SIGGRAPH ASIA 2013

Combining Photon Mapping and Bidirectional Path Tracing

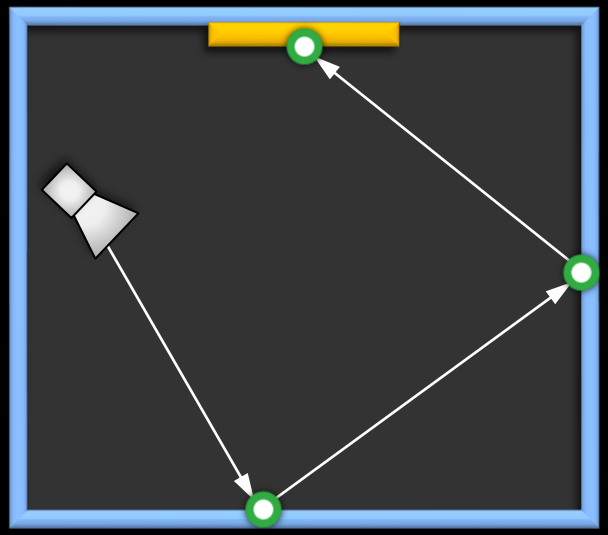
SPONSORED BY

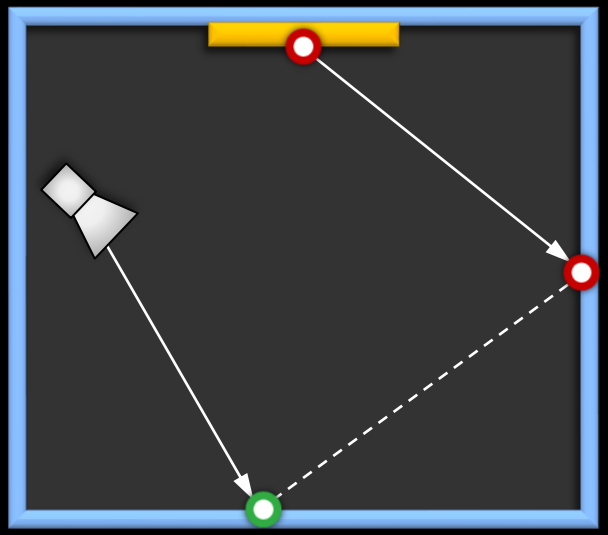
Bidirectional path tracing (30 min)

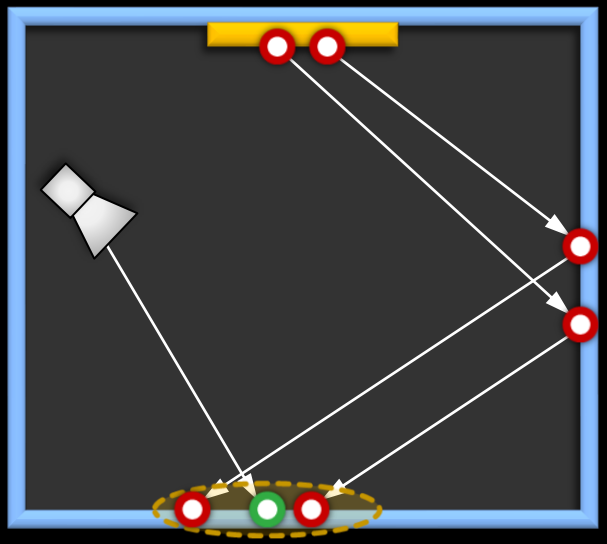
Stochastic progressive photon mapping (30 min)

Combined algorithm (30 min)

BPT vs PM







Unidirectional sampling

Vertex connection

Density estimation

Bidirectional path tracing

Photon mapping

Problem statement

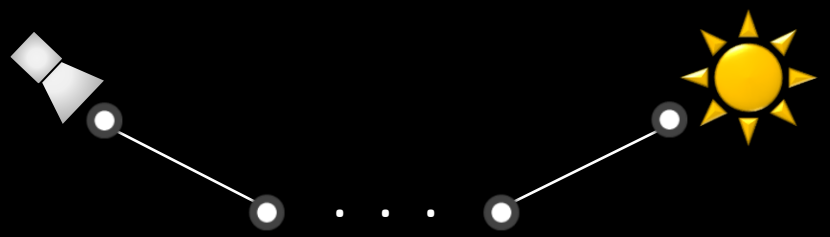
- **BPT** & **PM**: different solutions to the same problem
  - If we ignore bias in PM
- Want to combine
  - Best of both
  - Automatically
- ☹ Problem: Different mathematical frameworks
  - **BPT**: Monte Carlo integration
  - **PM**: Density estimation

Overview

- ☹ Problem: Different mathematical frameworks
- ☺ Solution: Cast both in the same framework
  - Path integral framework *[Veach 1997]*
  - Multiple importance sampling
  - New insight

$$I_j = \int_\Omega f_j(\bar{\mathbf{x}})\, d\mu(\bar{\mathbf{x}})$$

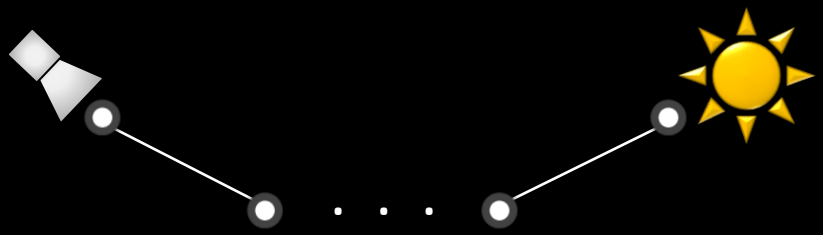
$$\langle I_j \rangle = \frac{f_j(\bar{\mathbf{x}})}{p(\bar{\mathbf{x}})}$$



