Adaptive Multiple Control Variates for Many-Light Rendering

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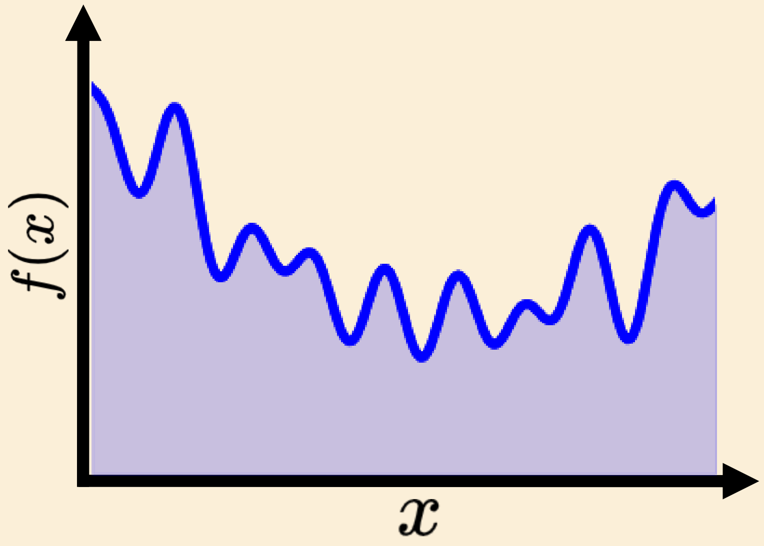
Shandong University, China

Problem Statement



$$F = \int_{[0,1]^D} f(x)dx$$

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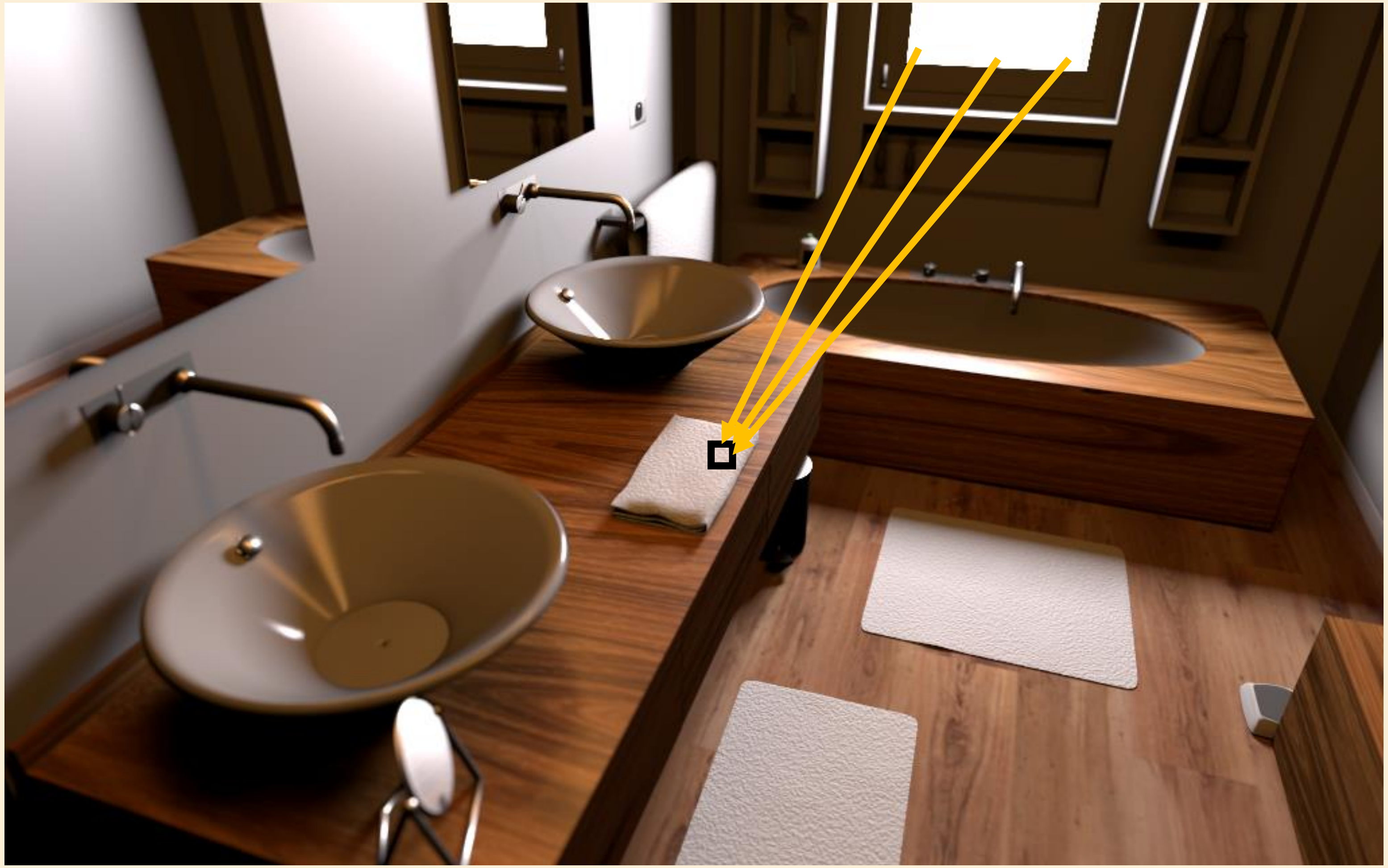
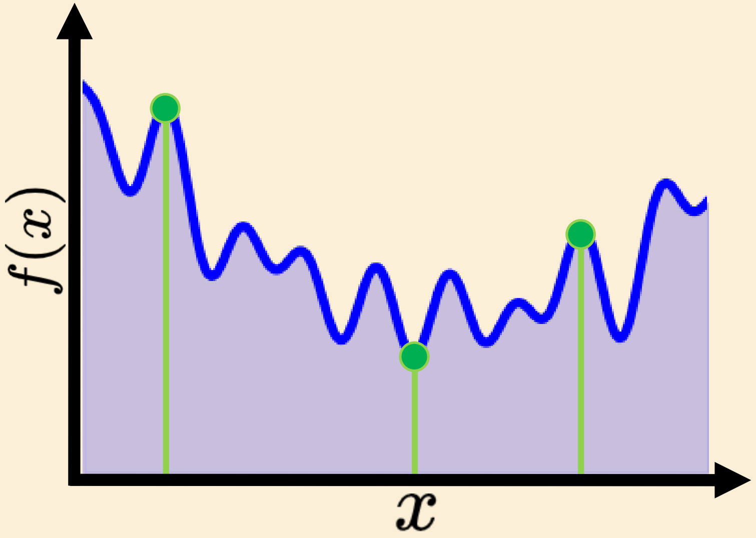
Light Transport Context





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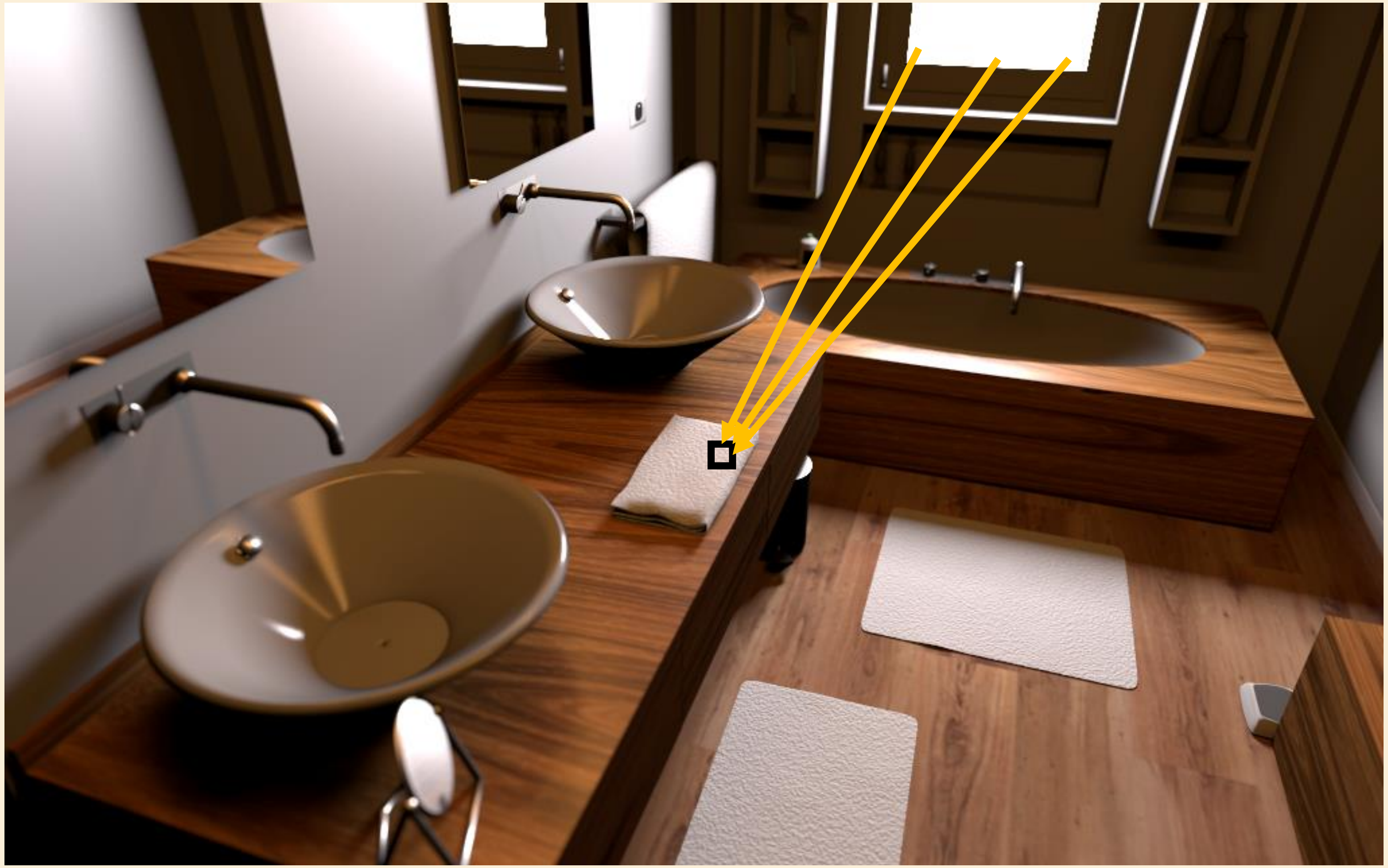
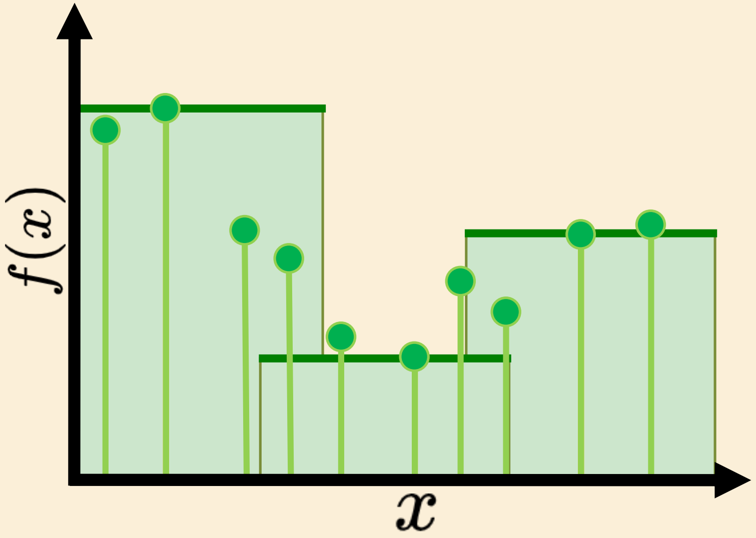
Monte Carlo





