Cornell Caustic

University of Minho

Master in Informatics Engineering

Computer Graphics

Display and Lighting II

June 2016

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Abstract

This report explains the entire process of a brief analysis under the subject of Computer Graphics, more specifically about Photorealistic Image Rendering through the Ray Tracing technique. The project was carefully structured in order to easily understand its real purpose. First of all, we start by identifying the actual problem which is, in a few words, the simulation of caustic shadows. Caustics are defined as a group of light rays that are reflected or refracted by curved transparent objects. The next step was planning the experimentation and predict some of the possible results according to each possible approach. Then, it was time to proceed to the rendering experimentation where beyond the final image, it is also taken into account the elapsed time. At last, comes the study of the obtained results and the choice of the best relation between image quality and time spent on it.

Introduction

This project intends to evaluate different global illumination algorithms' performance and quality. To do this, the group was given a scene to work with (represented on Figure 1). This image's resolution is 1024 by 1024 and was rendered using PBRT version 2 (using the surface integrator "path"). The PBRT will also be used to fulfil the purpose of this project by rendering the various experiments. The scene to be studied has various typical surfaces seen on global illumination demos, such as a glossy teapot and ceiling, a mirror, and a crystal-like "killeroo" model. Our particular focus will be on the "killeroo" model, by trying to get the best caustic shadow possible.

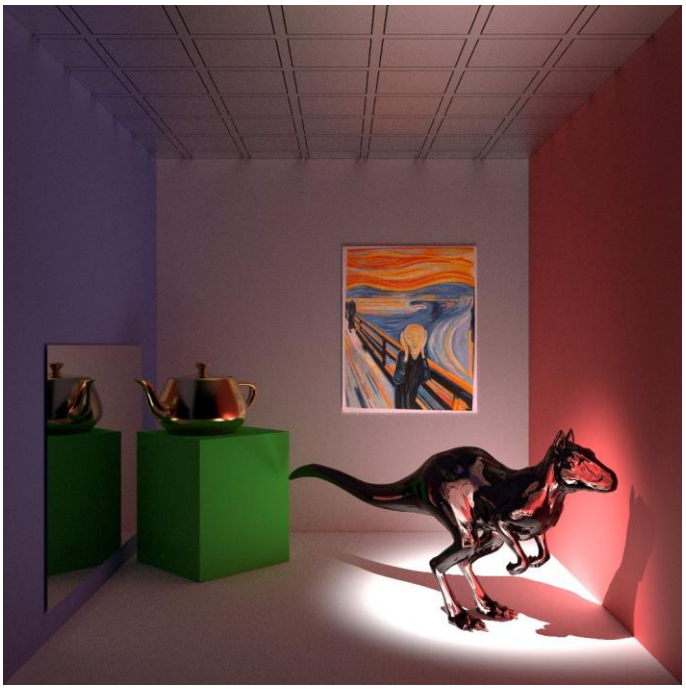


Figure 1. Default scene, rendered with path tracing.

Experiments

In order to achieve the best result, and have a basis for comparison, some surface integrators and samplers to test were selected. Each surface integrator is tested with a different sampler. The planned elements are shown on Table 1. All experiments were done on SeARCH on 662 nodes.

Table 1. Planned experiments.

Surface Integrators	Samplers
Path	Adaptive
Photon Map	Best Candidate
	Halton
	Low Discrepancy
	Random
	Stratified

The result of each connection should generate an image and the time it took to render, for example, the path surface integrator with an unknown sampler generated Figure 1, which as given to the group to present the scene. The imagens to be rendered will have a width and a height of 800 pixels. The samplers' "pixelsamples" argument will be 256, at the exception of the adaptive ("minsamples" set to 128 and "maxsamples" set to 256) and stratified samplers ("xsamples" and "ysamples" set to 16, with jitter). The Photon Map surface integrator receives the argument "causticphotons" as 10.000 and the "indirectphotons" as 20.000.

Hypotheses

Caustics are the consequence of light rays being focused in specific regions as a result of refraction (light rays passing through the "killeroo" model on this case). In the current case study, it is believed that the photon map surface integrator will produce a better result than the rest. This is simply because the path tracing is unable to produce a caustic, due to its random nature, when a ray hits a point that should be a caustic, a random ray is generated, and the probability of this ray being on the right direction (the "killeroo" model) is very low (shown in Figure 2 as red rays). And so the caustic would be no more than a normal shadow using path tracing. The photon map, on the other hand, is the ideal algorithm for this scene, and can generate very realistic caustics.