Combination

- Multiple importance sampling *[Veach and Guibas 1995]*
  - Balance heuristic for n techniques

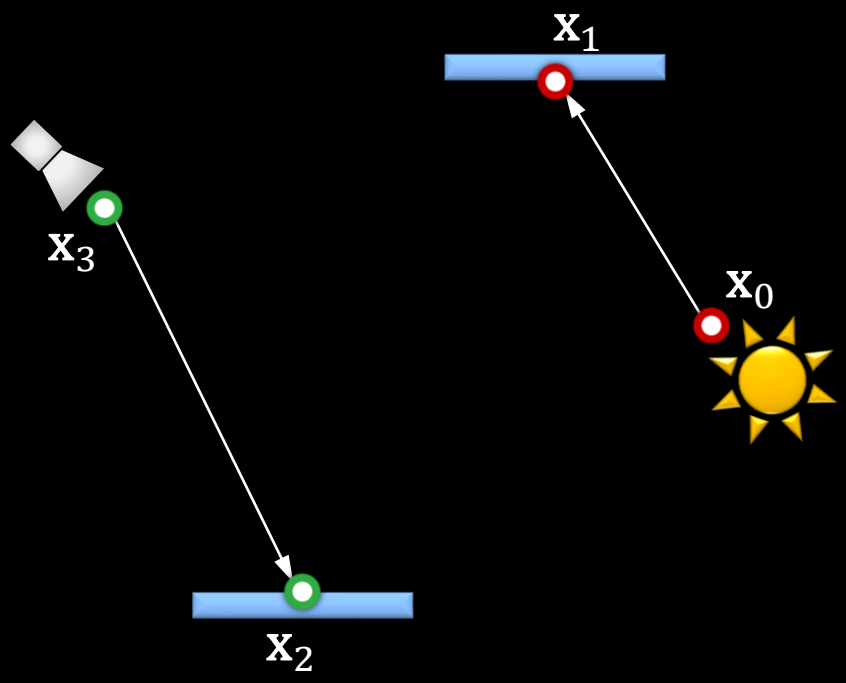
$$w_j(\bar{\mathbf{x}}) = \frac{p_j(\bar{\mathbf{x}})}{\sum_{k=1}^{n} p_k(\bar{\mathbf{x}})}$$



- Need to:
  1) Find a common definition of a path
     - In a common space
  2) Derive path probability density function (pdf)
     - With common units

