SIGGRAPH ASIA 2020 VIRTUAL

Pre-recorded sessions:
From 4 December 2020

Live sessions:
10 – 13 December 2020

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CPPM: Chi-squared Progressive Photon Mapping

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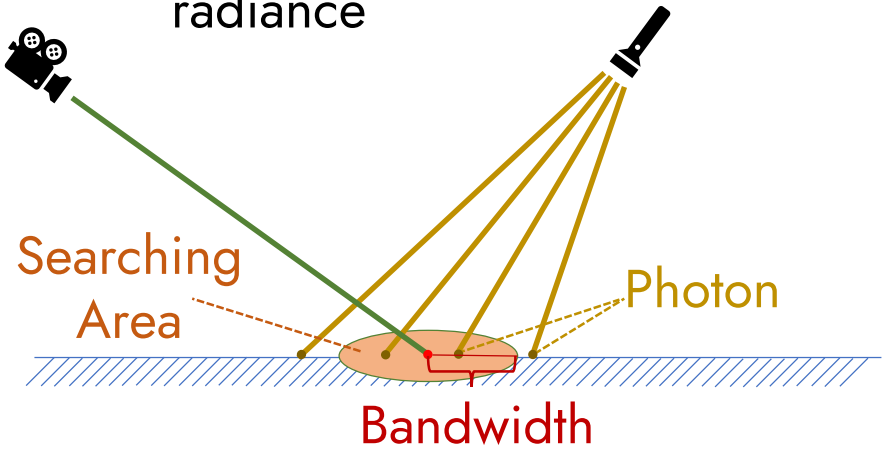
Outline

- Background
- Challenge
- Key Idea
- Algorithm
- Results
- Limitation
- Summary

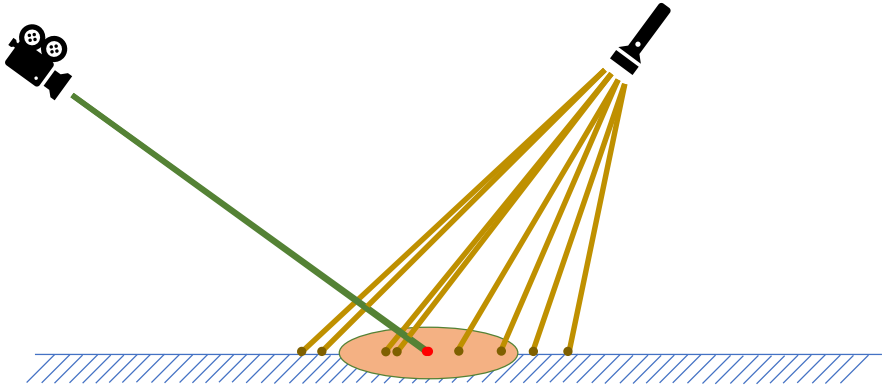
Background

- Photon Mapping [Jensen 1996] can solve S-D-S paths:
  - Light sources emit photons
  - Collect photons to estimate radiance



Background

- SPPM [Hachisuka and Jensen 2009] converges to the correct pixel measurement:
  - Multiple iterations
  - Bandwidth converges to infinitesimal



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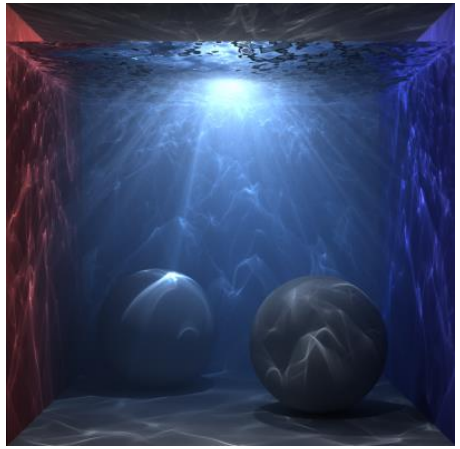
Background



Progressive Photon Mapping: A Probabilistic Approach

[Knaus and Zwicker 2011]

Adaptive Progressive Photon Mapping

[Kaplanyan and Dachsbacher 2013]

Deep Kernel Density Estimation for Photon Mapping

[Zhu et al. 2020]

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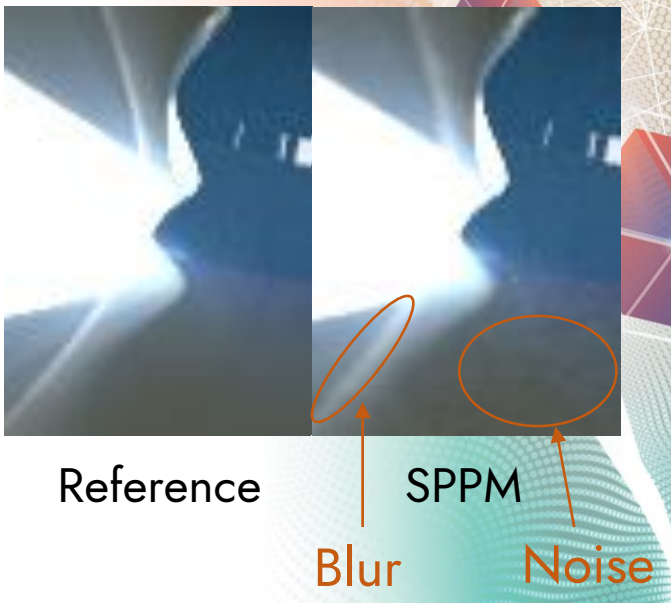
Challenge

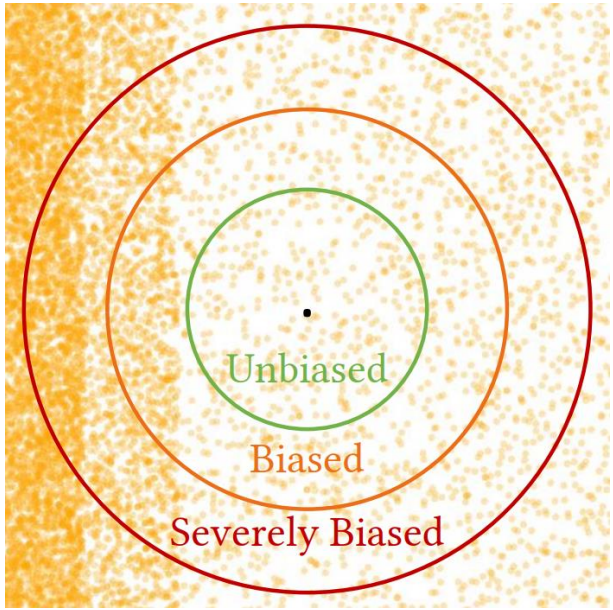
Challenge

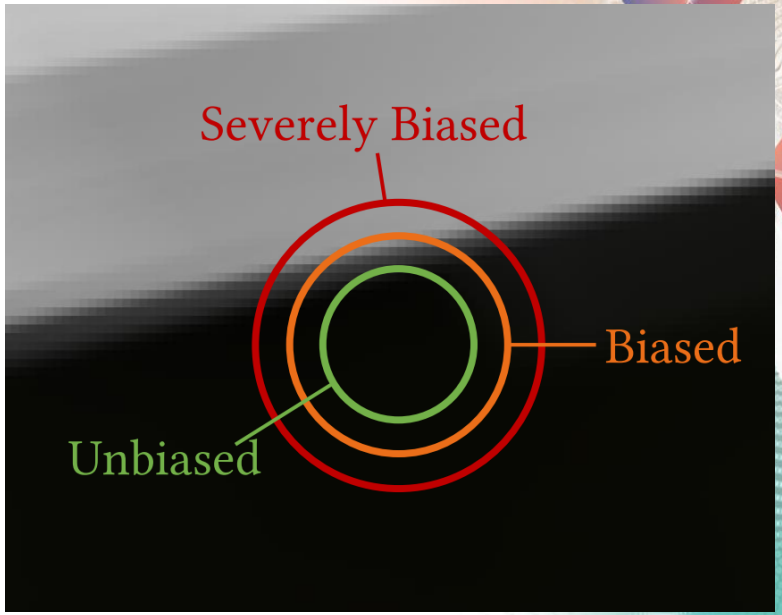
- Challenge: Blur and Noise
  - Blur:
    - Caused by bias
    - Bandwidth too large
  - Noise:
    - Caused by variance
    - Bandwidth too small
- Difficult to eliminate them at the same time



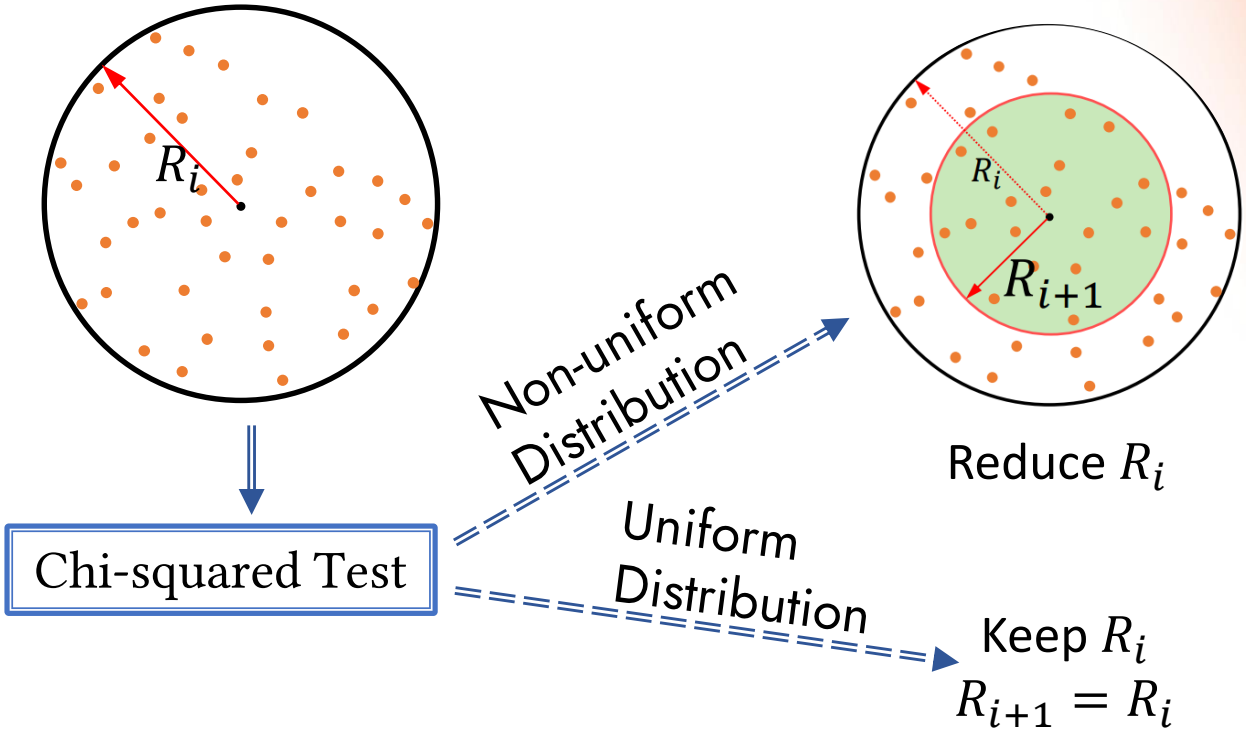
Key Idea: Benefits of Uniform Distribution

