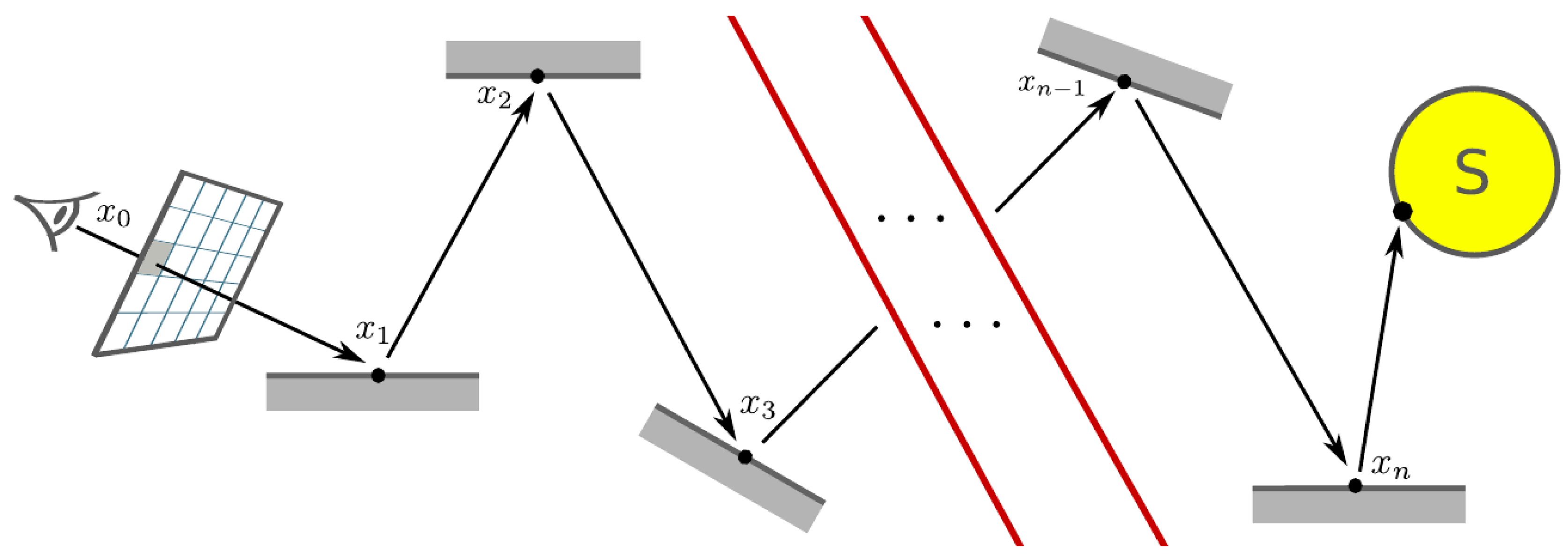
Firefly Removal in Monte Carlo Rendering with Adaptive Median of meaNs

J. Buisine, S. Delepoulle and C. Renaud (IMAP Team)

This research was funded by ANR support: project ANR-17-CE38-0009. Experiments presented in this paper were carried out using the CALCULCO computing platform, supported by ScoSI/ULCO.

https://diglib.eg.org:443/handle/10.2312/sr20211296

Monte Carlo Rendering and Firefly problem



Light simulation process in a 3D scene is known as global illumination and was formalised by Kajiya **[Kaj86]** with the light transport rendering equation. Monte Carlo (MC) approaches are generally used to estimate the value of the final image pixels. Sampling is performed through the construction of random light paths between the camera and the lightsources lying in the 3D scene.

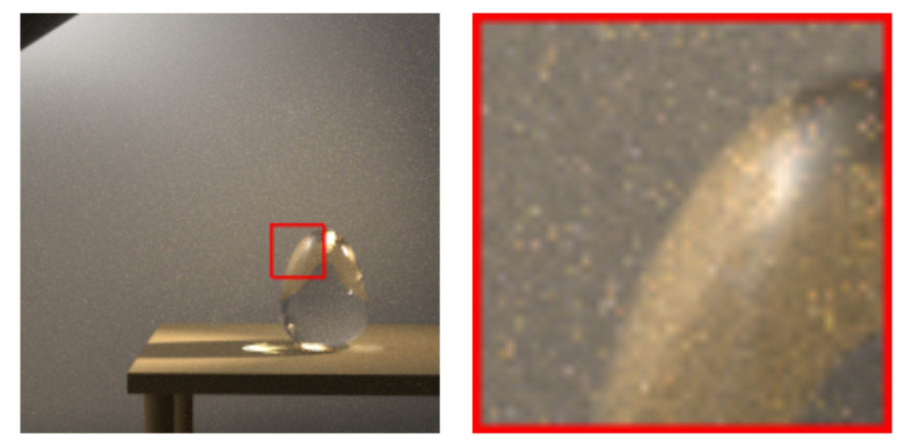
The final MC estimator approximation of the expected pixel value for n samples is obtained from the empirical mean:

$$\bar{\theta} = \frac{1}{n}\sum_{i=0}^{n} x_i$$

Where x_i is a sample for a specific pixel obtained during rendering.