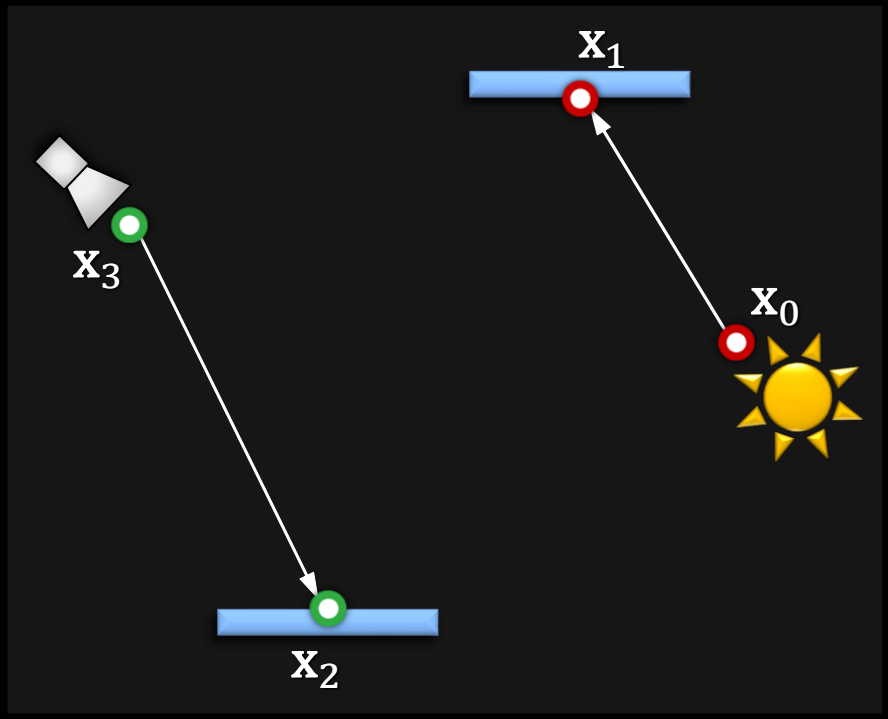
Bidirectional path sampling

- Light vertex
- Camera vertex



Bidirectional path sampling

- Light vertex
- Camera vertex

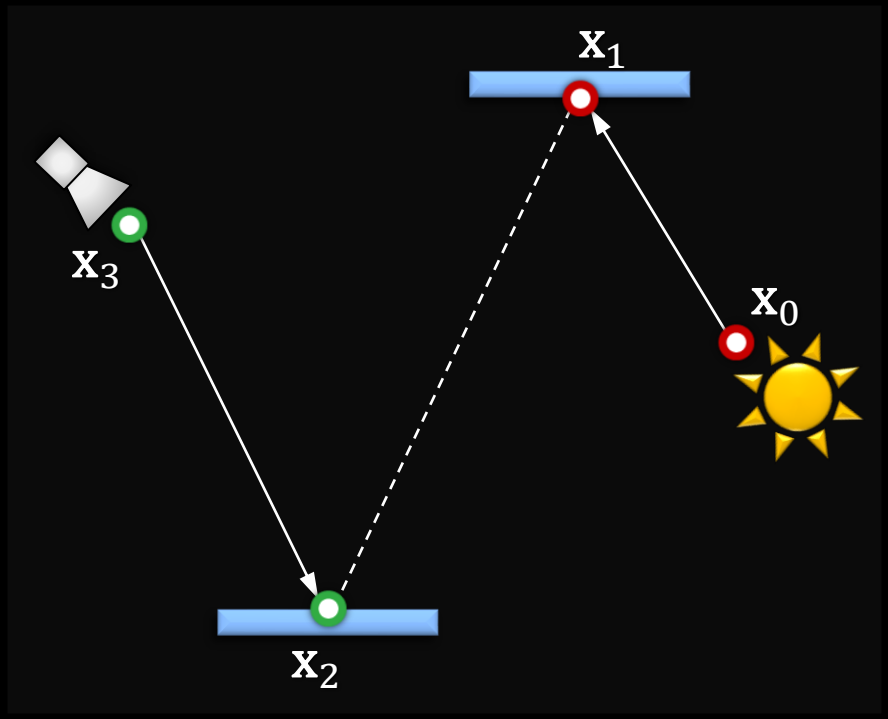


Bidirectional path tracing

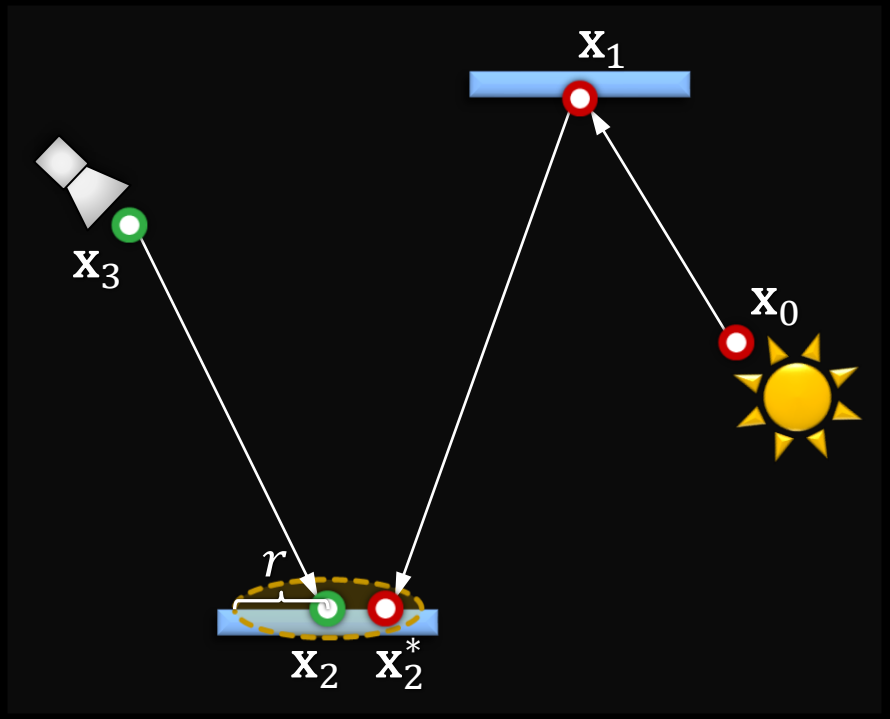
Photon mapping

Bidirectional path sampling

- Light vertex
- Camera vertex



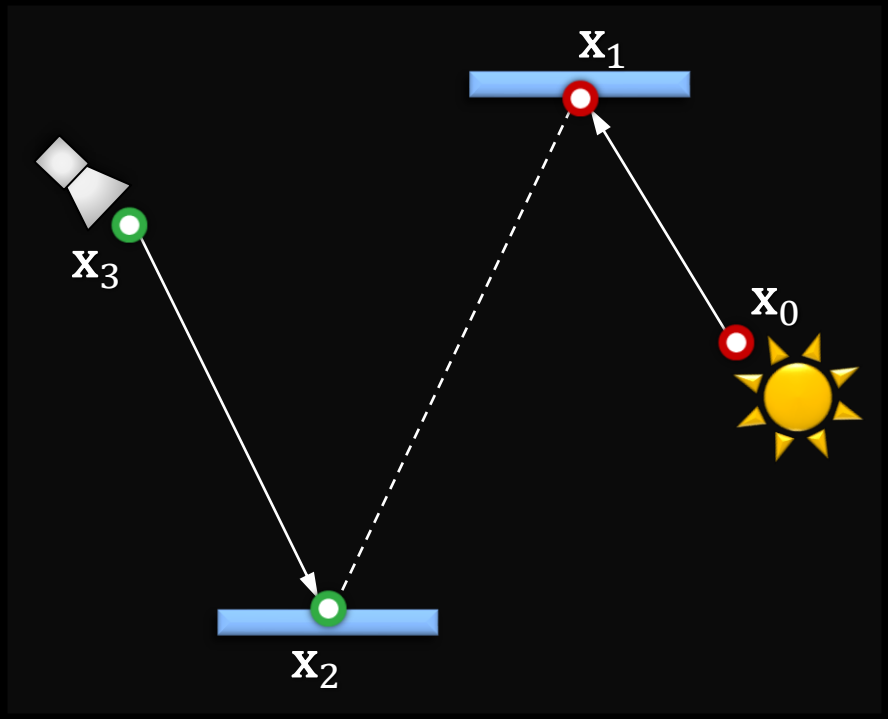
Bidirectional path tracing



Photon mapping

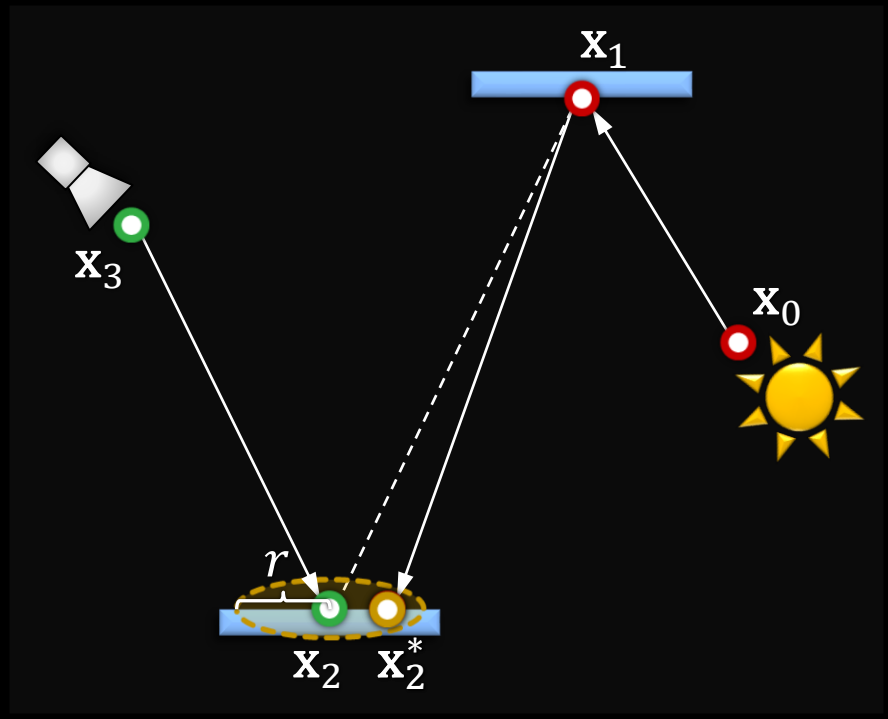