$$\langle F \rangle = \frac{1}{N} \sum_{i=1}^{N} f(x_i)$$

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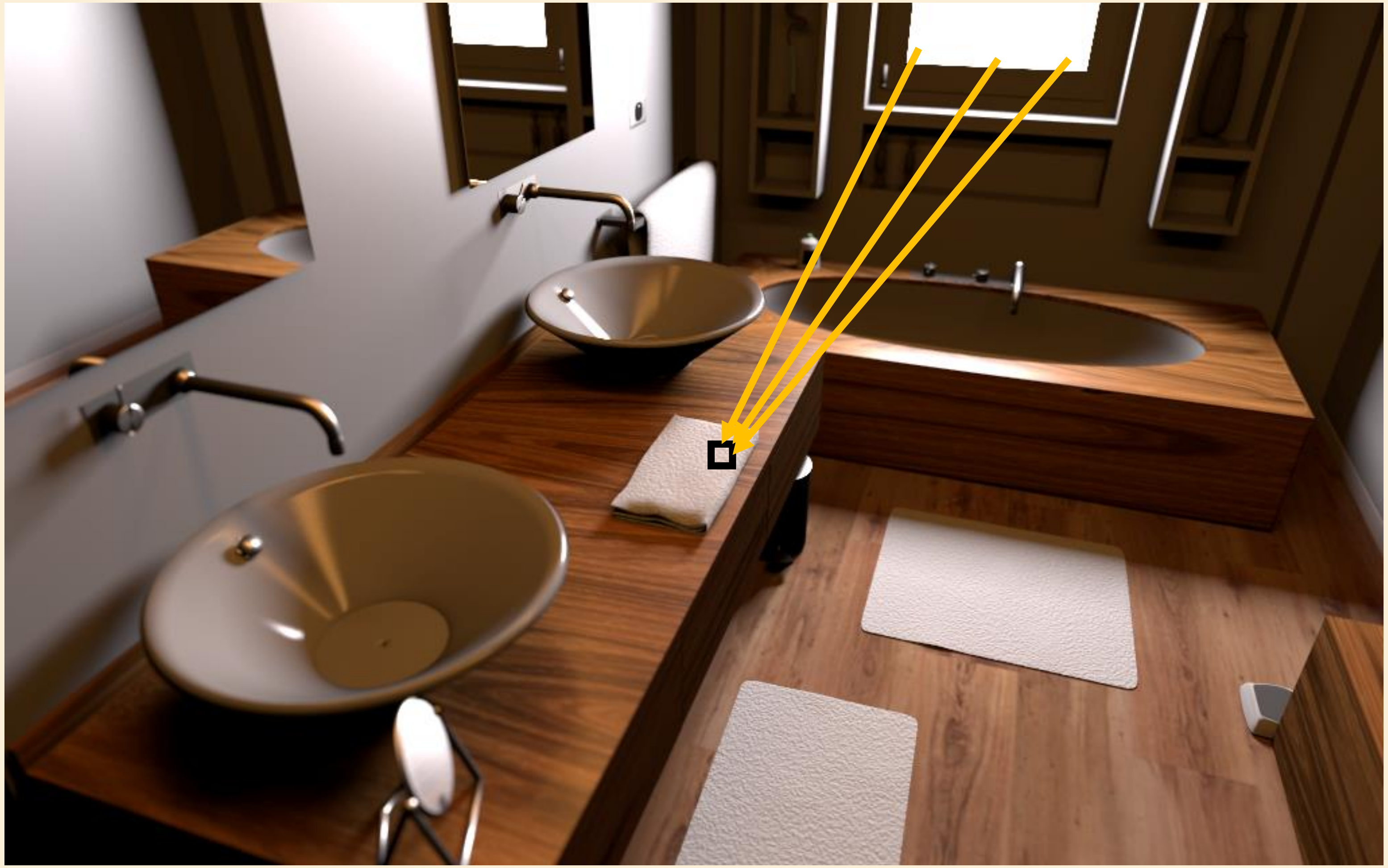
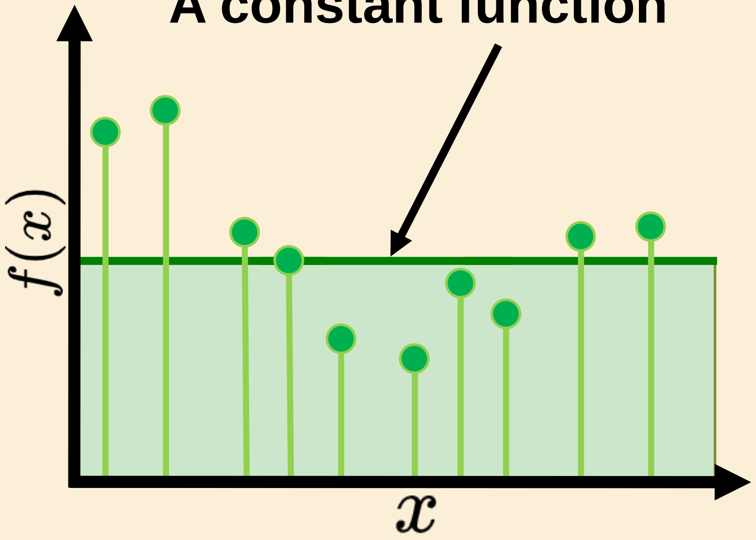
Calculus-oriented interpretation





$$\langle F \rangle = \frac{1}{N} \sum_{i=1}^{N} f(x_i)$$

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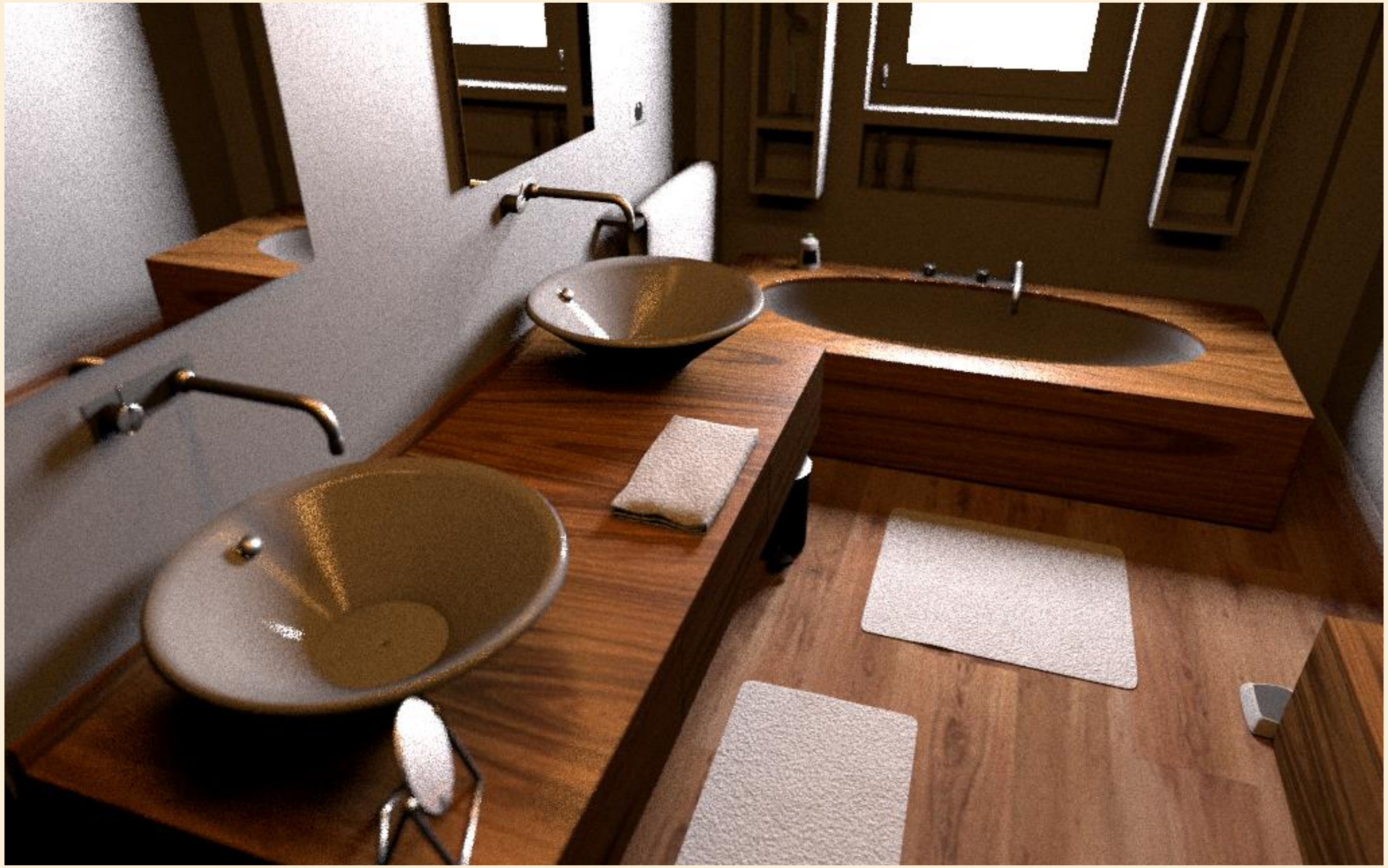
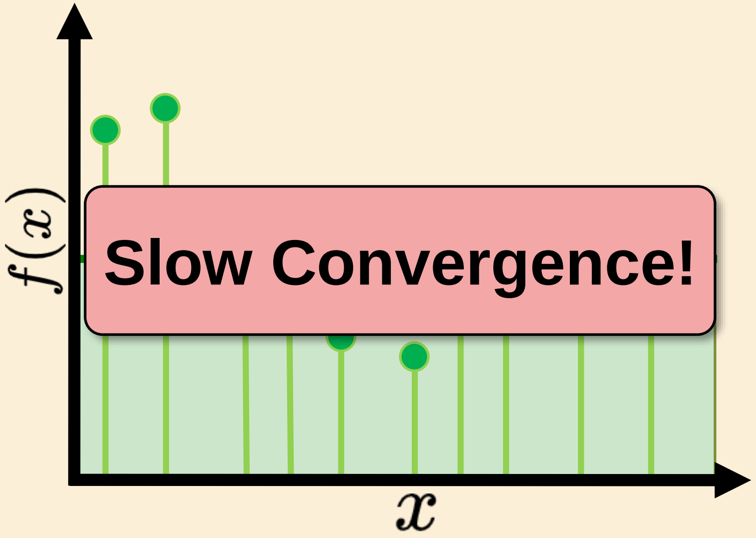
Limitations of Monte Carlo Integration

256 samples per pixel





$$\langle F \rangle = \frac{1}{N} \sum_{i=1}^{N} f(x_i)$$

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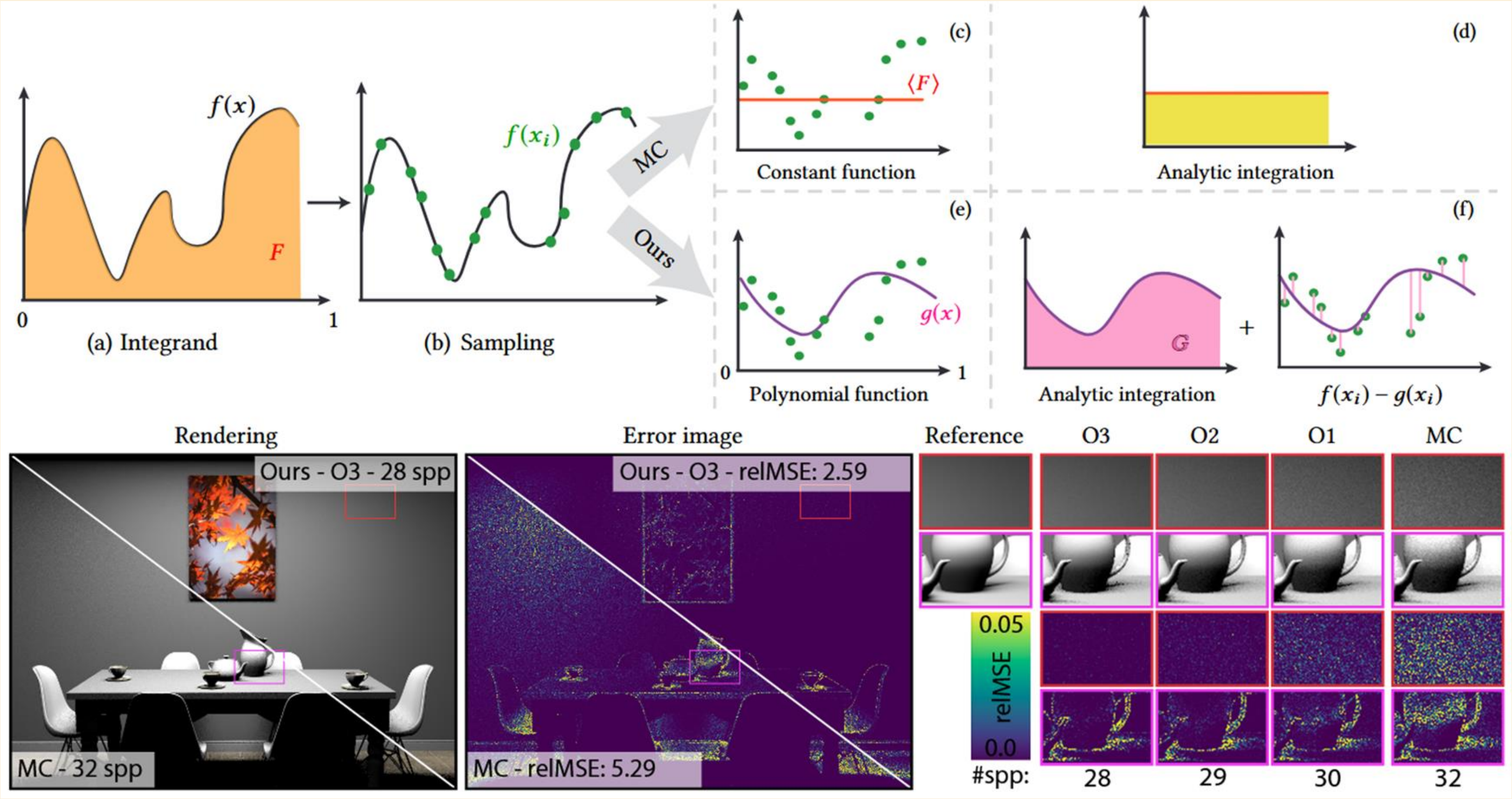
Regression-based Monte Carlo Integration



Regression

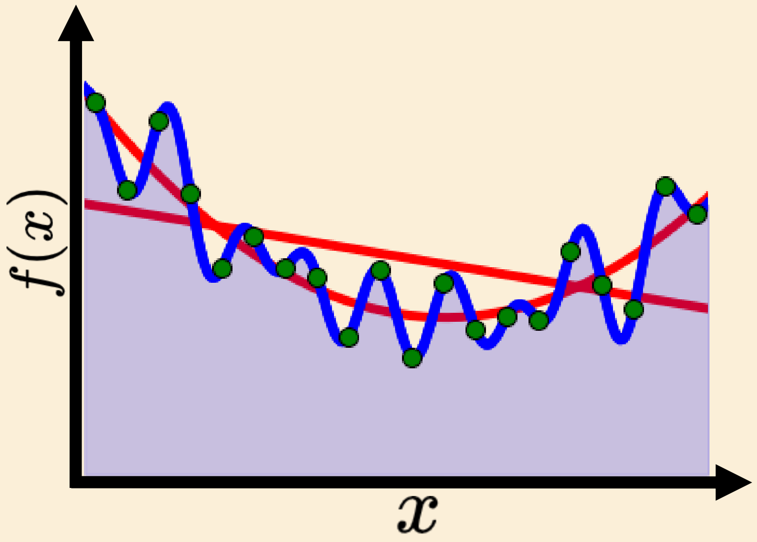
Control Variates

MC Integration

SIGGRAPH 2022
VANCOUVER+ 8-11 AUG

Salaün, C., Gruson, A., Hua, B. S., Hachisuka, T., & Singh, G. (2022). Regression-based Monte Carlo integration. ACM Transactions on Graphics (TOG), 41(4), 1-14.

