Bayesian online regression for adaptive direct illumination sampling

Petr Vévoda, Ivo Kondapaneni, and Jaroslav Křivánek

Render Legion, a.s.
Charles University, Prague
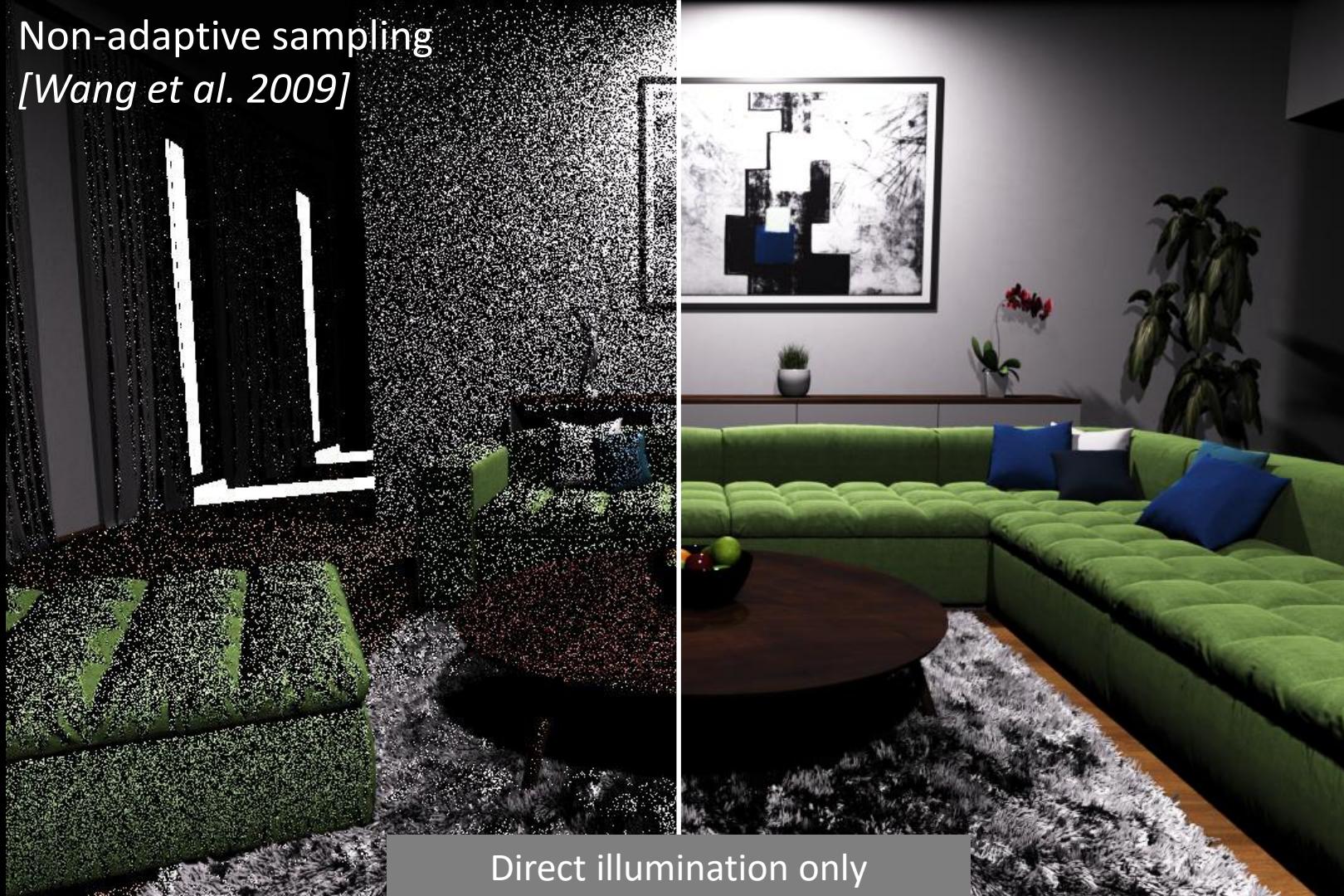
Direct + indirect illumination

Direct + indirect illumination

Non-adaptive sampling
[Wang et al. 2009]
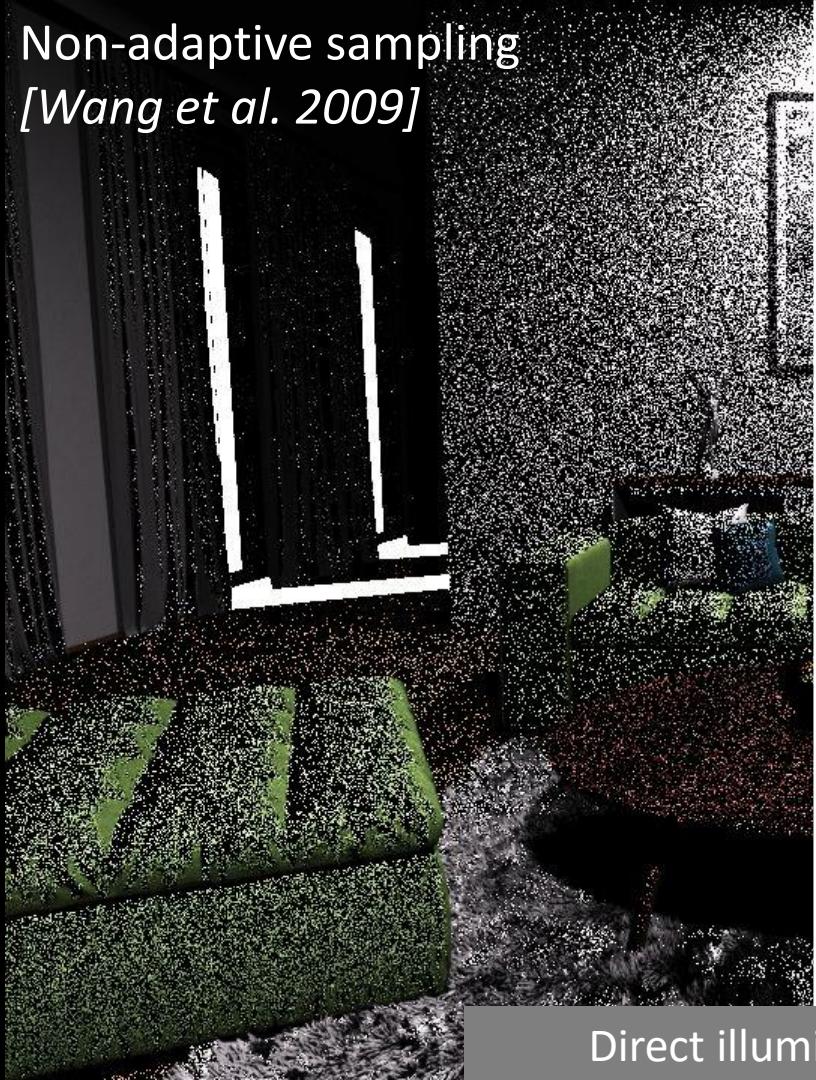
Direct illumination only

