Computer Graphics Seminar

Real-time Rendering of Refractive Objects in Participating Media

Michael Pfeuti

Universität Bern

Contents

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Basis

ACM SIGGRAPH 2008 Paper

Interactive Relighting
Of
Dynamic Refractive Objects

by

Xin Sun, Kun Zhou, Eric Stollnitz, Jiaoying Shi, and Baining Guo

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Goal

- Demo
- **Our goal**:
  - Reimplementation
  - Acceleration of pipeline

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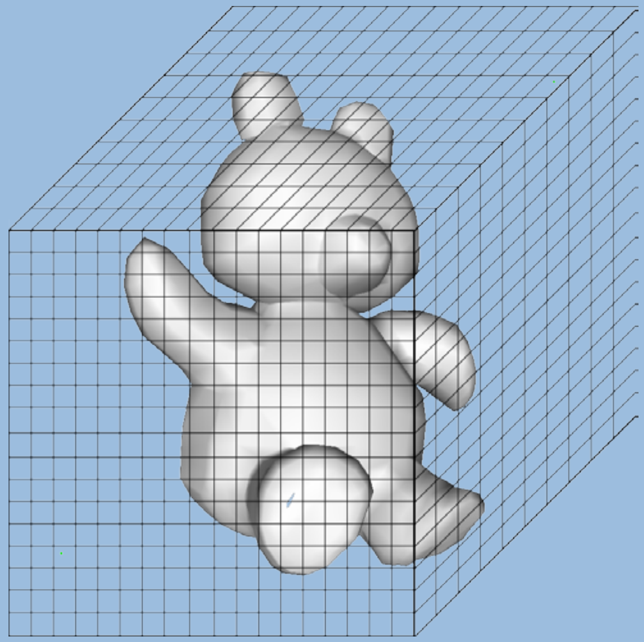
Contents

Reference Pipeline

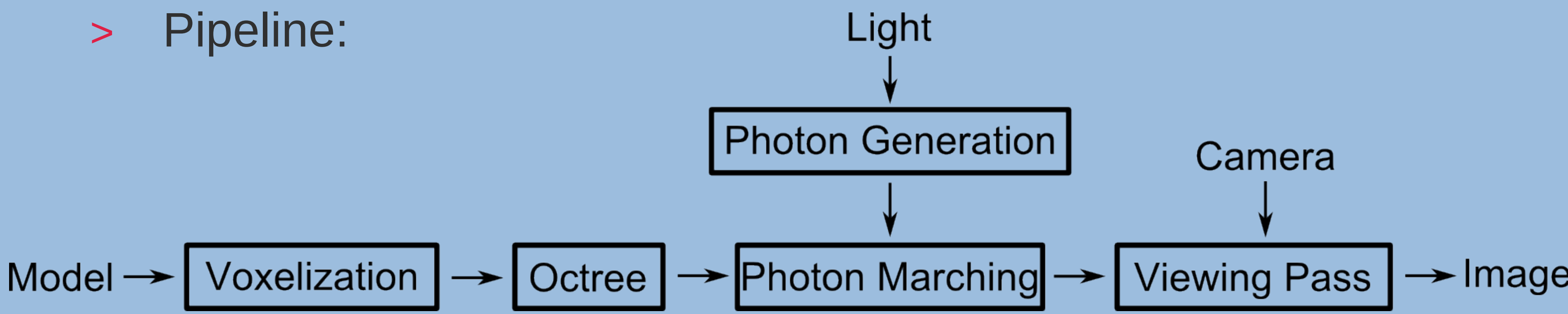
- Main idea:
  - Photon Marching
  - Store data in 3D arrays (voxel grids)
  - GPU implementation
- Data:
  - Scene (refraction indices/model, participating medium coefficients)
  - Illumination (radiance)
- Voxel grids cover participating media.



Voxel Grid

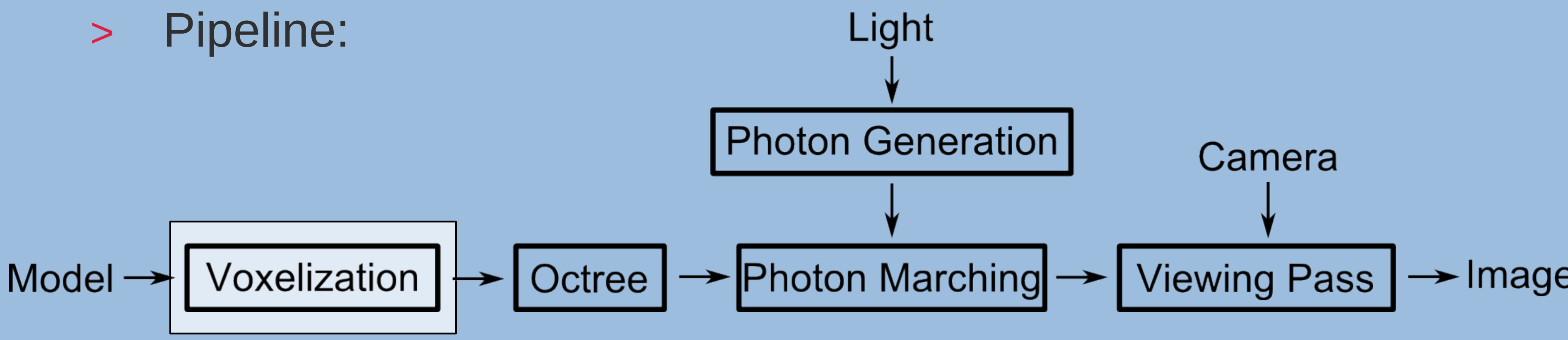
Reference Rendering Pipeline Passes

> Pipeline:



Reference Rendering Pipeline Passes

> Pipeline:



> Voxelization:

— Build voxel grids

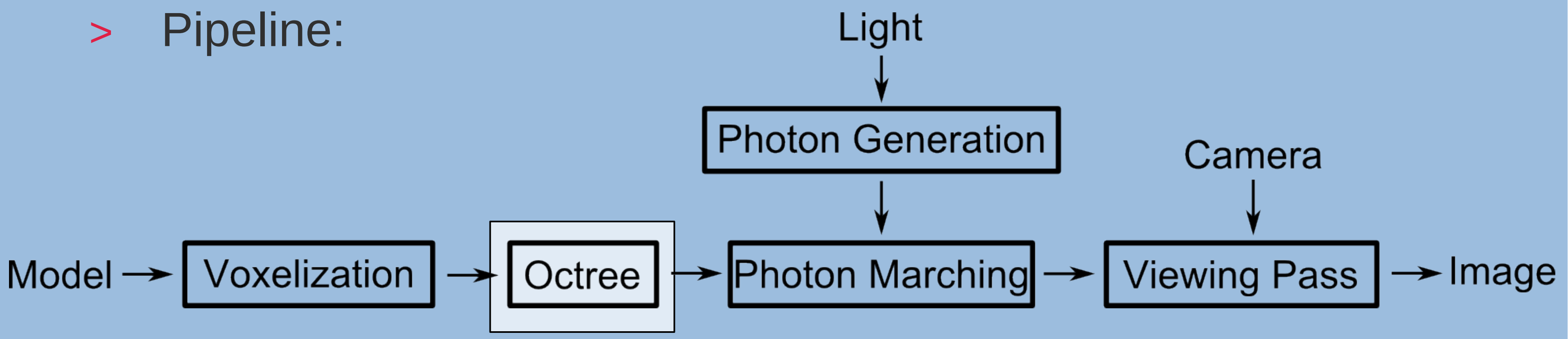
— Model represented through refraction indices

Model

Voxel Grid

Reference Rendering Pipeline Passes

> Pipeline:



> Octree:
  — Acceleration structure for photon marching

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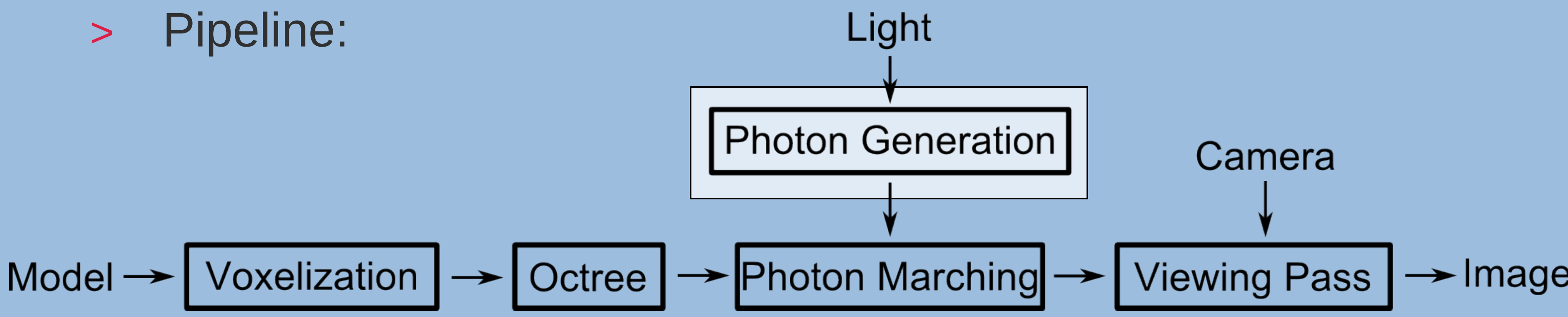
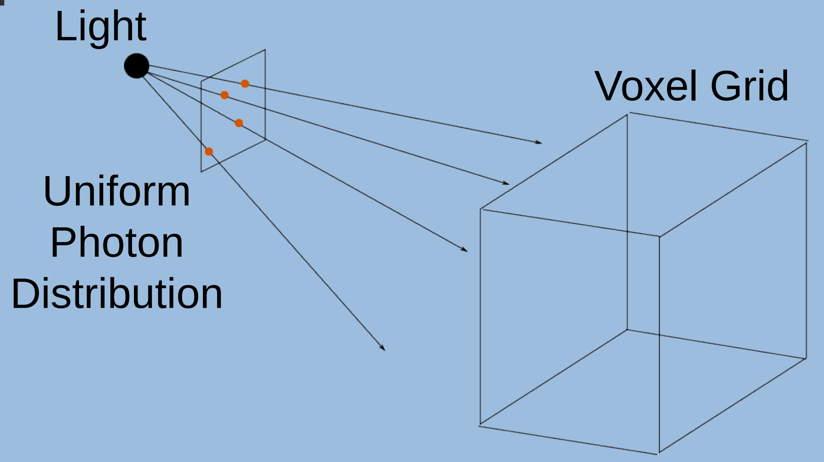
Reference Rendering Pipeline Passes

> Pipeline:

