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Robust Adaptive Sampling for Monte-Carlo-based rendering

Anthony Pajot, Loïc Barthe, Mathias Paulin

Monte-Carlo rendering

- Value of each pixel defined as the expected value of a random variable X

$$I = E[X]$$

- estimated using samples of X

$$< I >= \frac{1}{N} \sum_{i=1}^{N} x_i$$

Our goals

- **Focus** processing power where convergence is harder to reach during Monte-Carlo based rendering
- Make the error over the pixels **uniform** at any moment for progressive or time-constrained rendering

Previous work and their limitations

- Adaptive sampling based on the statistical nature of the estimation [Purgathofer 1987]

  Not a relative error: does not take into account dynamic reduction during tonemapping

- Adaptive sampling based on information-theoretic approaches and entropy measures [Xu et al 2007]

  Does not make the error uniform during rendering, thus less adapted for progressive or time-constrained rendering

Both approaches can lead to poor sampling due to low-samples error estimations which underestimate the actual error

Our approach

- Use a **relative error** to avoid focusing all processing power on areas receiving more energy. These zones are not necessarily the most noticeable after tonemapping, *e.g.* undersampling in shadows leads to highly visible noise
- **Alternate** between uniform and adaptive sampling, to ensure that error estimations of all pixels improve during rendering

Relative error and robustness to outliers

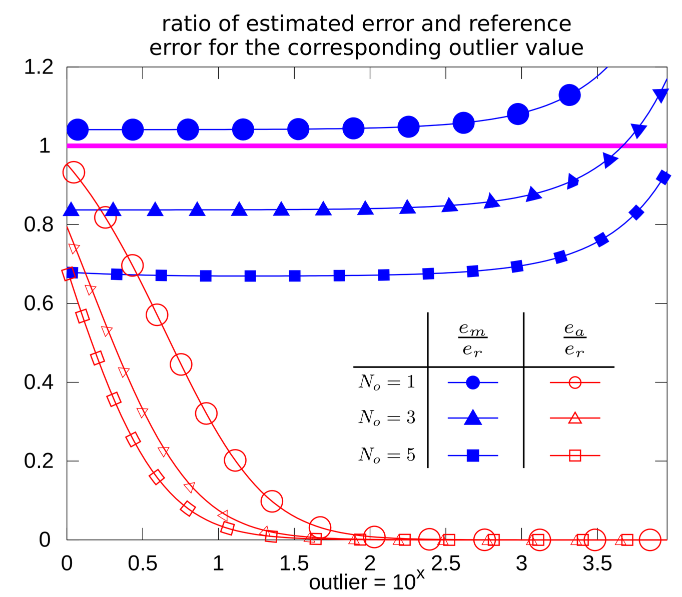
For each pixel, relative error:

$$e_r(I) = \frac{V(x_1, \ldots, x_n)}{E[X]}$$

Standard estimation:

$$e_a(I) = \frac{V(x_1, \ldots, x_n)}{<I>}$$

Not robust to outliers
➜ underestimation

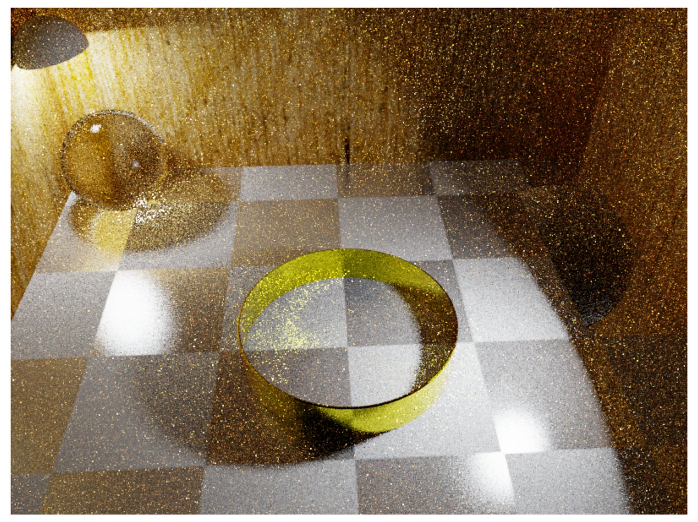


Our proposal: approximate median

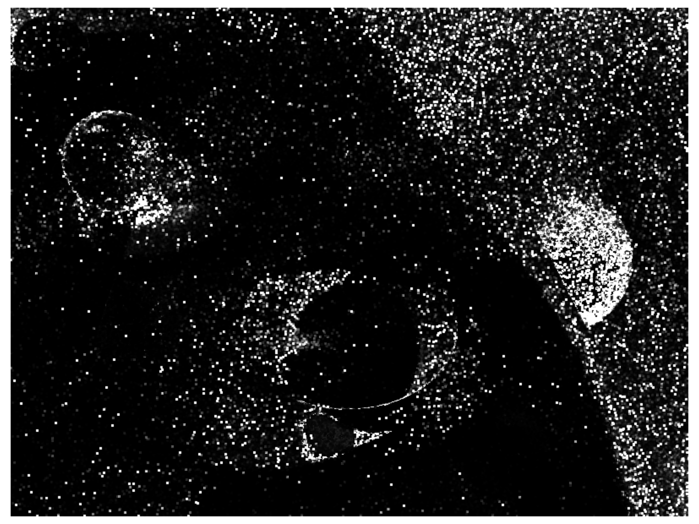
$$e_m(I) = \frac{V(x_1, \ldots, x_n)}{M_x}$$