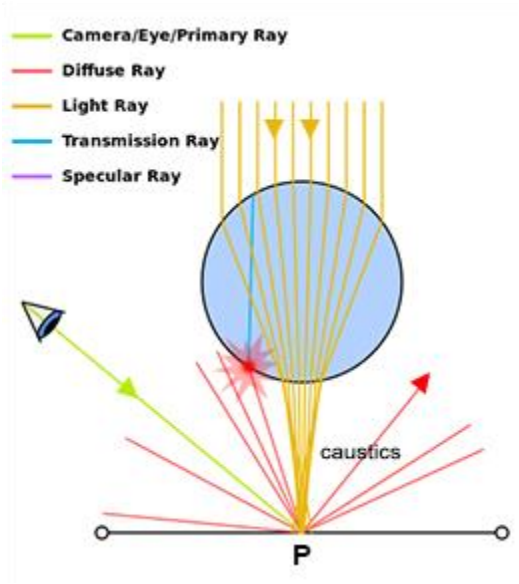
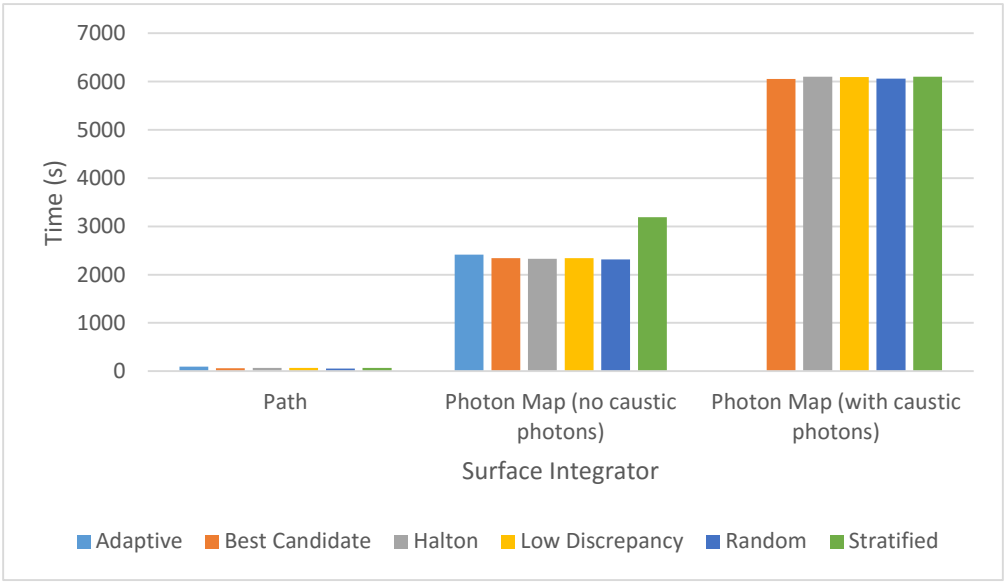


Figure 2. How a caustic shadow is formed.

Results

On this section will be displayed all the images obtained, such as their rendering time. On Graph 1 is shown a global comparison between surface integrators and samplers.

