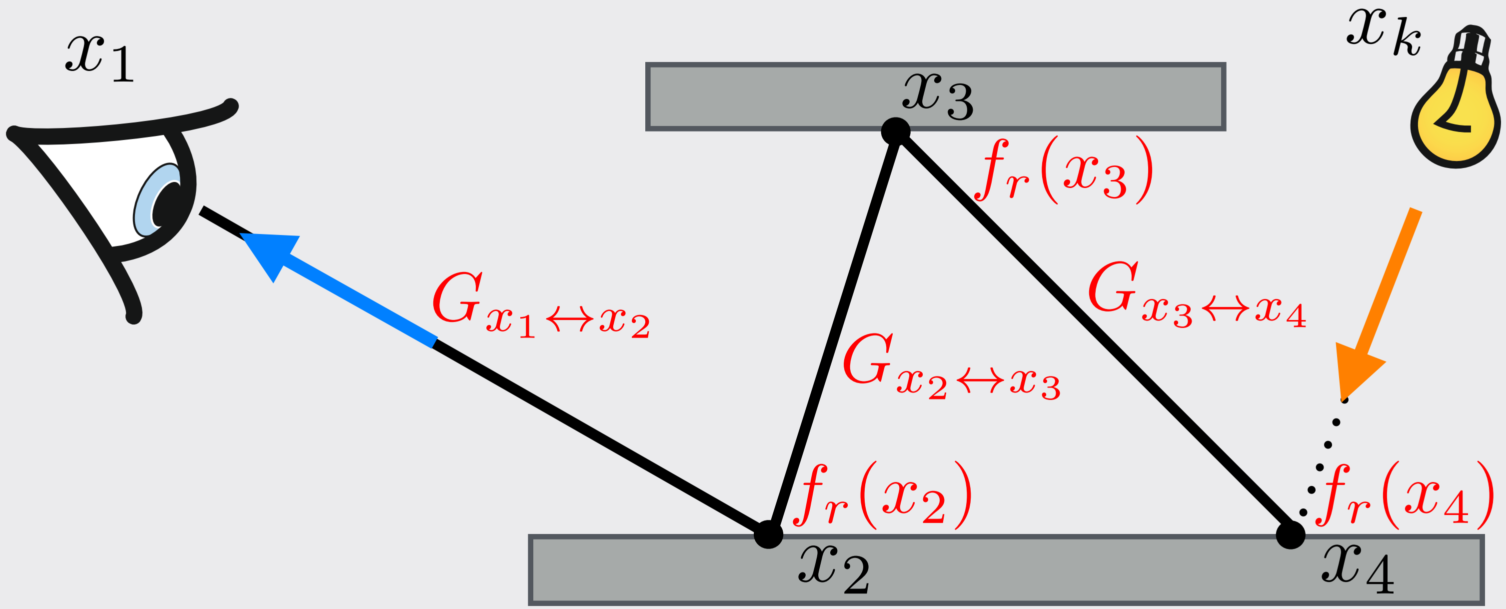
more refinement

Results - Garage 5h

Rich-VPLs | Photon Mapping | Path Tracing



Importance Sampling



$$f(X) = W_e(x_2 \to x_1) \left(\prod_{i=1}^{k-1} G_{x_i \leftrightarrow x_{i+1}} \right) \left(\prod_{i=2}^{k-1} f_r(x_i) \right) L_e(x_k \to x_{k-1})$$