Vertex merging *[Georgiev et al. 2012]*

- Light vertex
- Camera vertex



Vertex connection

$$p_{VC}(\bar{\mathbf{x}}) = p(\mathbf{x}_0)p(\mathbf{x}_0 \to \mathbf{x}_1)\, p(\mathbf{x}_3)p(\mathbf{x}_3 \to \mathbf{x}_2)$$

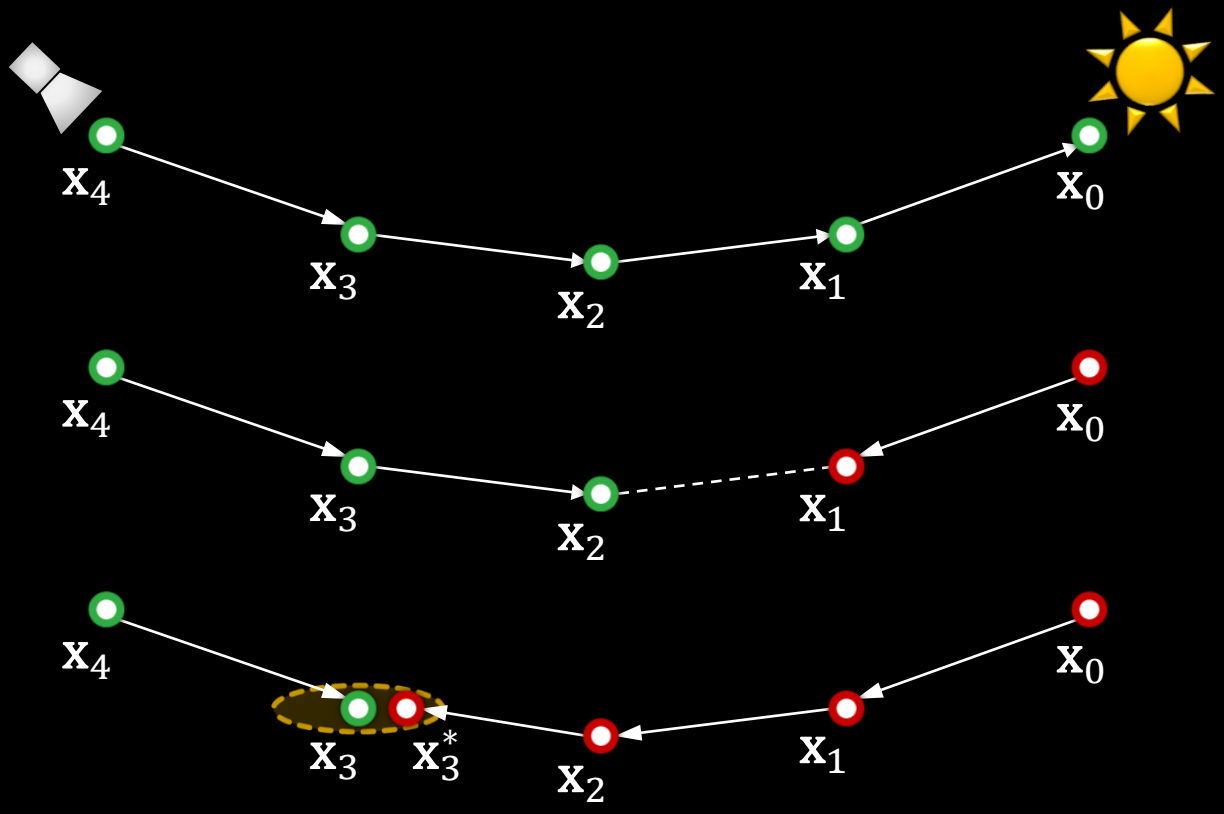


Photon mapping

$$p_{VM}(\bar{\mathbf{x}}) \simeq p(\mathbf{x}_0)p(\mathbf{x}_0 \to \mathbf{x}_1)\, p(\|\mathbf{x}_2 - \mathbf{x}_2^*\|^2 < r)\, p(\mathbf{x}_3)p(\mathbf{x}_3 \to \mathbf{x}_2)$$