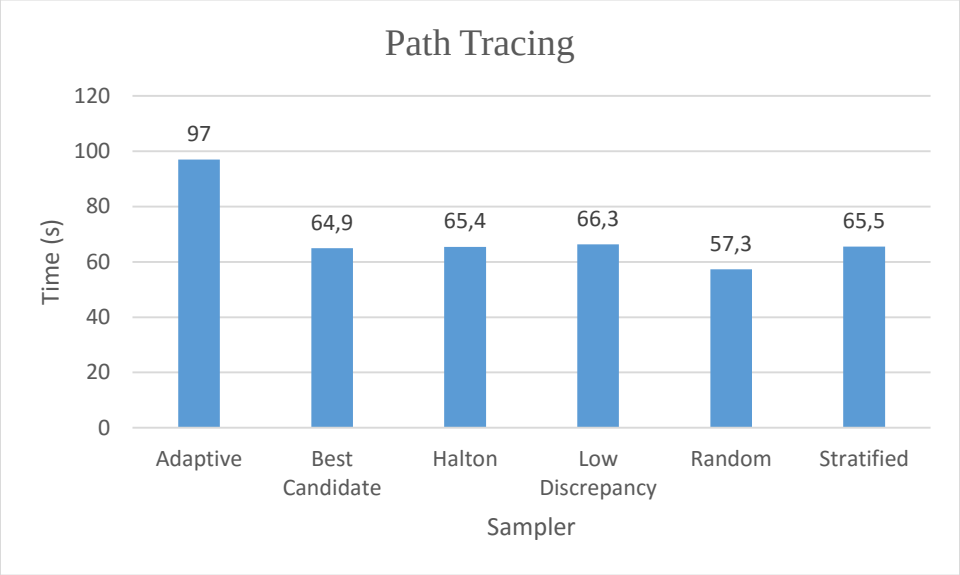


Graph 1. Global comparison between the studied algorithms.

Path Tracing

This subsection is dedicated to the experiments with path tracing. On Graph 2 is displayed the rendering time of the images produced. It can be verified that the elapsed time was similar with a peak on the adaptive sampler.

As we are going to see in the next subsections, due to the nature of this exact surface integrator, the resultant images have a lot of noise, mainly on non-direct lighted surfaces as well as on shadows. As formulated on Hypotheses section, this surface integrator is not ideal for the simulation of caustic shadows. The path tracing is limited by two main factors: the number of rays shot and the randomness of the direction of news rays. More rays mean more accuracy, precision and quality but it means a huge increment on the rendering time. On the other hand, caustics are a unique light effect and the randomness of rays' direction can make things much harder.



Graph 2. Rendering time comparison between samplers using the path tracing surface integrator.