- Uniformly distributed photons have advantages
- Unnecessary to use a smaller bandwidth



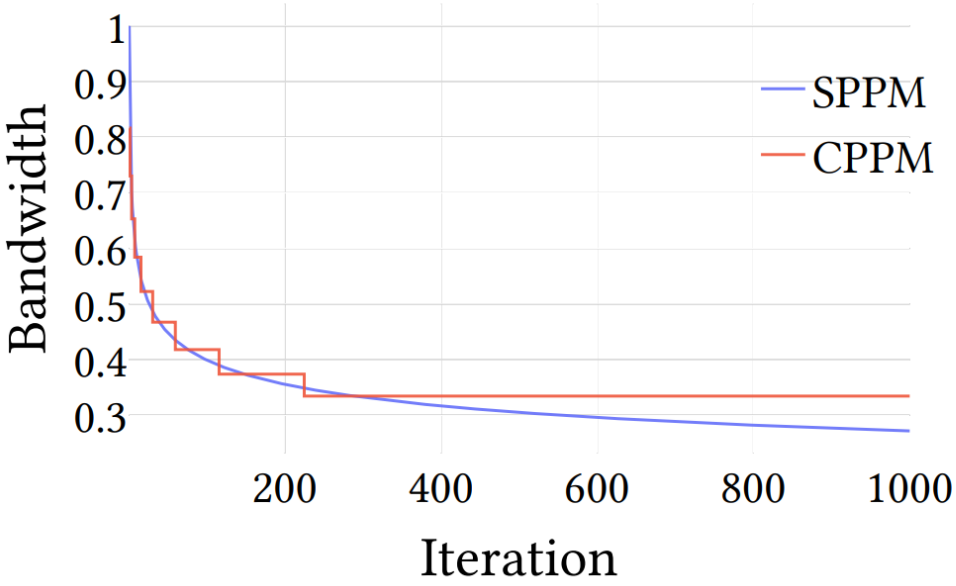


Key Idea: Chi-squared Test on Photons

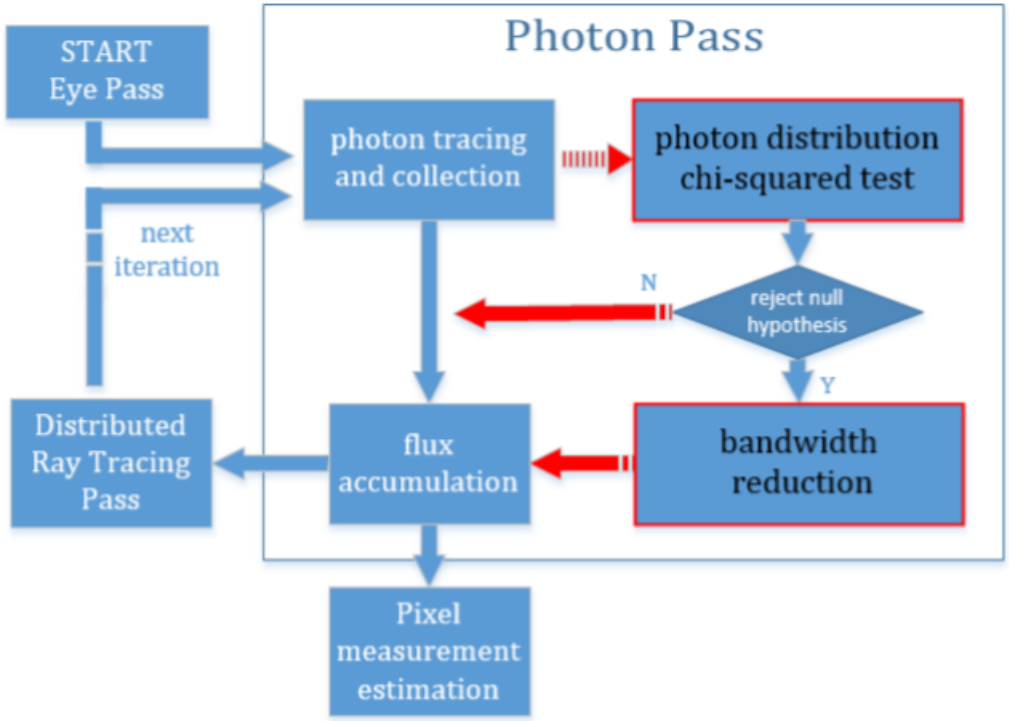


Key Idea: Bandwidth Reduction Scheme

- A novel bandwidth reduction scheme to work with chi-squared test

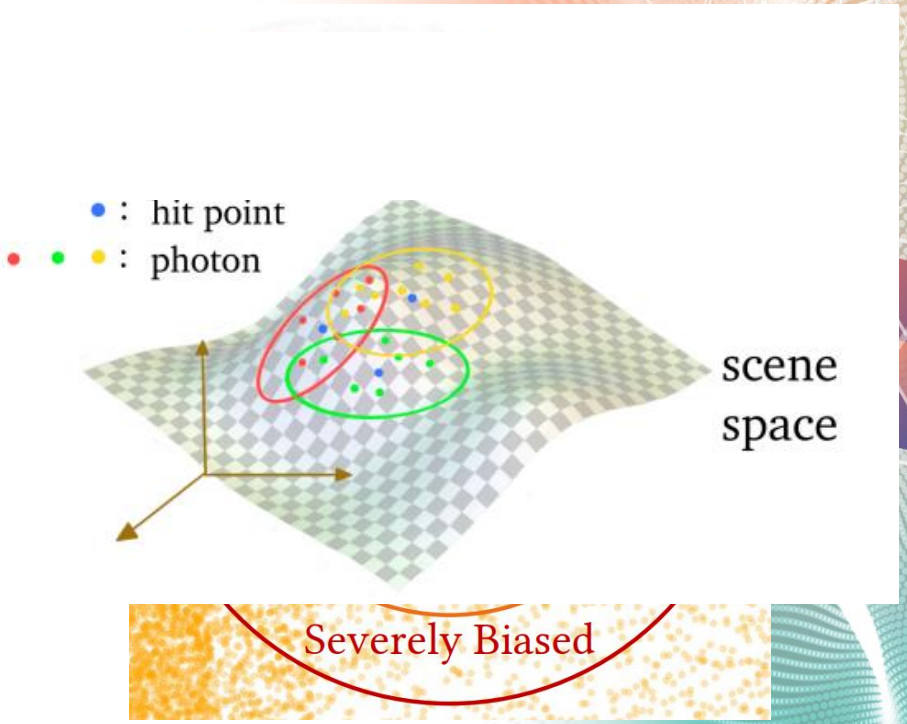


Algorithm: Pipeline



Algorithm: Theoretical Foundation

- How to define a uniform distribution on multiple searching areas?
- A unified space can be a solution



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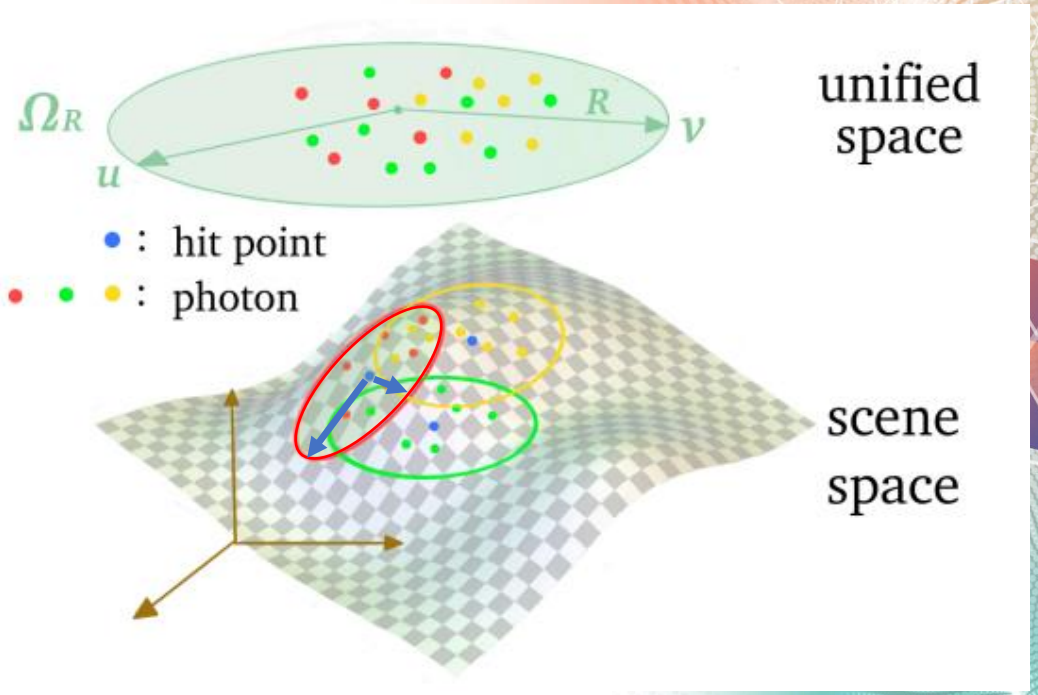