(a) 1 sample (b) 20 samples (c) $10,000$ samples

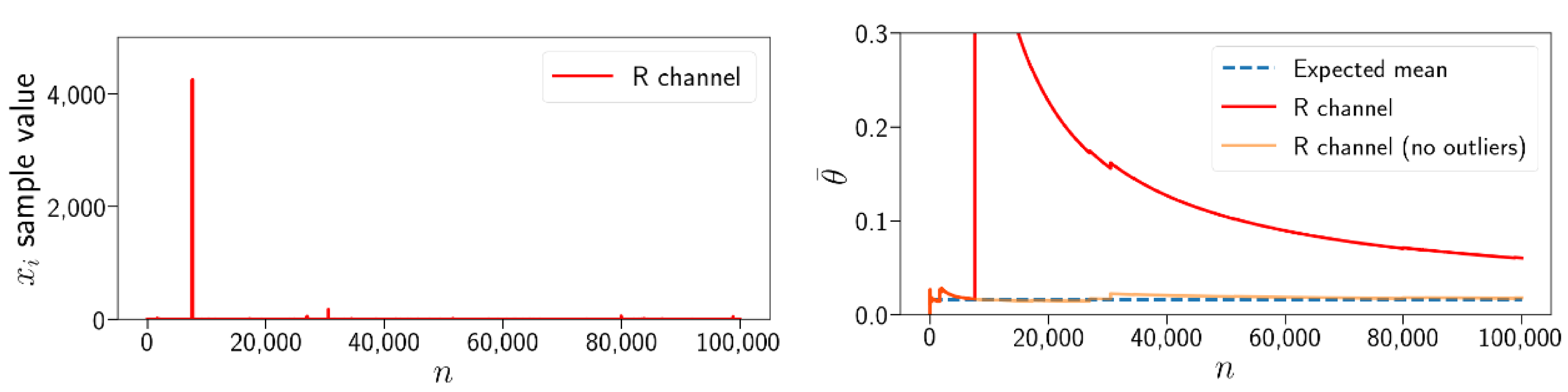
This computation initially causes considerable noise when generating the image, but as the calculation progresses, this noise is reduced and almost invisible.



(a) $100,000$ *samples* **(b)** $100,000$ *samples*

When generating such images from certain scenes, however, some visual artefacts known as ***fireflies*** may be still present and highly perceptible to the human visual system even with huge number of samples.

Median of meaNs

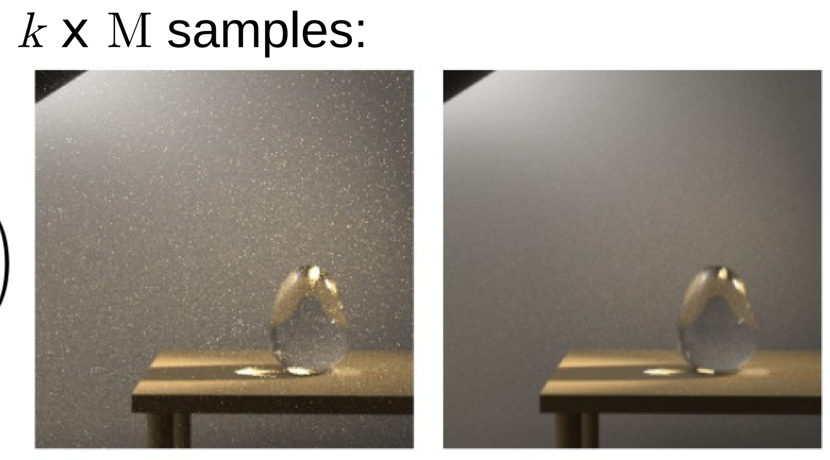


(a) *Red spectrum luminance values of firefly pixel with 1 high contribution.* **(b)** *Comparison of the mean without and with outlier value on the Red spectrum luminance values.*

Even if the mean estimator is considered as a good estimator, it is also strongly perturbed by these kind of very large values and their contribution can only be smoothed by evaluating many other samples. During the rendering of a pixel, it is difficult to decide whether the contribution of a path is such a rare value that could generate a ***firefly*** or the first occurrence of an important estimate for the pixel.