M_x = average of median of chunks of samples

Goal: focus on bright spots


Scene prone to bright spots


using e_a : too uniform

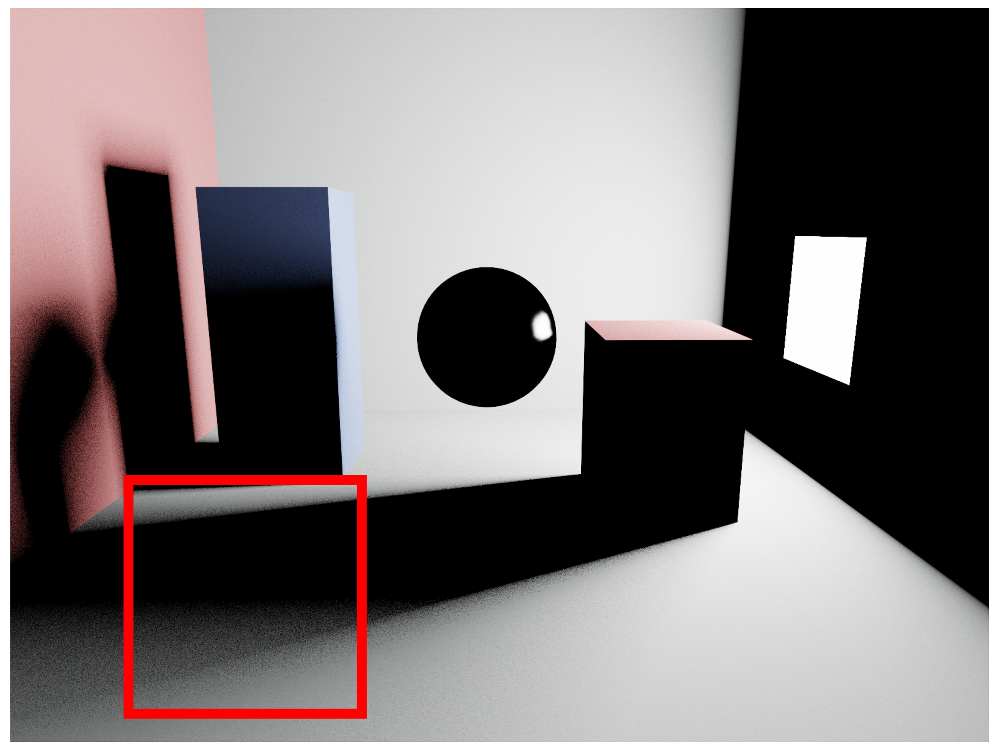

using e_m : focused on bright spots

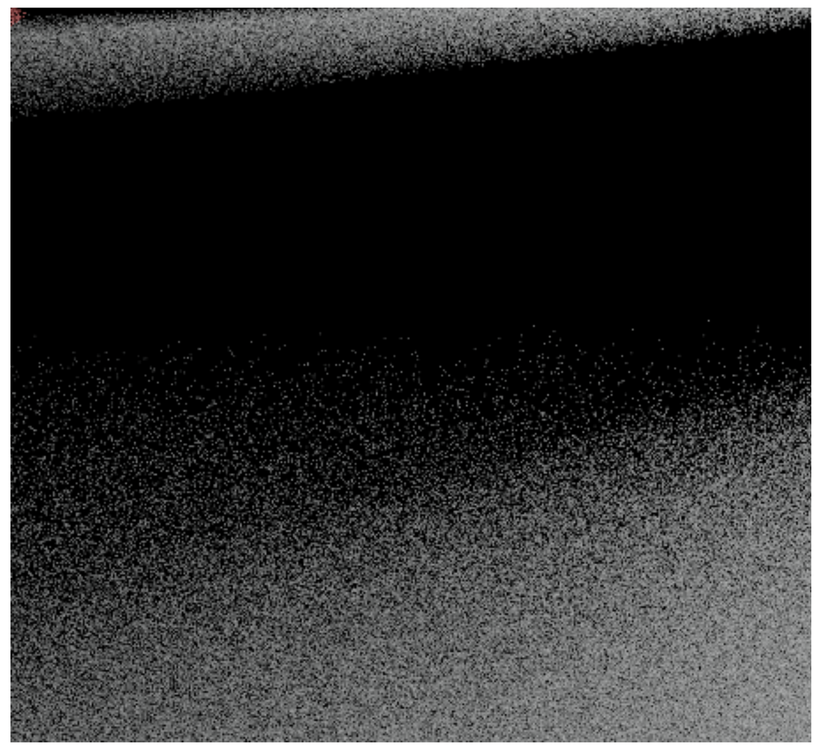
Alternation: avoid poor low-samples error estimation

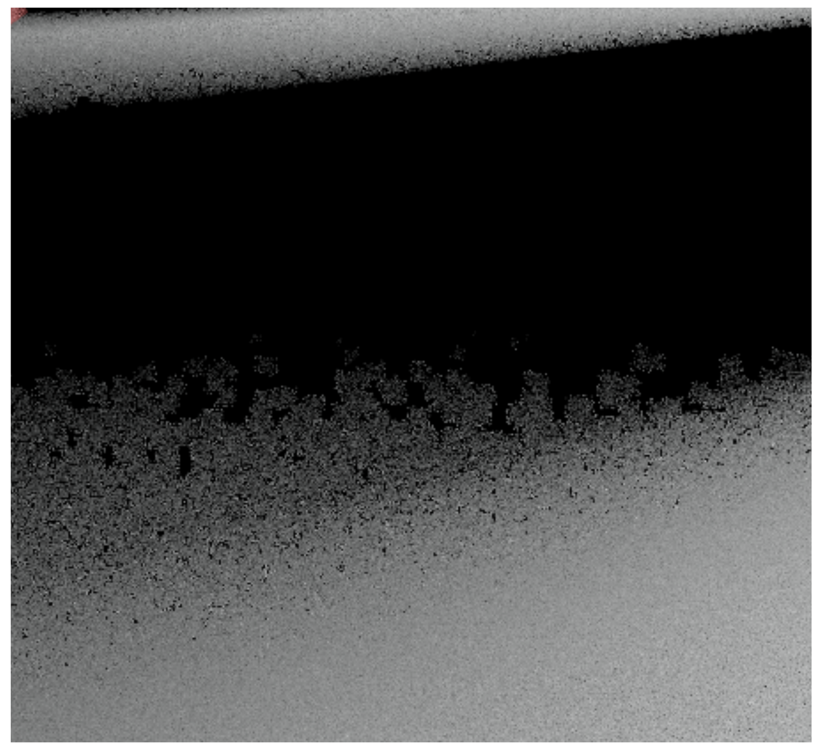
Adaptive sampling based on error measure.