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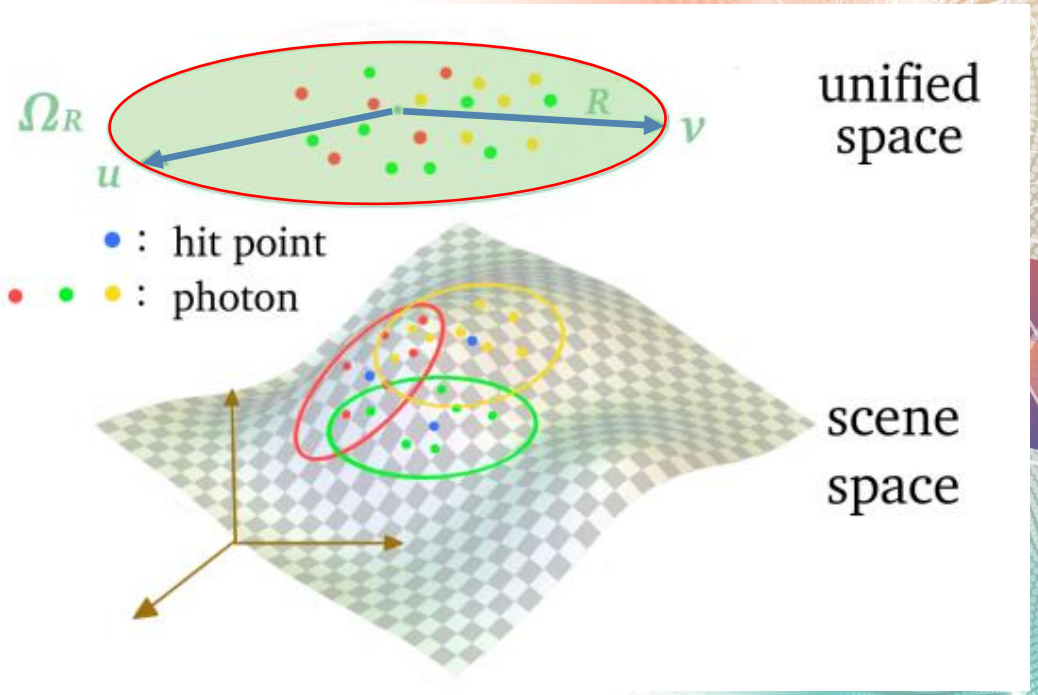

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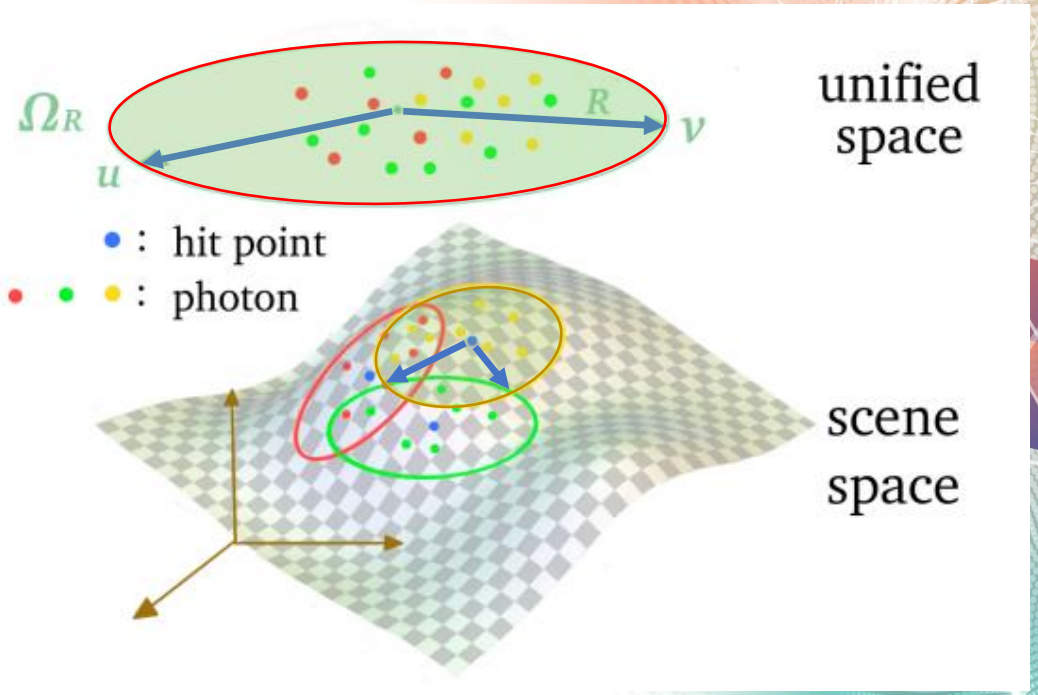

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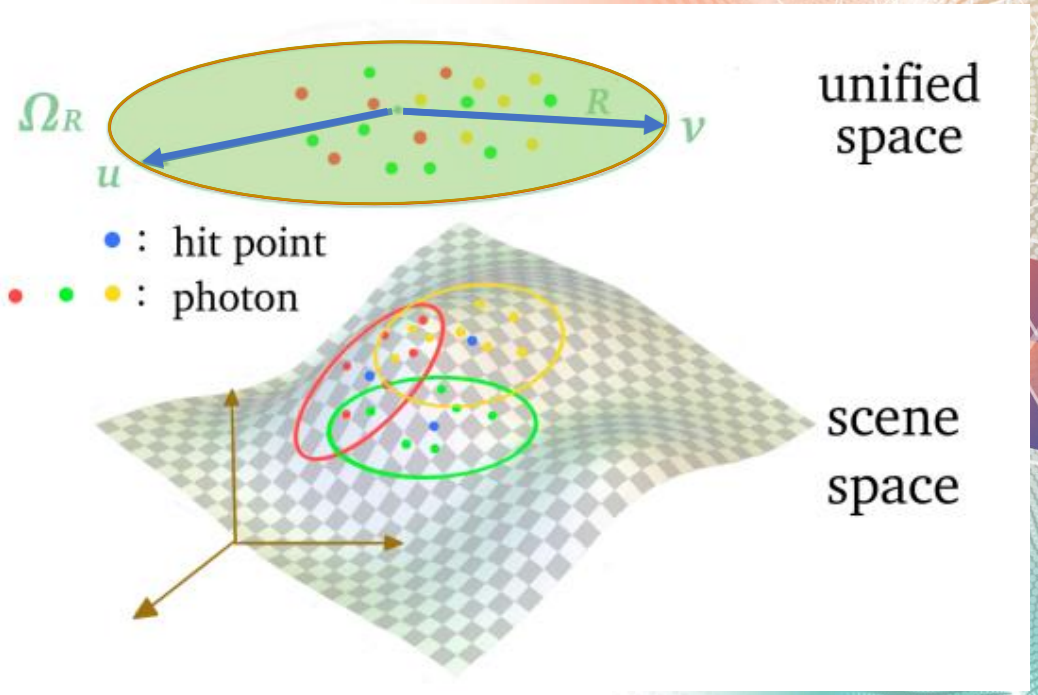
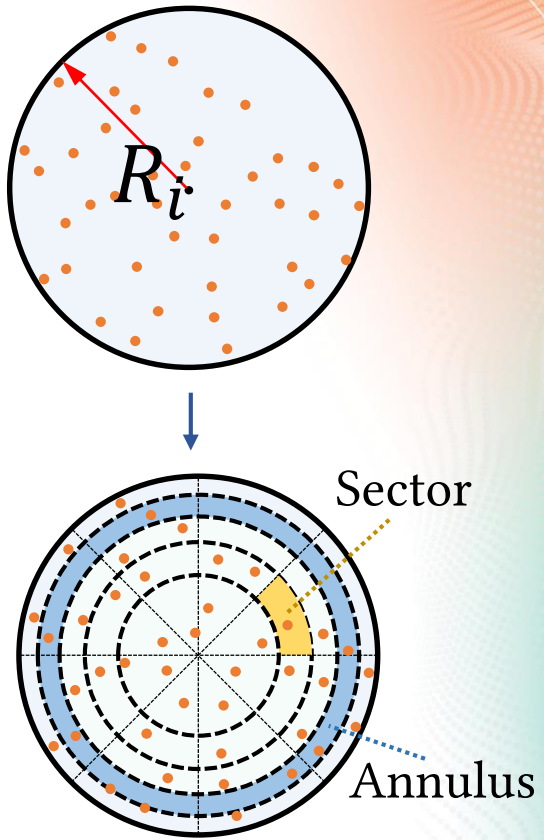


Algorithm: Chi-squared Test on Photons

- Partition the disc
- Count photons in sectors
- Calculate chi-squared statistic to identify uniform distribution