Regression



[Salaün et al. 2022] proposed using a more complex function instead of a constant function.

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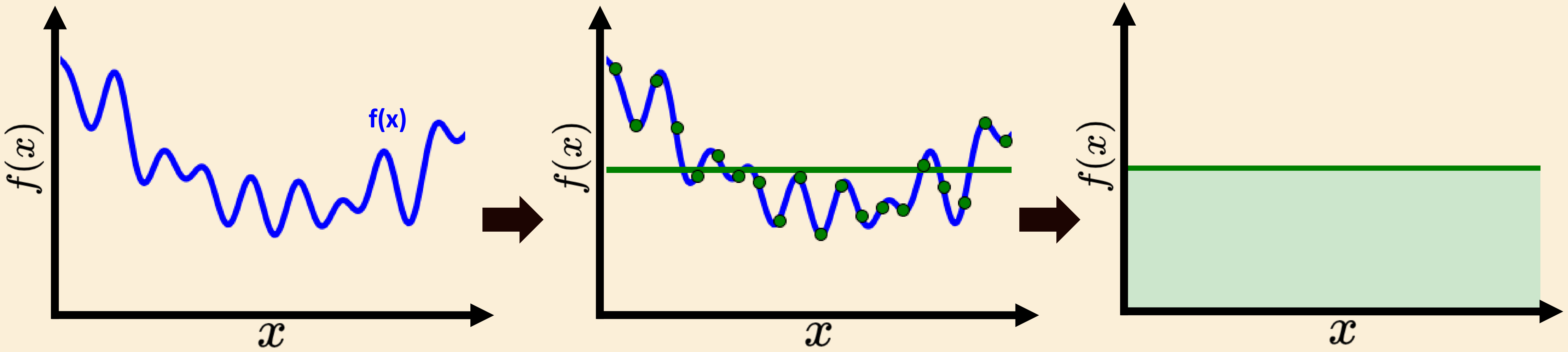
Regression



Regression

Integrand

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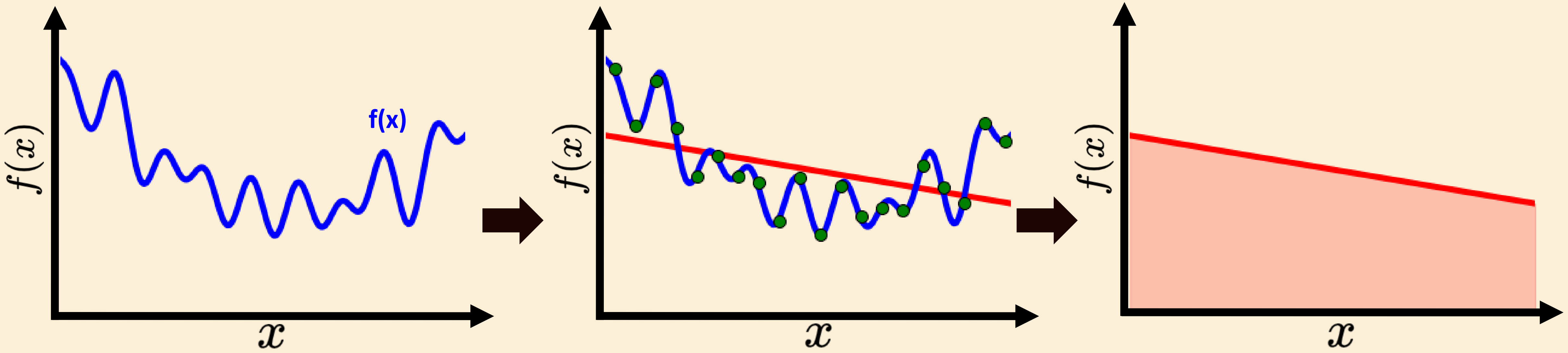
Regression



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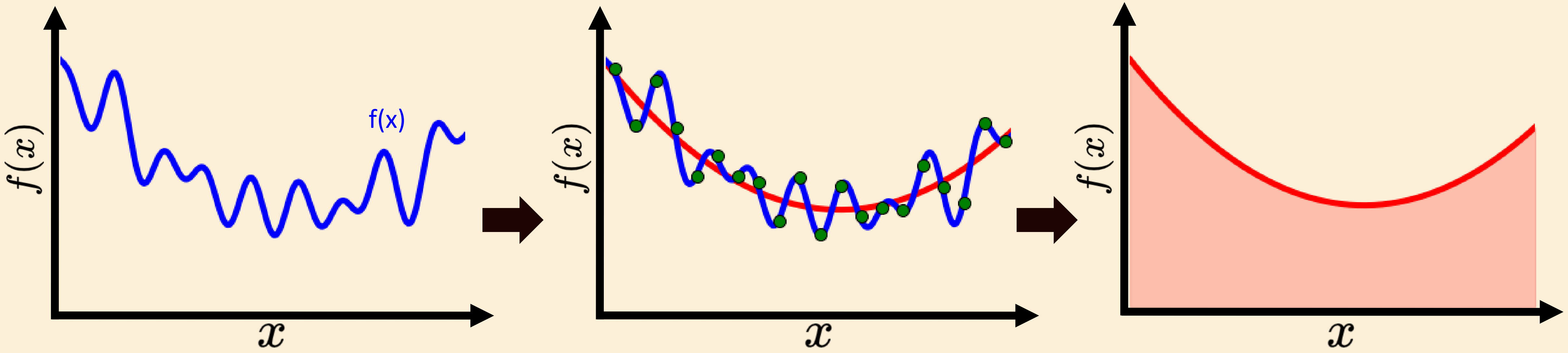
Regression



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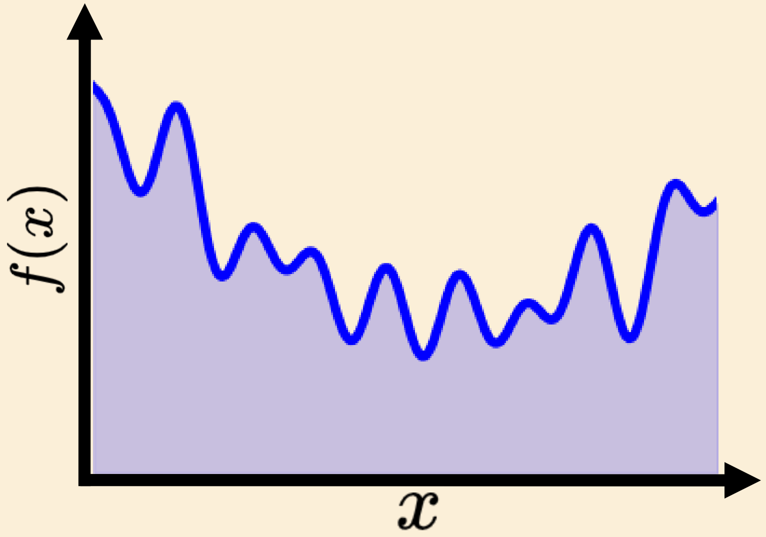
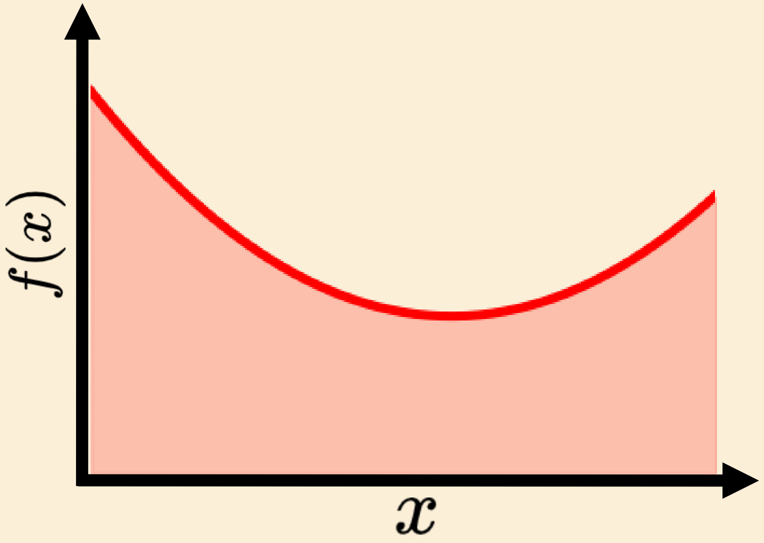
Regression Leads to Biased Result





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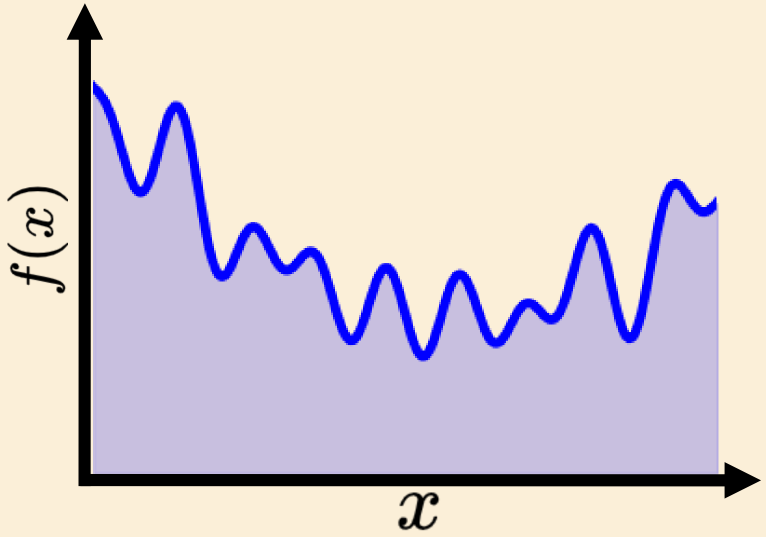
Regression Leads to Biased Result



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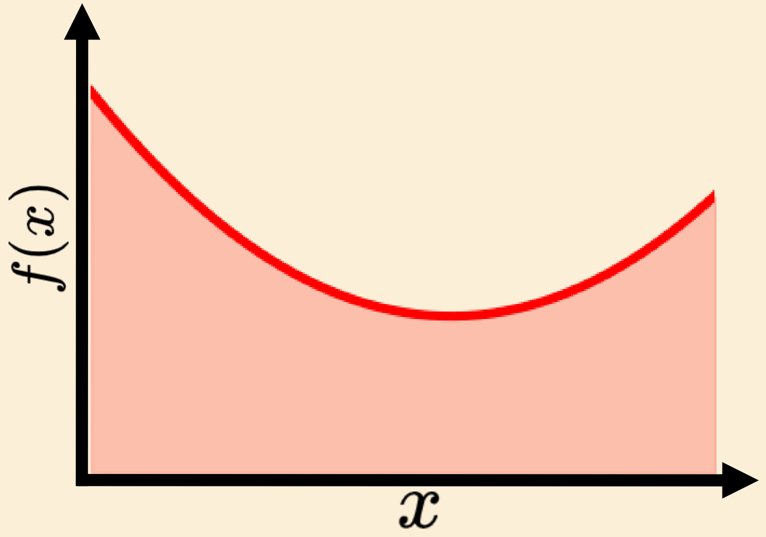