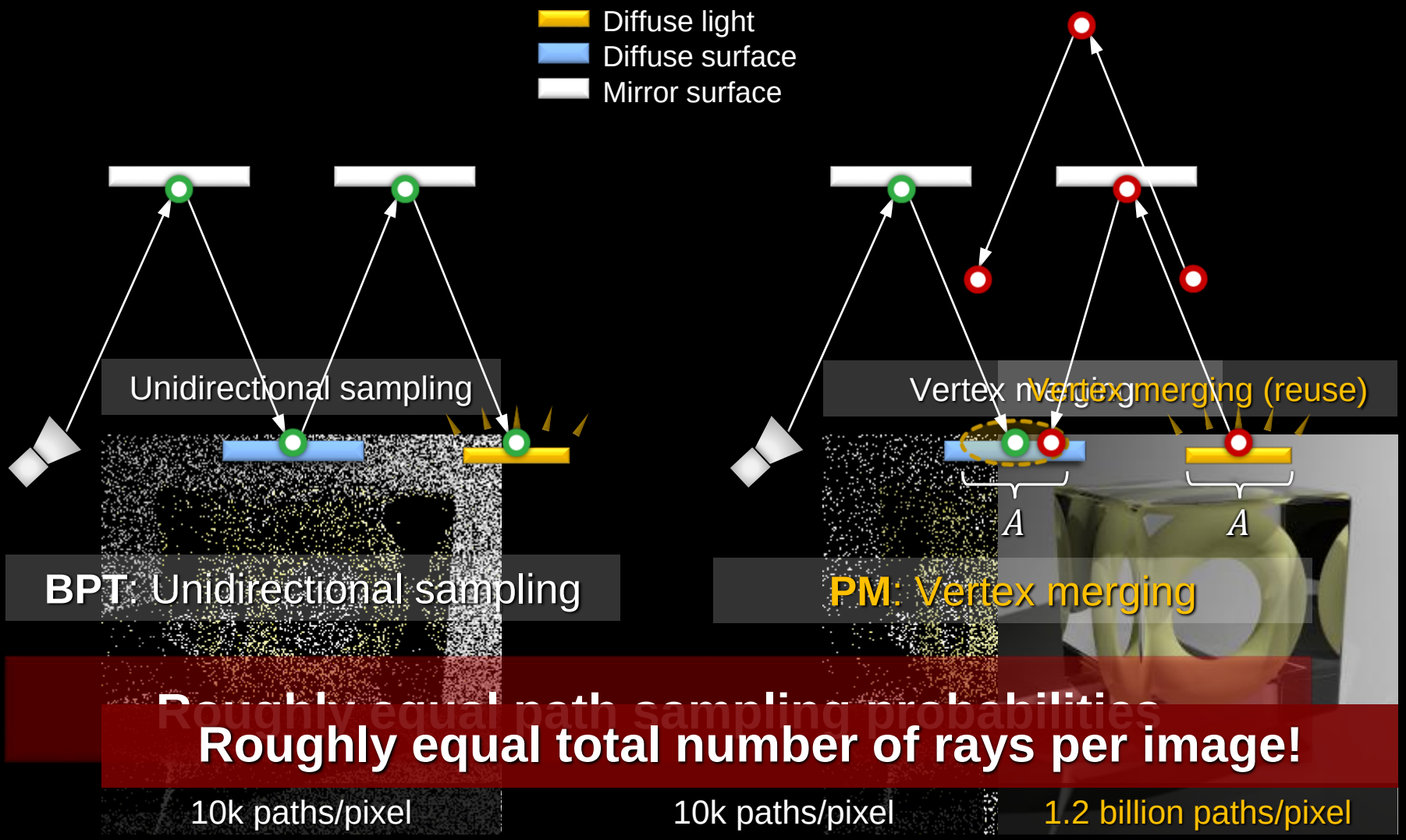
Sampling technique summary

Light vertex
Camera vertex



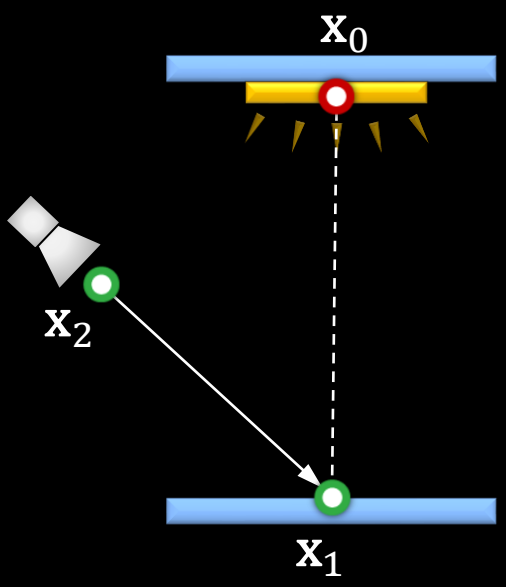
Unidirectional	2 ways
Vertex connection	4 ways
Photon mapping	**5 ways**
Total	**11 ways**