Algorithm: Conditional Bandwidth Reduction

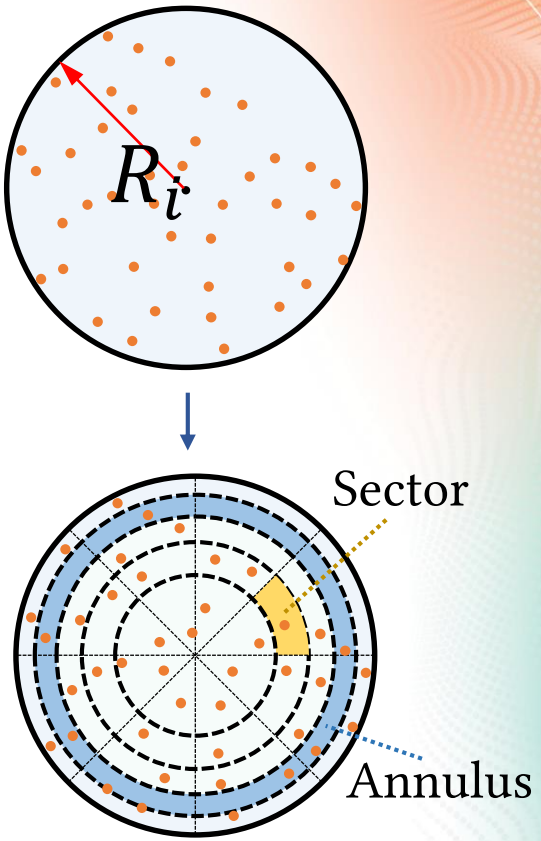
Photons

Uniformly distributed

$R_{i+1} = R_i$

Not uniformly distributed

$R_{i+1} < R_i$



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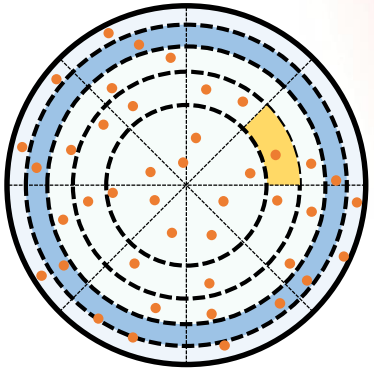
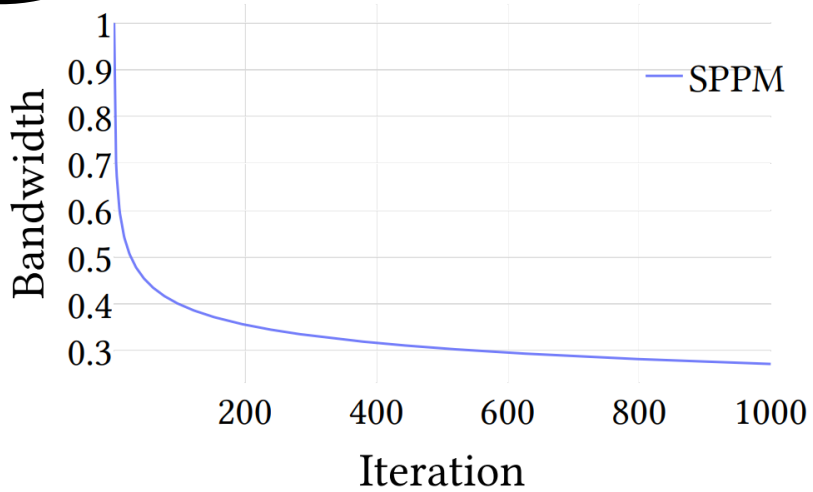
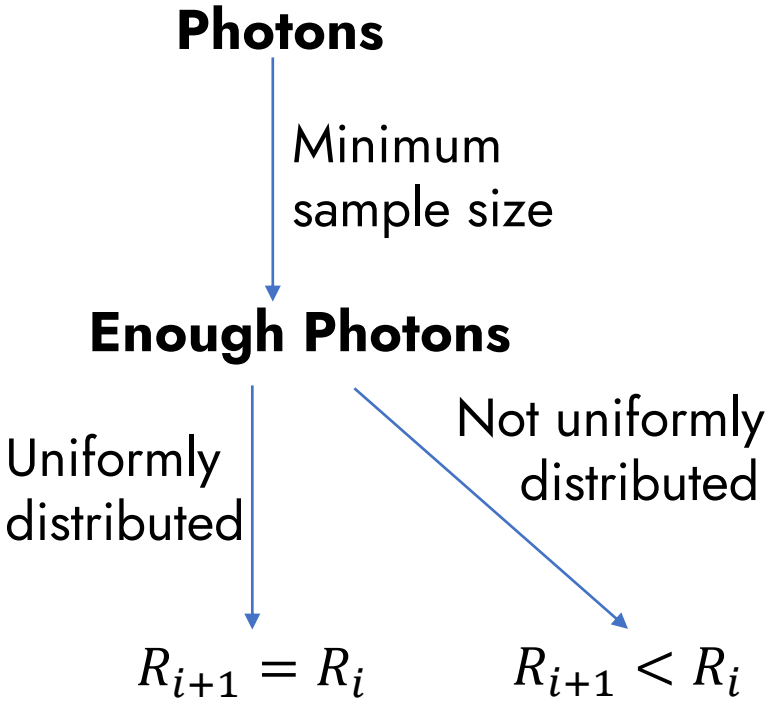
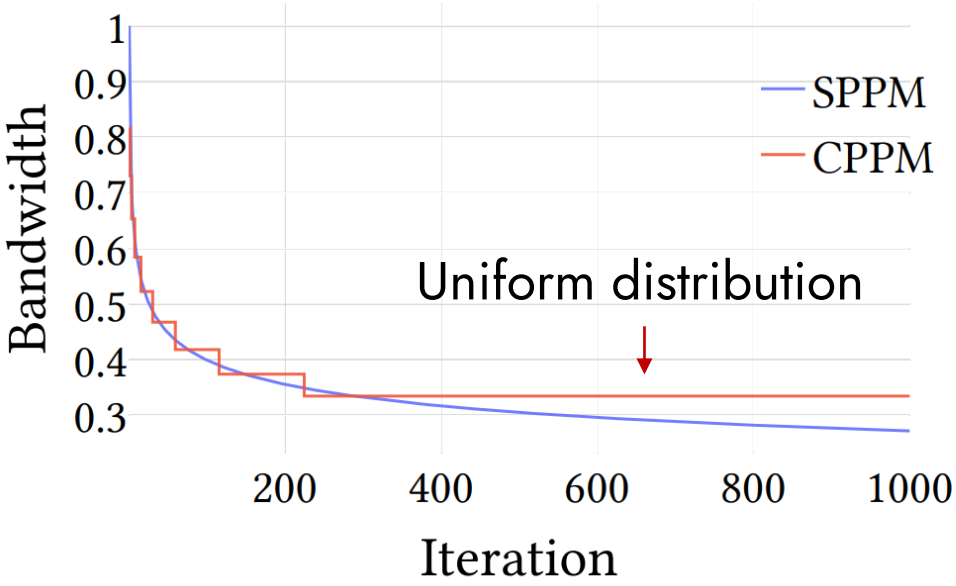


- How to get enough samples for the chi-squared test?

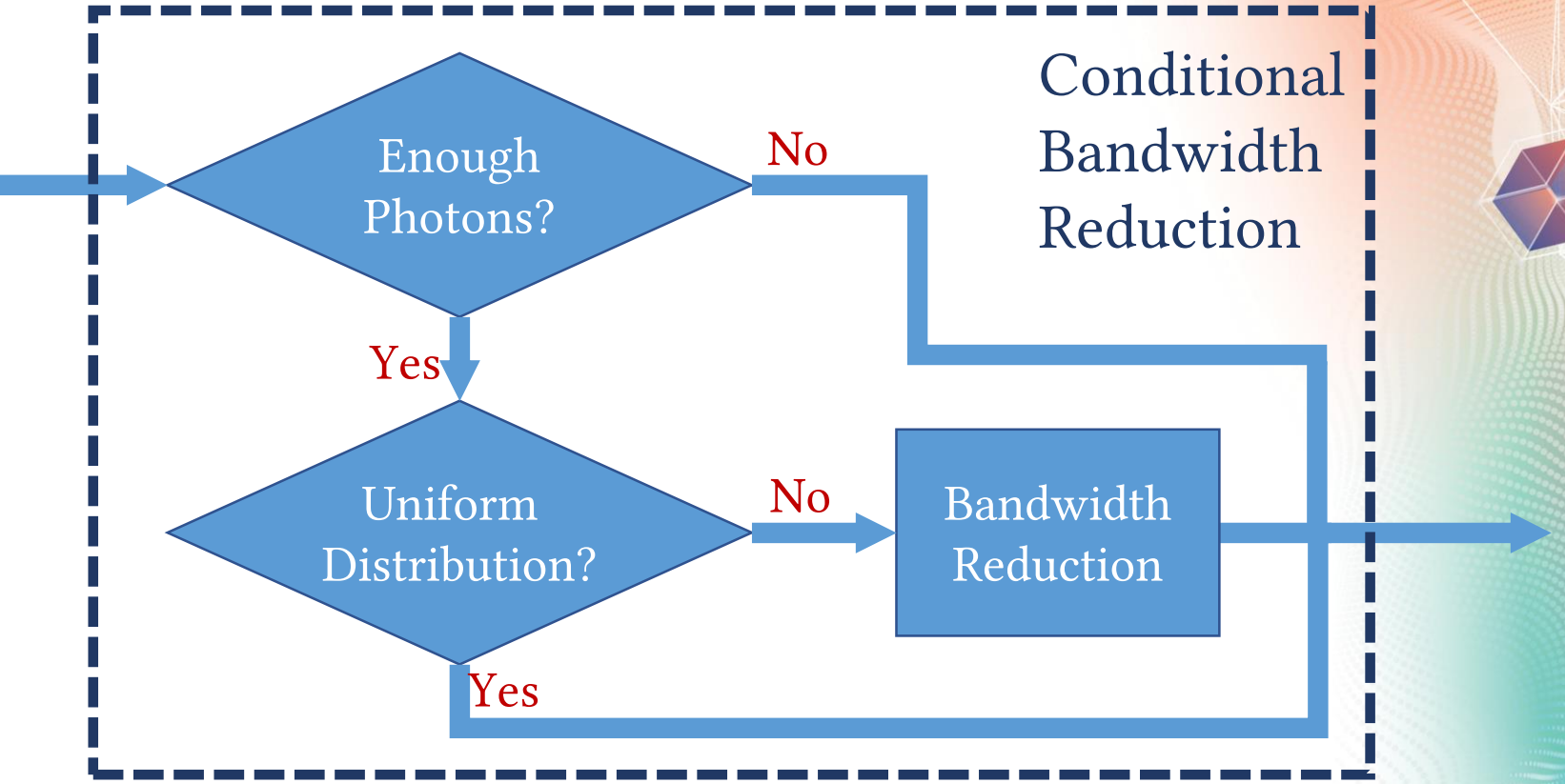


Algorithm: Bandwidth Reduction Scheme





CPPM Pipeline



Algorithm: Convergence

- Worst case:

$$R_N = O\left(N^{-\frac{1}{2}\log_{\frac{\beta}{k}}\frac{1}{k}}\right)$$

  - equivalent to SPPM
- Best case:

  Bias $= 0$

  Variance $= O(N^{-1})$

Exceptional Cases of the Chi-squared Test

- The chi-squared test may get wrong results:

1. Reject a uniform distribution

   Acceptable 

2. Not reject a non-uniform distribution

   Critical 

   Solution: keep testing 

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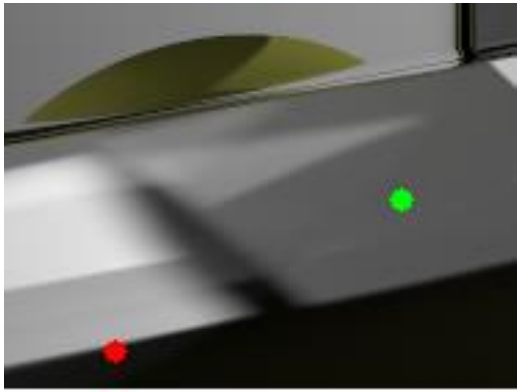
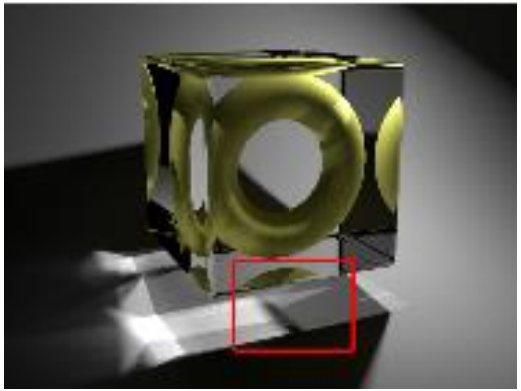
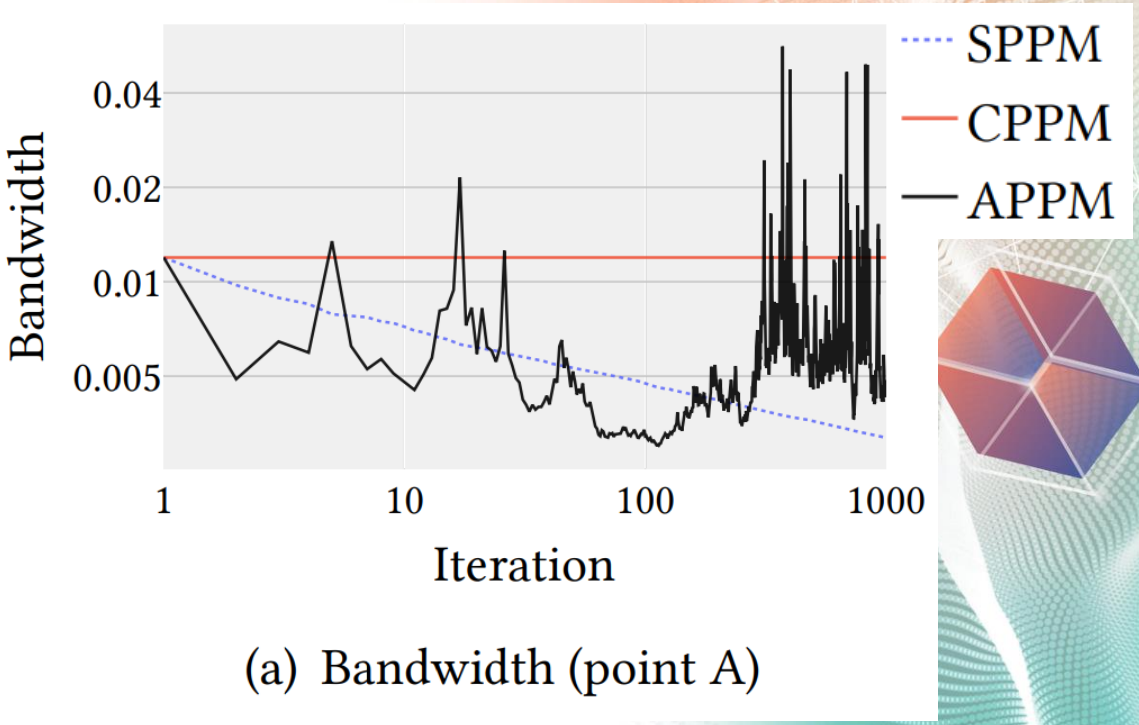
Results