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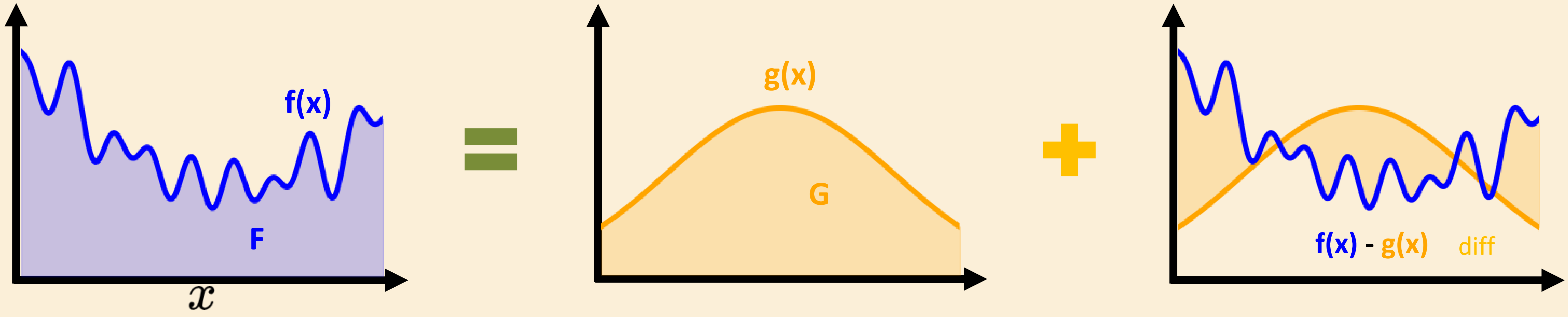
Control Variates Estimator



$$F = G + (F - G)$$

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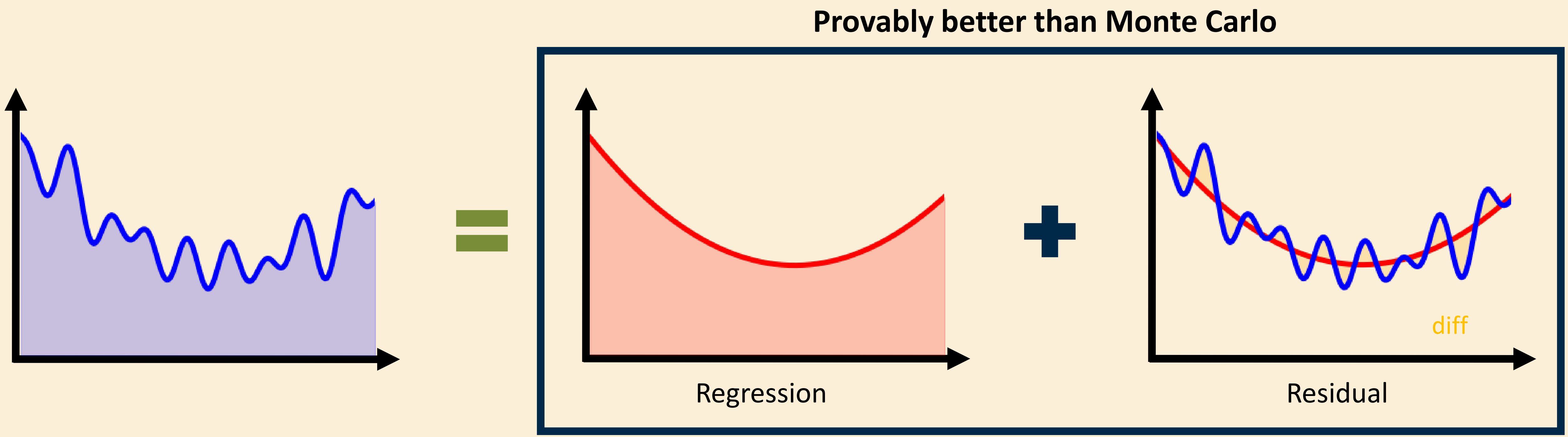
Regression-based Monte Carlo Integration



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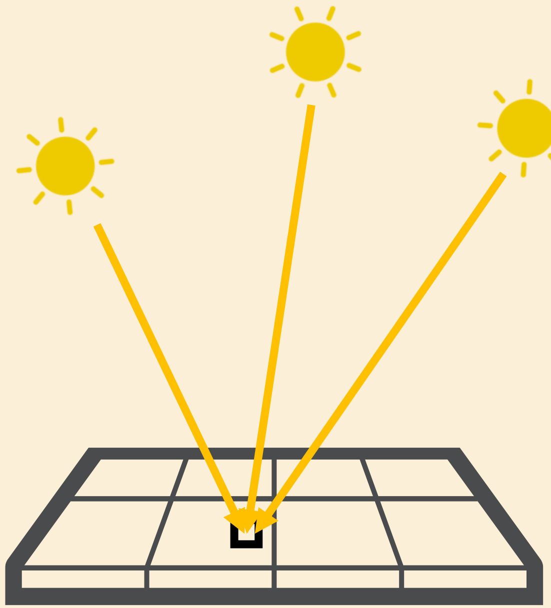
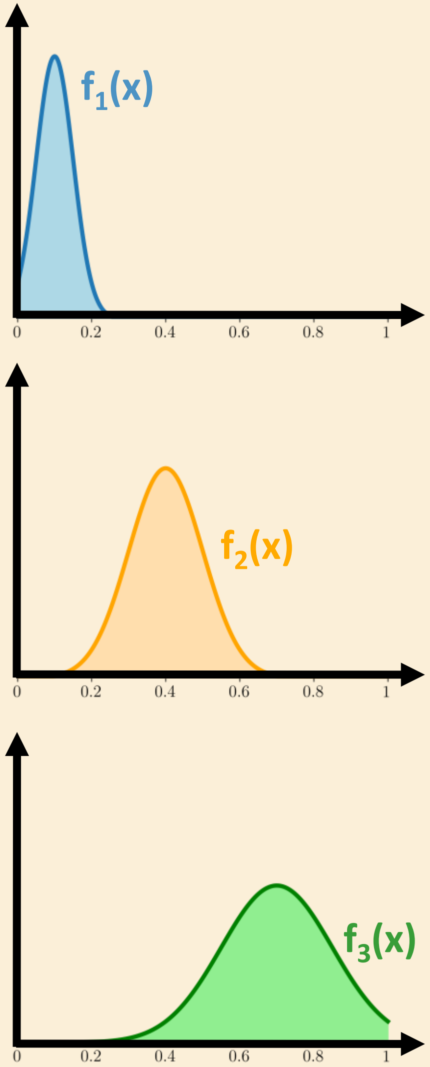
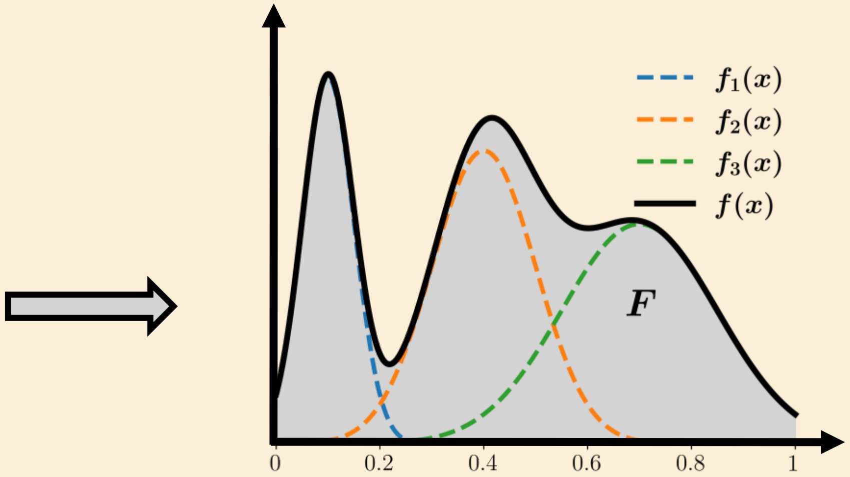
Challenges

- The least-squares regression solution is not exact for any finite number of samples.
- The integrand can be highly discontinuous due to complex scene configurations (especially in scenes with many lights or complex visibility).

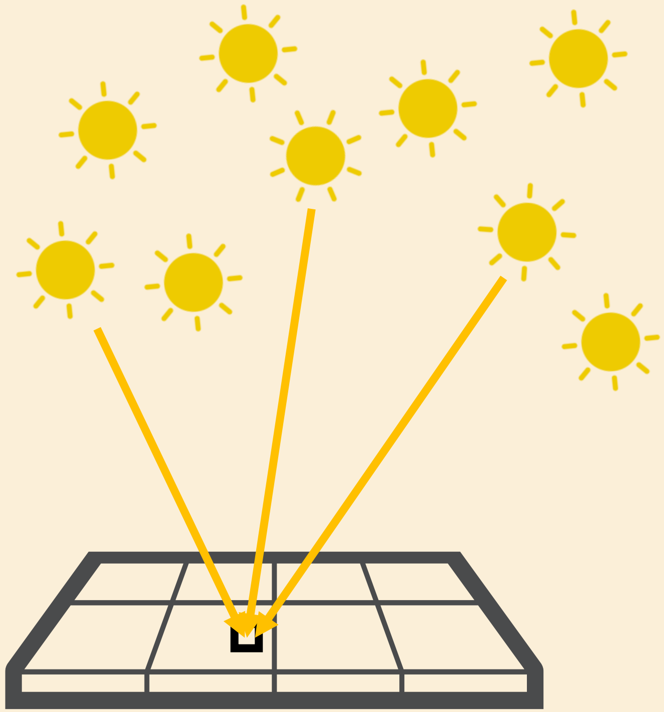
An Example Scene

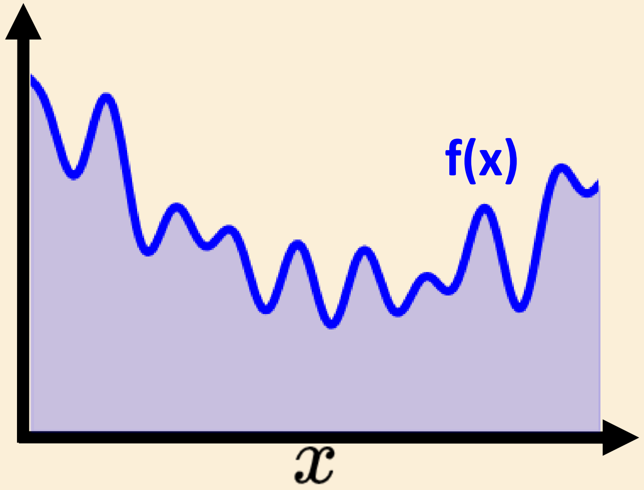






An Example Scene

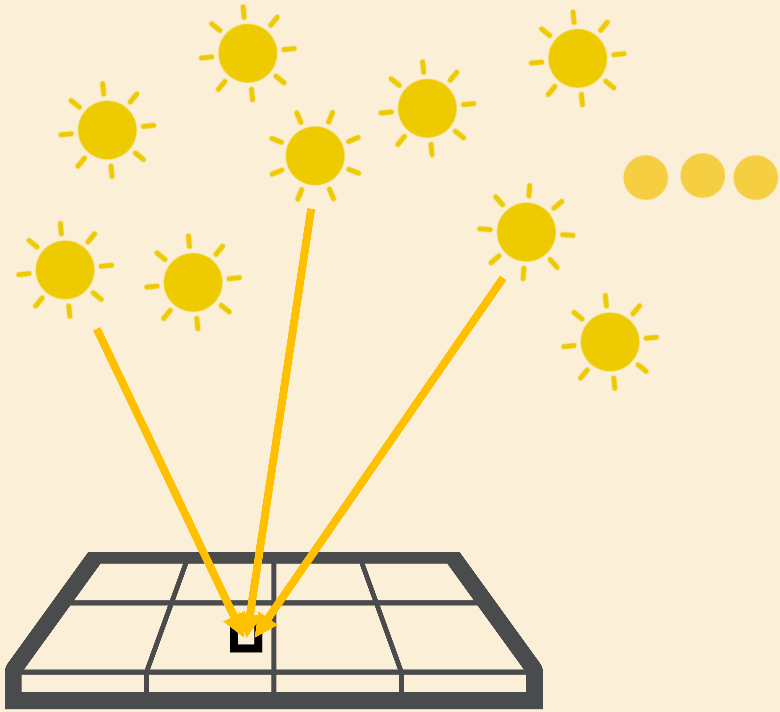


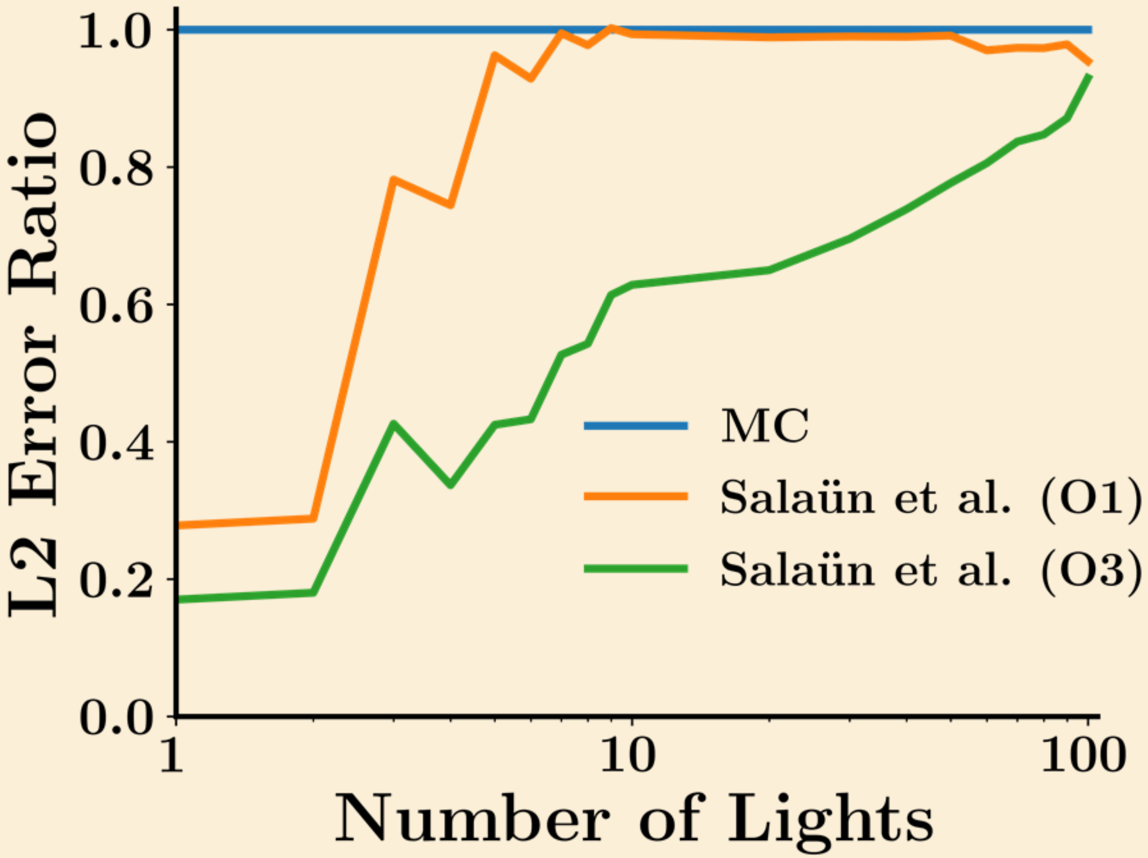


High-frequency!