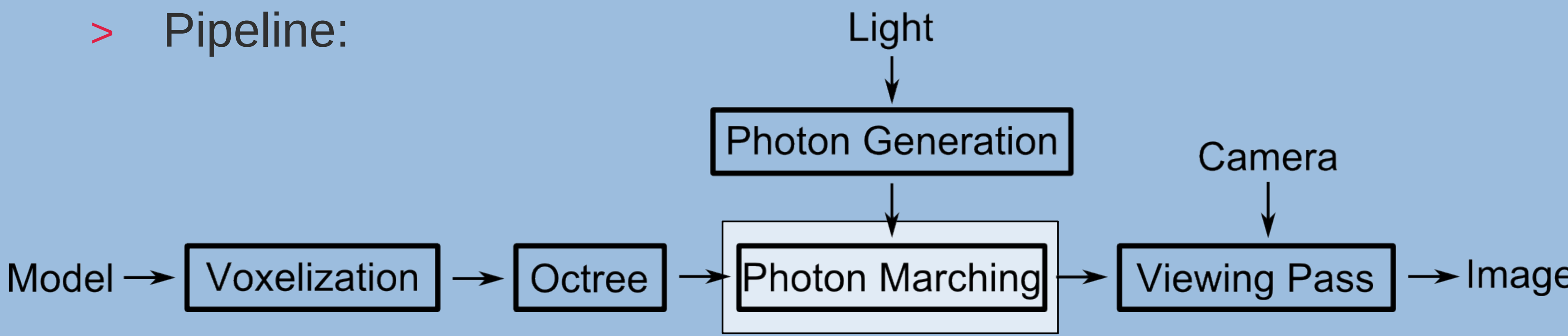


> Photon Generation:



Reference Rendering Pipeline Passes

> Pipeline:

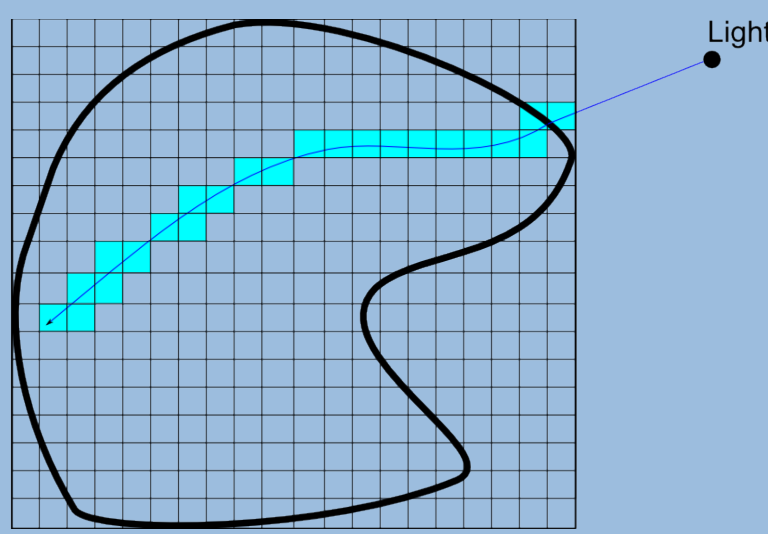


> Photon Marching:

— Move photons stepwise

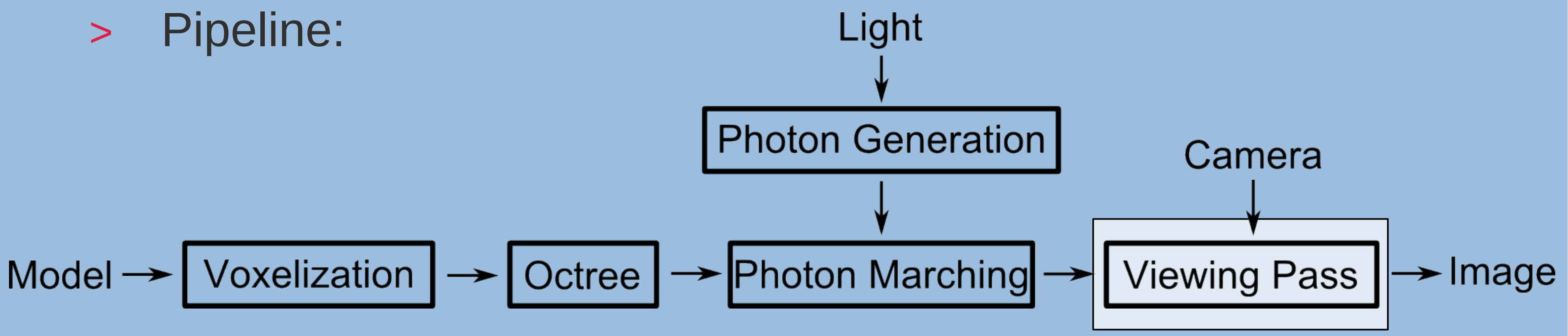
— Thread for each photon

⟶ atomic write

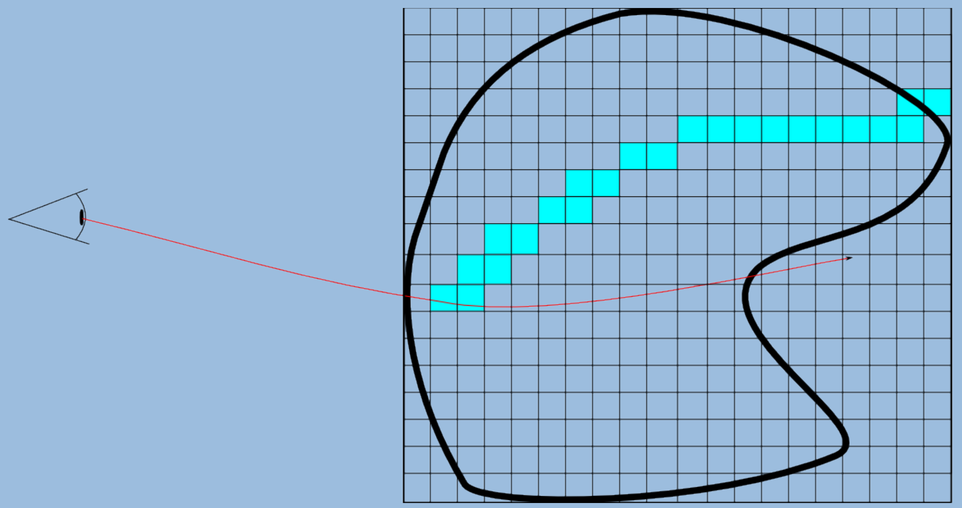


Reference Rendering Pipeline Passes

> Pipeline:



> Viewing Pass:
- — Ray marching
- — Radiance lookup after each step



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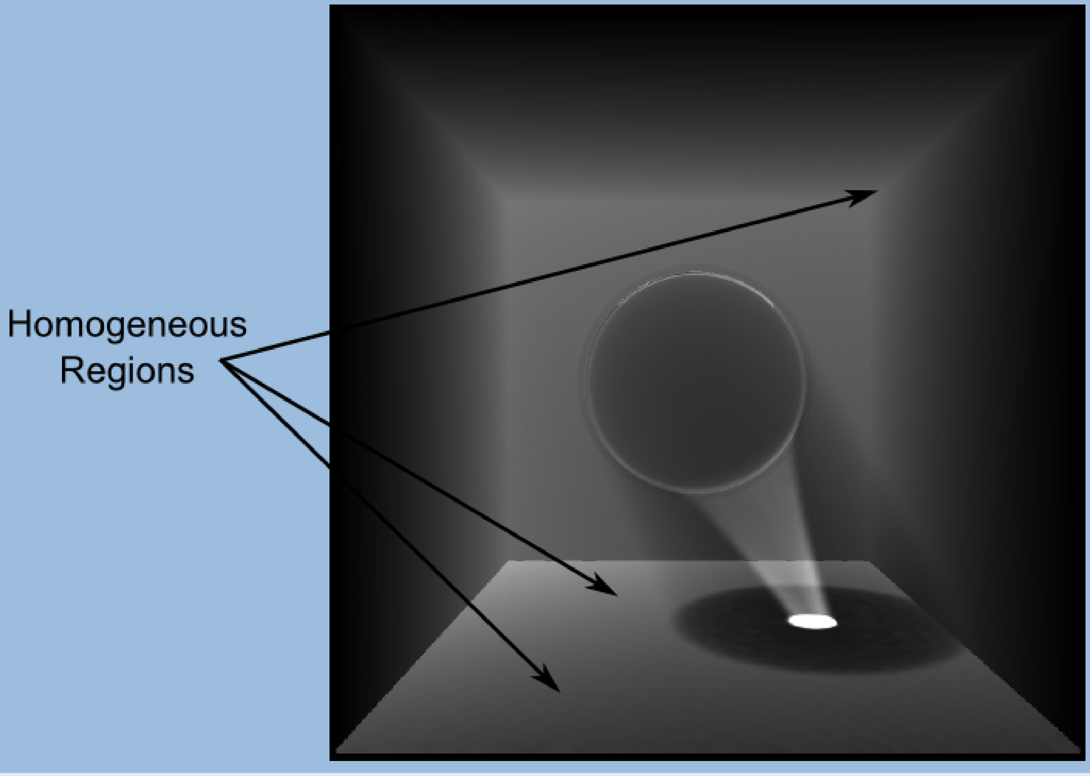
Contents

Adaptive Rendering Pipeline

- Main idea: Reduce photons to accelerate pipeline.
- Shoot less photons through homogeneous regions.



Adaptive Rendering Pipeline

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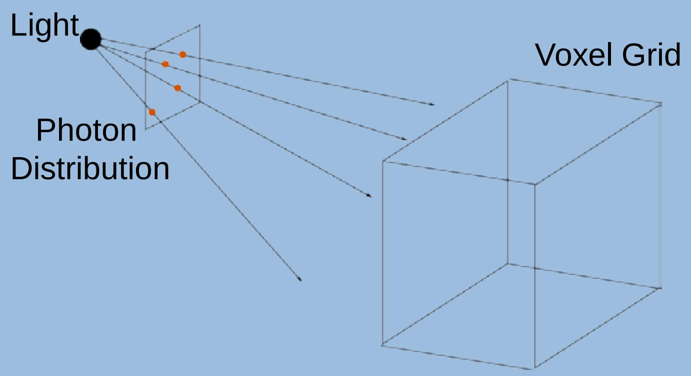
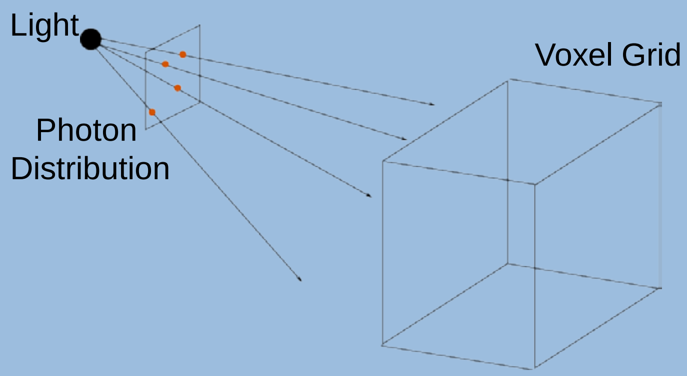
> This means distributing the photons **non-uniformly**.