Non-adaptive sampling
[Wang et al. 2009]

Adaptive sampling
[Donikian et al. 2006]

Direct illumination only

Non-adaptive sampling
[Wang et al. 2009]

Adaptive sampling
[Donikian et al. 2006]

Direct illumination only

Non-adaptive sampling
[Wang et al. 2009]

Ours
(Bayesian learning)

Adaptive sampling
[Donikian et al. 2006]

Direct illumination only

Non-adaptive sampling
[Wang et al. 2009]

Ours
(Bayesian learning)

Adaptive sampling
[Donikian et al. 2006]

510x faster

Direct illumination only

Non-adaptive sampling
[Wang et al. 2009]

Ours
(Bayesian learning)

Adaptive sampling
[Donikian et al. 2006]

510x faster

Robust

Direct illumination only

Previous work

Adaptive sampling

- General Monte Carlo
  - Vegas algorithm
    - [*Lepage 1980*]
  - Population MC
    - [*Cappé et al. 2004, …*]
- Rendering
  - Image sampling
    - [*Mitchell 1987, …*]
  - Indirect illumination (path guiding)
    - [*Dutre and Willems 1995, Jensen 1995, Lafortune et al. 1995, …*]
    - [*Vorba et al. 2014, Muller et al. 2017*]
  - Direct illumination
    - [*Shirley et al. 1996, Donikian et al. 2006, Wang et al. 2009*]

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Bayesian methods in rendering
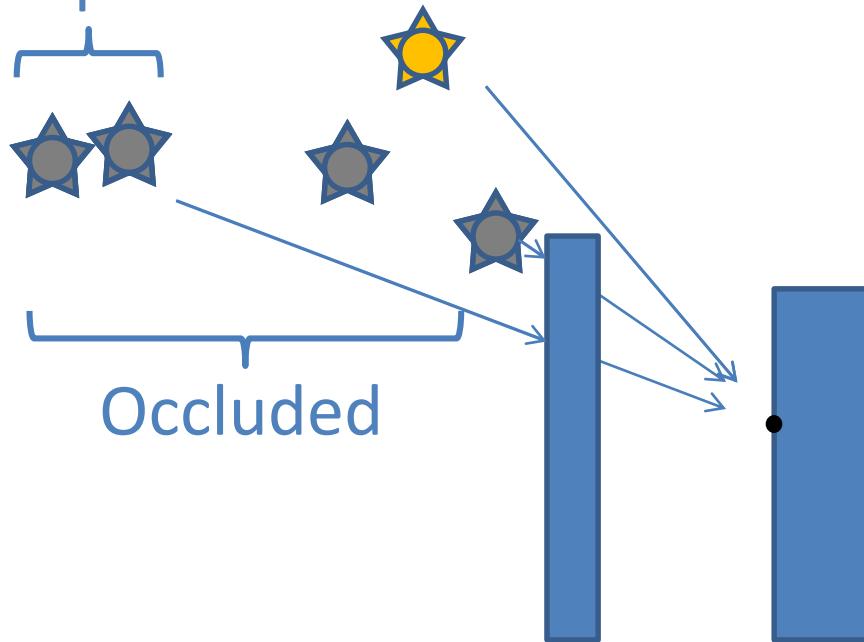
- Filtering
  - NonLocal Bayes [*Boughida and Boubekeur 2017*]

- Global illumination
  - Bayesian Monte Carlo [*Brouilat et al. 2009, Marques et al. 2013*]
 - Path guiding [*Vorba et al. 2014*]

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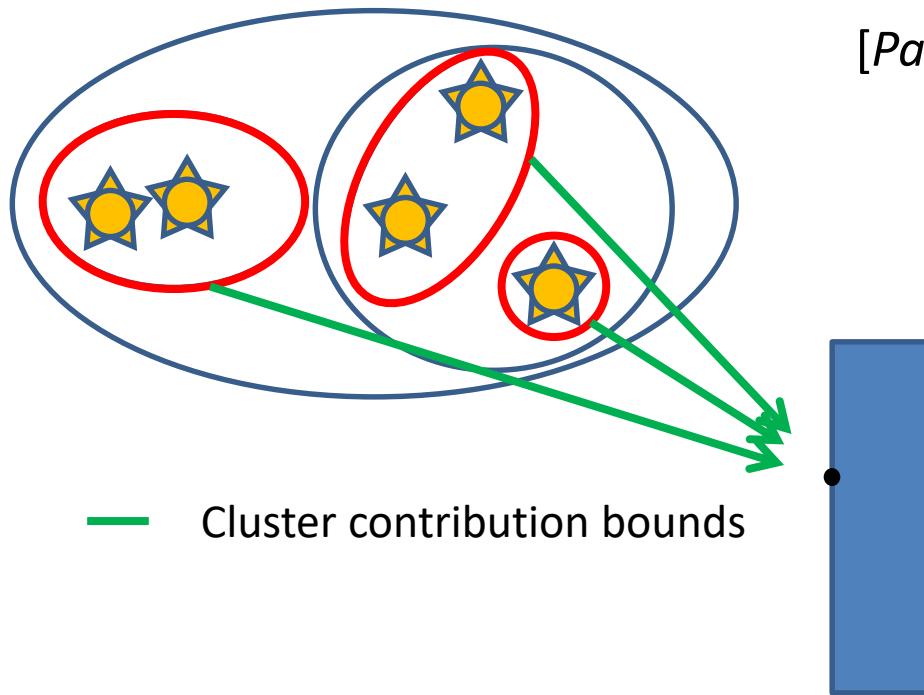
Background