The Median of meaNs (MoN) **[CH94, DP04]** consists of separating all the samples obtained into M sets of the same size (if possible). The mean is calculated for each of the M sets and the median over the M sets (the median set) is used as the final estimator. Given independent and identically distributed random x_i sample estimation, the median of means with M sets of size k with a total of $n = k$ x M samples:

$$\hat{\mu}_{MoN} = \text{median}\left(\frac{1}{k}\sum_{i=1}^{k} x_i, \ldots, \frac{1}{k}\sum_{i=n-k+1}^{n} x_i\right)$$



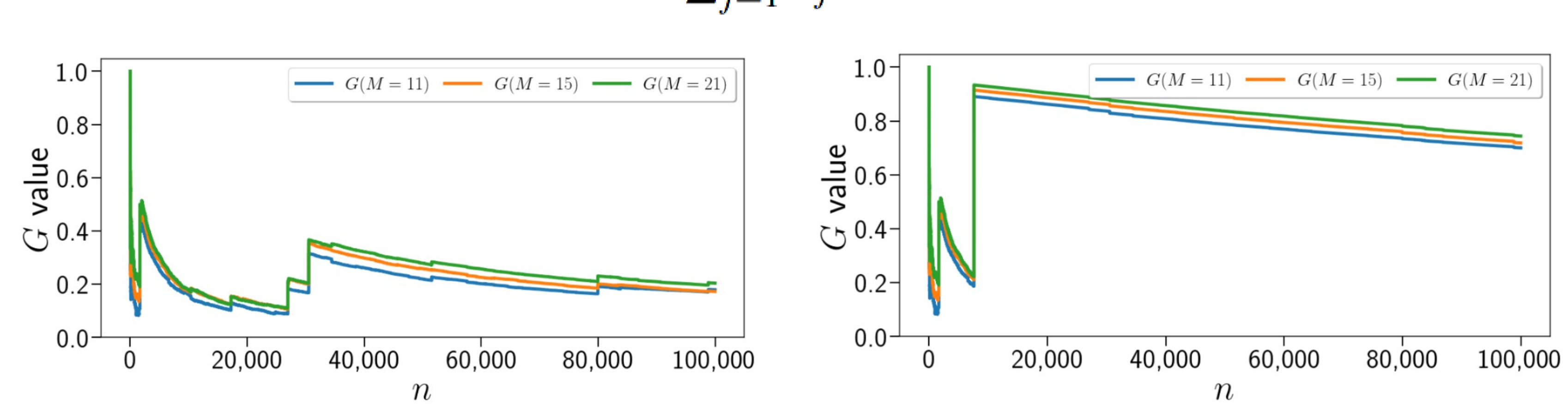
(c) *Mean* **(d)** *MoN* $(M = 17)$

The MoN significantly reduces the presence of firefly but tends to underestimate (with darker image) the expected value even after *10,000* samples due to the use of the median in the estimator formula.

Adaptive Median of meaNs with use of Gini Coefficient

The Gini coefficient **[Dor79]** is used in econometrics to highlight social inequalities. If the value obtained from this coefficient is 0 then there is a perfect equality and 1 (which cannot be achieved) means total inequality. In **[Bui21]**, we focus on this coefficient in order to detect the presence or not of a firefly. Gini coefficient is computed over ordered M means :

$$G = \frac{2\sum_{j=1}^{M} j\hat{\theta}_j}{M\sum_{j=1}^{M}\hat{\theta}_j} - \frac{M+1}{M}$$