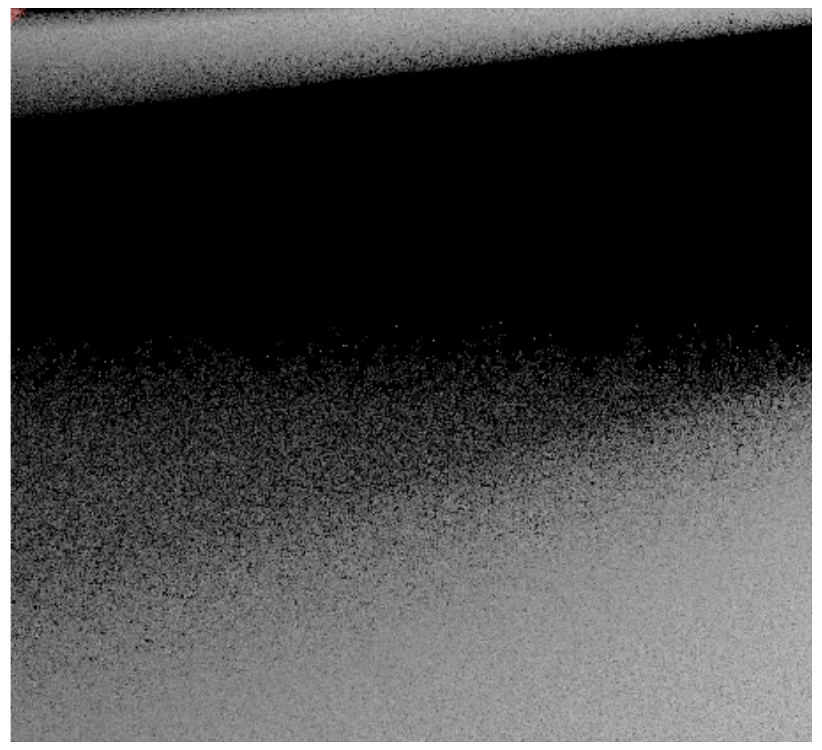
poor error estimate
➜ poor sampling

Our proposal: alternate adaptive and uniform sampling

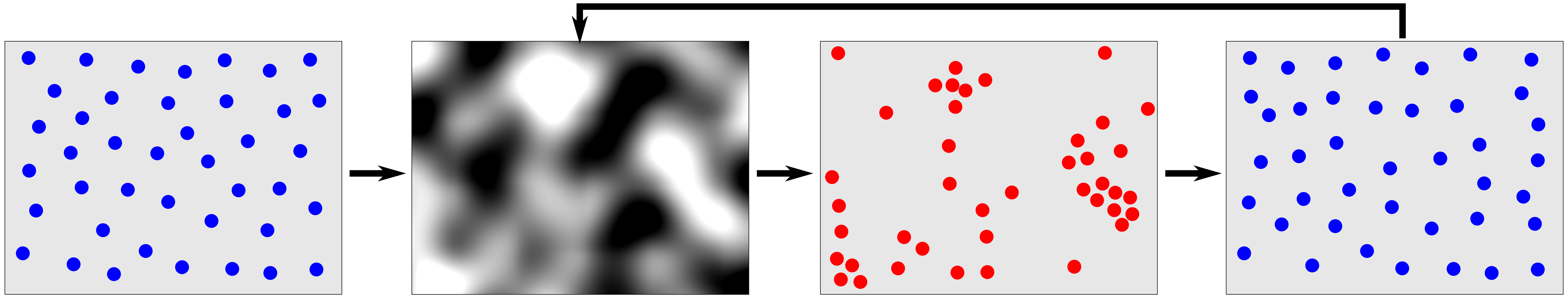

Complete scene.
Penumbra prone to poor sampling


Uniform sampling

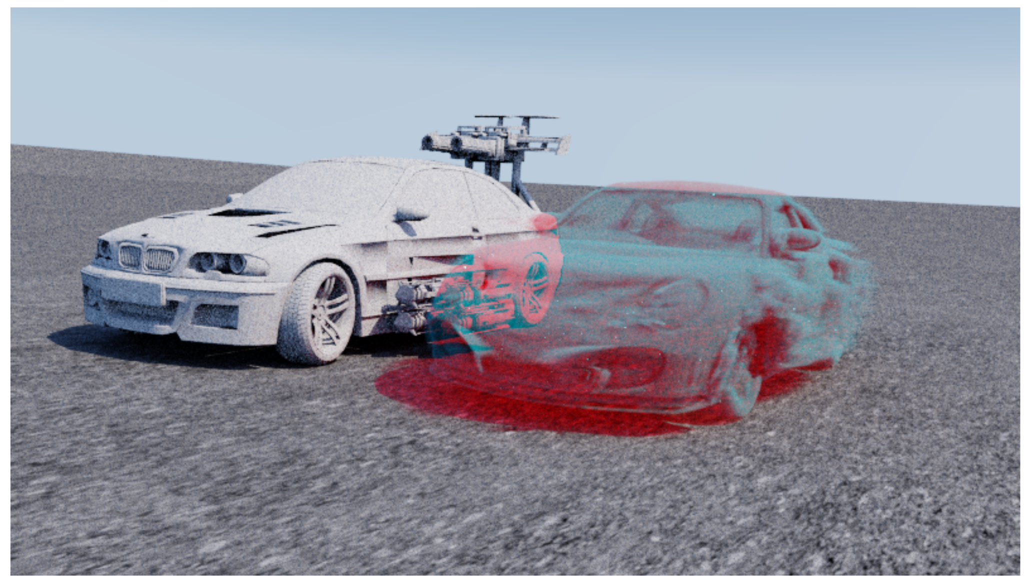

Adaptive sampling, no alternation.
Patterns in the penumbra


Adaptive sampling, alternation.
No patterns in the penumbra