Direct illumination

Less important

Occluded
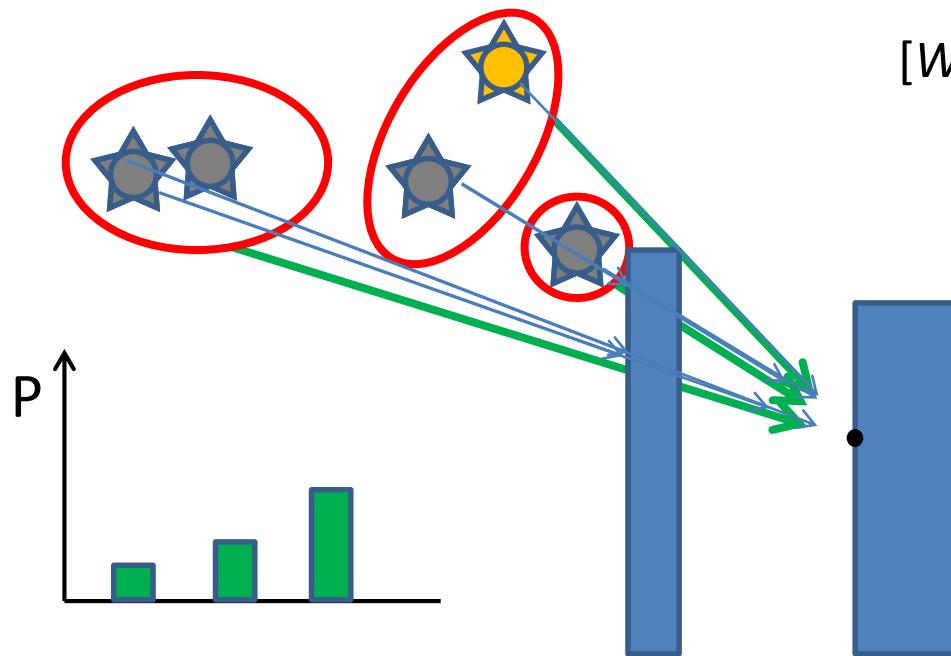
Clustering (Lightcuts)
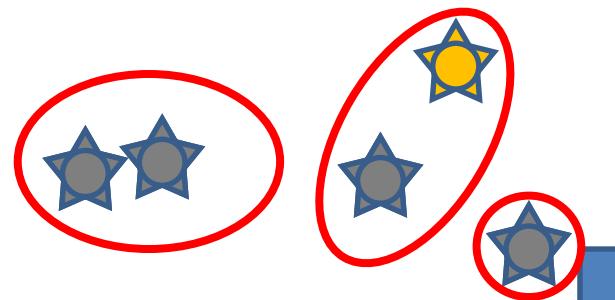
[*Paquette et al. 1998,*

Walter et al. 2006]

Cluster contribution bounds

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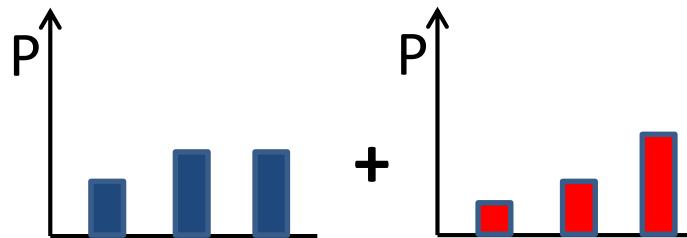
Cluster sampling

[*Wang and Akerlung 2009*]
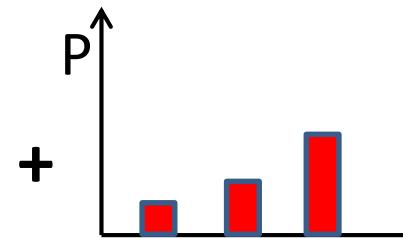
Adaptive light sampling

[*Donikian et al. 2006*]

Ad-hoc combination

P

P

+

screen space

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Problem summary

Cluster contribution bounds

MC estimate
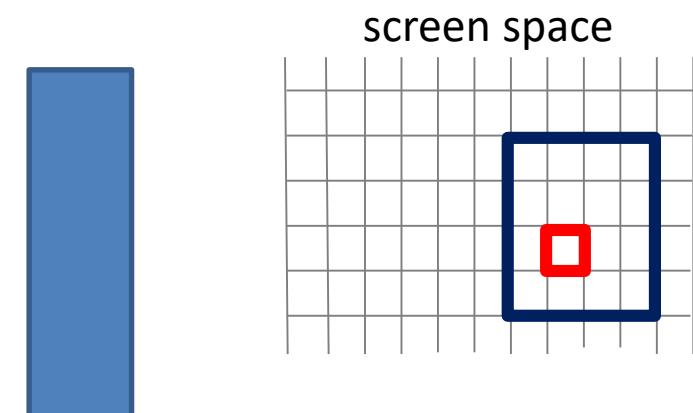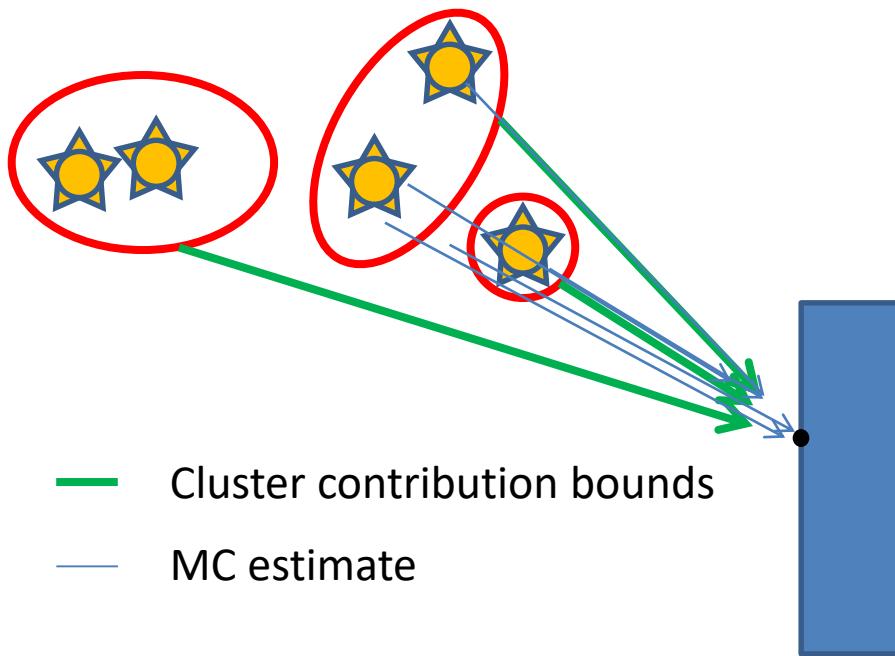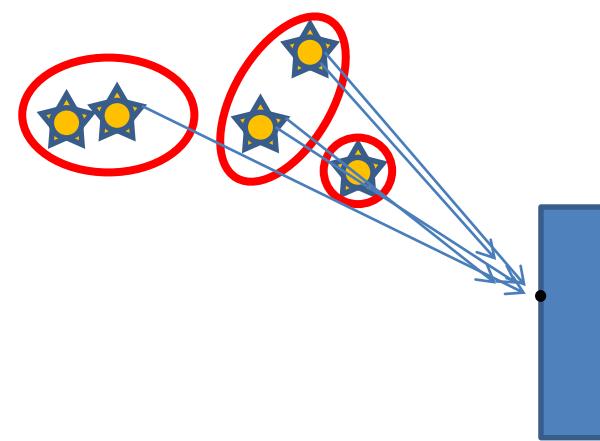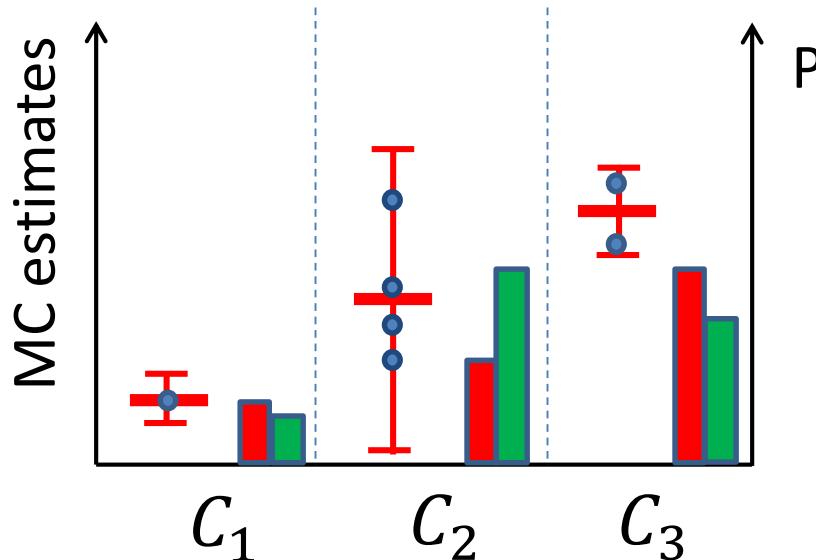
Our approach