Hard for regression!

Many-light Discontinuity

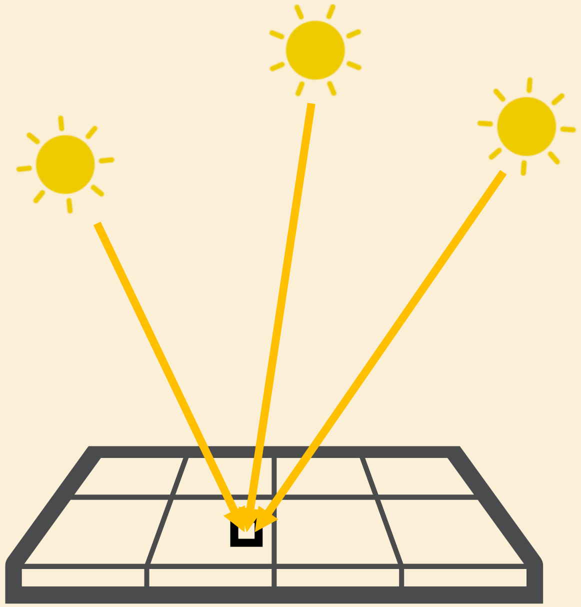




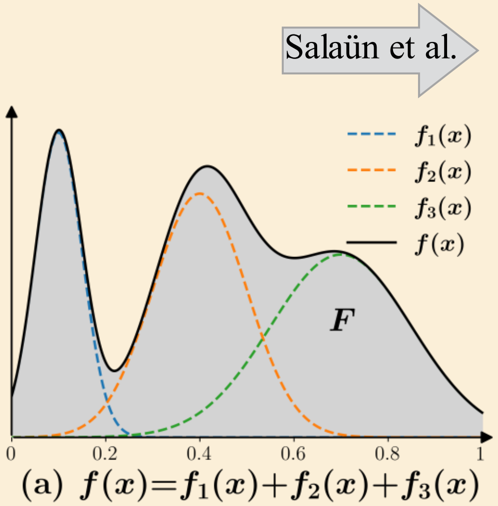
2 1

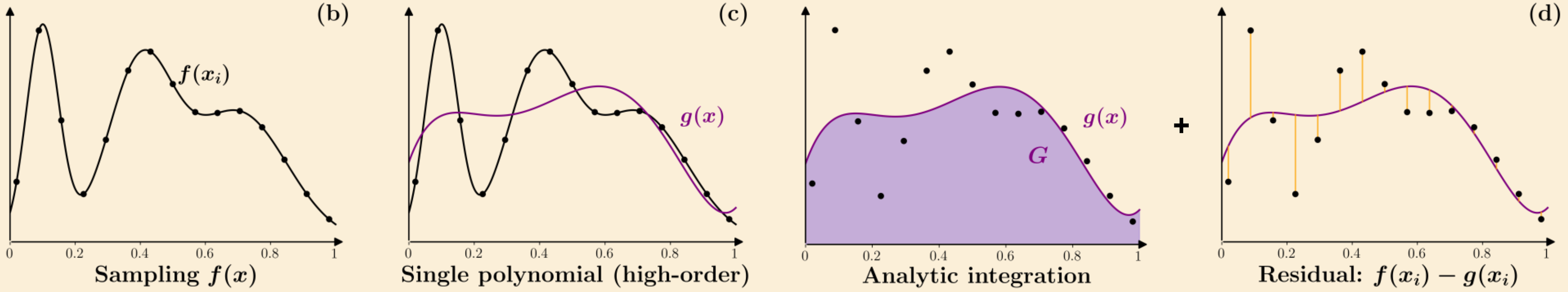
Adaptive Multiple Control Variates

An Example Scene



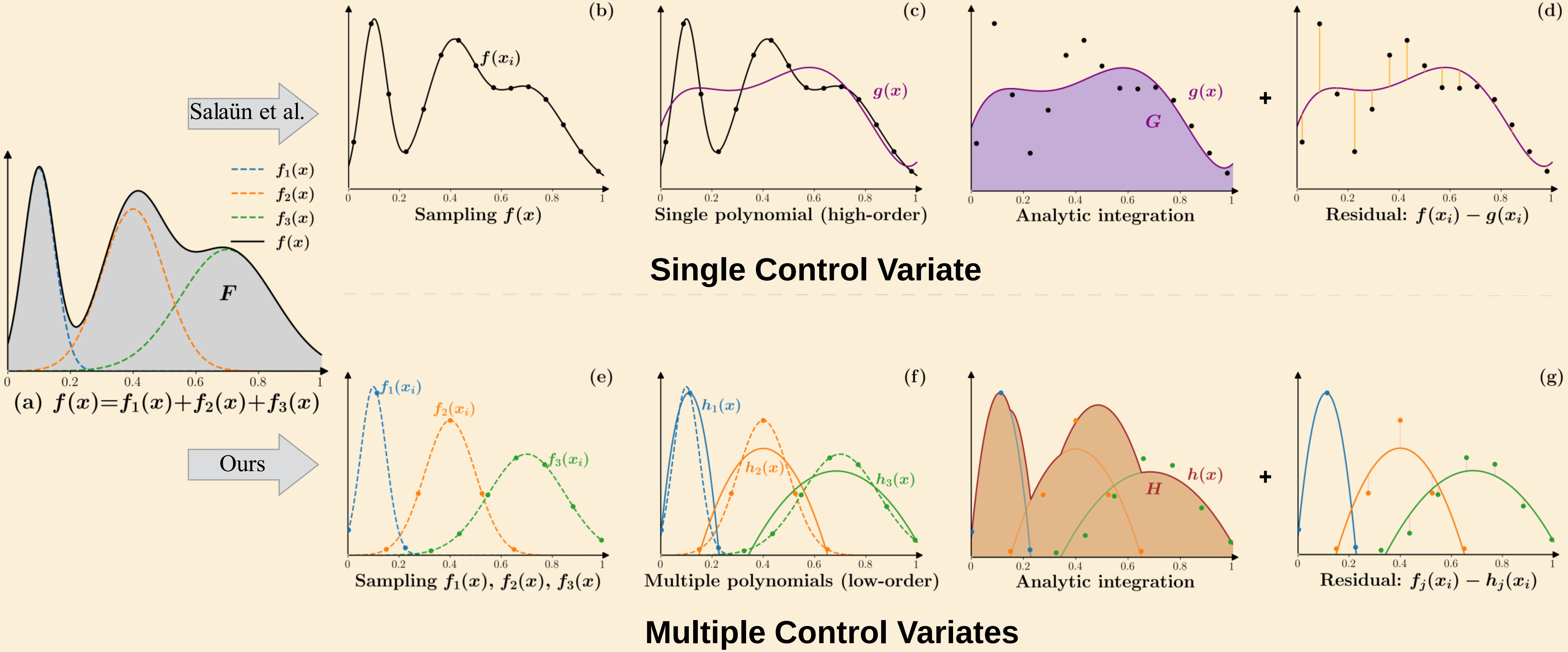
Multiple Control Variates vs. Single Control Variate