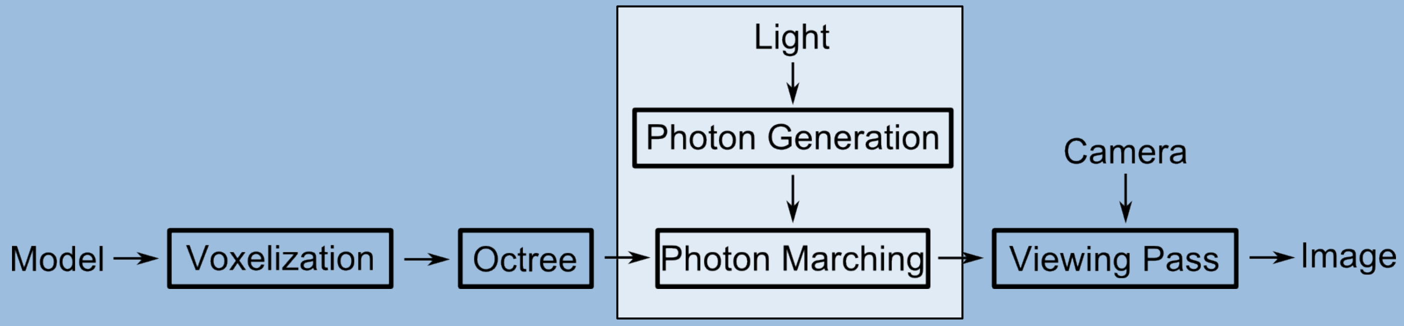


Adaptive Rendering Pipeline

> This means distributing the photons **non-uniformly**.

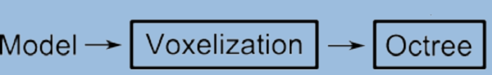


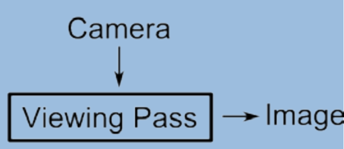
> We substitute the Photon Generation and Tracing pass.



Adaptive Rendering Pipeline

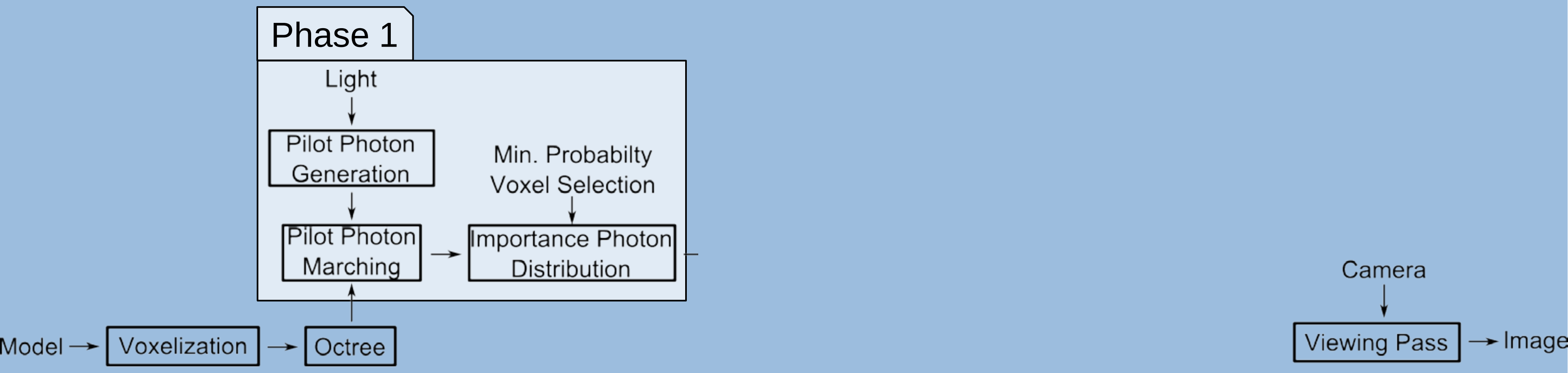
> Adaptive photon tracing





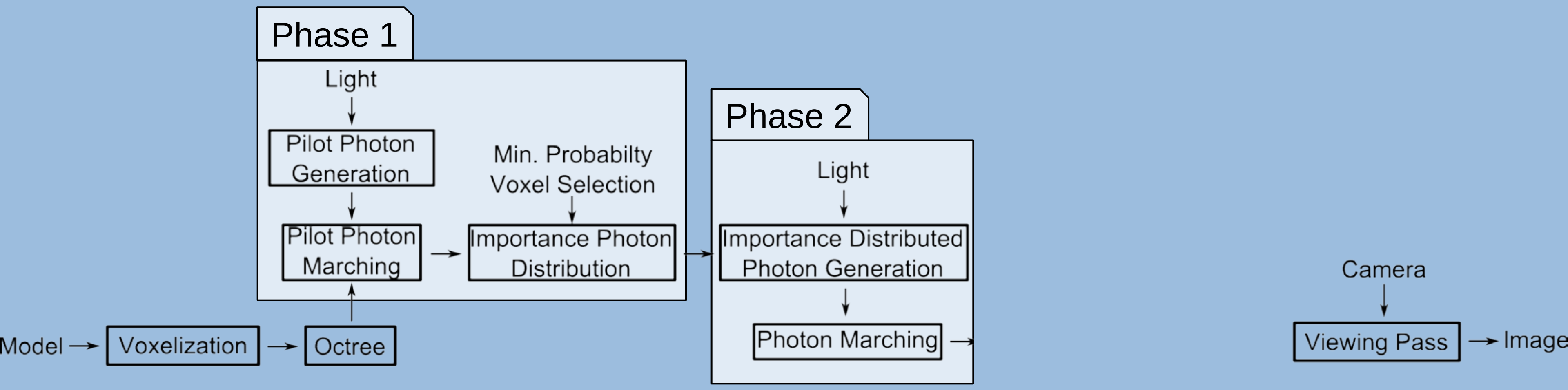
Adaptive Rendering Pipeline

> Adaptive photon tracing
  — Phase 1: Determine distribution



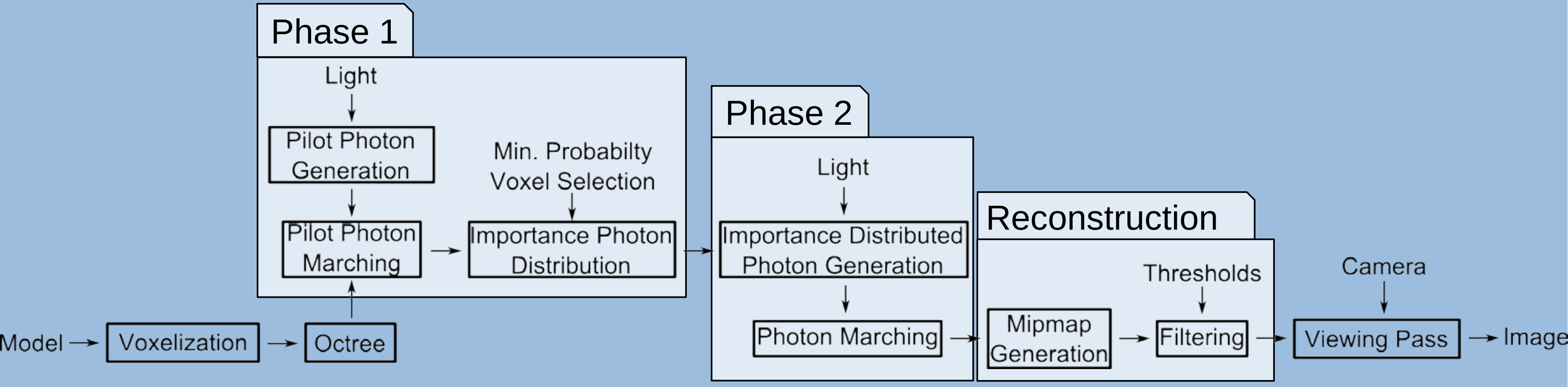
Adaptive Rendering Pipeline

> Adaptive photon tracing
  - Phase 1: Determine distribution
  - Phase 2: Compute illumination in voxel grid



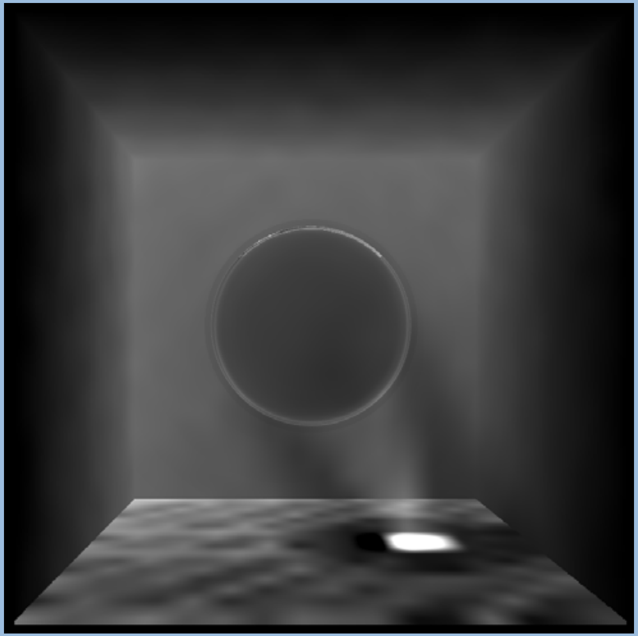
Adaptive Rendering Pipeline

> Adaptive photon tracing
  - Phase 1: Determine distribution
  - Phase 2: Compute illumination in voxel grid
  - Reconstruction: Compute a smooth radiance distribution



Phase 1

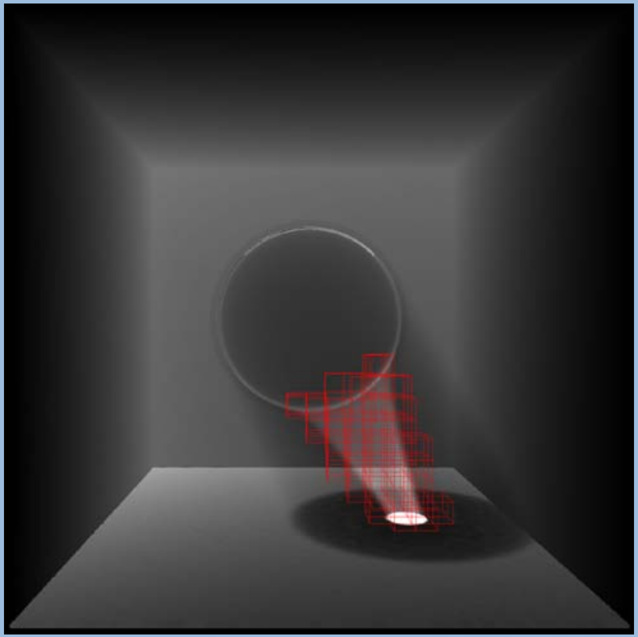
- Find in-/homogeneous regions.
- Shoot few “pilot” photons (~4000 photons)
- Select voxels for tight sampling