Adaptive

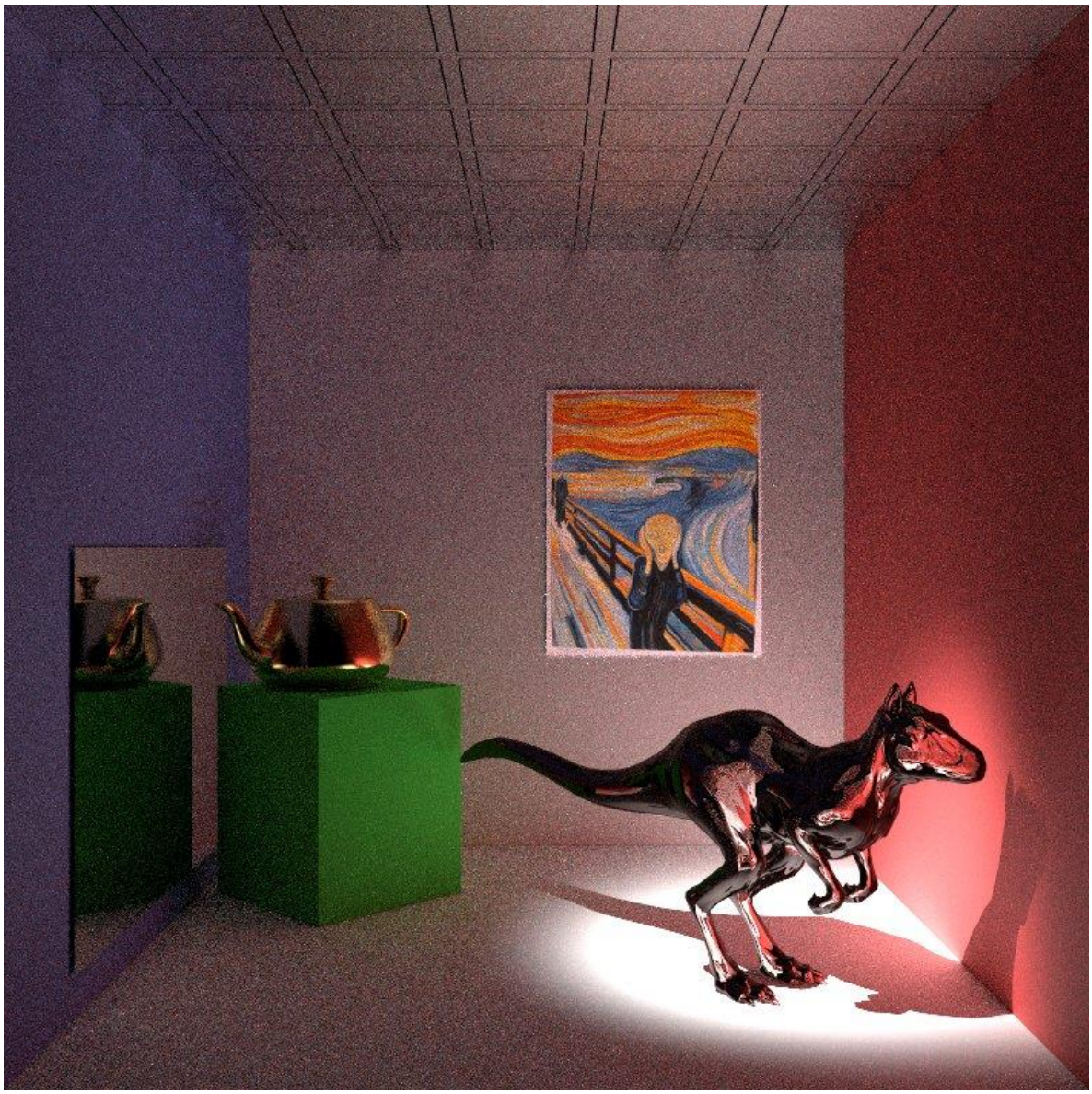


Figure 3. Scene rendered with path tracing and an adaptive sampler.

Best Candidate

Figure 4. Scene rendered with path tracing and a best candidate sampler.