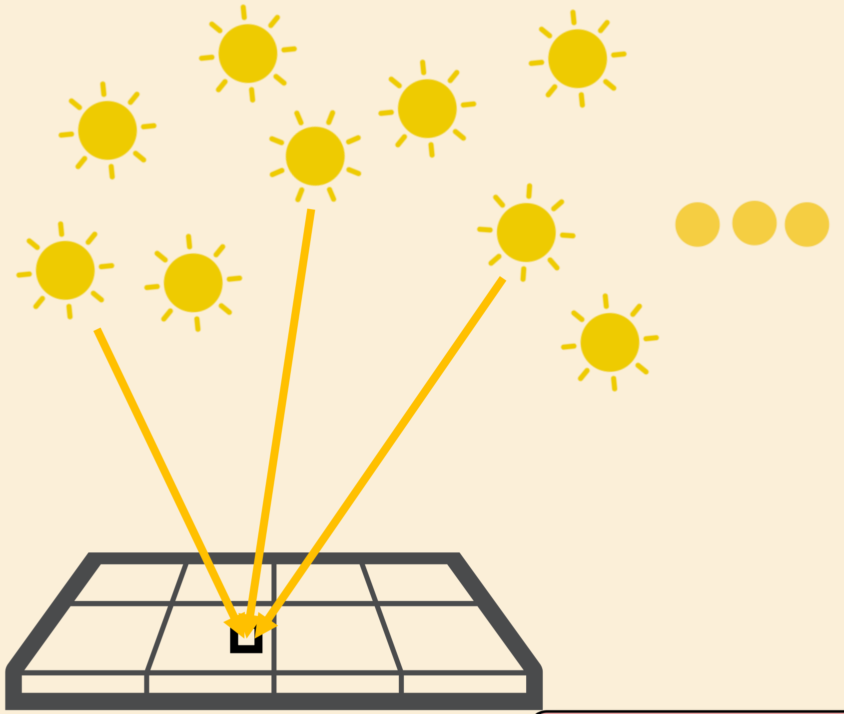


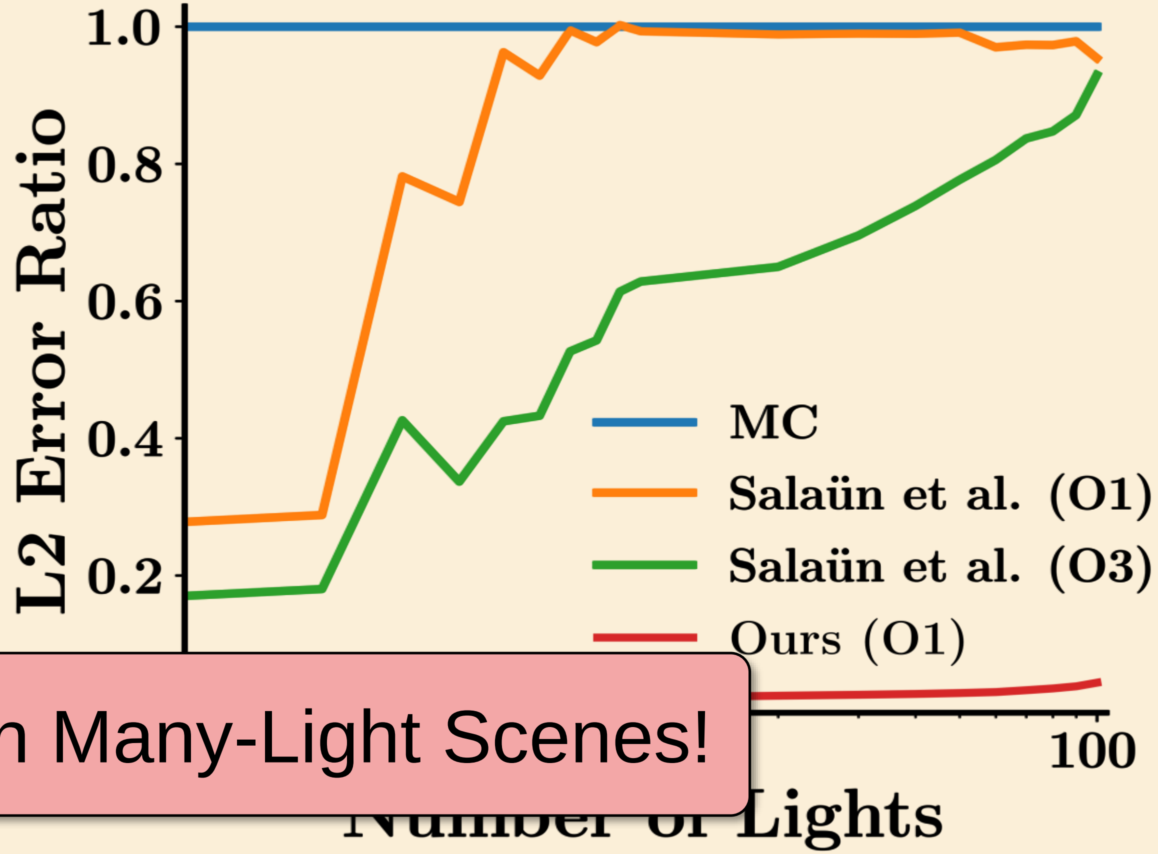
Single Control Variate

Multiple Control Variates vs. Single Control Variate



Results of Multiple Control Variates

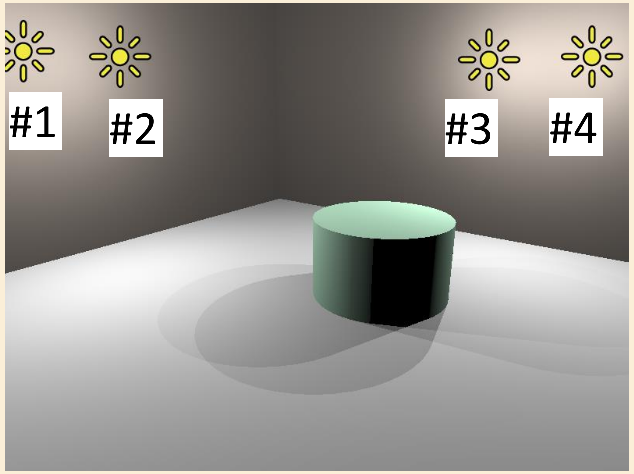




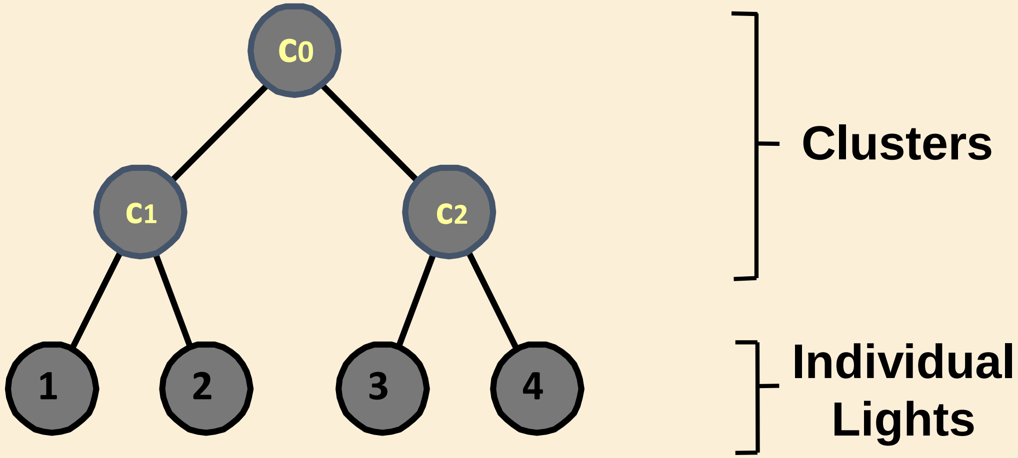
Scalability with Many-Light Scenes!

Lightcuts

Simple Example



Light Tree



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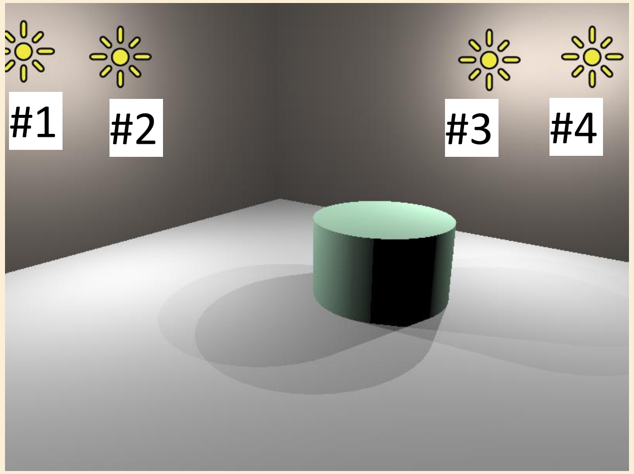
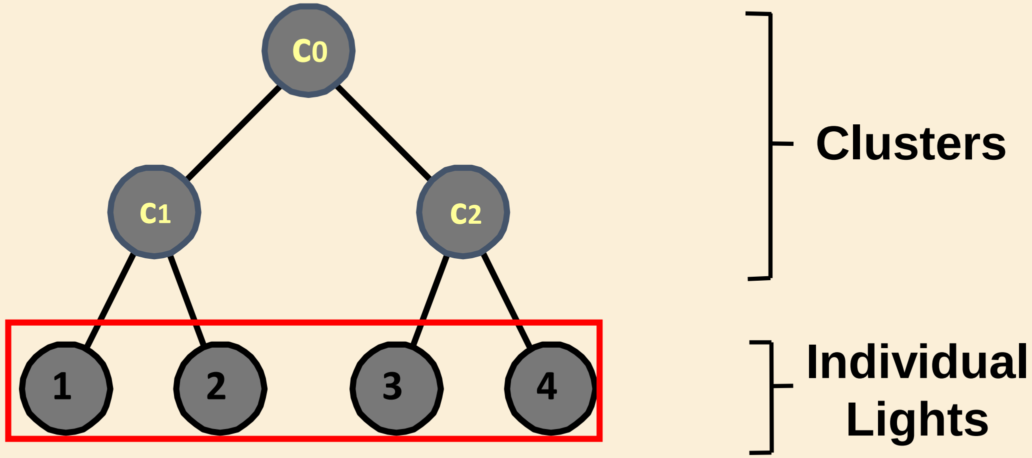
Lightcuts

Simple Example



Light Tree



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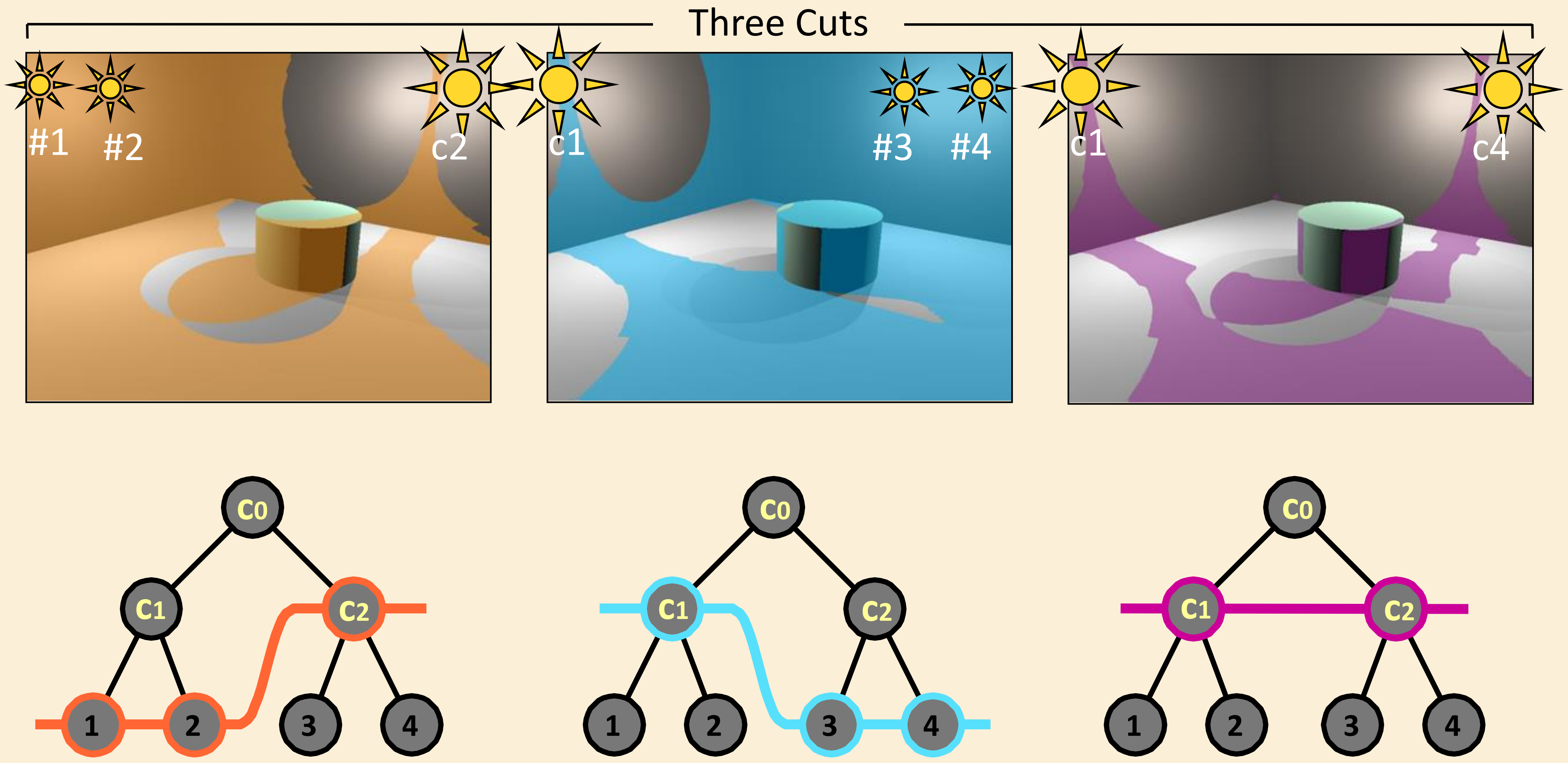
Lightcuts



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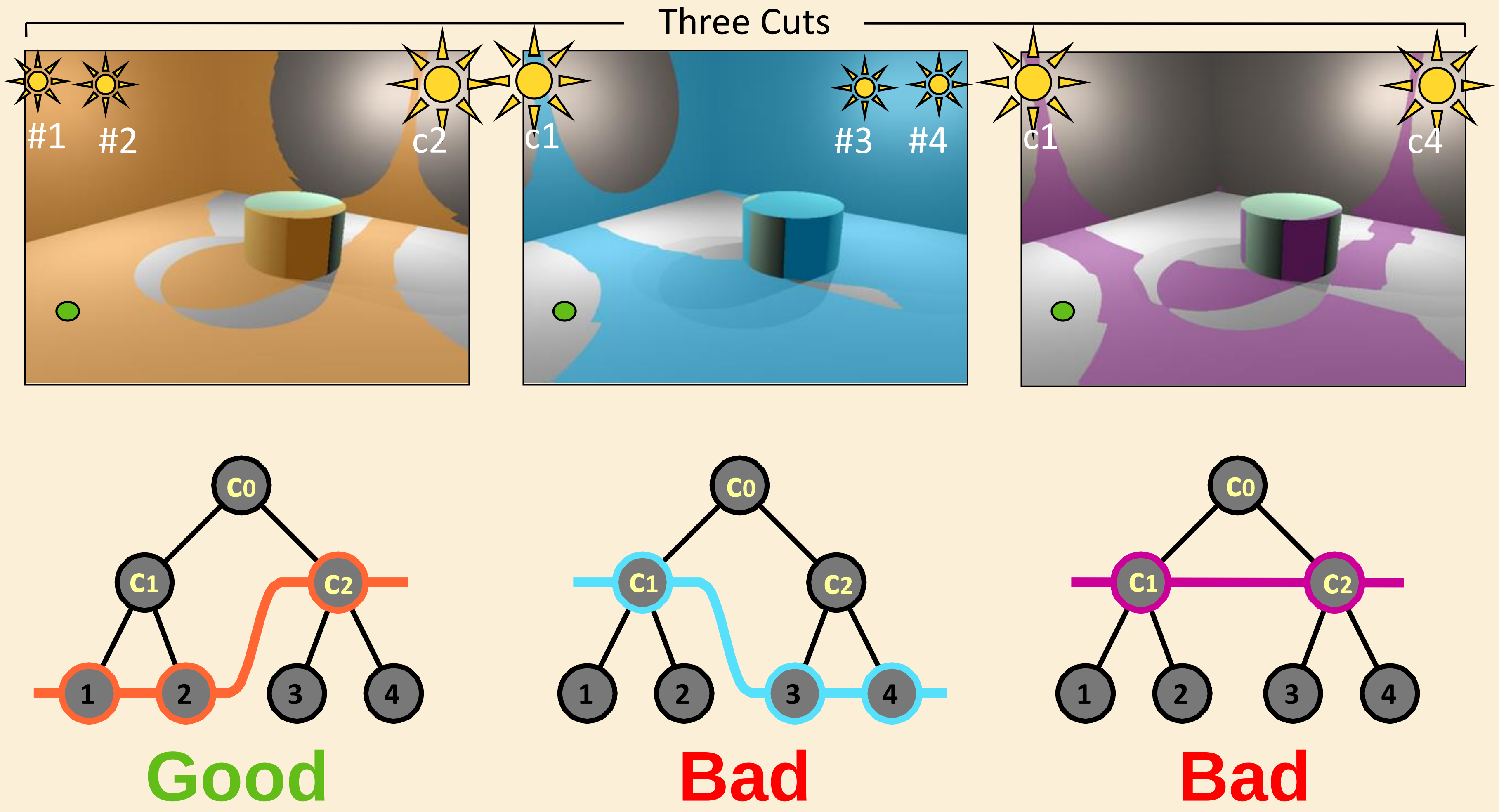
Lightcuts



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Lightcuts

Spatially adaptive control variates!