Pilot photon result

Phase 1

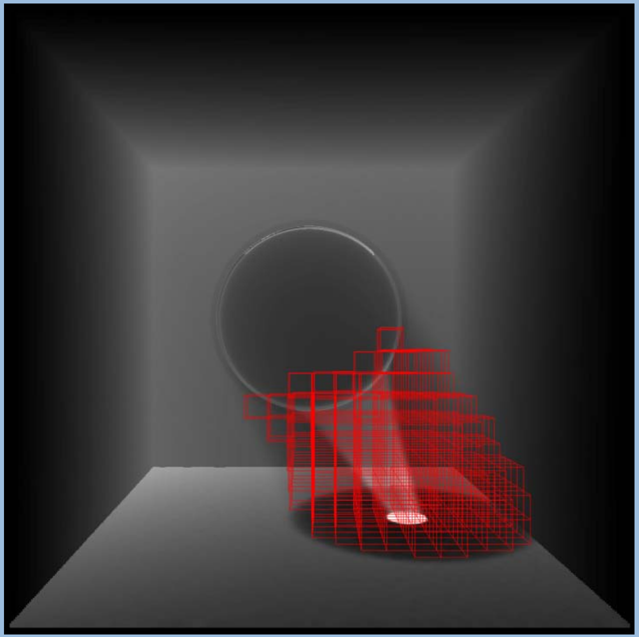
- Find in-/homogeneous regions.
- Shoot few “pilot” photons (~4000 photons)
- Select voxels for tight sampling
  - Gradient threshold for selecting voxel with larger gradients



Selection in reference image

Phase 1

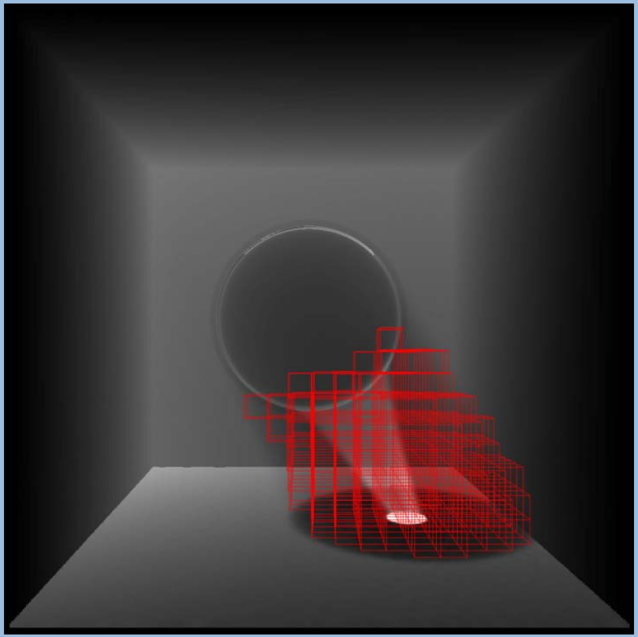
- Find in-/homogeneous regions.
- Shoot few “pilot” photons (~4000 photons)
- Select voxels for tight sampling
  - Gradient threshold for selecting voxel with larger gradients
  - Luminance threshold for selecting voxels in shadow



Selection in reference image

Phase 1

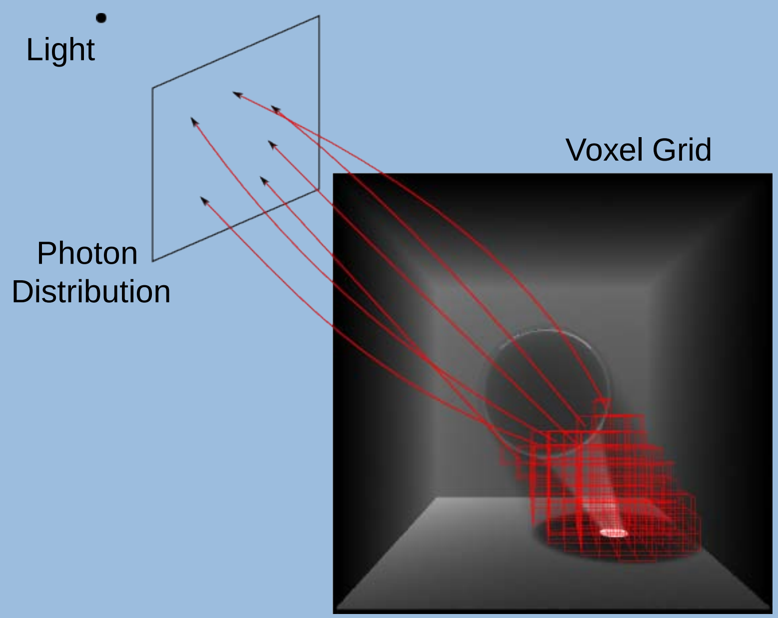
- Find in-/homogeneous regions.
- Shoot few “pilot” photons (~4000 photons)
- Select voxels for tight sampling
  - Gradient threshold for selecting voxel with larger gradients
  - Luminance threshold for selecting voxels in shadow
- Pilot Photon Marching:
  - Store **origin data** per voxel



Selection in reference image

Phase 1 (cont.)

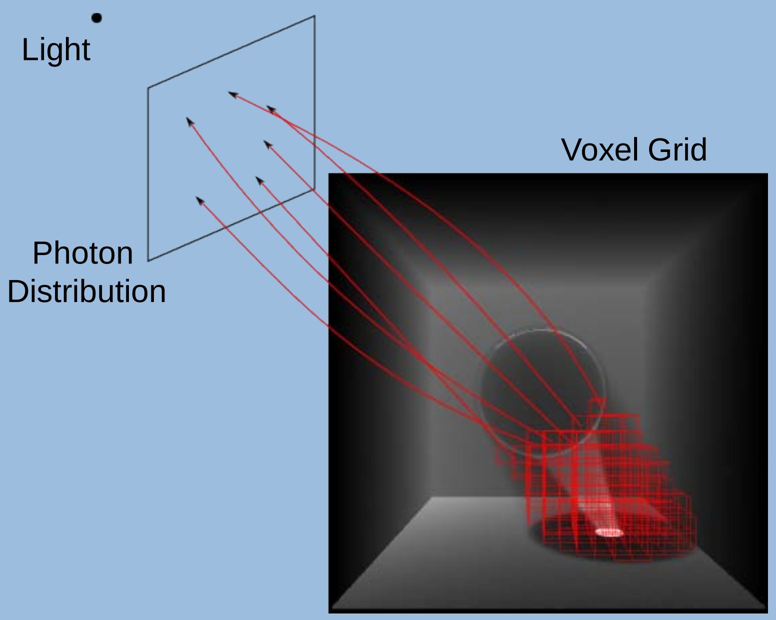
> Compute probability density function for photon distribution.



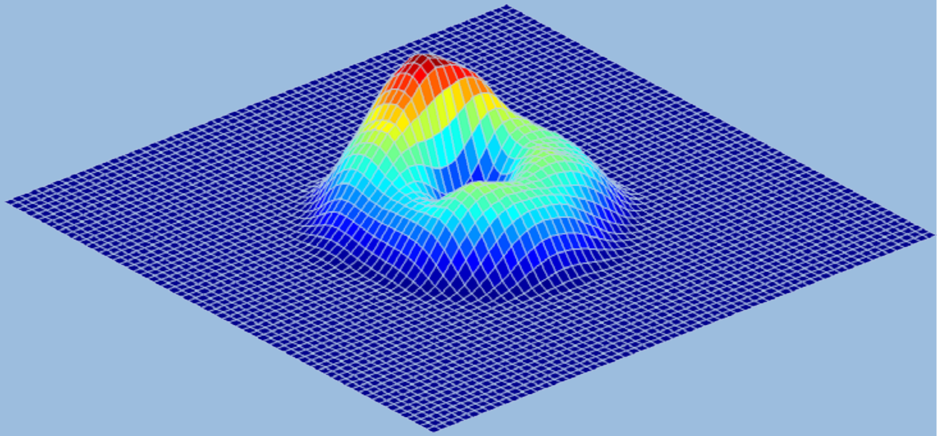
Origin Data for each Voxel

Phase 1 (cont.)

> Compute probability density function for photon distribution.



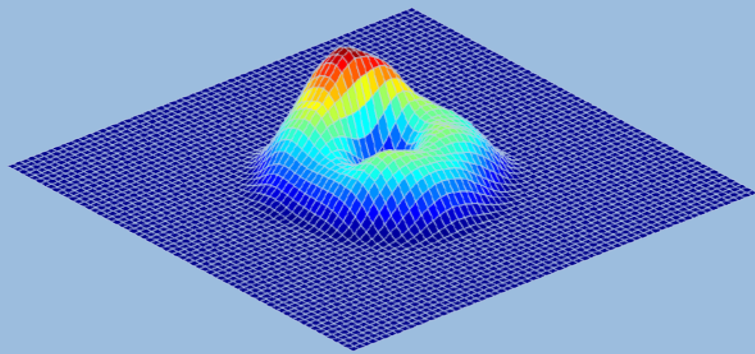
Origin Data for each Voxel



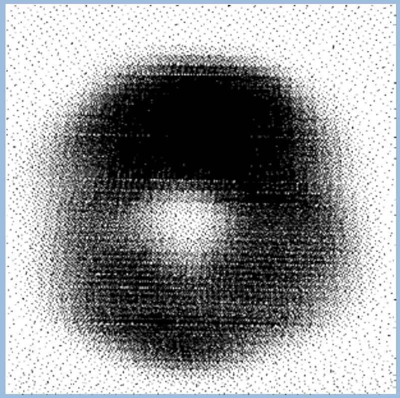
2D PDF
for photon sampling

Phase 2

- Photon generation according to the photon distribution from Phase 1



2D PDF

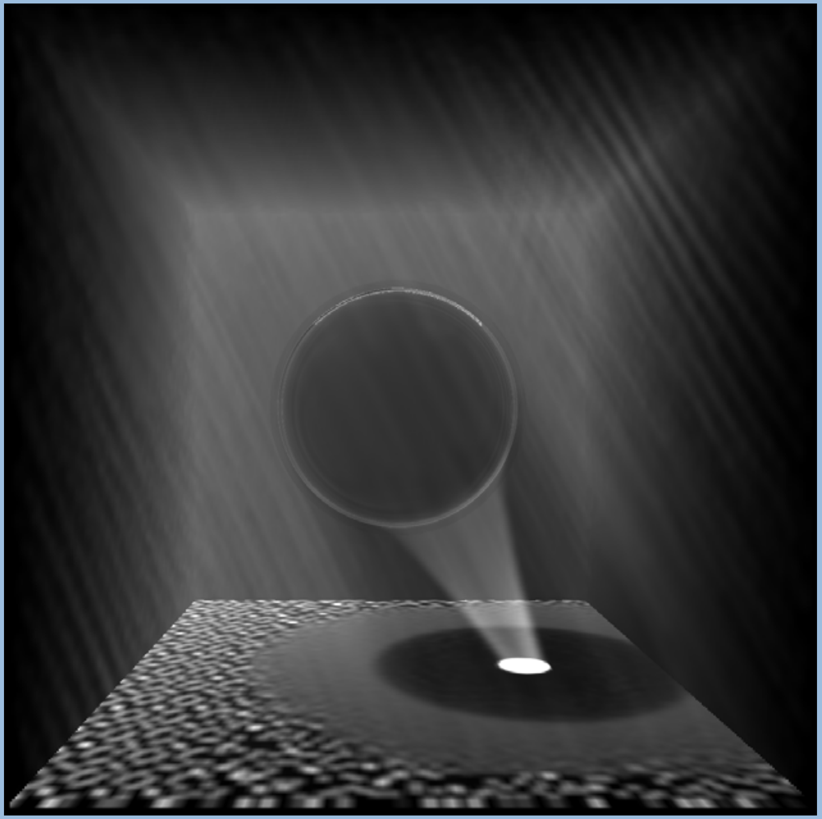


Distributed Photons

- Photon marching as in reference except:
  - Collect photon count per voxel
  - Collect average photon weight per voxel (from Monte-Carlo Integration)