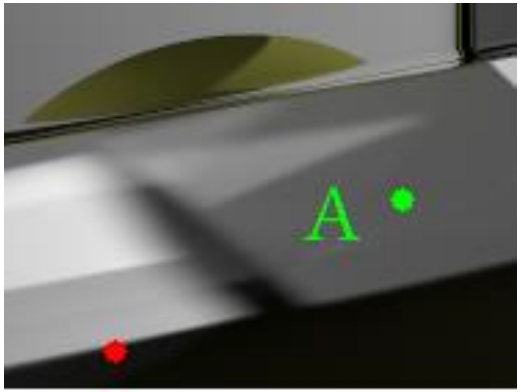


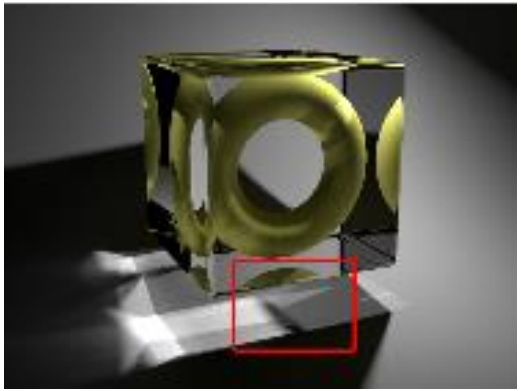


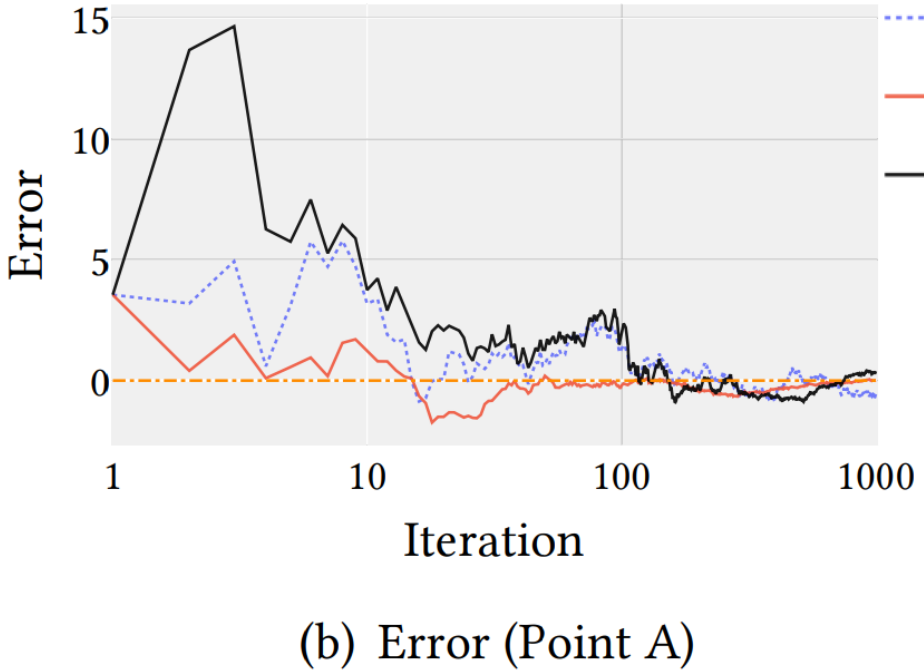


(a) Bandwidth (point A)

Results

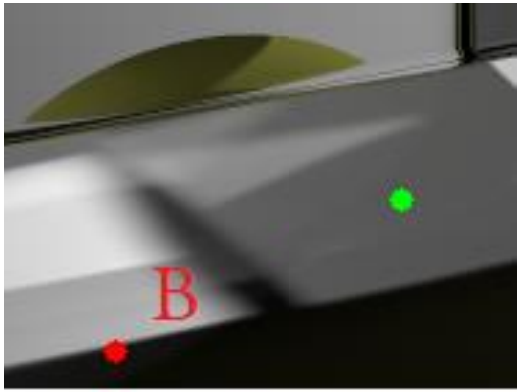


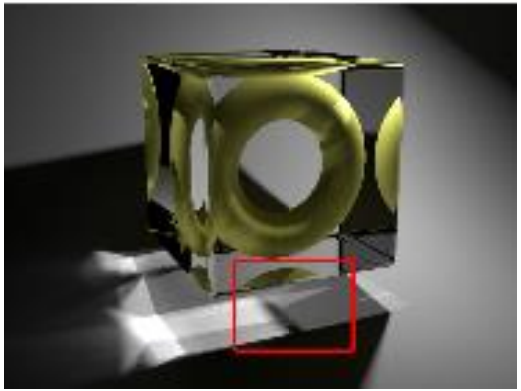




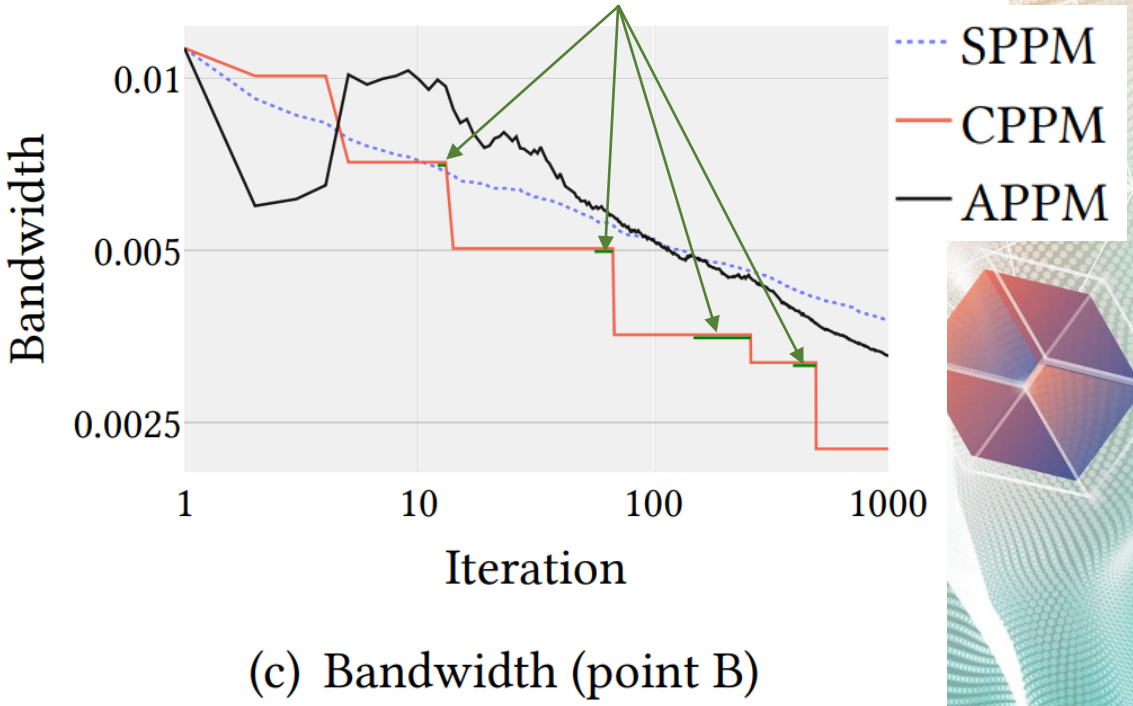
(b) Error (Point A)

Results



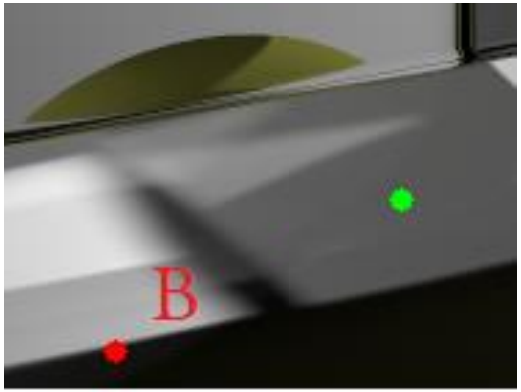


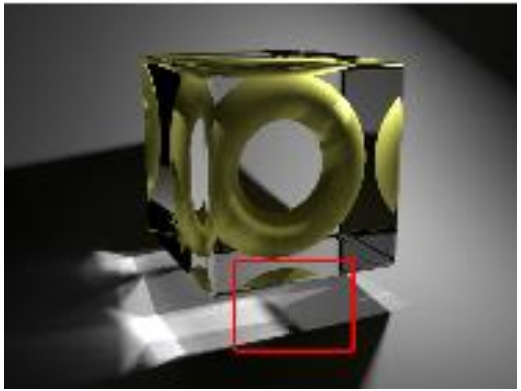
Chi-squared test fails to reject a non-uniform distribution