Halton

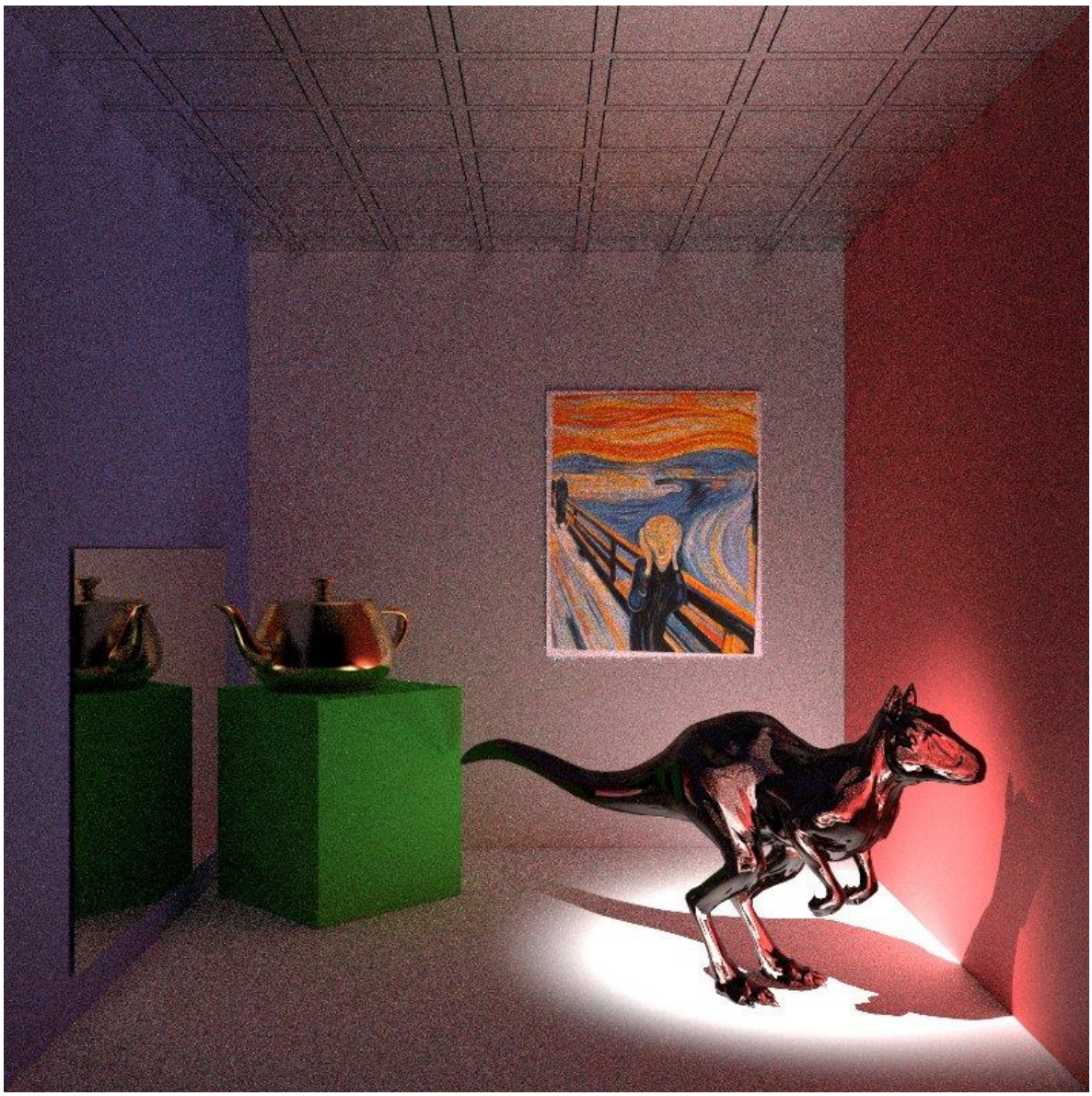


Figure 5. Scene rendered with path tracing and a halton sampler.