Reconstruction

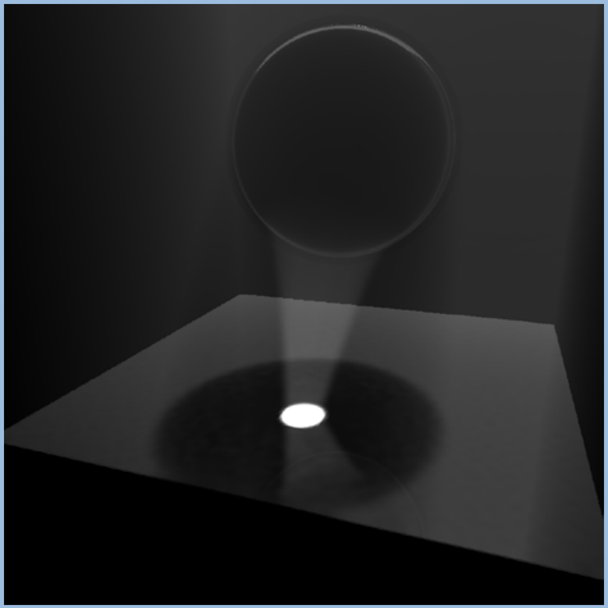
- Radiance voxel grid needs filtering.
- Tightly sampled regions
  - Hardly any filtering necessary
- Sparsely sampled regions
  - Much filtering needed

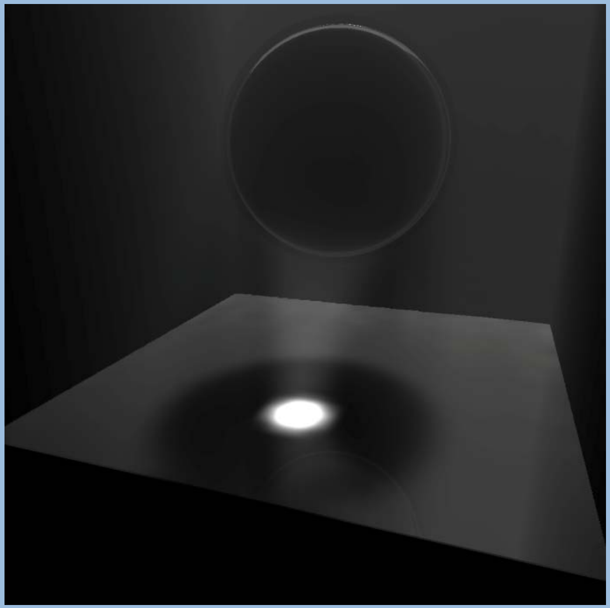


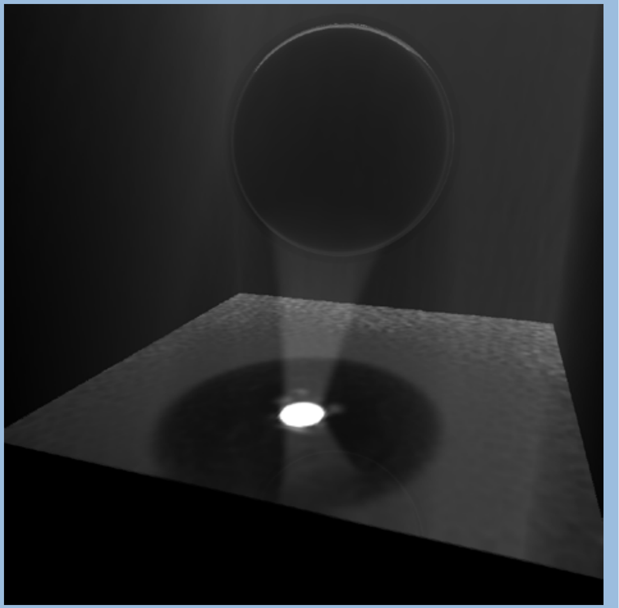
Noise in Voxel Grid

Reconstruction

> Simple approaches do not work (constant filter radius, k-NN).


Reference


Constant Radius


1-NN

Advanced Filtering

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> We built a new filter:
  — Based on average photon weight
  — Center-surround filter

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Advanced Filtering

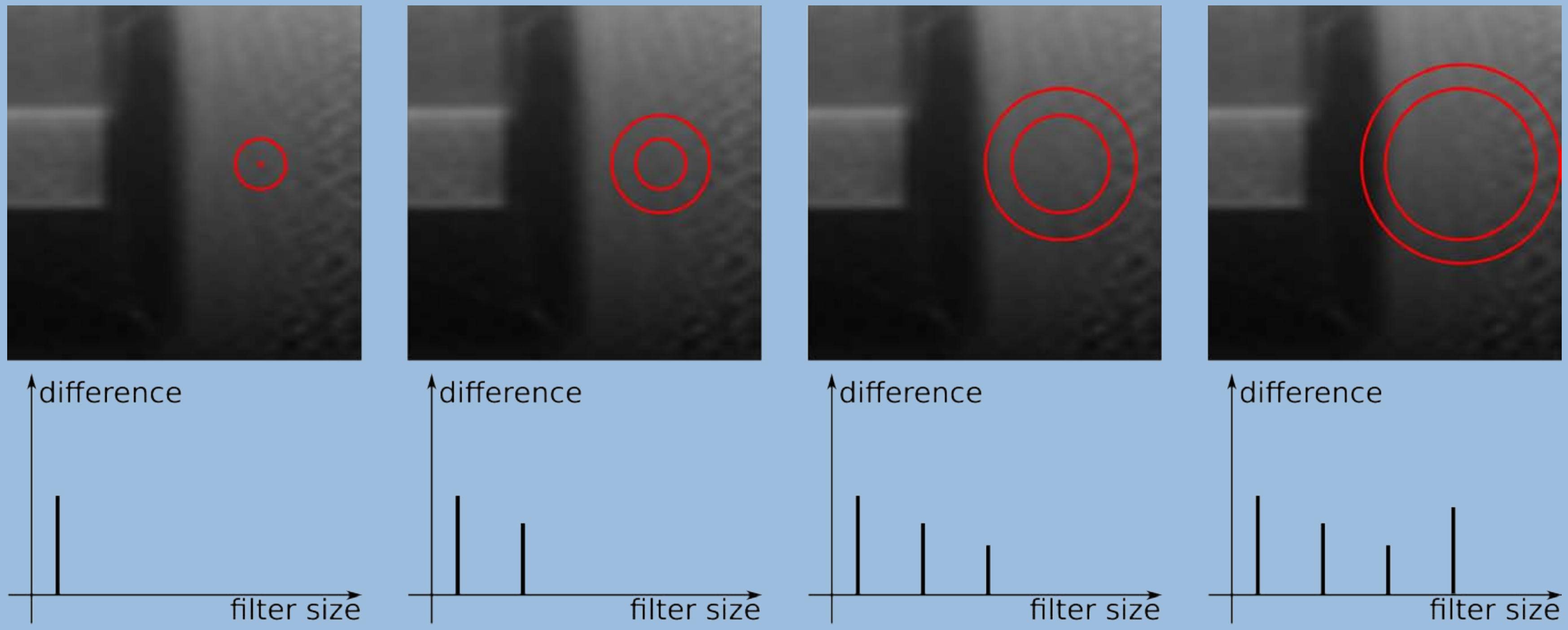
- We built a new filter:
  - Based on average photon weight
  - Center-surround filter

- Photon Weight Filter:
  - When photon weight
    - Large $\longrightarrow$ Sparse sampled region $\longrightarrow$ large filter radius
    - Small $\longrightarrow$ Tight sampled region $\longrightarrow$ small filter radius
  - Linear scaling of weight determines filter radius

$$radius = \alpha \cdot photon\_weight$$

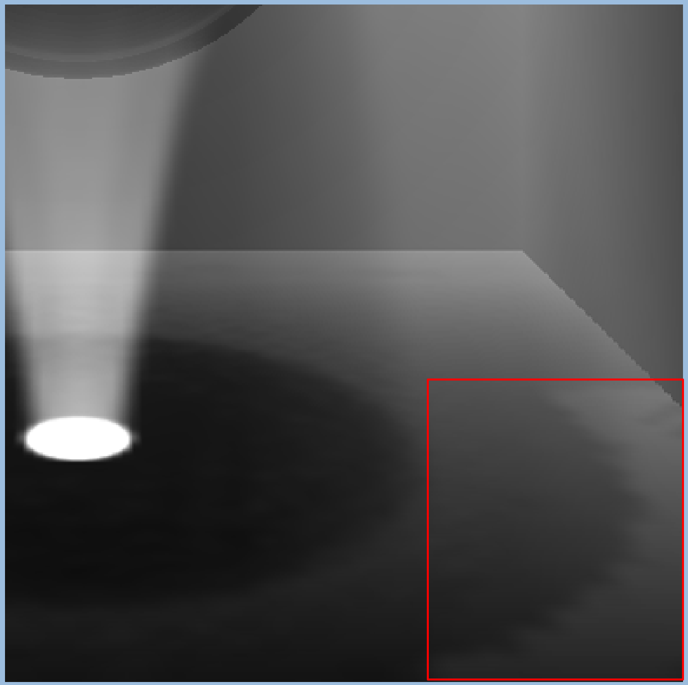
Center-Surround Filter

- Compares two filter radii
  - Increase radius as long as difference decreases
  - Stop at increase

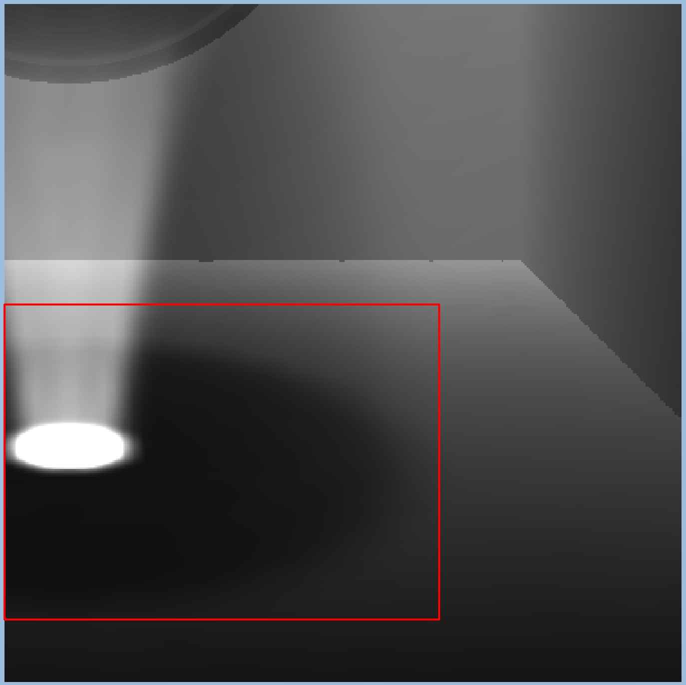


Combination

> Neither on its own is sufficient
  - Photon-Weight: Too large radii in sparse sampled regions
  - Center-Surround: Too large radii in tight sampled regions