Contributions

- Optimal sampling of clusters

- Adaptive sampling by Bayesian inference

Optimal cluster sampling

$$P(C) \propto \sqrt{\text{mean}^2 + \text{variance}}$$

Direct illumination only

Mean only (Previous)

Mean + Variance (Ours)
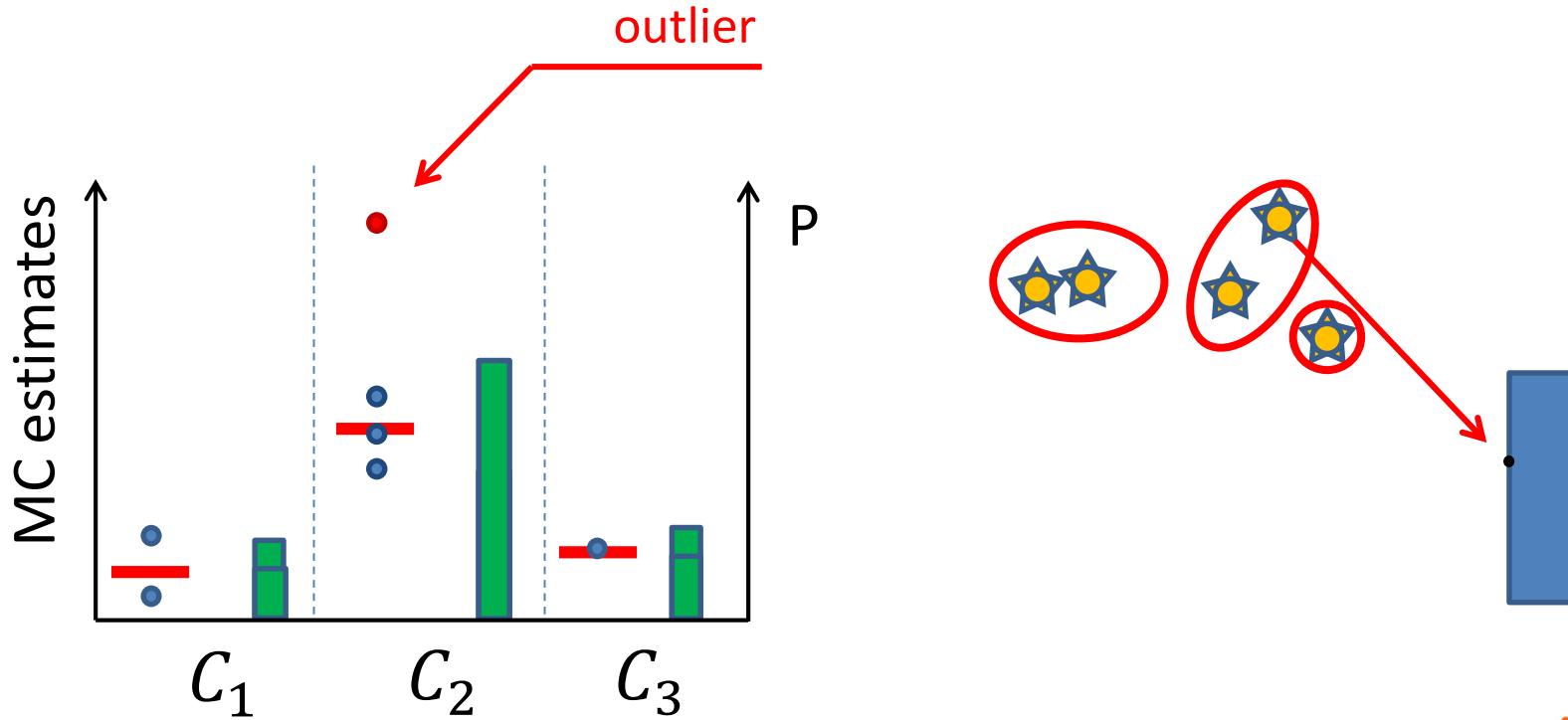
Direct illumination only
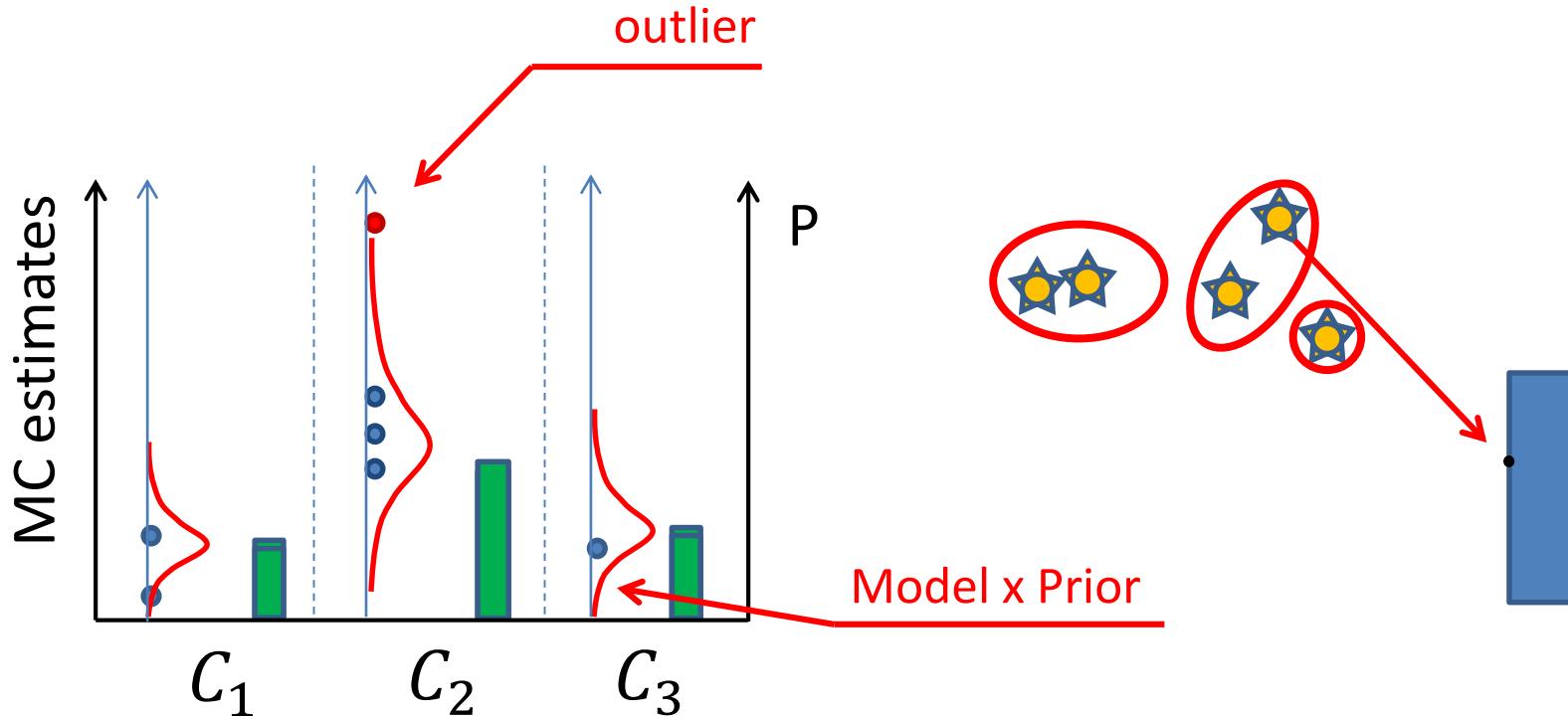
Contributions