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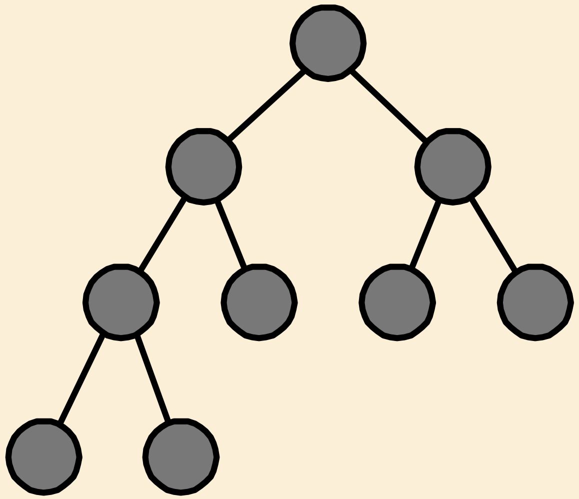
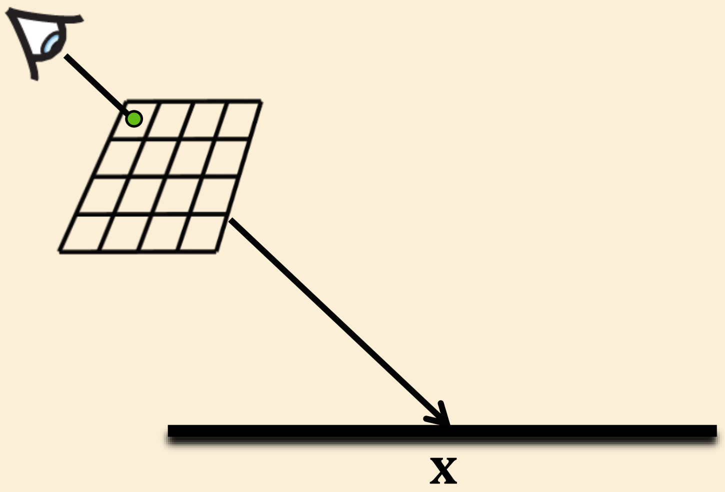
Multiple Control Variates Construction Based on Lightcuts

- For all lights, we first construct a light BVH tree.



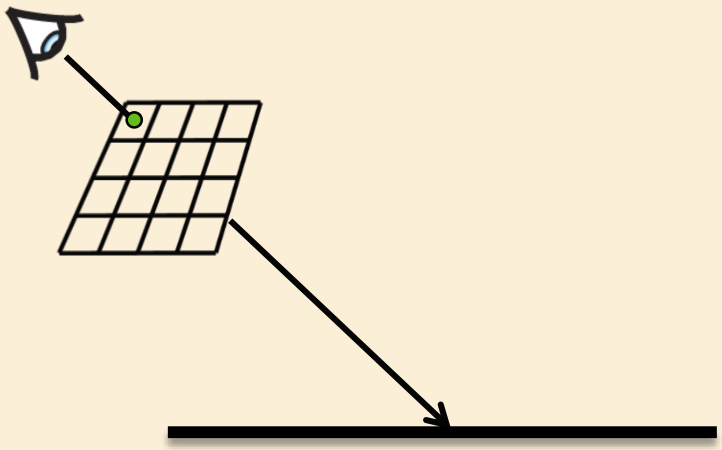
Multiple Control Variates Construction Based on Lightcuts

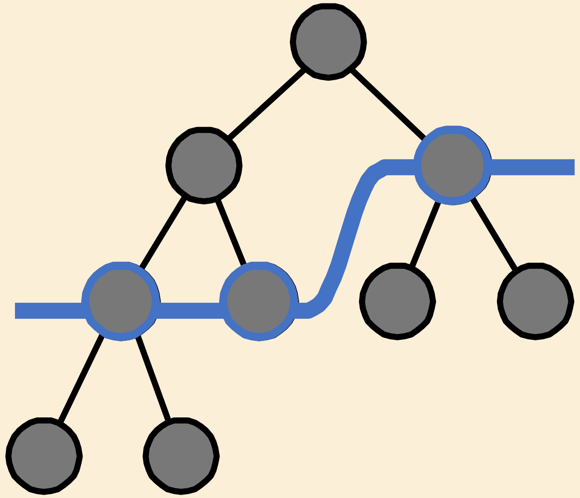
- For all lights, we first construct a light BVH tree.
- For each pixel, we select a representative point and shoot a camera ray to obtain the corresponding shading point **x**.

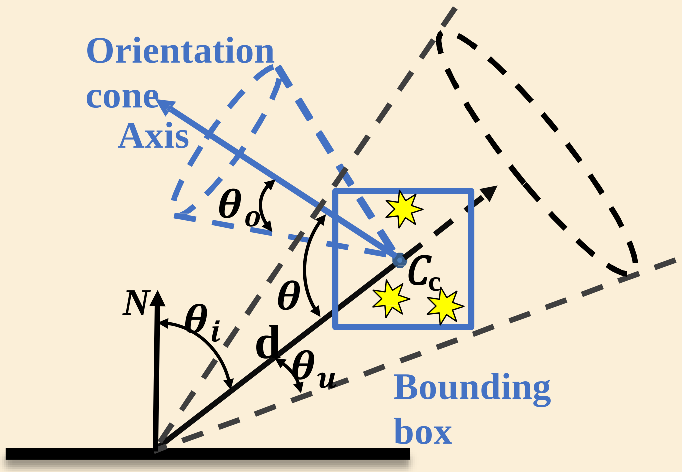


Multiple Control Variates Construction Based on Lightcuts

- For all lights, we first construct a light BVH tree.
- For each pixel, we select a representative point and shoot a camera ray to obtain the corresponding shading point **x**.
- For a shading point, we construct a light cut and compute the corresponding weight.





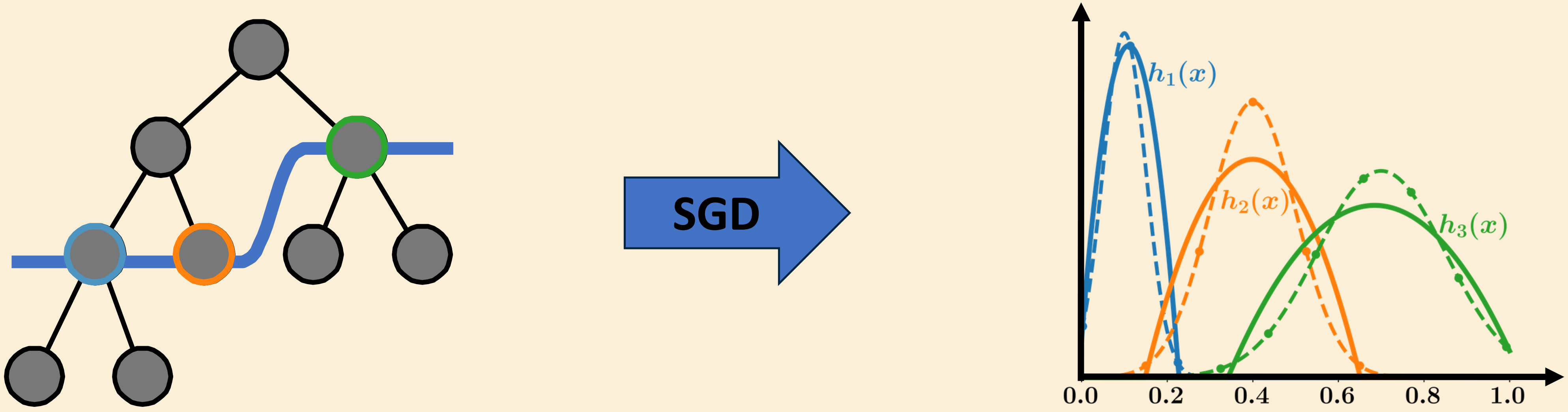


$$I_C(\mathbf{x}) = \frac{f_{\mathbf{x}} |\cos \theta_i'| \, E \cos(\theta')}{d^2}$$

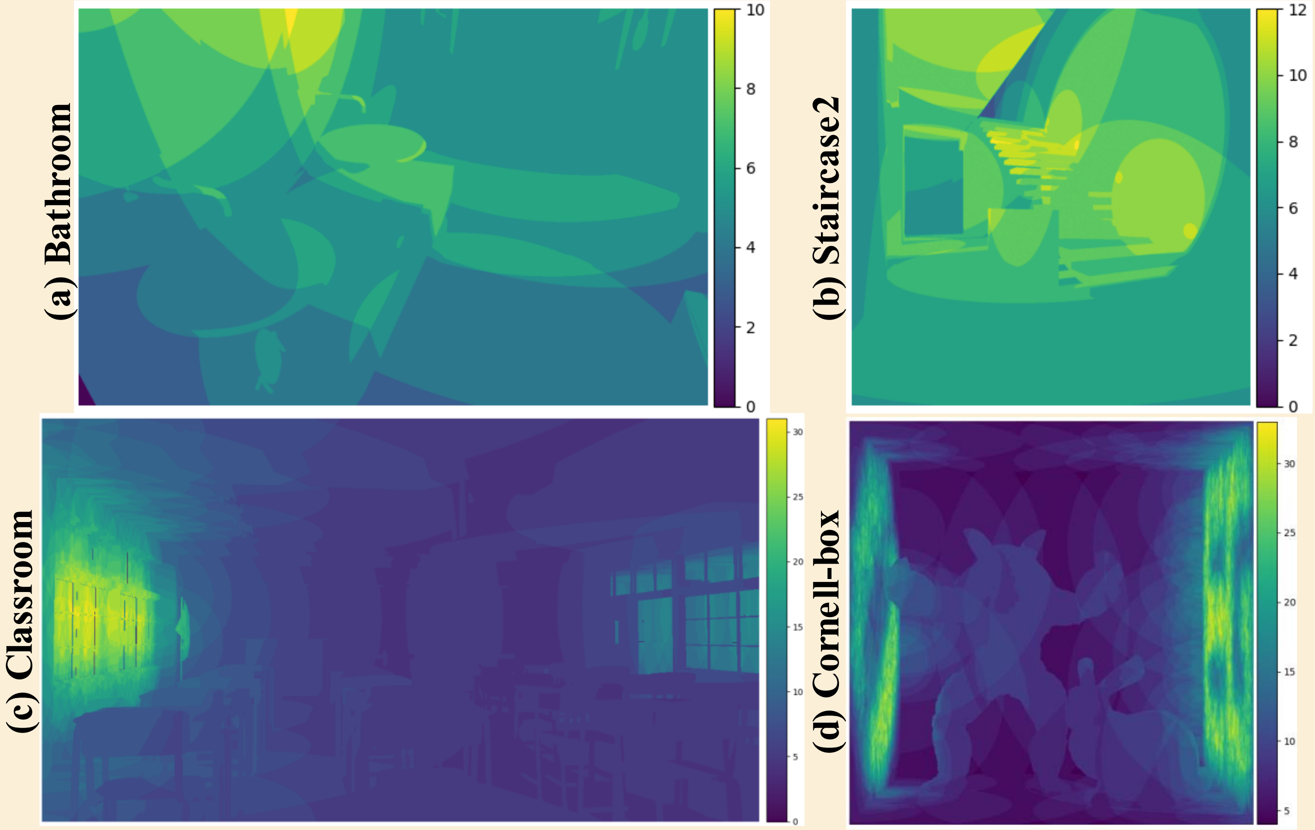
Conty Estevez, A., & Kulla, C. (2018). Importance sampling of many lights with adaptive tree splitting. Proceedings of the ACM on Computer Graphics and Interactive Techniques, 1(2), 1-17.

Multiple Control Variates Construction Based on Lightcuts

- For all lights, we first construct a light BVH tree.
- For each pixel, we select a representative point and shoot a camera ray to obtain the corresponding shading point **x**.
- For a shading point, we construct a light cut and compute the corresponding weight.
- For each node in the cut, we create a low-order polynomial as a control variate.



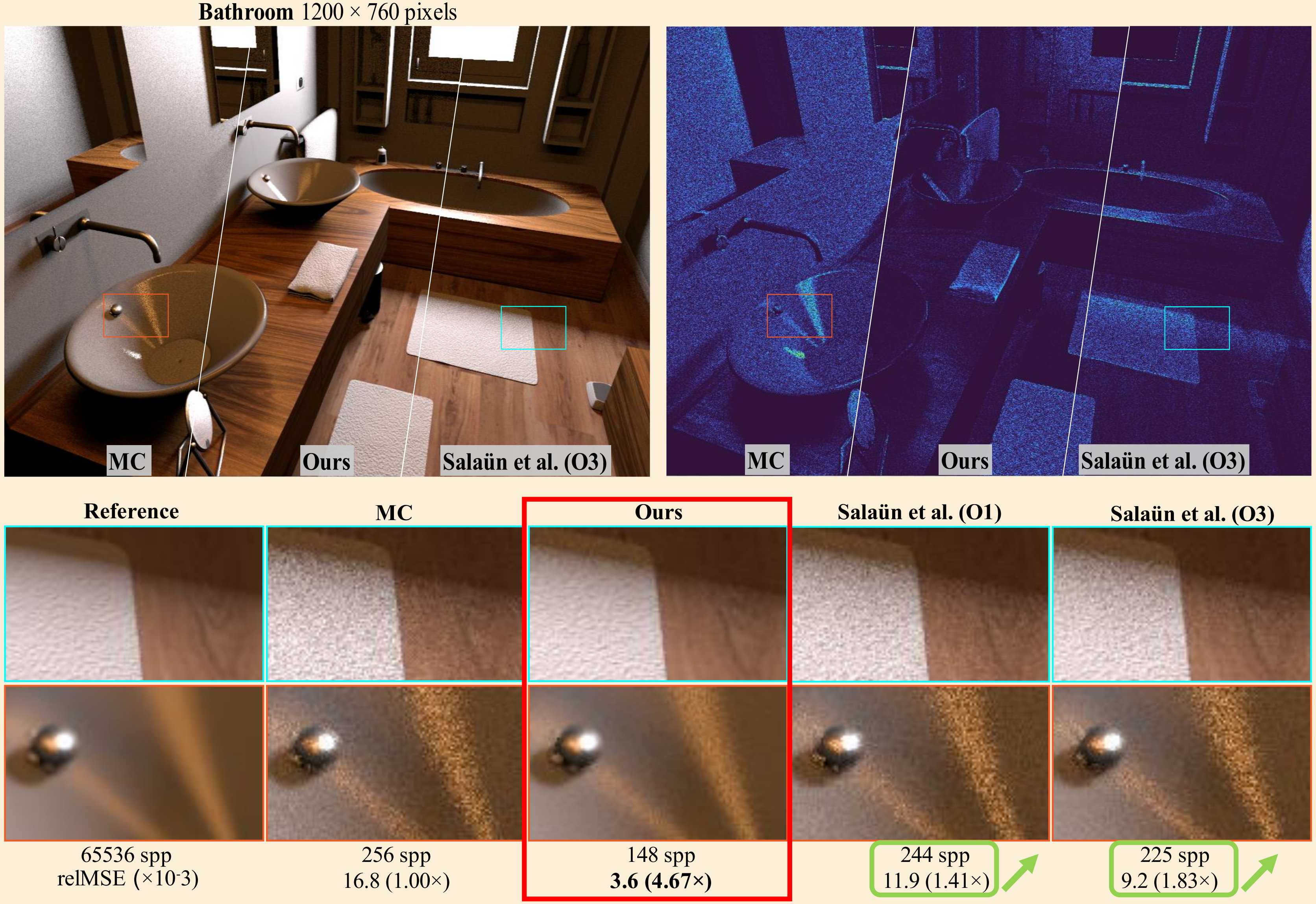
Visualization of the Number of Control Variates