Technique comparison

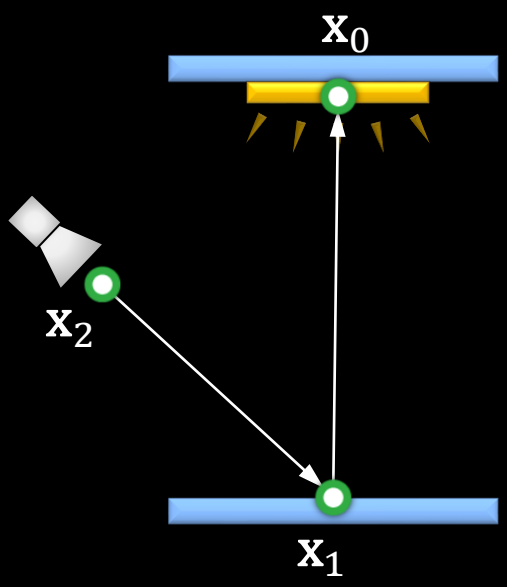


Technique comparison

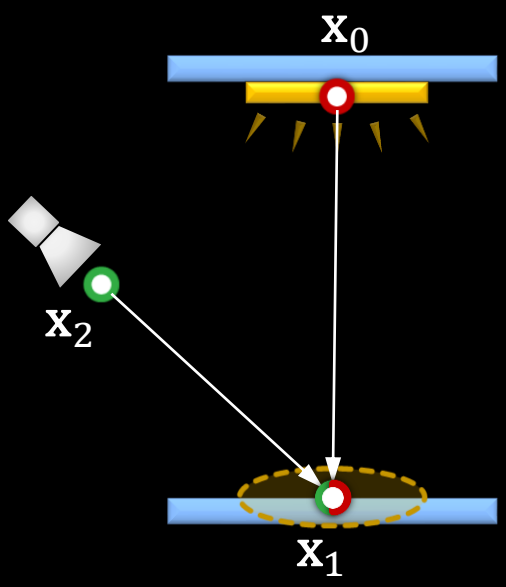
Diffuse light
Diffuse surface



Vertex connection (**VC**)



Unidirectional sampling (**US**)



Vertex merging (**VM**)

Roughly equal sampling densities

$$p_{US} \approx p_{VM} \approx \frac{p_{VC}}{100{,}000}$$

Combined algorithm

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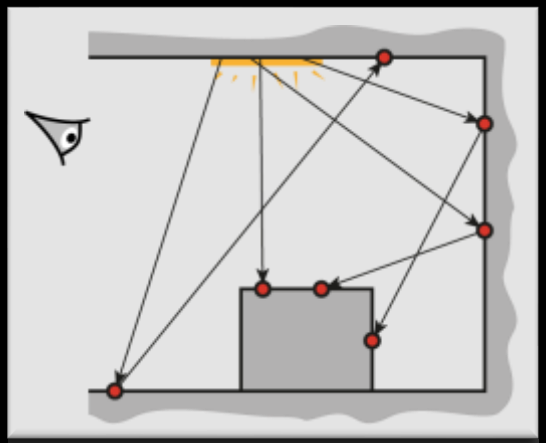
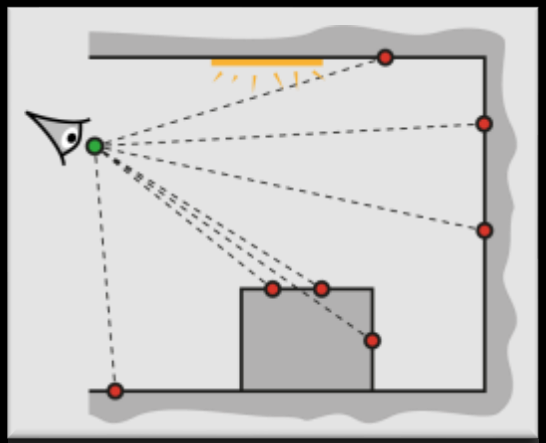
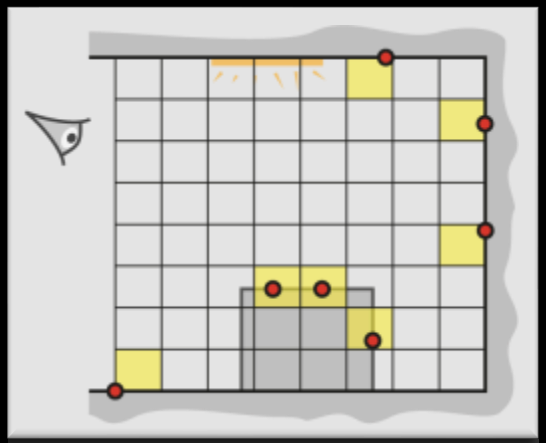
Stage 1: Light sub-path sampling



a) Trace sub-paths

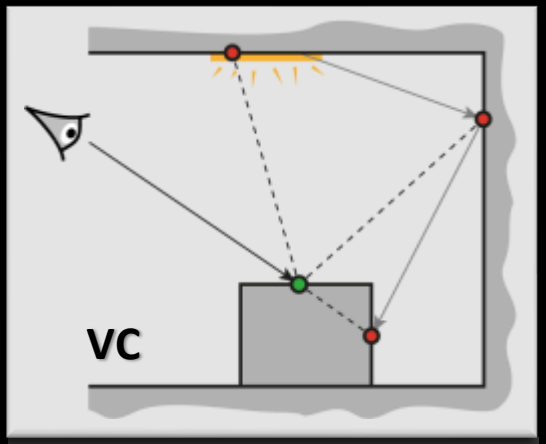


b) Connect to eye

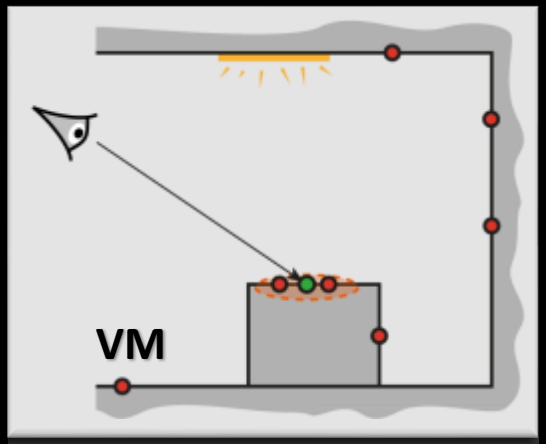


c) Build search structure

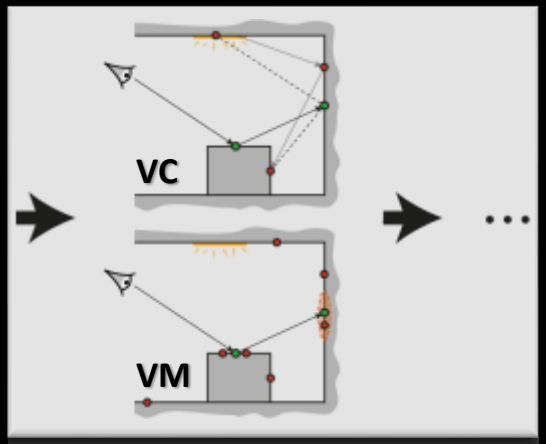
Stage 2: Eye sub-path sampling



a) Vertex connection



b) Vertex merging



c) Continue sub-path

Bidirectional path tracing (30 min)