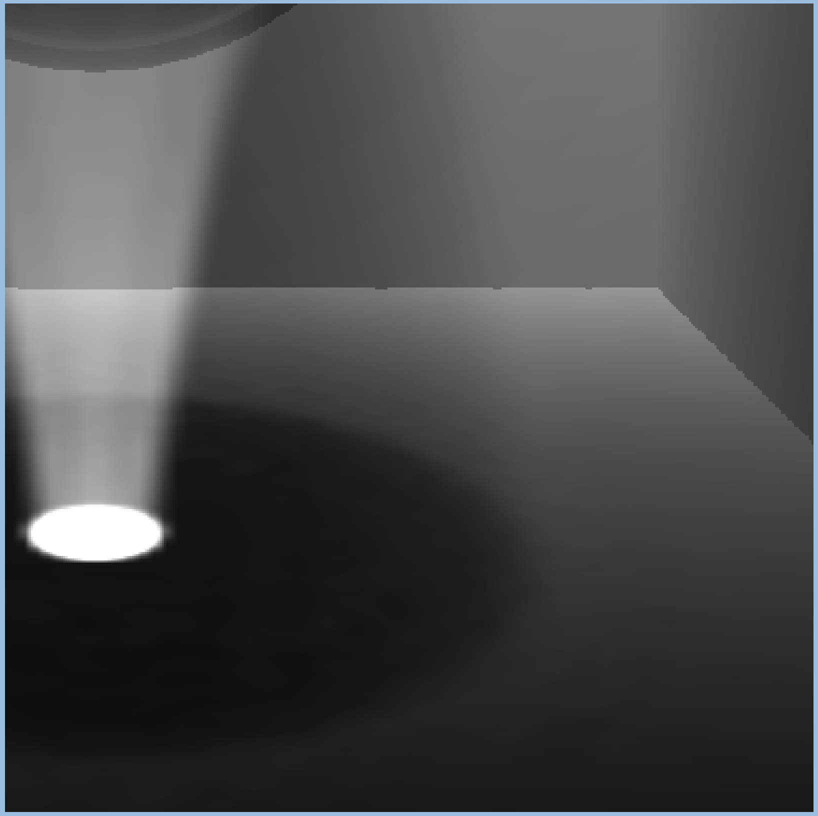
Photon-Weight



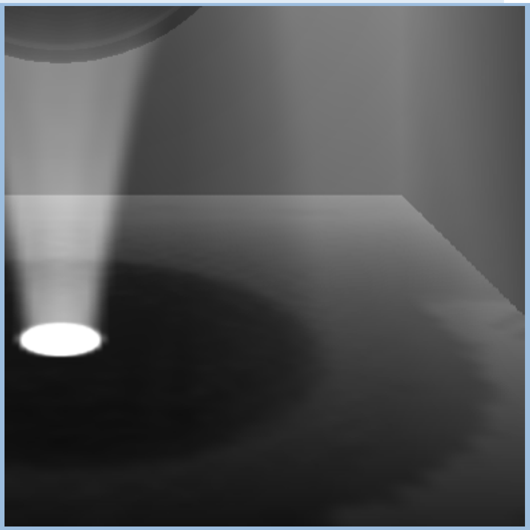
Center-Surround

Combination

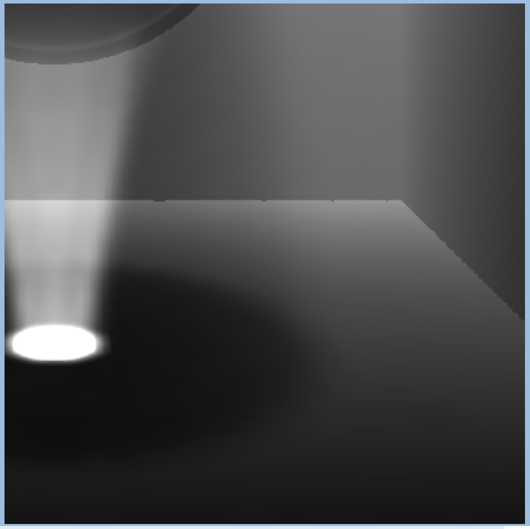
- Take minimum of the two.



Combination



Photon-Weight



Center-Surround

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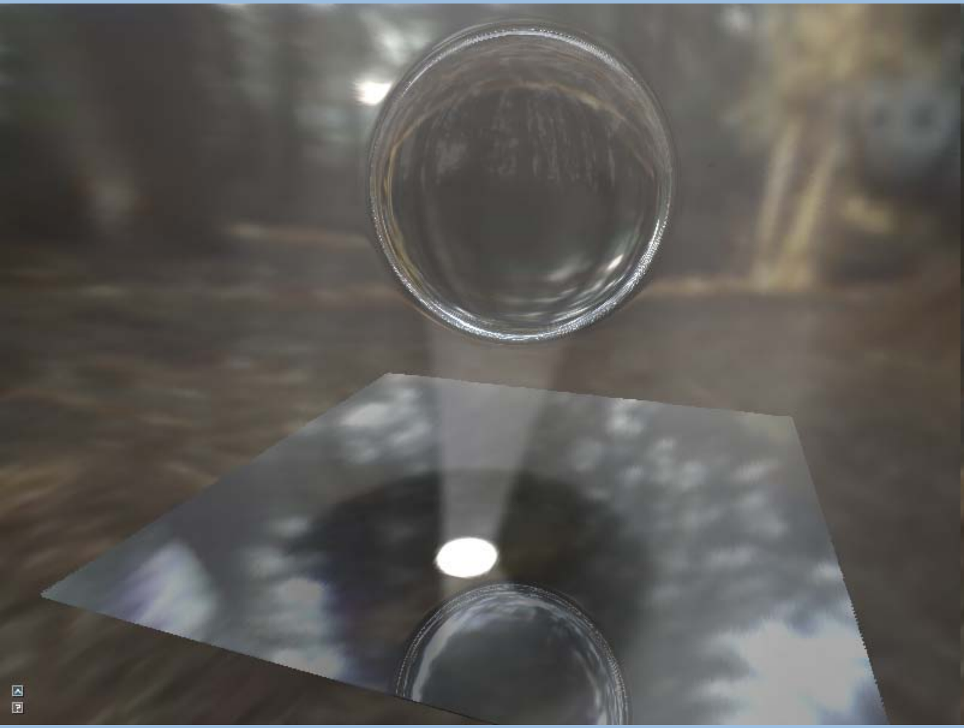
Evaluation

> Hardware:
  — nVdidia GTX 260, 896MB RAM

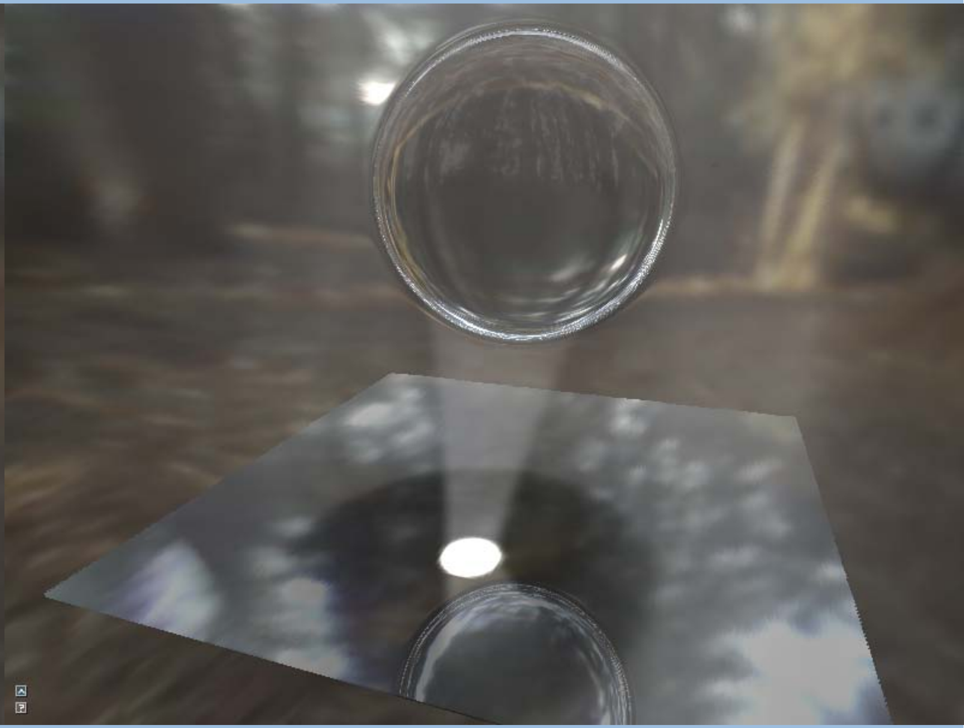
> General Settings:
  — 128x128x128 voxel grids
  — 800x600 images