- Optimal sampling of clusters
- Adaptive sampling by Bayesian inference
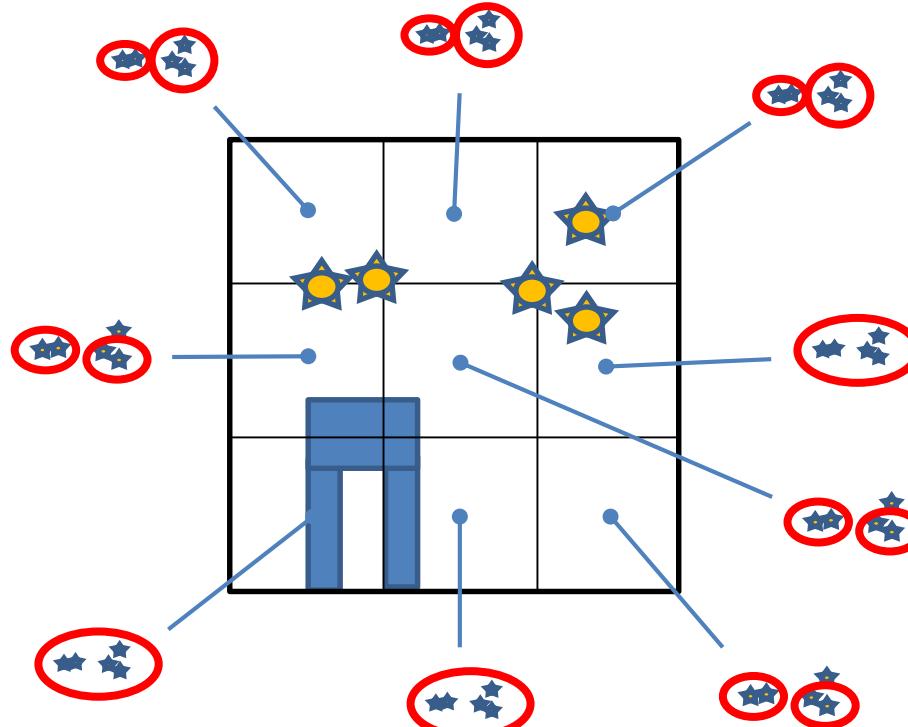
Naive adaptive cluster sampling
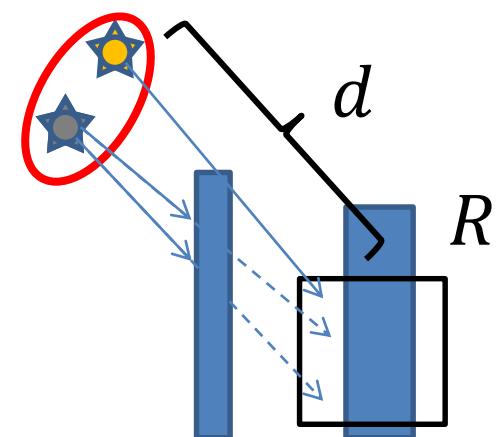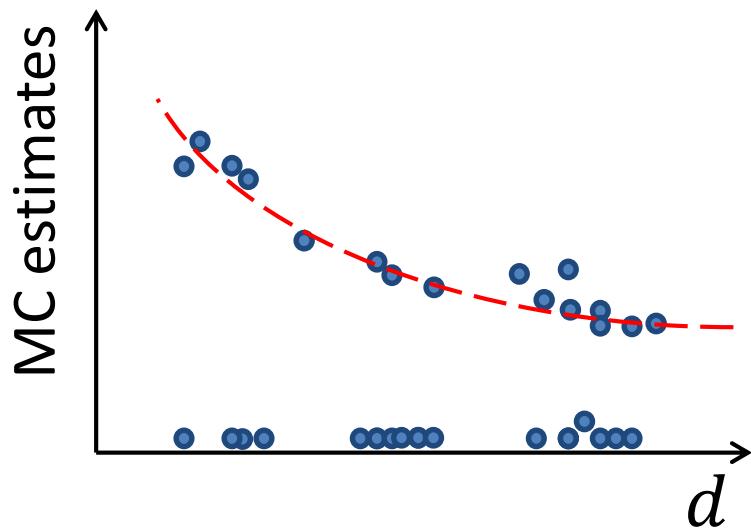
Bayes cluster adaptive sampling


outlier

P

MC estimates

C_1 C_2 C_3

Model x Prior

Cluster-region pairs
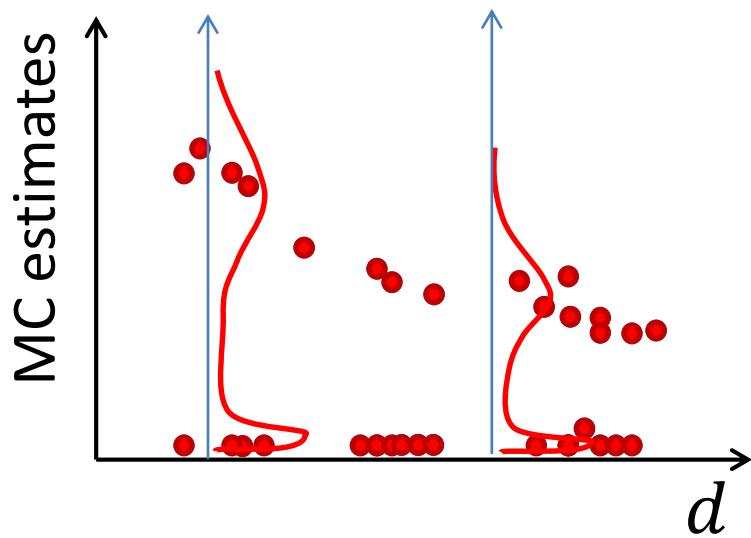
# Cluster-Region data

