

Frequency based Kernel Estimation for Progressive Photon Mapping

Laurent Belcour*
Grenoble University

Cyril Soler†
Inria

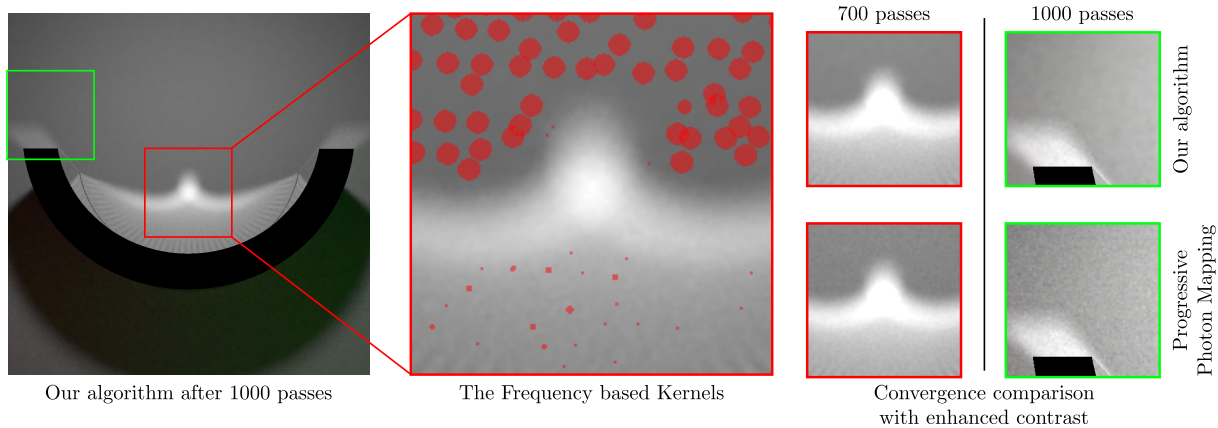


Figure 1: In this example, a caustic is created using a curved reflector. We estimate conservative density estimation kernels using frequency information. That permits to speed-up the convergence of the progressive photon mapping algorithm.

We present an extension to Hachisuka *et al.*'s Progressive Photon Mapping (or **PPM**) algorithm [Hachisuka *et al.* 2008] in which we estimate the radius of the density estimation kernels using frequency analysis of light transport [Durand *et al.* 2005]. We predict the local radiance frequency at the surface of objects, and use it to optimize the size of the density estimation kernels, in order to accelerate convergence. The key is to add frequency information to a small proportion of photons: *frequency photons*. In addition to contributing to the density estimation, they will provide frequency information.

1 Algorithm Overview

Our algorithm works as follow: First, we ray trace *hitpoints* in the scene from the camera. Second, we iteratively trace a proportion of *frequency photons* and "*classical*" photons in the scene. These frequency photons are used to update the frequency estimate at *hitpoints*.

Classical progressive photon mapping progressively reduces the size of the density estimation kernel to cancel the bias of density estimation, at the expense of increasing variance. However, if the radiance is smooth enough, this size can be kept constant, and additional photons will only decrease variance of the estimate. The role of frequency photons is precisely to conservatively predict this phenomenon.

Consequently, we update the hitpoints' collecting size using the following heuristic: if the kernel size of classical PPM is greater than our prediction we decrease the radius just as the standard progressive photon mapping method does. Otherwise, we don't decrease the kernel size. We make this process iterative by always using a fixed proportion of frequency photons to update the desired size of all hitpoints.

Tracing Frequency Photons Durand [2005] presents a Fourier analysis of the light transport in 4D. For efficiency reasons, we assume the radiance function to be isotropic in space and isotropic in angle, reducing the dimensionality of the spectrum of the radiance function to 2. We also approximate this spectrum by a Gaussian

$\hat{l}(\Omega_x, \Omega_\theta) \simeq e^{-(a\Omega_x^2 + 2c\Omega_x\Omega_\theta + b\Omega_\theta^2)}$ whose compact representation (a, b, c) is stored per photon and per hitpoint. At light sources, frequency photons are initialized with (a, b, c) values corresponding to the local radiance spectrum of the light source. When a photon is traced in the scene, we update these coefficients for each light transport atomic operation (travel in free space, partial occlusion, and reflection). Each of these atomic operation translates into a simple arithmetic operator on (a, b, c) . Please refer to our supplementary materials for the derivation of the different operations.

Accumulating Frequency Information At each reflection of a frequency photon we query for neighboring hitpoints and update each hitpoint's spectrum with the photon's spectrum if the latter falls in the hitpoint's kernel. We update the hitpoint's coefficients using its assigned (a, b, c) coefficients. To ensure a conservative frequency kernel size, for each coefficient, we take the max value across collected frequency photons.

To estimate the kernel size from the frequency estimation, we take as new radius the min between the radii estimated from the spatial and the angular frequencies. The spatial radius equals $r_x = \pi\sqrt{a} \beta_{95\%}$, where $\beta_{95\%} = -\log(0.95)$. The angular radius equals $r_\theta = \tan(\pi\sqrt{b} \beta_{95\%})z$, where z is the distance from the hitpoint center to the camera projected on the hitpoint's normal.

2 Results

Our algorithm converges faster for low frequency parts such as diffuse non-occluded regions or indirectly lit diffuse regions as shown in Figure 1. The frequency analysis enables us to detect specific lighting situations, such as a caustic's focus point, which corresponds to a frequency spectrum with no energy along the angular axis.

References

- DURAND, F., HOLZSCHUCH, N., SOLER, C., CHAN, E., AND SILLION, F. X. 2005. A frequency analysis of light transport. In *ACM SIGGRAPH 2005 Papers*, ACM, New York, NY, USA, SIGGRAPH '05, 1115–1126.
- HACHISUKA, T., OGAKI, S., AND JENSEN, H. W. 2008. Progressive photon mapping. In *ACM SIGGRAPH Asia 2008 papers*, ACM, New York, NY, USA, SIGGRAPH Asia '08, 130:1–130:8.

*e-mail: laurent.belcour@inrialpes.fr

†e-mail: cyril.soler@imag.fr