Stochastic progressive photon mapping (30 min)


Combined algorithm (30 min)

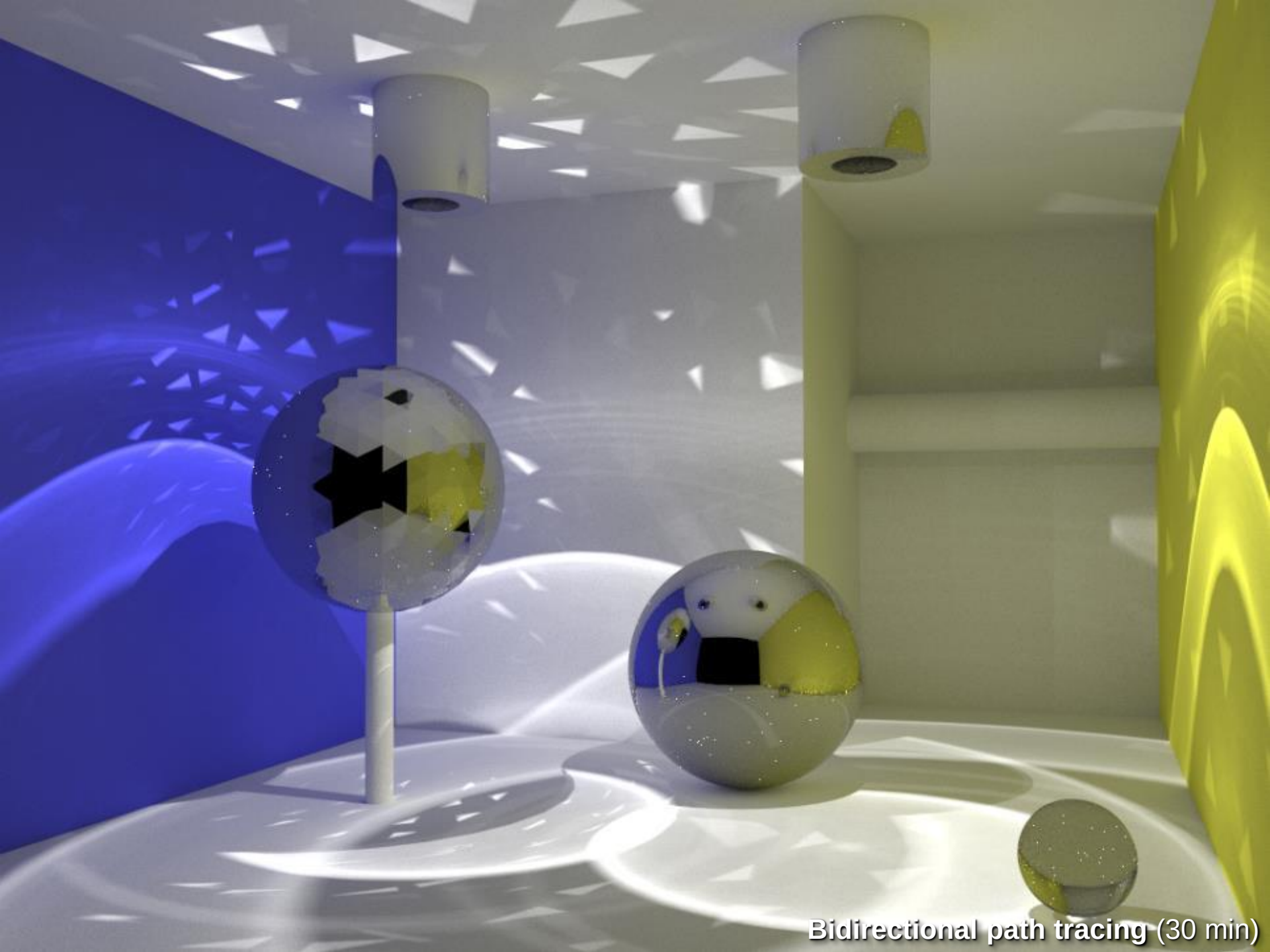

PM
BPT
Relative technique contributions

Bidirectional path tracing (30 min)

Stochastic progressive photon mapping (30 min)

Combined algorithm (30 min)