Regresion Data model

Cluster-Region data

Parameters:
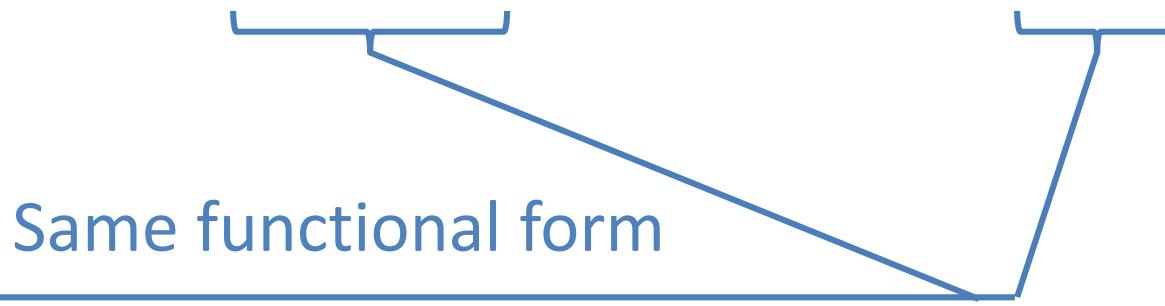
k, h - normal distr. parameters

p_0 - probability of occlusion

$$(1 - p_0) \times N(\text{est.} | \frac{k}{d^2}, \frac{h}{d^4})$$

$$p_0 \times \delta(\text{est.})$$

Conjugate prior

$$\textbf{\textcolor{red}{posterior}} \propto \text{likelihood} \times \textbf{\textcolor{red}{prior}}$$

Same functional form

Our (conjugate) Priors

$$p_0 \sim \text{Beta}(p_0| \; ... \;)$$

$$k, h \sim \text{Normal inverse gamma}(k, h|\mu_0, ... \;)$$

Hyperparameters

Cluster contrib. estimate

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Summary

- Light preprocess (clustering)
- During each Next event estimation:
  - Obtain clustering (Cut) cached in a region
  - Compute distributions of estimates for each cluster in Cut
    -> mean, variance
  - Build distribution over clusters
  - Sample direct illumination
  - Record new data for sampled cluster

Results

Tests

- Performance
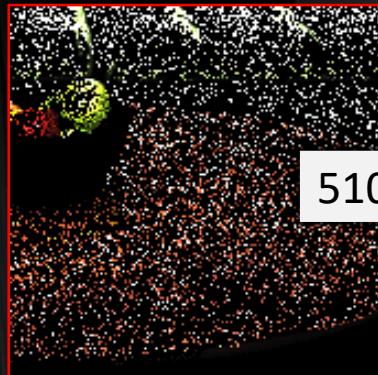
	Direct only	Direct + indirect
Simple occlusion		
Complex occlusion		

- Grid resolution

- Temporal coherence

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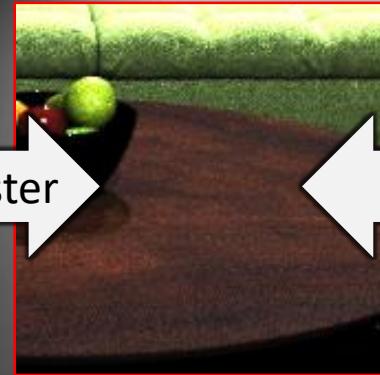
Direct illumination only
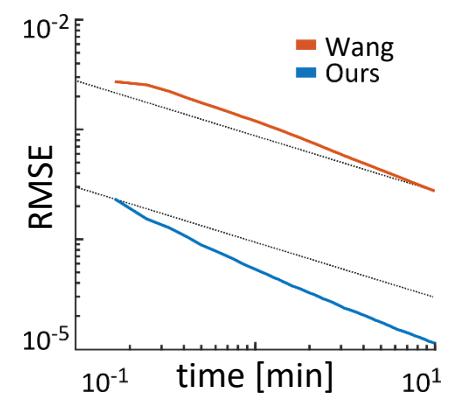
Wang Ours Donikian