> Adaptive Pipeline Setting:
  — ~4000 pilot photons

Sphere Scene

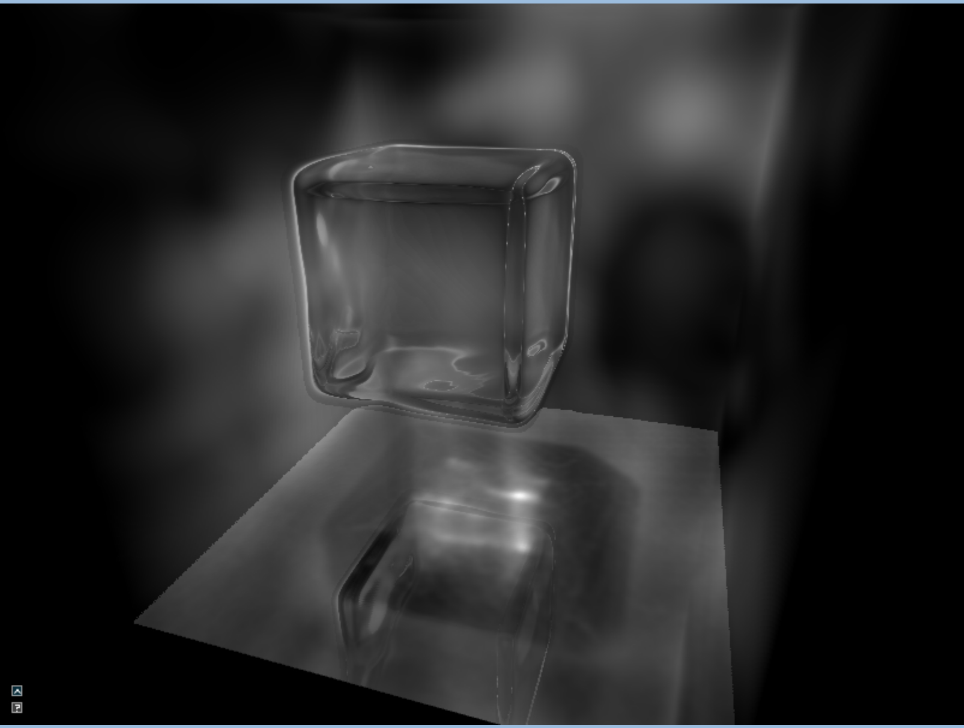


Reference
~122’000 photons
~2.6 FPS

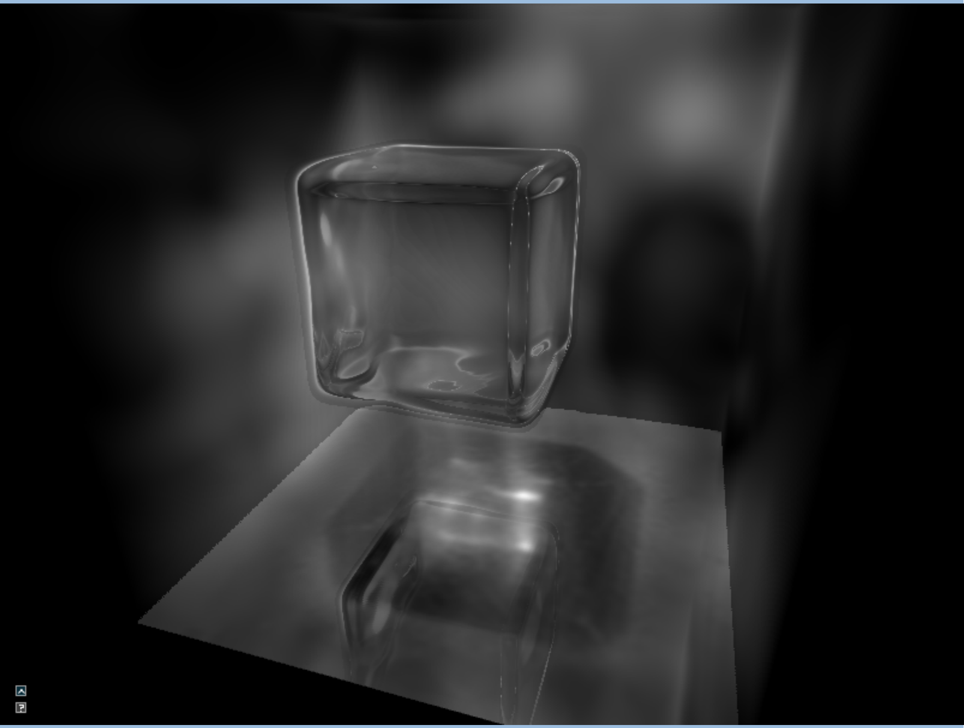


Adaptive
~50’000 photons
~2.5 FPS

Cube Scene



Reference
~125’000 photons
~2.2 FPS



Adaptive
~46’000 photons
~2.2 FPS

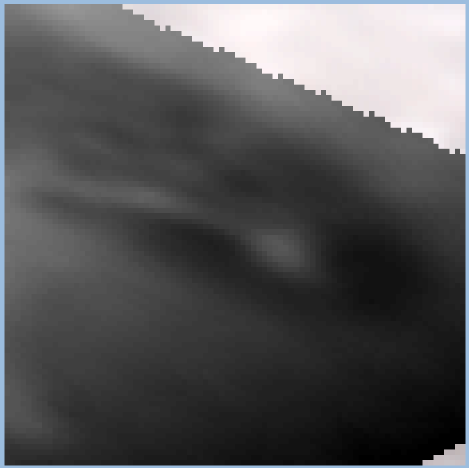
Armadillo Scene

Reference
~106’000 photons
~2.1 FPS

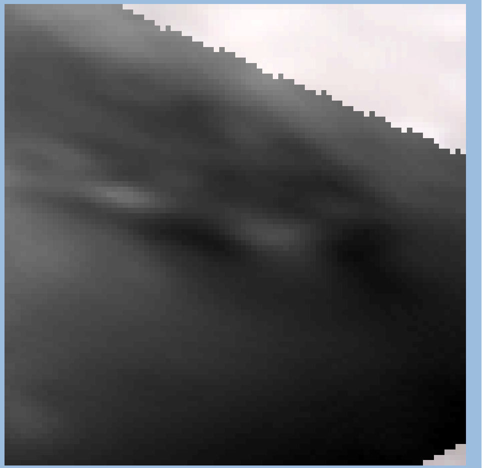
Adaptive
~49’000 photons
~2.0 FPS

Armadillo Close-Ups

Scene



Reference



Adaptive

Performance

Sphere Scene

	Reference	**Adaptive**
Voxelization	25 ms	25 ms
Octree	5 ms	5 ms
Photon Generation	< 1 ms	< 1 ms
Photon Marching	110 ms	10 ms
Photon Distribution	-	5 ms
Photon Generation	-	2 ms
Photon Marching	-	85 ms
Filtering	-	30 ms
Viewing Pass (+copy)	189 (+ 44) ms	189 (+ 44) ms
	373 ms	**395 ms**

47 ms overhead !!!

Problem

> Half of the photons does not lead to a photon marching twice as fast.

> Reason:
  - Atomic conflicts in photon marching (we trace the photon that are most likely to cause collisions)
  - Collection of additional data (photon weight, photon count)

> Additional passes take more time than we could save with photon reduction
  - Adaptive pipeline is faster when reference pipeline uses >200’000 photons

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Conclusion

> Implemented Sun et al. pipeline
> Extended Sun et al. pipeline with adaptive photon sampling
> We were able to halve the number of photons with equal quality.
> We were **not** able to accelerate the pipeline
  — Additional passes are too costly
  — Photon marching more expensive than expected

Future Work

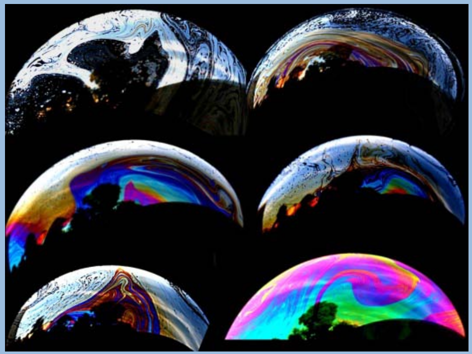
> Overhead minimization

> Atomic conflict reduction

> Automatic threshold adjustment

> Management of large scenes

> Multiple scattering, thin-film interference, …



Thin-film interference

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Thank you for your attention!

Questions?

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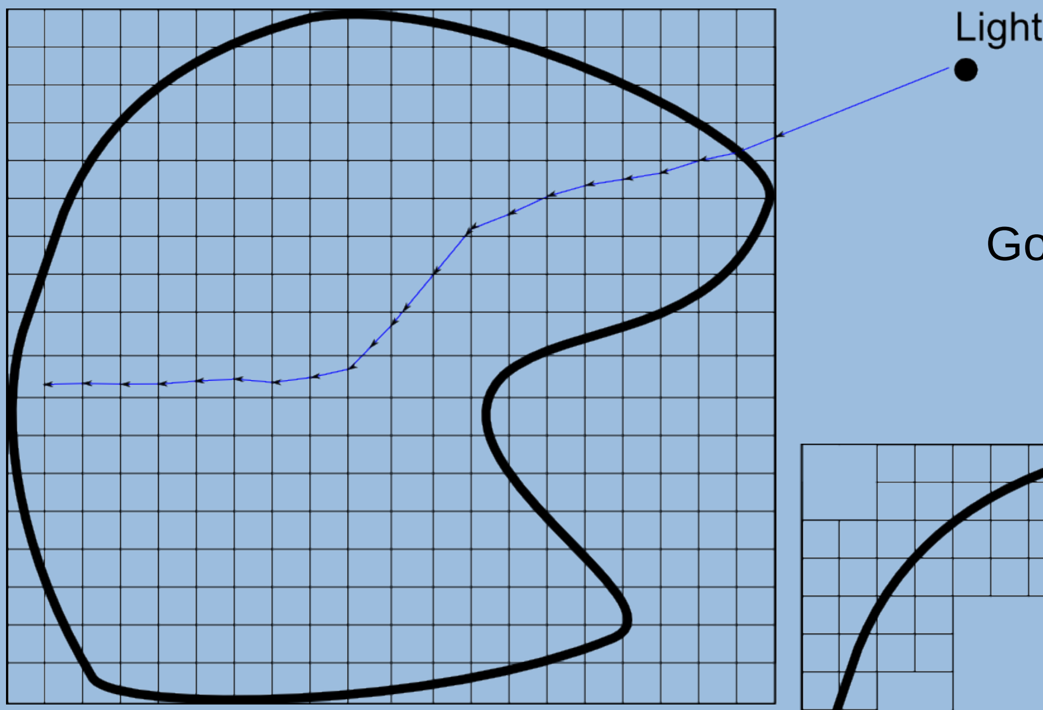
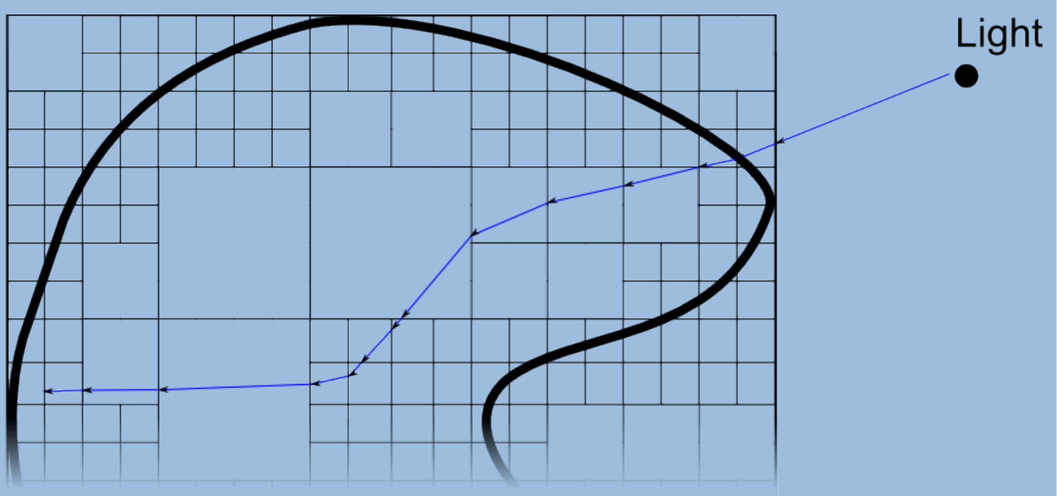
Octree