PM
BPT
Relative technique contributions



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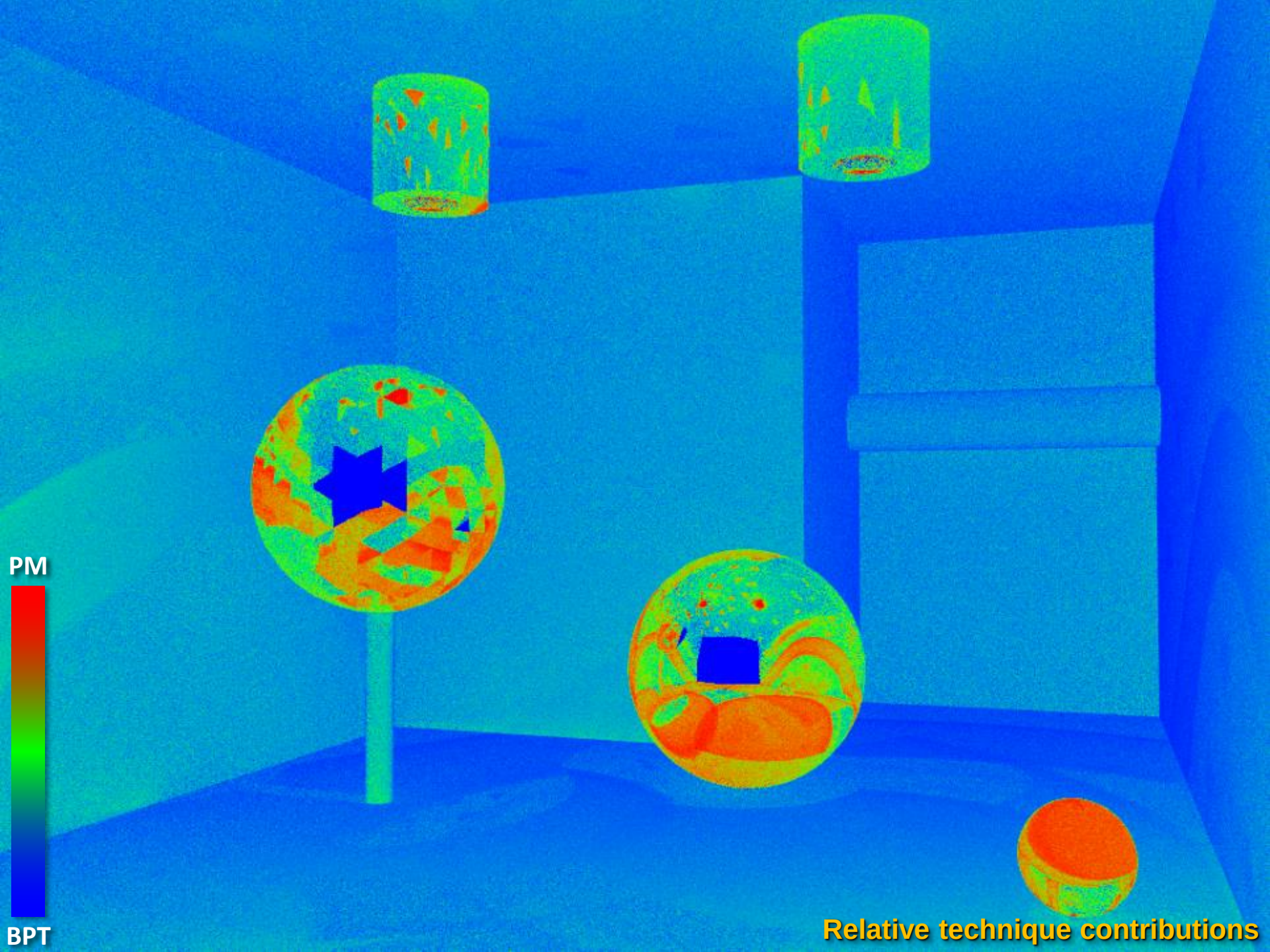

PM
BPT
Relative technique contributions

Good practices

- No merging for
  - Direct illumination
  - Directly visible caustics
- Memory efficiency
  - ☹ Heavyweight light vertices
    - Hit point data, BSDF parameters, …
  - ☺ Reorganize computations
    - Classic BPT *(one light & eye path at a time)*
    - Store compact photons
    - Merge at next iteration

Good practices

- Merging radius
  - Compute from pixel footprint (ray differentials)
  - Don’t reduce (or use $\alpha = 0.75$)
- MIS weights: efficient accumulation during sub-path sampling

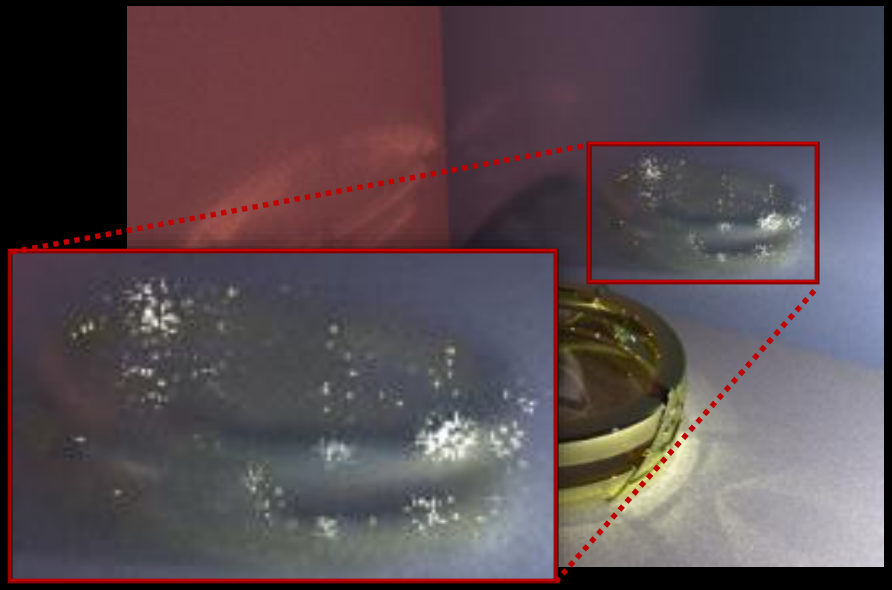
Additional material

- **A path space extension for robust light transport simulation**
  [Hachisuka et al. 2012]
  - Paper, supplemental analysis *[http://cs.au.dk/~toshiya/]*

- **Light transport simulation with vertex connection & merging**
  [Georgiev et al. 2012]
  - Paper, tech. report, image comparisons *[http://www.iliyan.com]*

Wrap up

- Two approaches
  - Same result
- Error convergence
  - BPT: $O(N^{-0.5})$
  - PPM: $O(N^{-0.33})$
  - Combined: $O(N^{-0.5})$
- Remaining challenges



Try it out

SmallVCM

http://www.smallvcm.com

http://www.corona-renderer.com