510x faster Robust

RMSE vs time [min]
Wang
Ours
10^{-2}
10^{-5}
10^{-1} 10^{1}

Direct illumination only

Tests

- Performance

|	Direct only	Direct + indirect
Simple occlusion	✓	
Complex occlusion		

- Grid resolution

- Temporal coherence

Direct + indirect illumination

Wang

Wang

6.7x faster

6.7x faster

Ours

Ours

Direct + indirect illumination
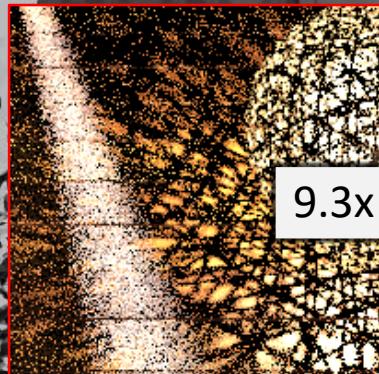
Tests

- Performance

	Direct only	Direct + indirect
Simple occlusion	✓	✓
Complex occlusion		

- Grid resolution

- Temporal coherence
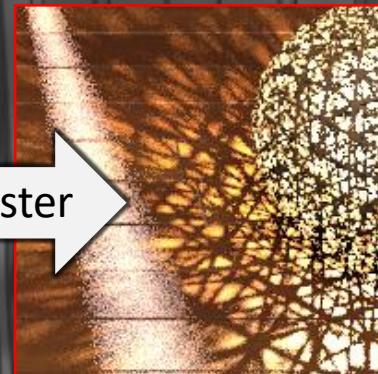
Direct illumination only
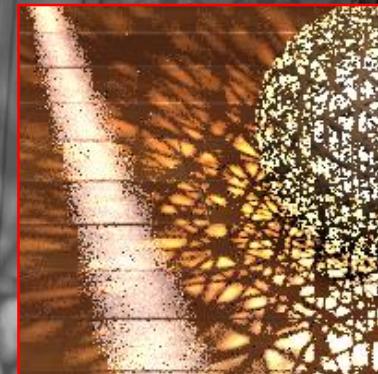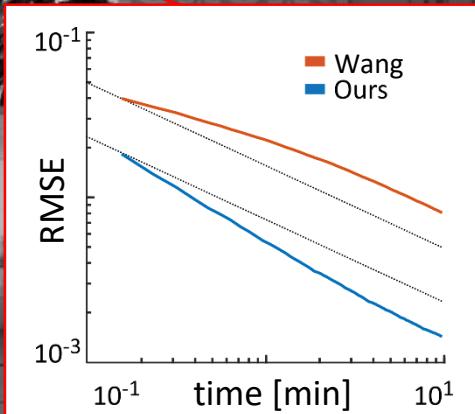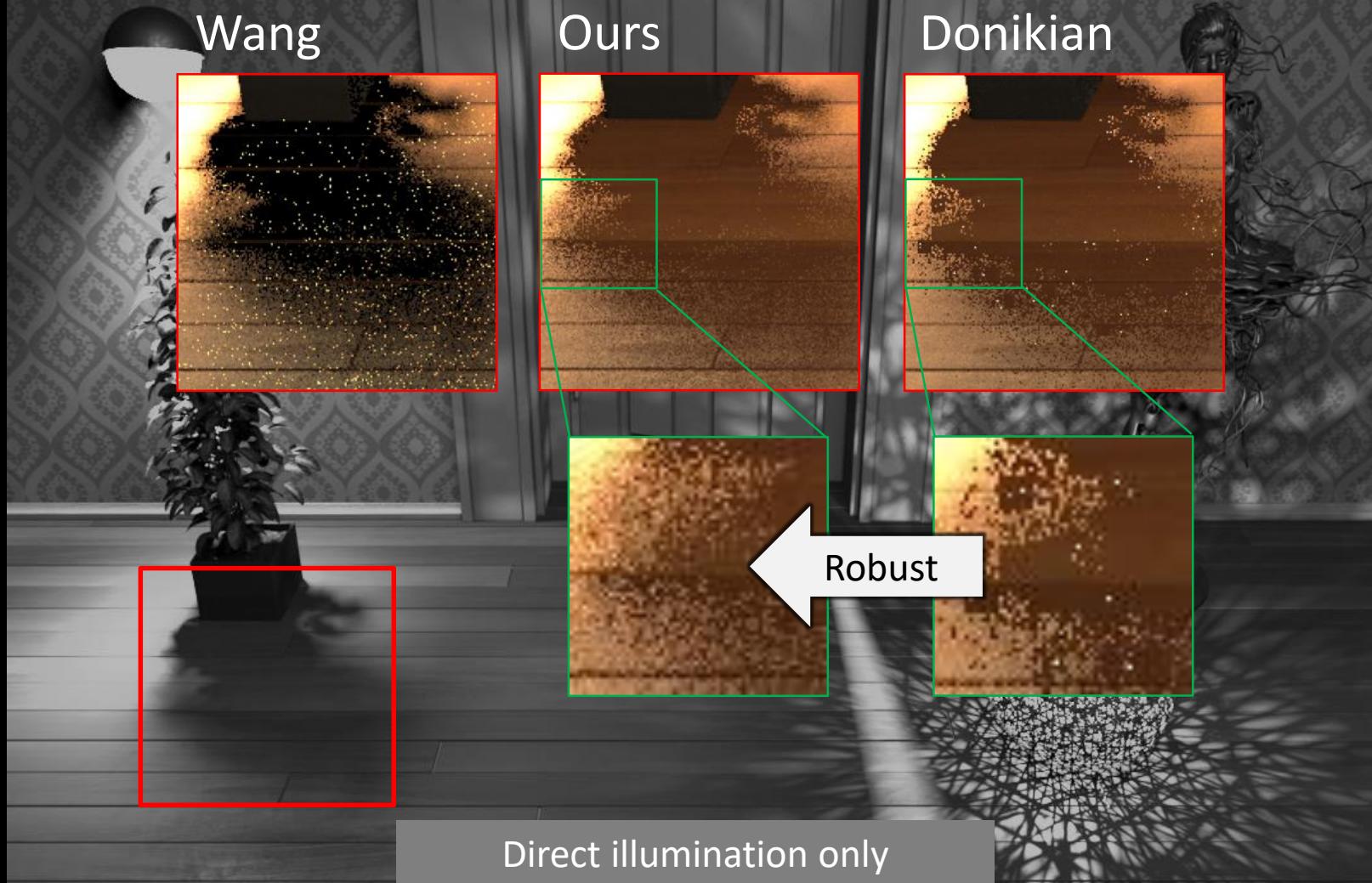
Wang

Ours

Donikian

9.3x faster

Direct illumination only
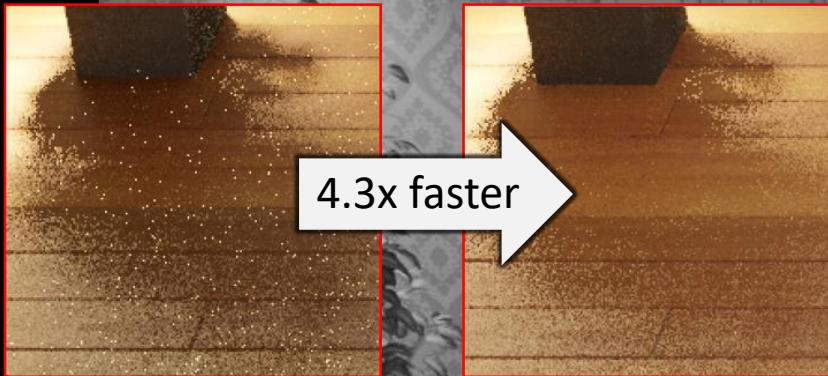
Wang

Ours

Donikian

Robust

Direct illumination only

Tests

- Performance

|	Direct only	Direct + indirect
Simple occlusion	✓	✓
Complex occlusion	✓	

- Grid resolution

- Temporal coherence
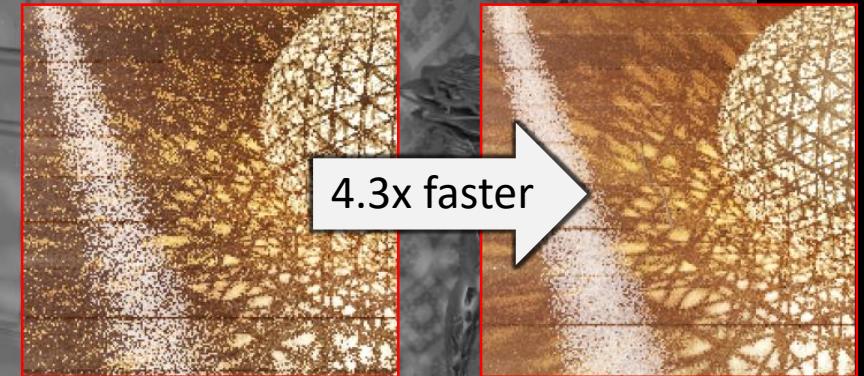
Direct + indirect illumination