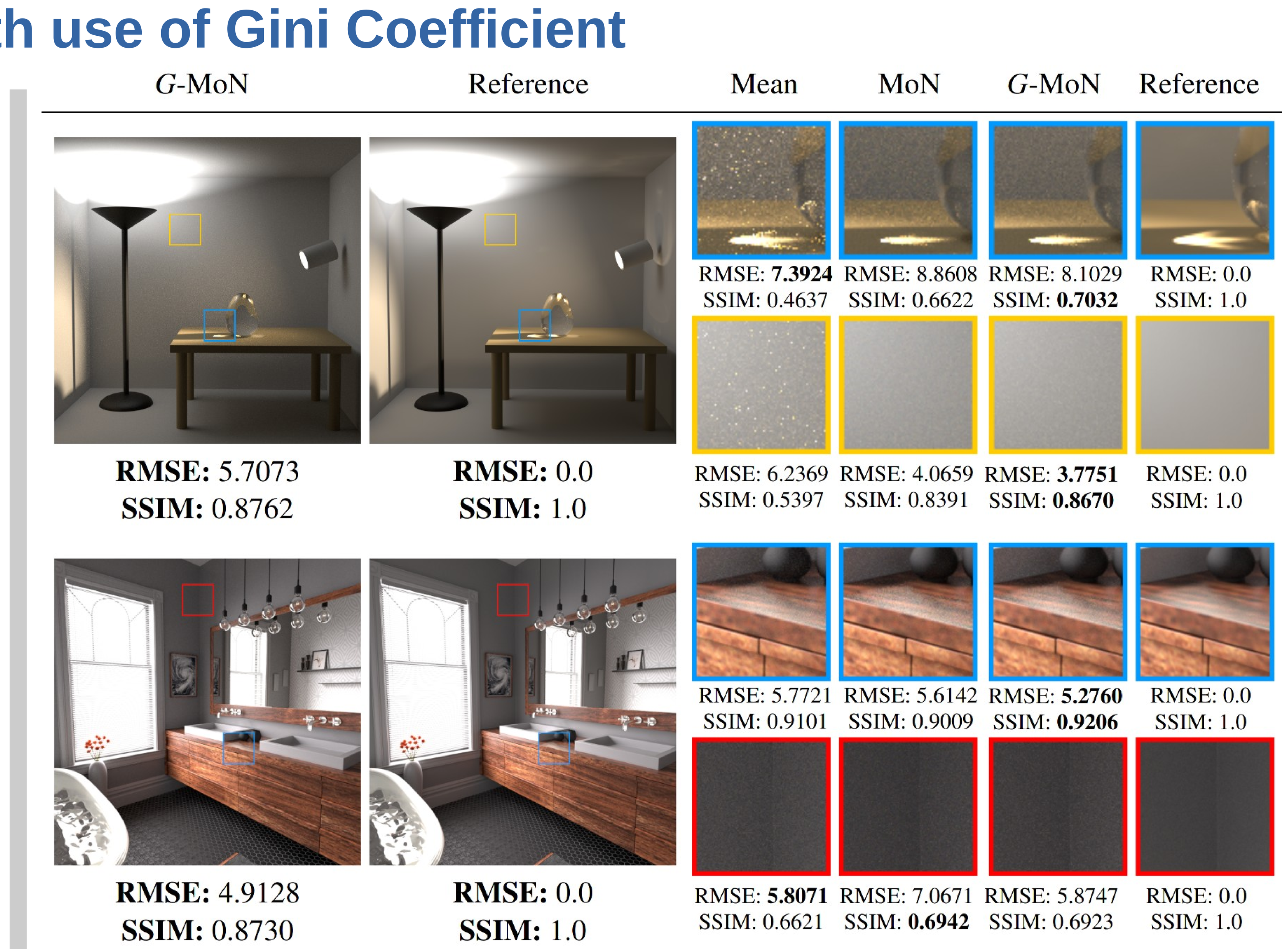


(a) *G coefficient evolution on samples with no outliers.* **(b)** *G coefficient evolution on samples with some outliers.*

Based on this idea, this adaptive MoN approach called G-MoN wishes to take advantage of the information available in the neighboring sets of the median set defined by:

$$\hat{\mu}_{G\text{-}MoN} = \frac{\sum_{j=1+c}^{M-c}\hat{\theta}_j}{M-2c}$$

where $c = \lfloor G \times k \rfloor$ and $k = \lfloor \frac{M}{2} \rfloor$.



Comparisons of RMSE and SSIM obtained from different estimators with *10,000* samples on 2 images. Full size images and targeted areas are compared to references. MoN and G-MoN are set with M=21.

[Bui21] BUISINE, J, DELEPOULLE, S. et RENAUD C. 32nd Eurographics Symposium on Rendering (2021) https://diglib.eg.org:443/handle/10.2312/sr20211296
[Kaj86] KAJIYAJ. T.: The rendering equation. InProceedings of the 13th annual conference on Computer graphics and interactive techniques(1986), pp. 143–150.
[CH94] CHAN Y. M., HEX.: A simple and competitive estimator of location. Statistics & Probability Letters 19, 2 (Jan. 1994), 137–14.
[DP04] DAMILANO G., PUIG P.: Efficiency of a Linear Combination of the Median and the Sample Mean: The Double Truncated Normal Distribution. Scandinavian Journal of Statistics 31, 4 (2004), 629–6.
[Dor79] DORFMAN R.: A formula for the gini coefficient. The review of economics and statistics (1979), 146–14.