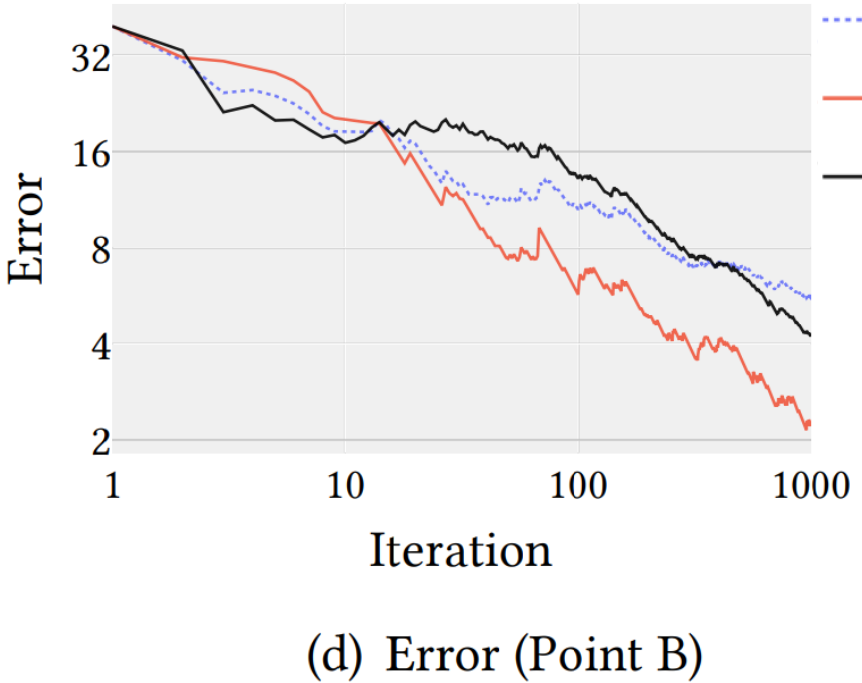


(c) Bandwidth (point B)

Results







(d) Error (Point B)

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Results

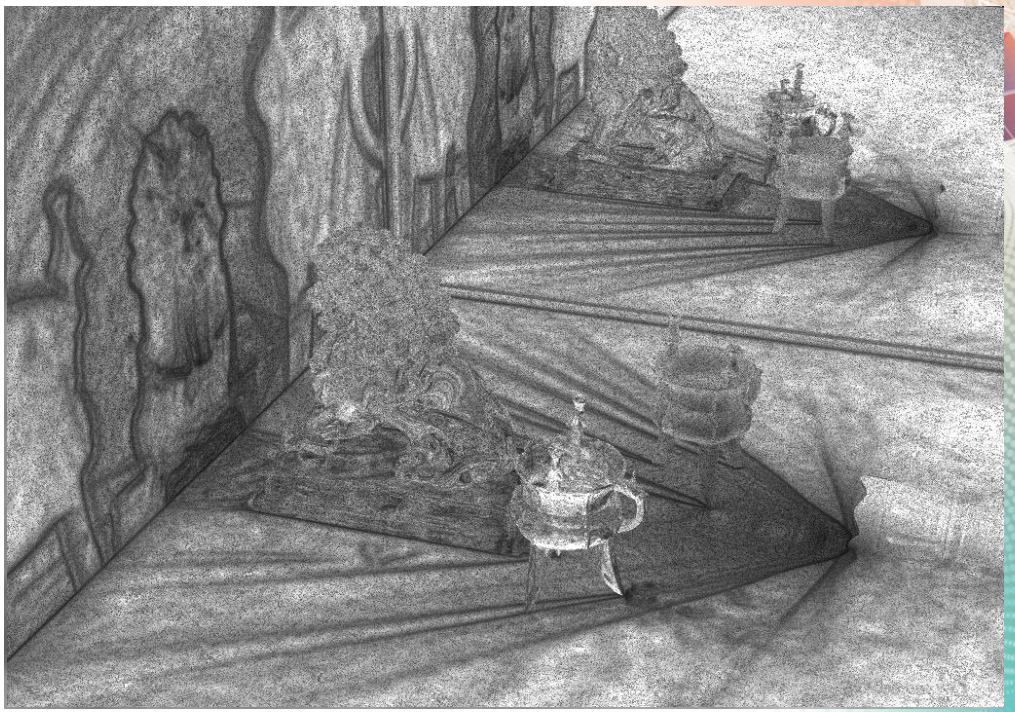
- How many pixels can find a uniform distribution?

Results

- How many pixels can find a uniform distribution?
- Bandwidth of SPPM:

Results

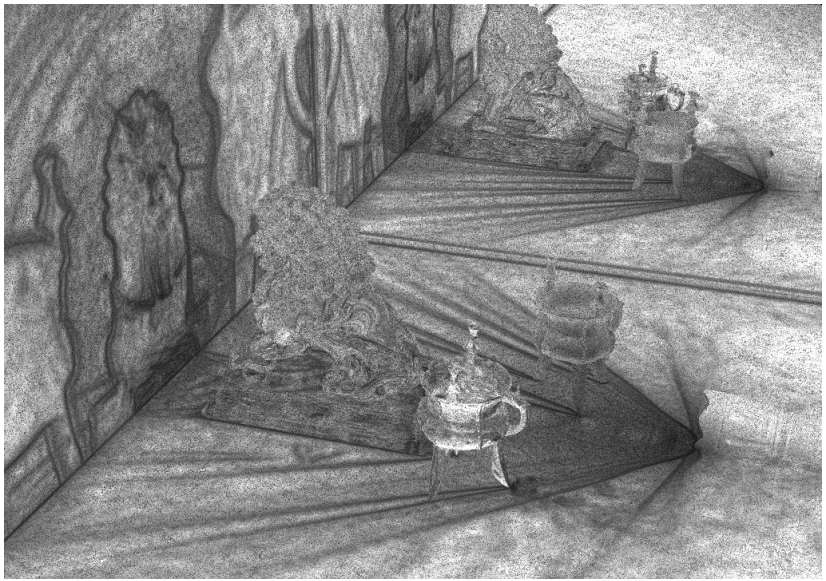
- How many pixels can find a uniform distribution?
- Bandwidth of CPPM:



Results

- Most pixels can find a uniform distribution

CPPM



SPPM

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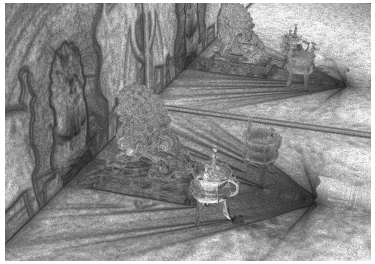
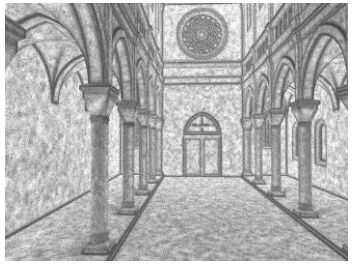
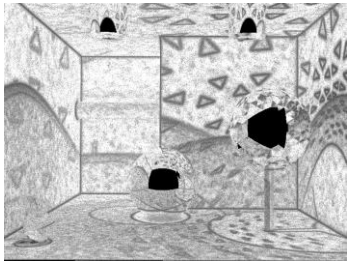
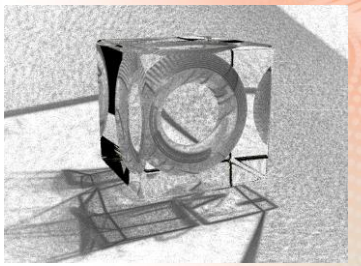
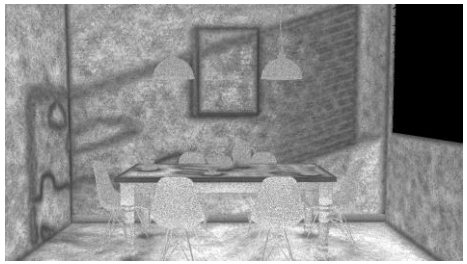
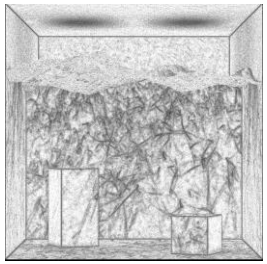
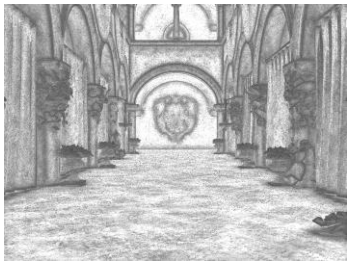
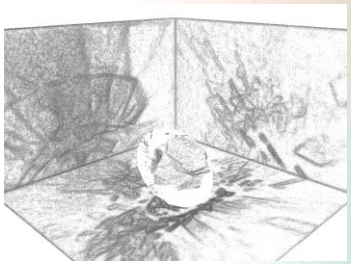
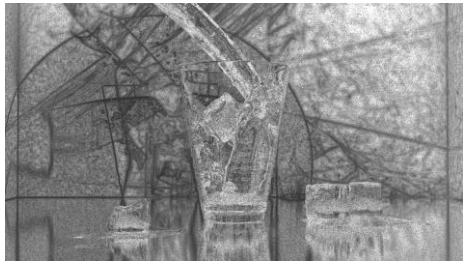
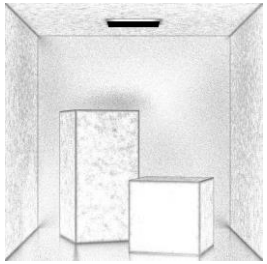
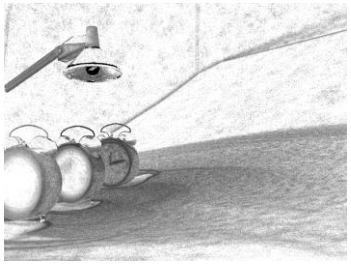
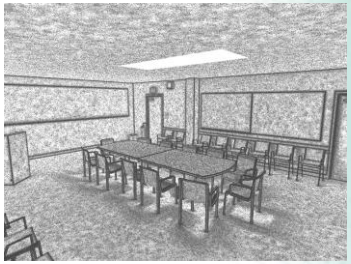
Results