Goal: Accelerate Photon Tracing



Photon Marching

- Photon paths are computed with

$$x_{i+1} = x_i + \frac{\Delta s}{n} v_i$$

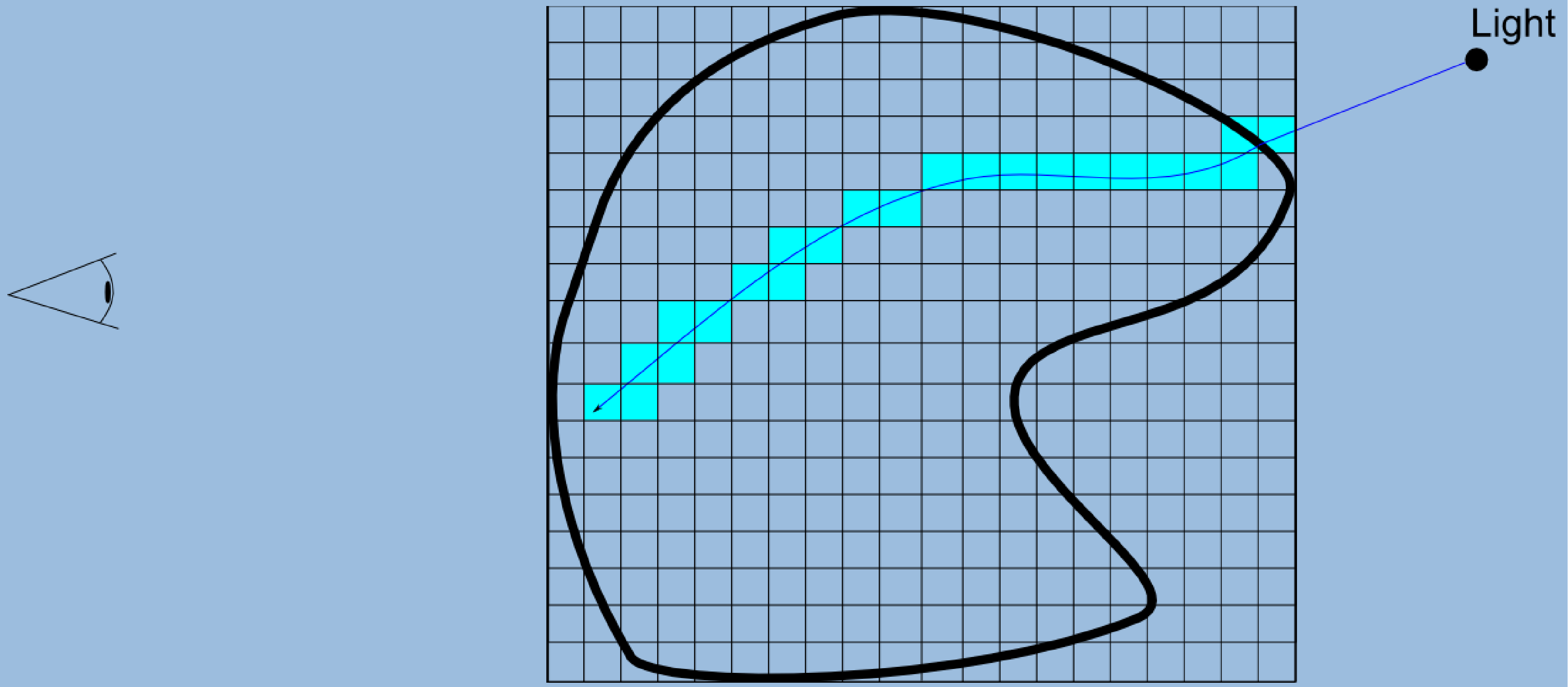
$$v_{i+1} = v_i + \Delta s \nabla n$$

- Arbitrary step size Δs (in our case given by octree)

- Formulas can be derived from the eikonal equation and the transport equation from geometric optics.

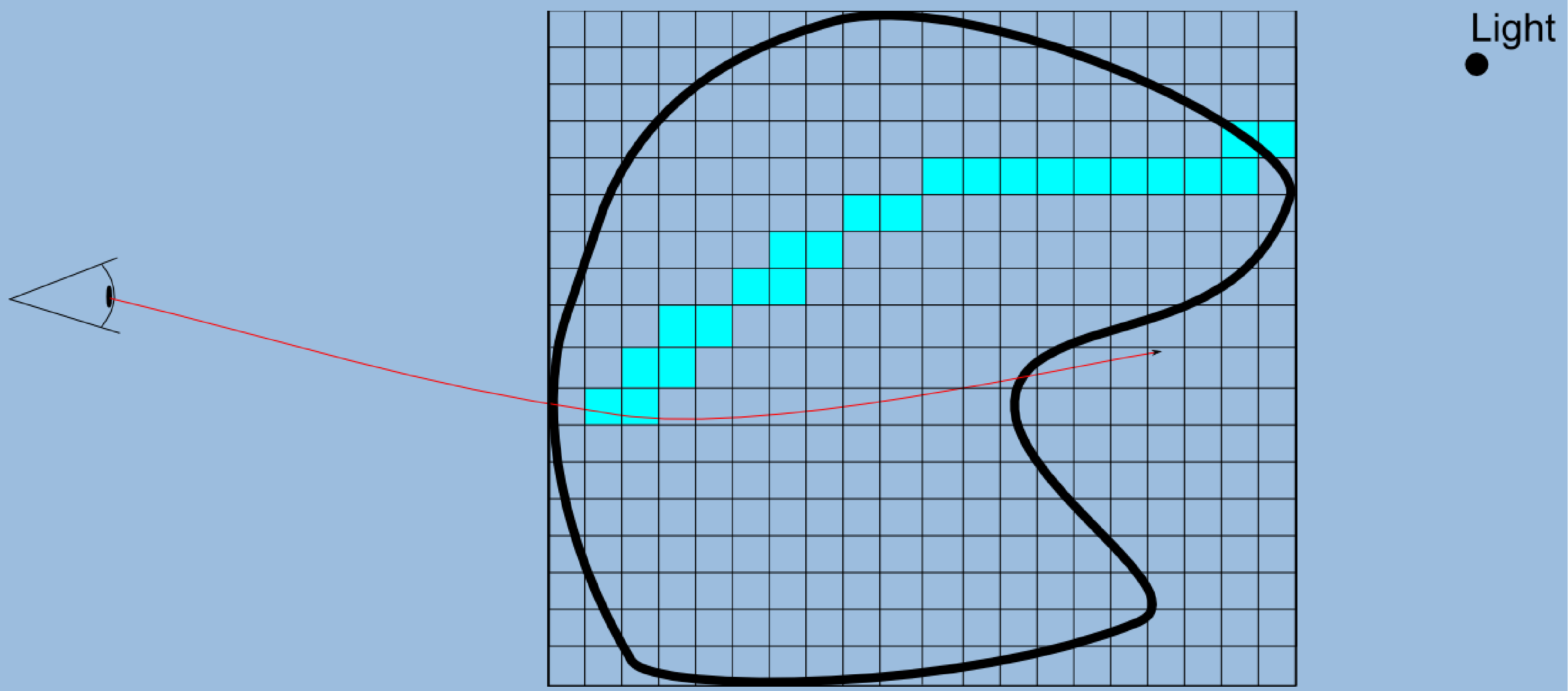
Photon Marching

- Update the radiance through every voxel a photon passed.
- Attenuate photon energy after each step (=> absorption).



Viewing Pass

- Shoot viewing rays and march as photons through grid.
- Evaluate scattering after each step (=> single scattering).

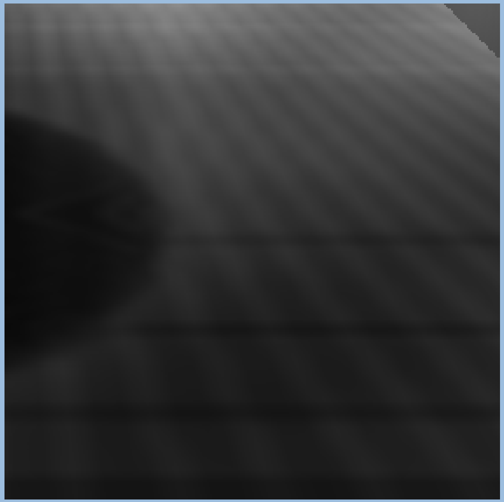


Performance (cont.)

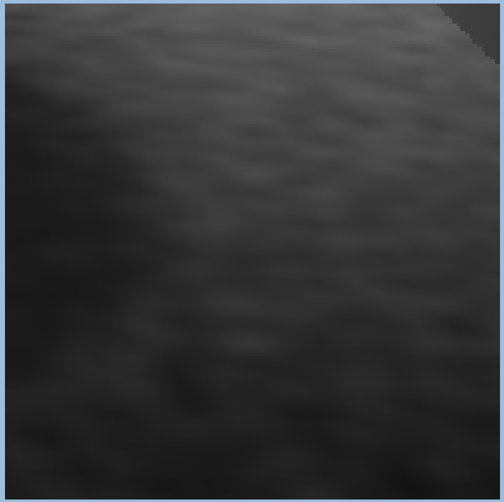
Performance and Sampling

- We use Hammersley sequence for sampling
  - Good visual results
  - Good performance

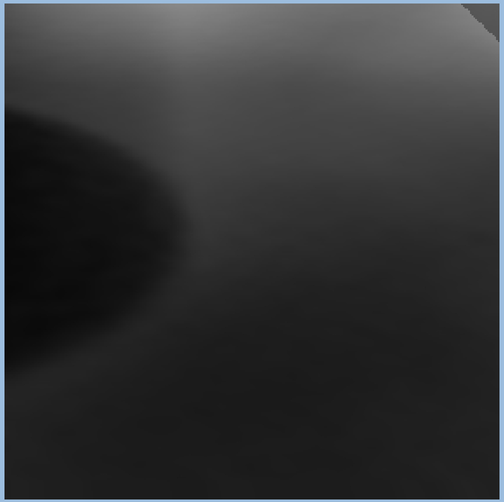
- Visual:
  - Hammersley shows hardly any noise



Grid



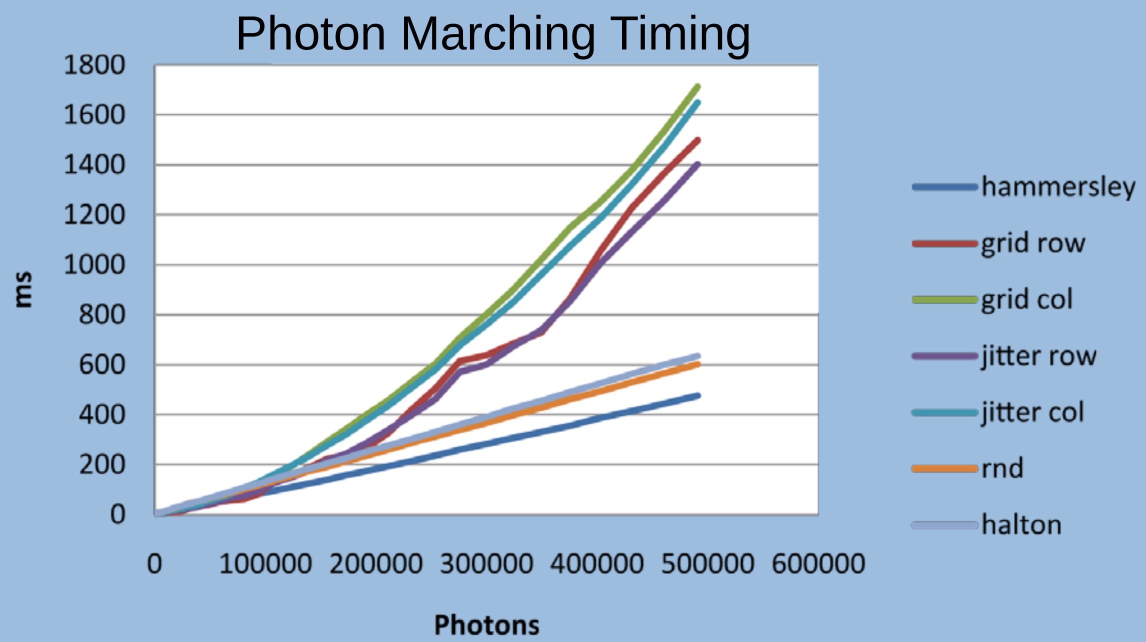
Random



Hammersley

Performance and Sampling (cont.)

- Performance:
  - Good trade-off between
    - Memory Access Pattern
    - Atomic Conflicts



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Performance and Sampling (cont.)