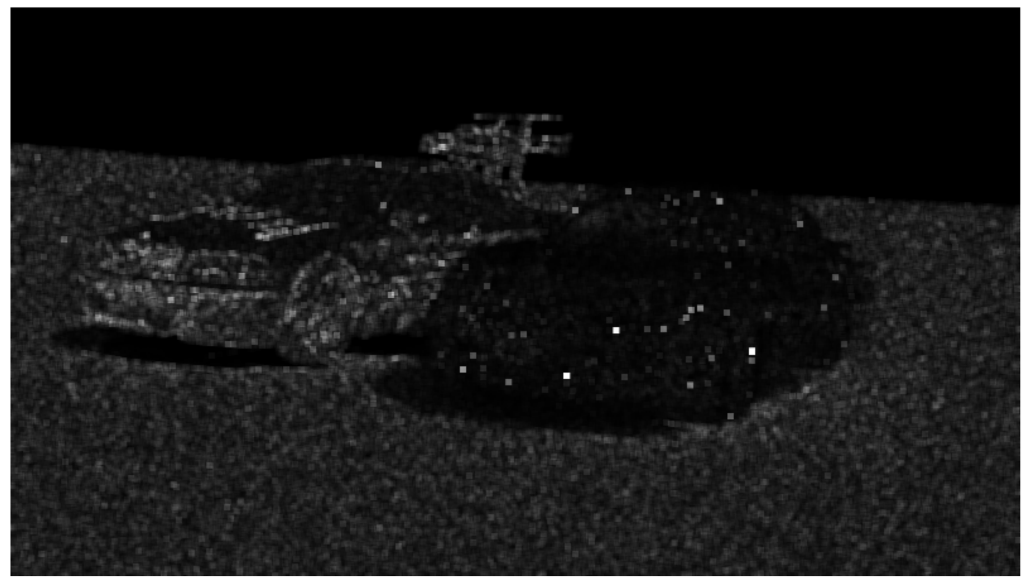
Complete adaptive sampling algorithm

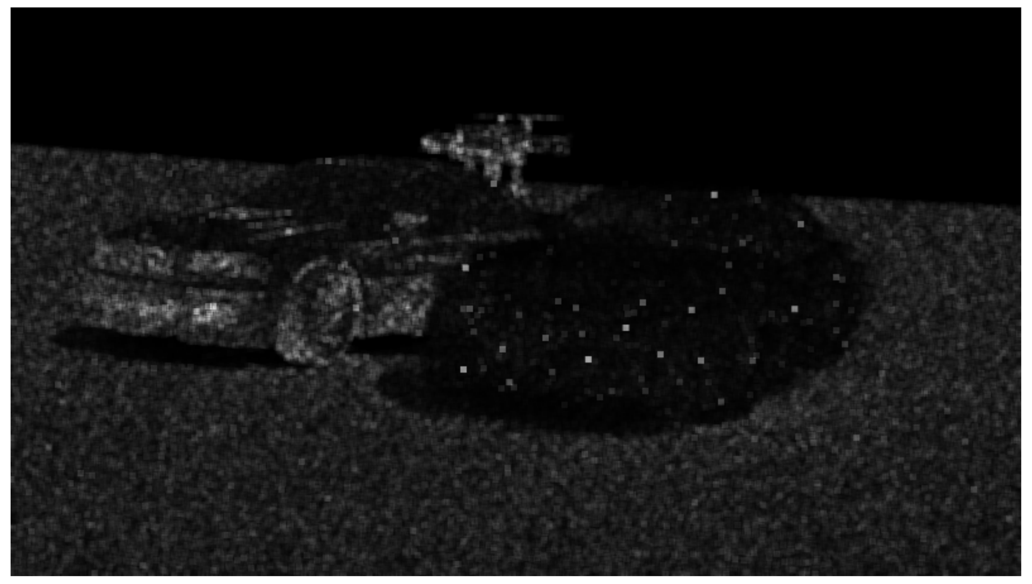

Uniform sampling — Update error and pixel probabilities — Adaptive sampling — Uniform sampling

Comparison with Tsallis entropy [Xu, Sbert, Xinh and Zhan 2007]


Test scene


Noise measure for uniform sampling


Noise measure for Tsallis entropy


Noise measure for our method