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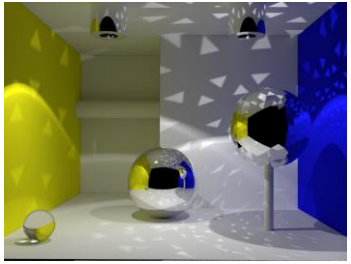
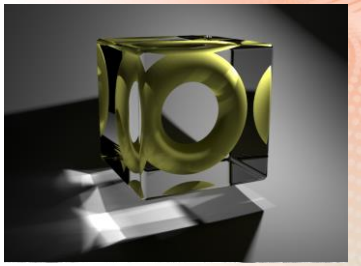
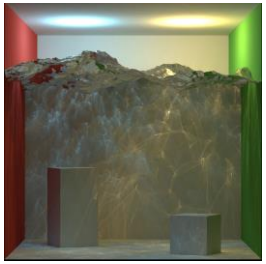
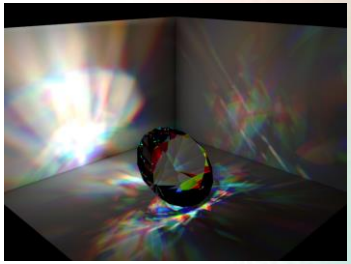
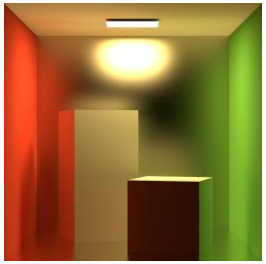
Results









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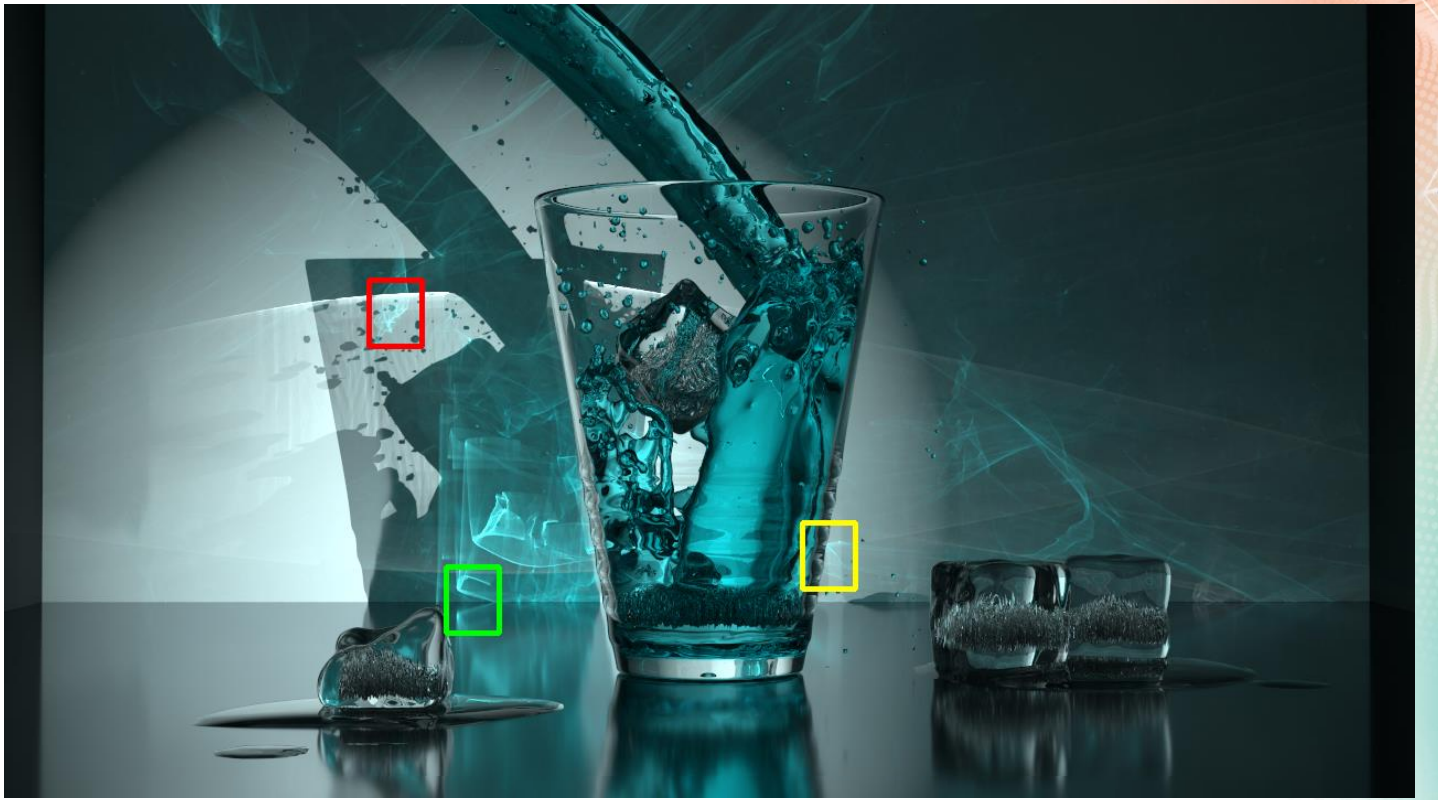

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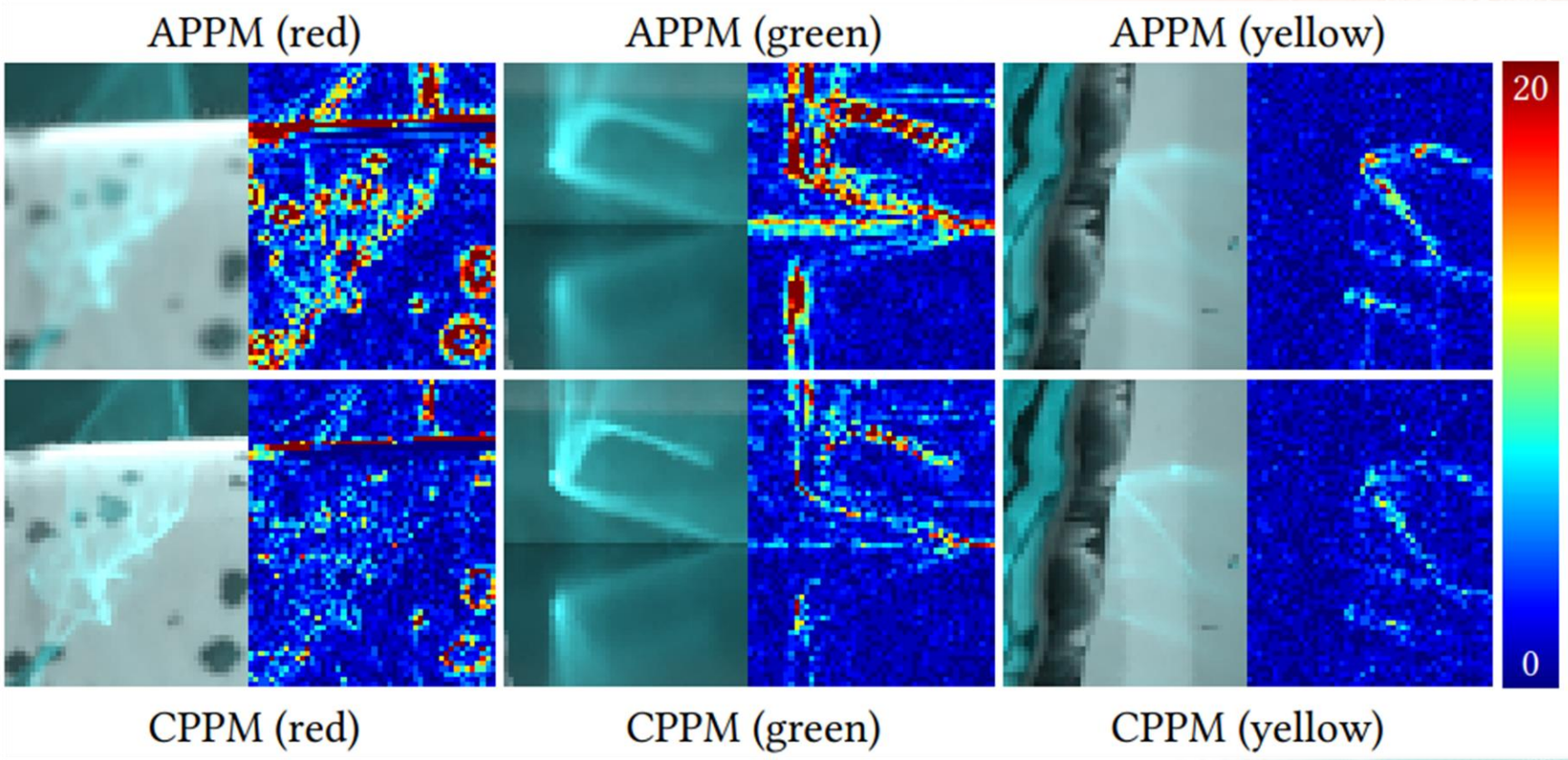
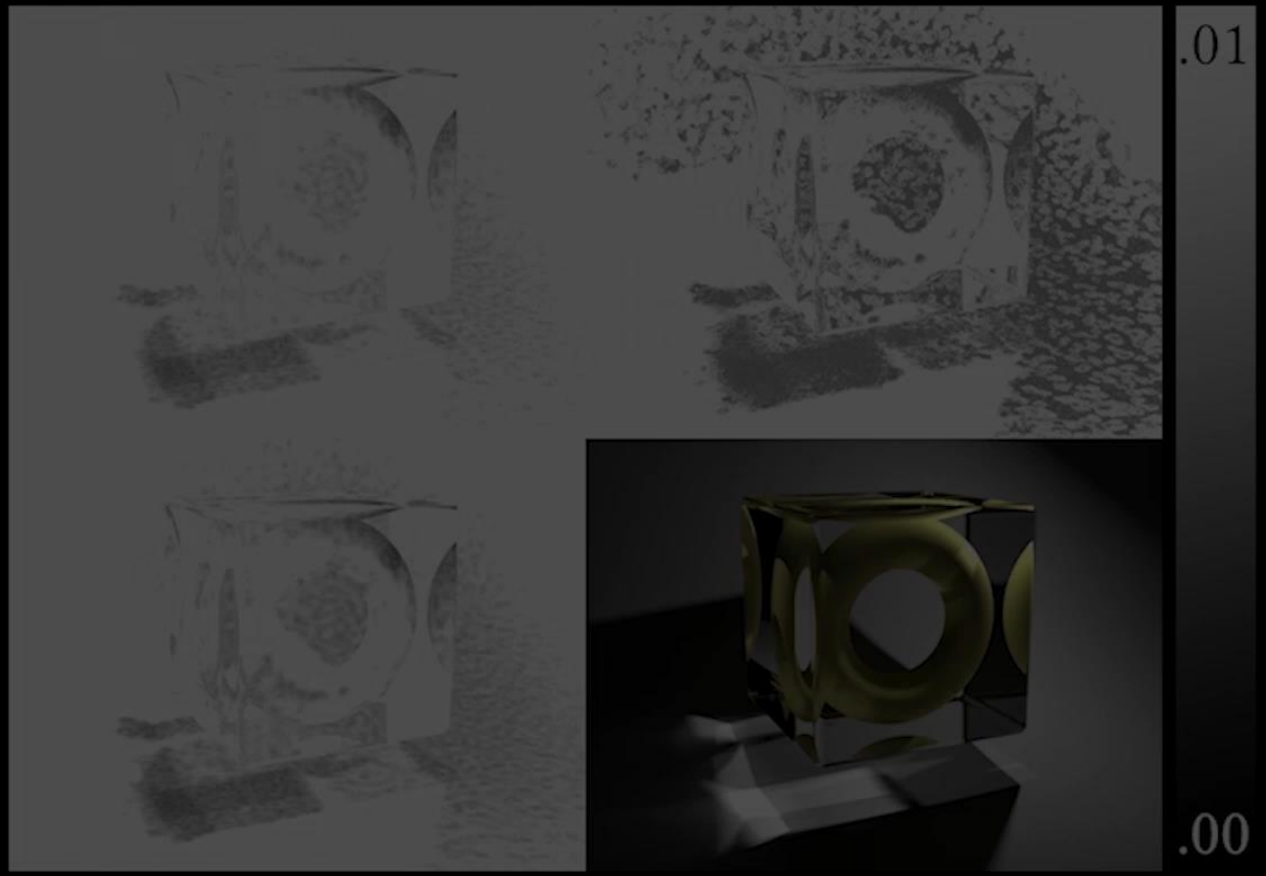
Results