Wang Ours Wang Ours

4.3x faster 4.3x faster

Direct + indirect illumination
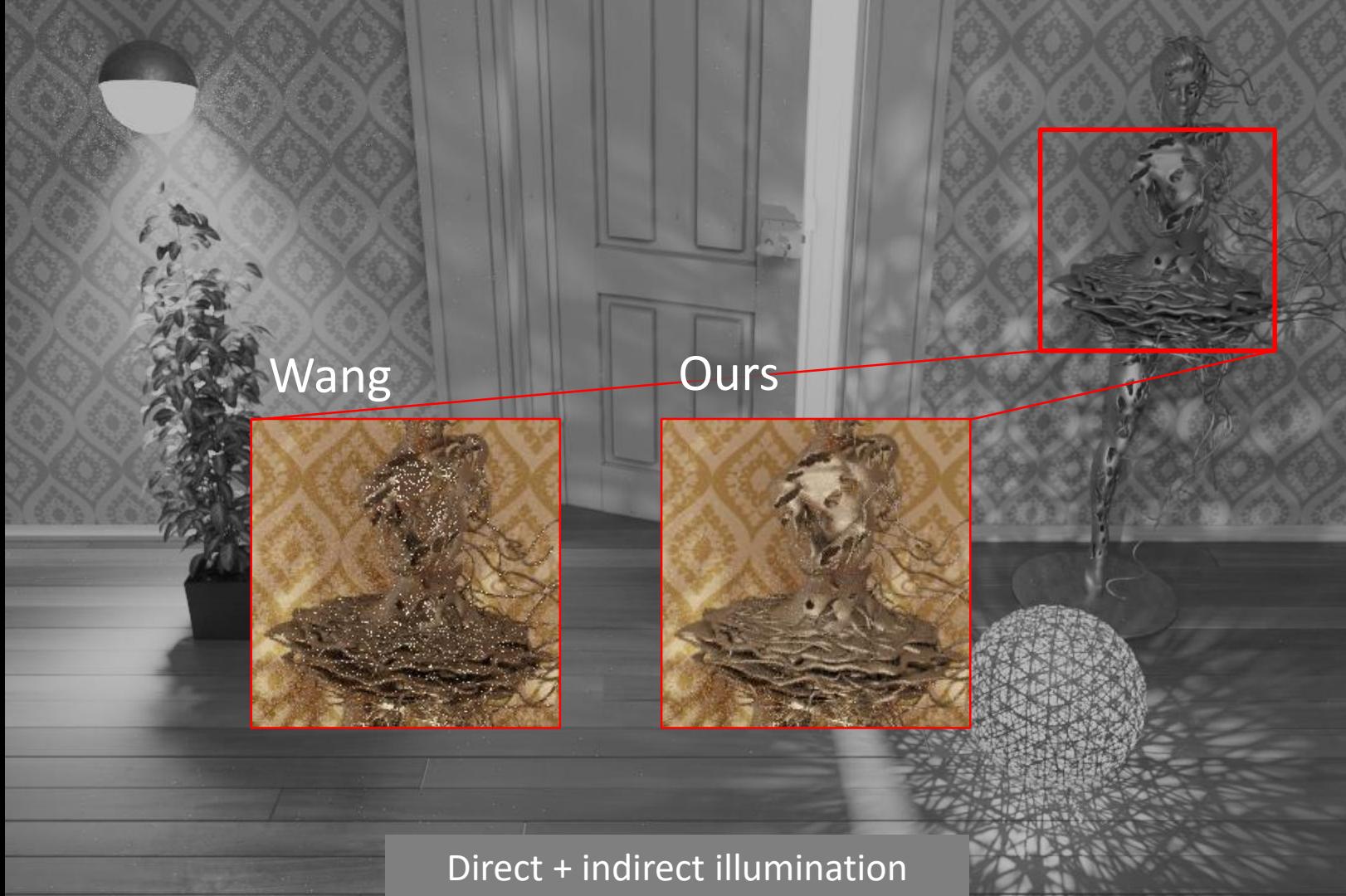
Wang

Ours

Direct + indirect illumination

Tests

- Performance ✓

	Direct only	Direct + indirect
Simple occlusion	✓	✓
Complex occlusion	✓	✓

- Grid resolution
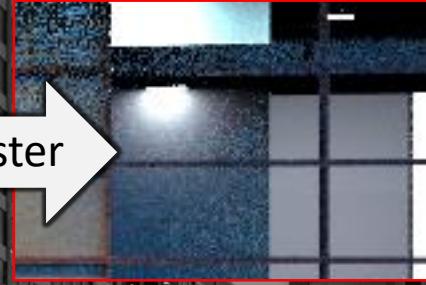
- Temporal coherence

Direct illumination only
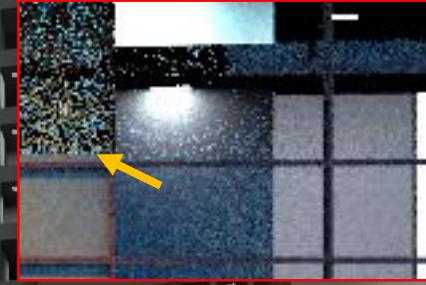
Wang   Ours (64)   No regression

3.6x faster
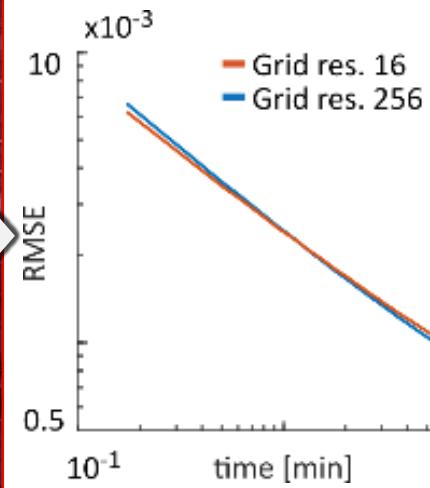
$$(1 - p_0) \times N\left(\text{est.} \middle| \frac{k}{d^2} \quad \frac{h}{d^4}\right)$$
$$p_0 \quad \times \delta(\text{est.})$$

Direct illumination only

Tests

- Performance ✓

	Direct only	Direct + indirect
Simple occlusion	✓	✓
Complex occlusion	✓	✓

- Grid resolution ✓

- Temporal coherence

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Ours

Wang

Direct illumination only

Conclusion

Future work

- BRDF incorporation

- Adaptive scene subdivision

- Rigorous hyperparameters derivation

- Combination with path guiding
  [*Vorba et al. 2014, Muller et al. 2017*]

Contribution

- **Bayesian framework for robust adaptivity**

- Optimal cluster sampling

- Algorithm for direct illumination

  - Unbiased, adaptive, robust
  - Easy to integrate into a path tracer

Acknowledgments

- Ludvík Koutný (a.k.a. rawalanche)

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Thank you!