Low Discrepancy

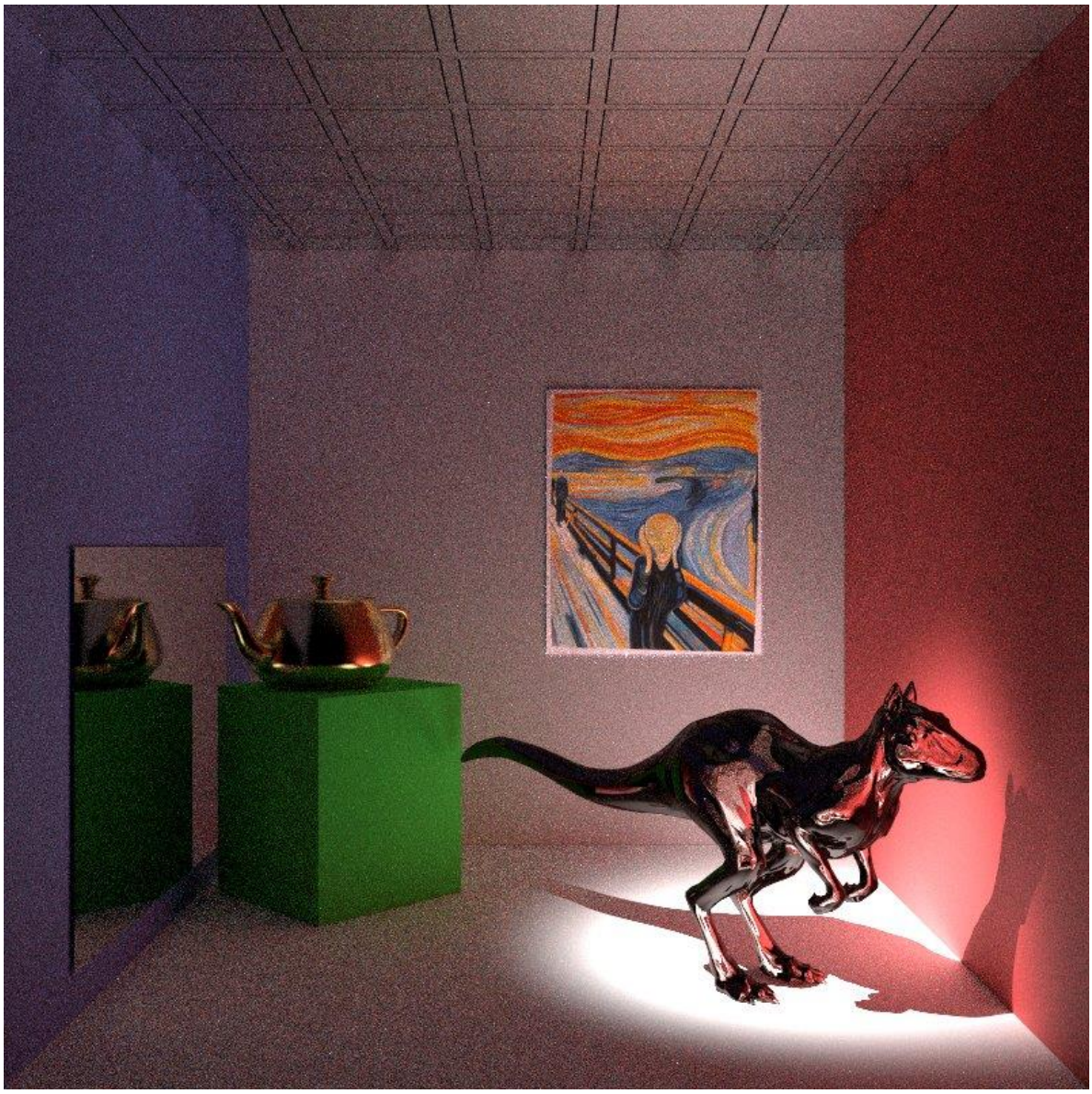


Figure 6. Scene rendered with path tracing and a low discrepancy sampler.

Random

Figure 7. Scene rendered with path tracing and a random sampler.

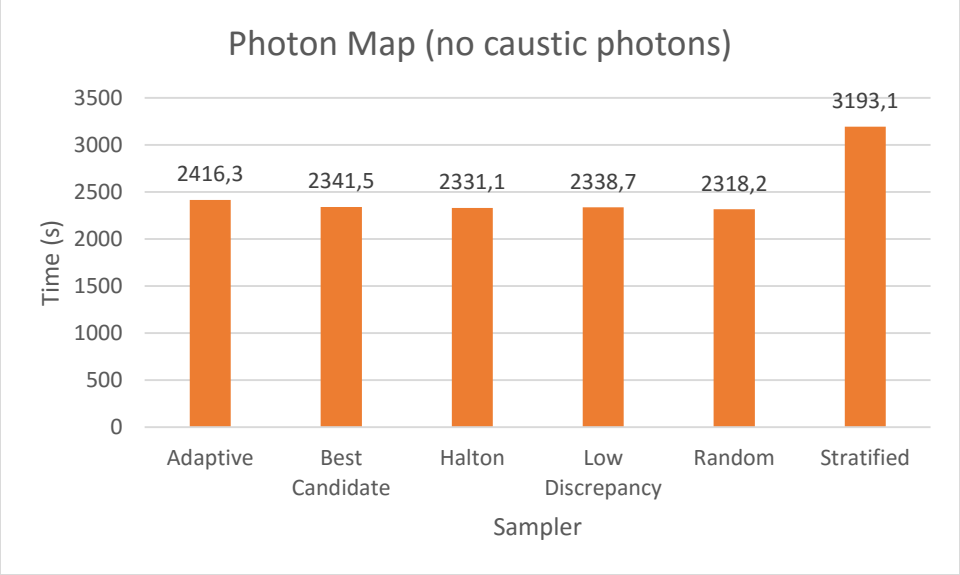
Stratified

Figure 8. Scene rendered with path tracing and a stratified sampler.

Photon Map With No Caustic Photons

From Graph 3 we also see that, in general, rendering times are very similar for all samplers. In this particular case, the outlier is the Stratified sampler. Comparing the elapsed times got from path tracing, a significant increase is easily detected. Photon Map (without Caustic Photons) rendering time is, in most cases, about 35 times greater. The reason behind this phenomenon is the number of photons chosen, which is significantly superior than the default path tracing settings. Consequently, the images' quality is clearly better, however as there are no caustic photons, the shadow continues unfitting.

The big part of problems related with the non-direct lighted surfaces are now solved. The noise is incredibly smaller, almost undetectable. There are still some places where we can see some undesired side effects: around the lines that result from the intersection between the roof (top plane) with the walls (right, front and left planes) are some reflected colors which don't make sense. We presume these artifacts appeared due to the fact the roof is a glossy surface, so it reflects like a blurred mirror. Similar things are visible among the floor (bottom plane) and the wall in front.