Scene	# lights	avg. cut size	# control variates
Staircase2	21	7.9	0 - 12
Bathroom	32	5.1	0 - 10
Classroom	162	7.6	0 - 31
Cornell-box	1494	10.28	4 - 33

Results (Equal Time Comparison)

Comparison to Salaün et al. [SGH∗22]



Bathroom scene has 32 mesh lights.

Ours

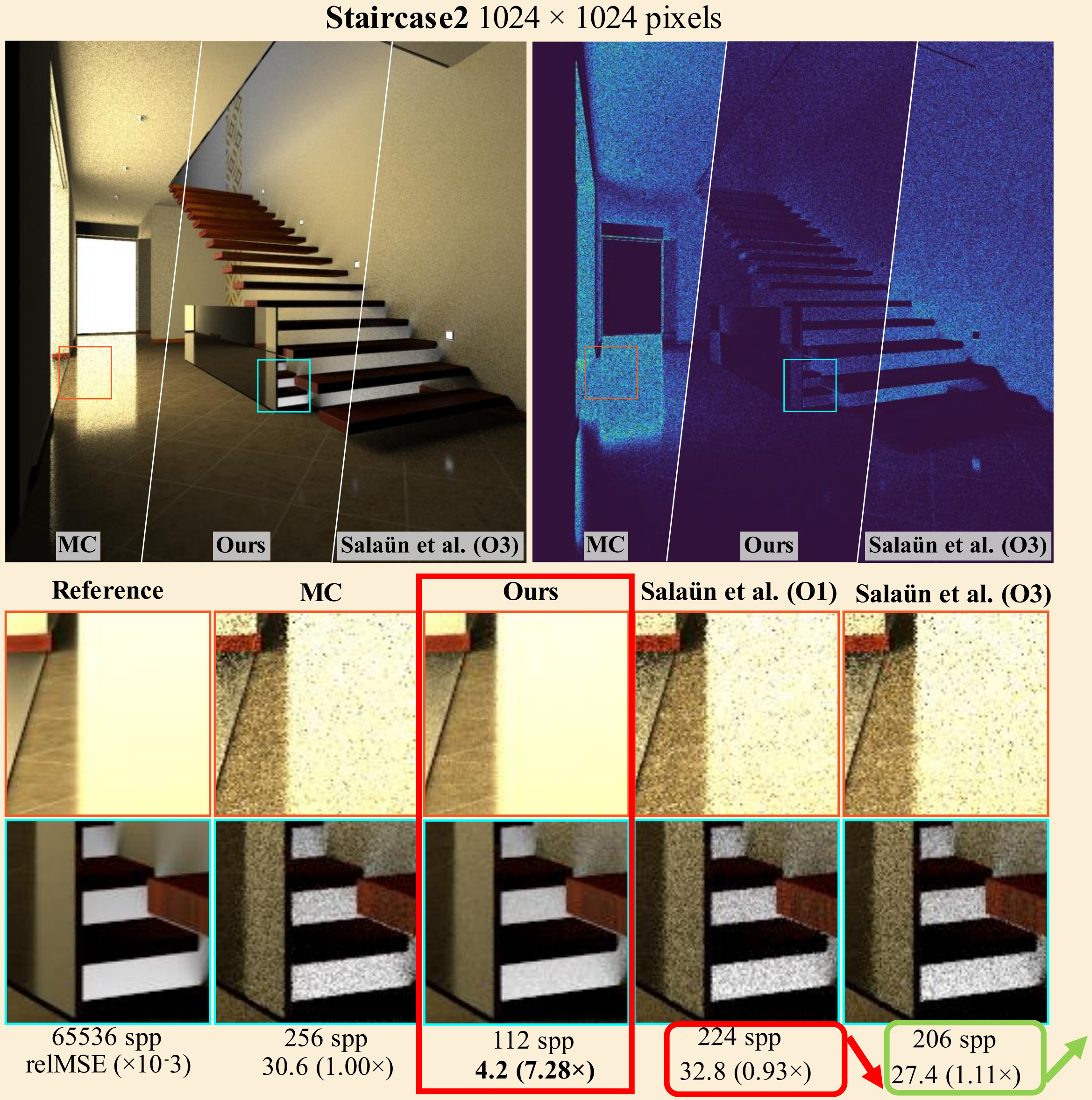
0-10 (avg. 5.1) control variates
(polynomial with order 1)

vs.

[SGH∗22]

Single control variate
(polynomials with order 1 & 3)

Comparison to Salaün et al. [SGH∗22]



Staircase2 scene has 21 mesh lights.

Ours

0-12 (avg. 7.9) control variates

(polynomial with order 1)

vs.

[SGH∗22]

Single control variate

(polynomials with order 1 & 3)

Comparison to Salaün et al. [SGH∗22]

Classroom scene has 162 mesh lights.

Ours

0-31 (avg. 7.6) control variates

(polynomial with order 1)

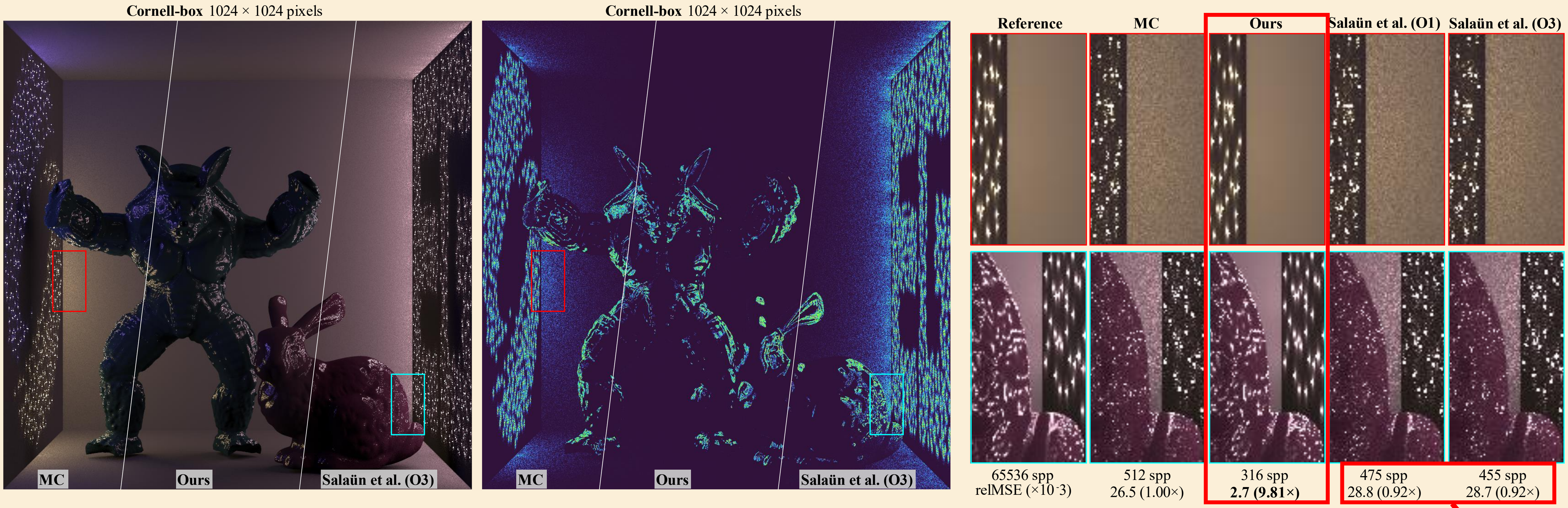
vs.

[SGH∗22]

Single control variate

(polynomials with order 1 & 3)

Comparison to Salaün et al. [SGH∗22]



Cornell-box scene has 1494 lights.

Ours

4-33 (avg. 10.28) control variates (polynomial with order 1)

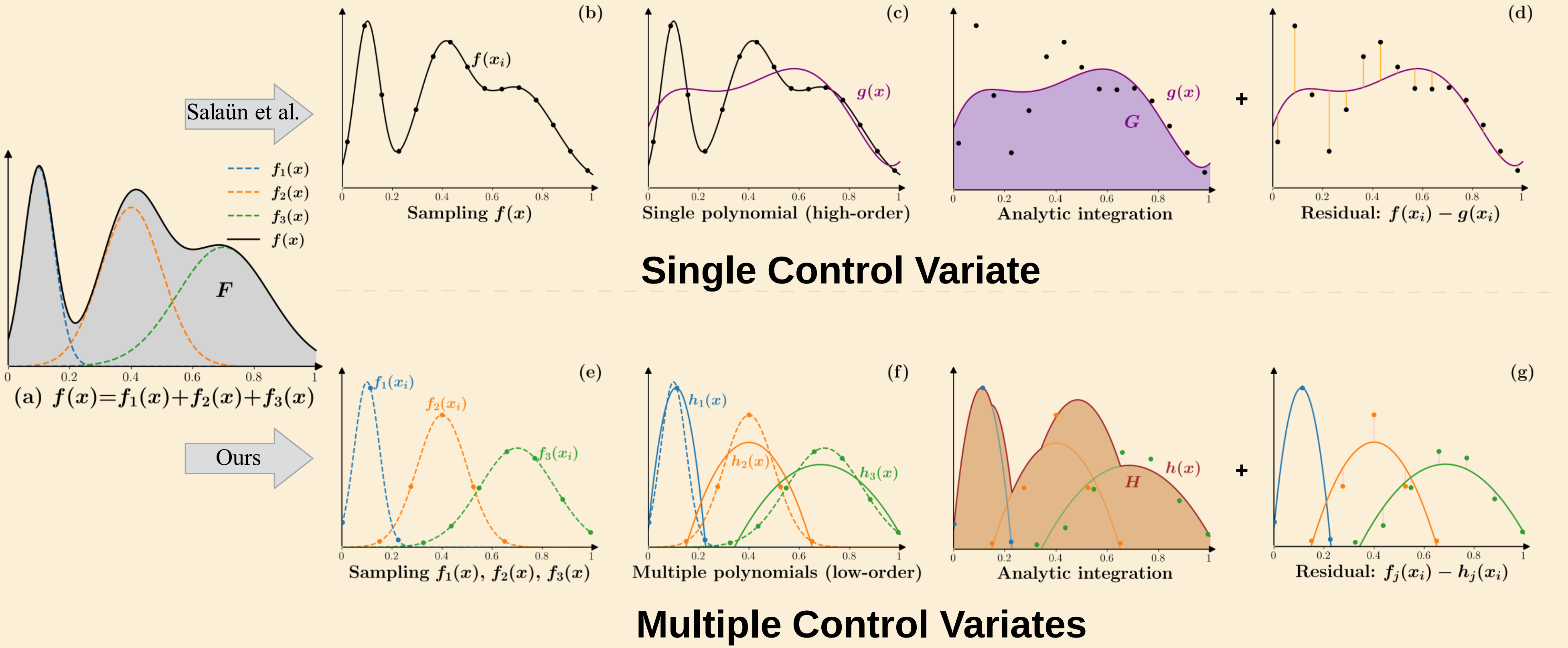
vs.

[SGH∗22]

Single control variate (polynomials with order 1 & 3)

Conclusion

- We introduce an adaptive multiple control variates framework to improve the Monte Carlo integration for many-light rendering.



Limitations and Future Work

Limitations

- Limited to specific many-light rendering.
- Visibility-related discontinuities are not yet handled.

Future work

- Extend to support other rendering applications.
- Incorporate visibility-aware strategies.

Acknowledgements

- We would like to thank the reviewers for the valuable comments.
- We would like to thank the following for scenes used in our experiments:

  nacimus (Bathroom), Veach (Veach-mis), NewSee2l035 (Staircase2),

  JayArtist (Living-room2), NovaZeeke (Classroom), Wig42 (Staircase1).
- We would like to thank Corentin Salaün for sharing the code and slides.

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Thank you!

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