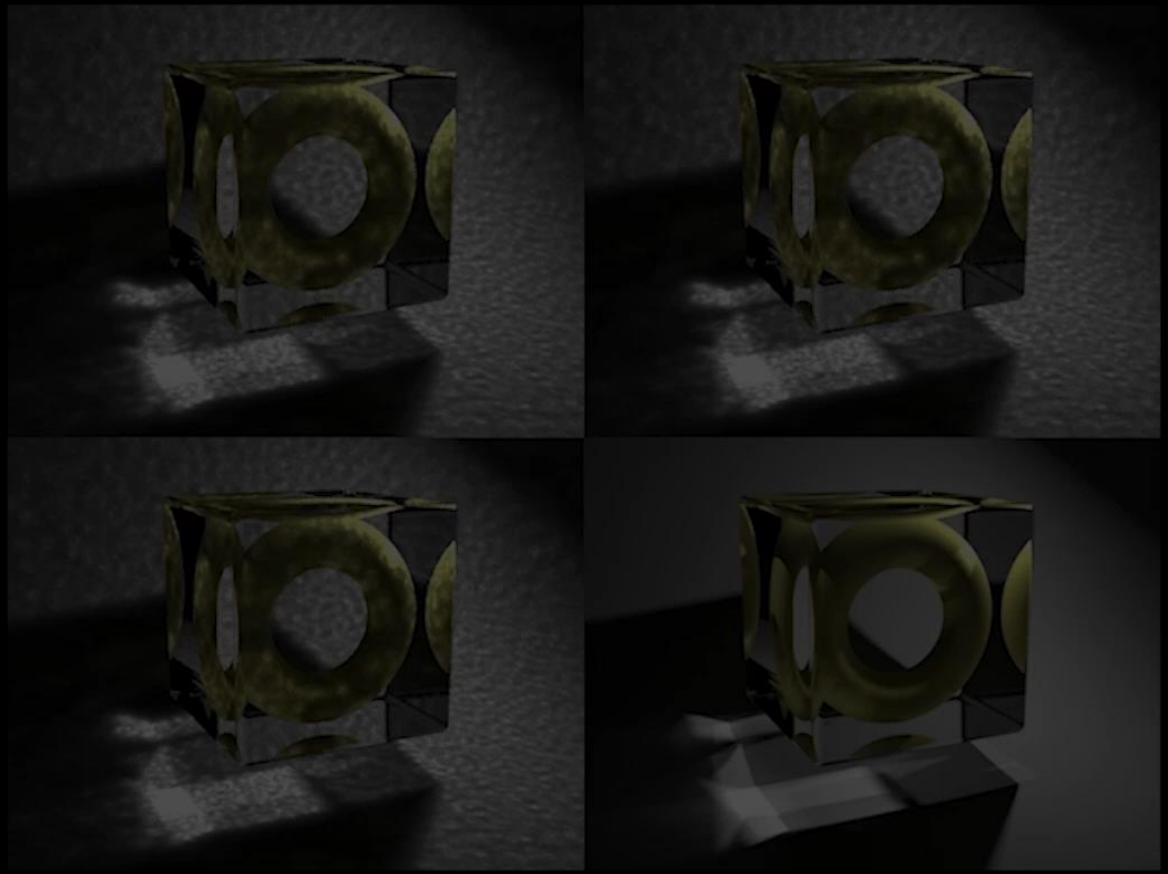



CPPM
Torus Bandwidth Visualization
APPM
.01
.00
SPPM
Iteration: 1
Photon: 0.1M
Reference

CPPM

Torus

APPM

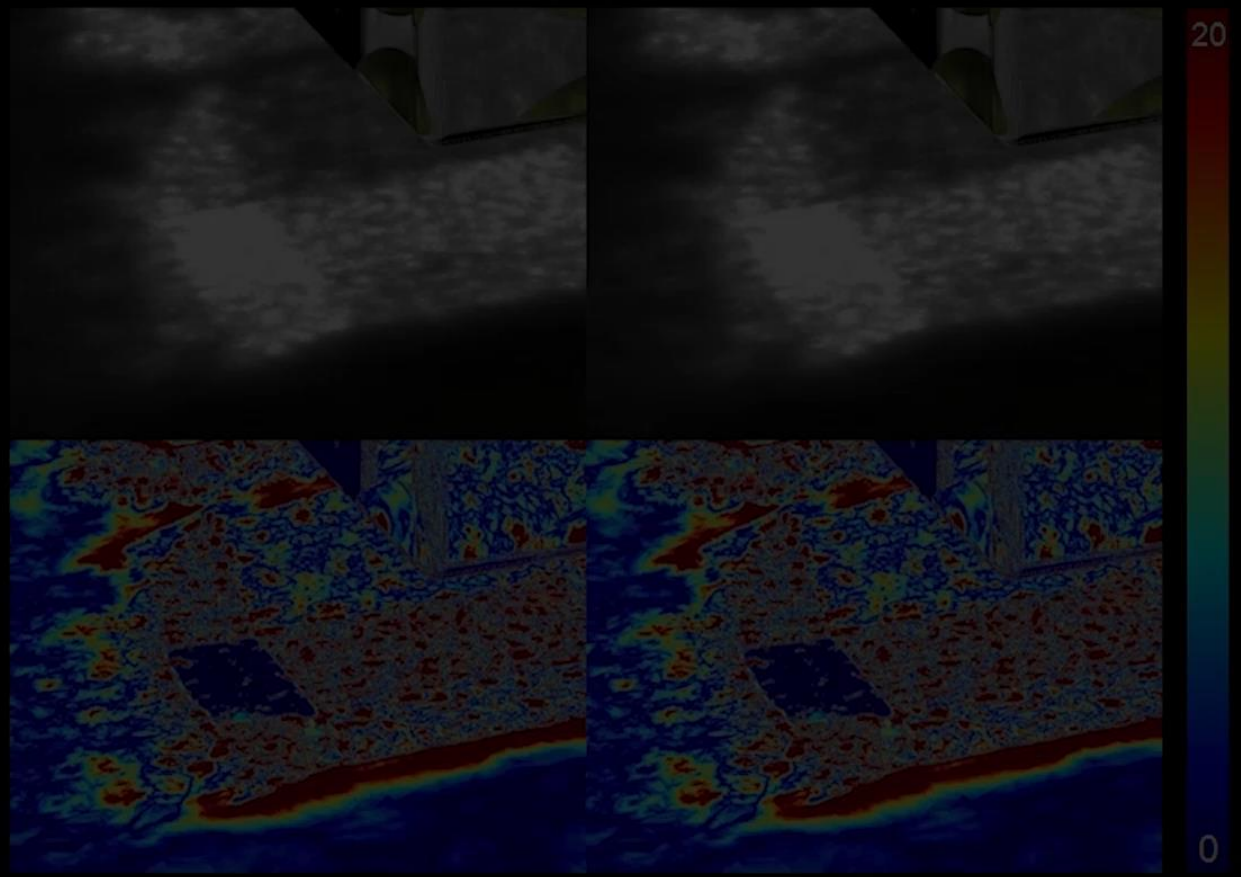


SPPM

Iteration: 1

Photon: 0.1M

Reference


CPPM
Torus
SPPM
20
0
Iteration: 1
Photon: 0.1M

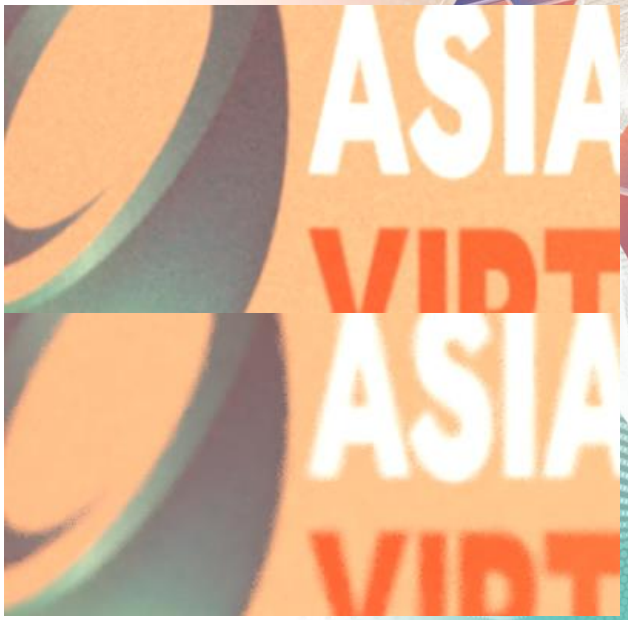
Limitation

- Uniformly distributed photons are not always good
- If the contribution of the photons depends on their location

Textured Spotlight:

SPPM

CPPM



Limitation

- If the contribution of the photons is related to their location
- Emit the photons proportional to the luminance:

SPPM

CPPM

CPPM+

Reference

SIGGRAPH ASIA 2020 VIRTUAL

Summary

Contributions:

+ Unnecessary to converge the bandwidth to infinitesimal
+ Reveal the benefits of uniformly distributed photons
+ Introduce the chi-squared test to check the photons
+ Propose a pipeline to robustly find a desired bandwidth

Future Work:

* Take contribution of photons into account
* Make bandwidth expansion possible
* Combine APPM and CPPM in a hybrid manner
* Integrate CPPM with other sampling-based techniques

Q & A

Contact: zehui@pku.edu.cn
Project Page: https://bactlink.github.io/CPPM

Thank you!

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