Graph 3. Rendering time comparison between samplers using the photon map tracing surface integrator with 0 caustic photons.

Adaptive

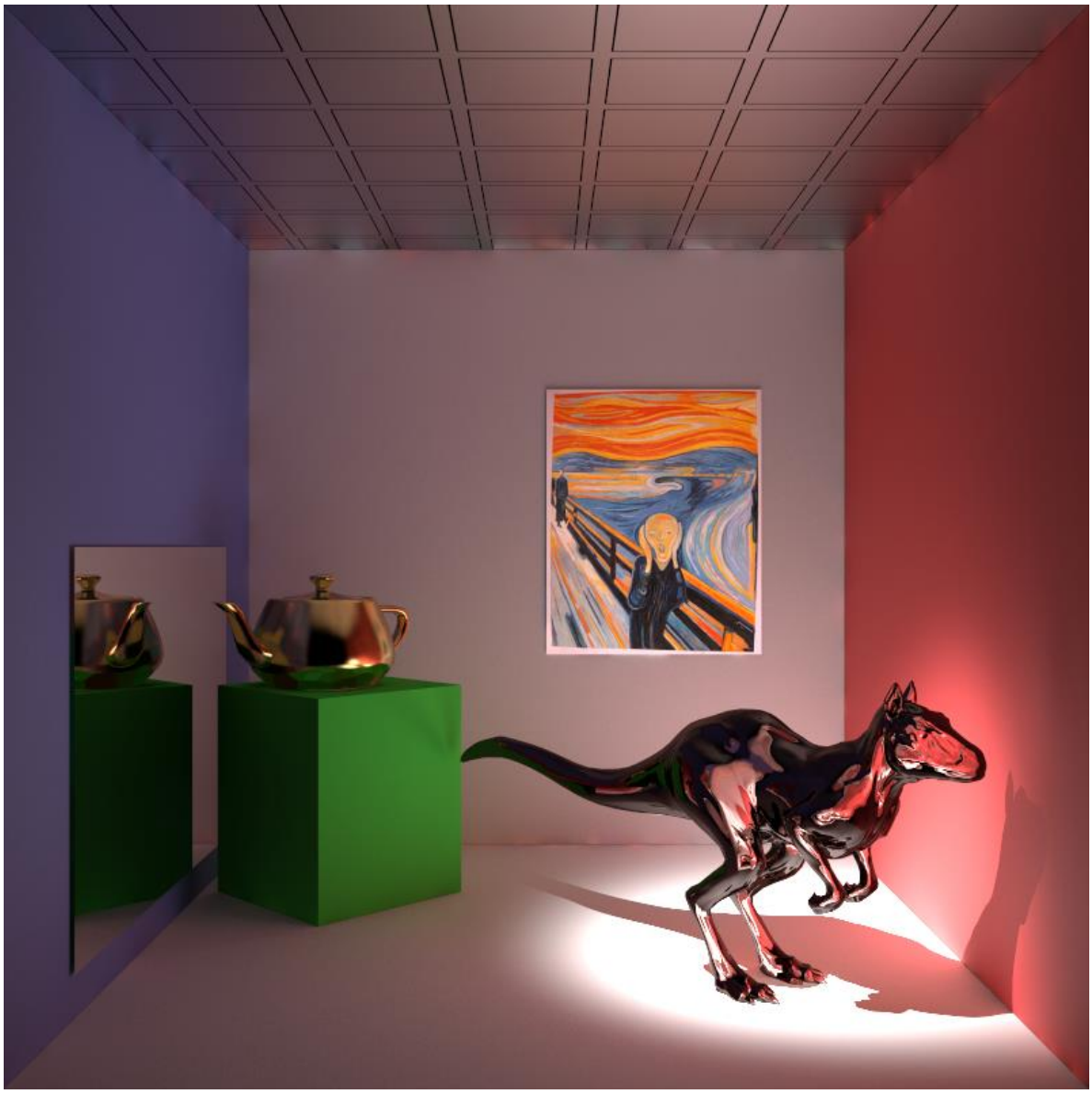


Figure 9. Scene rendered with photon mapping and an adaptive sampler.

Best Candidate

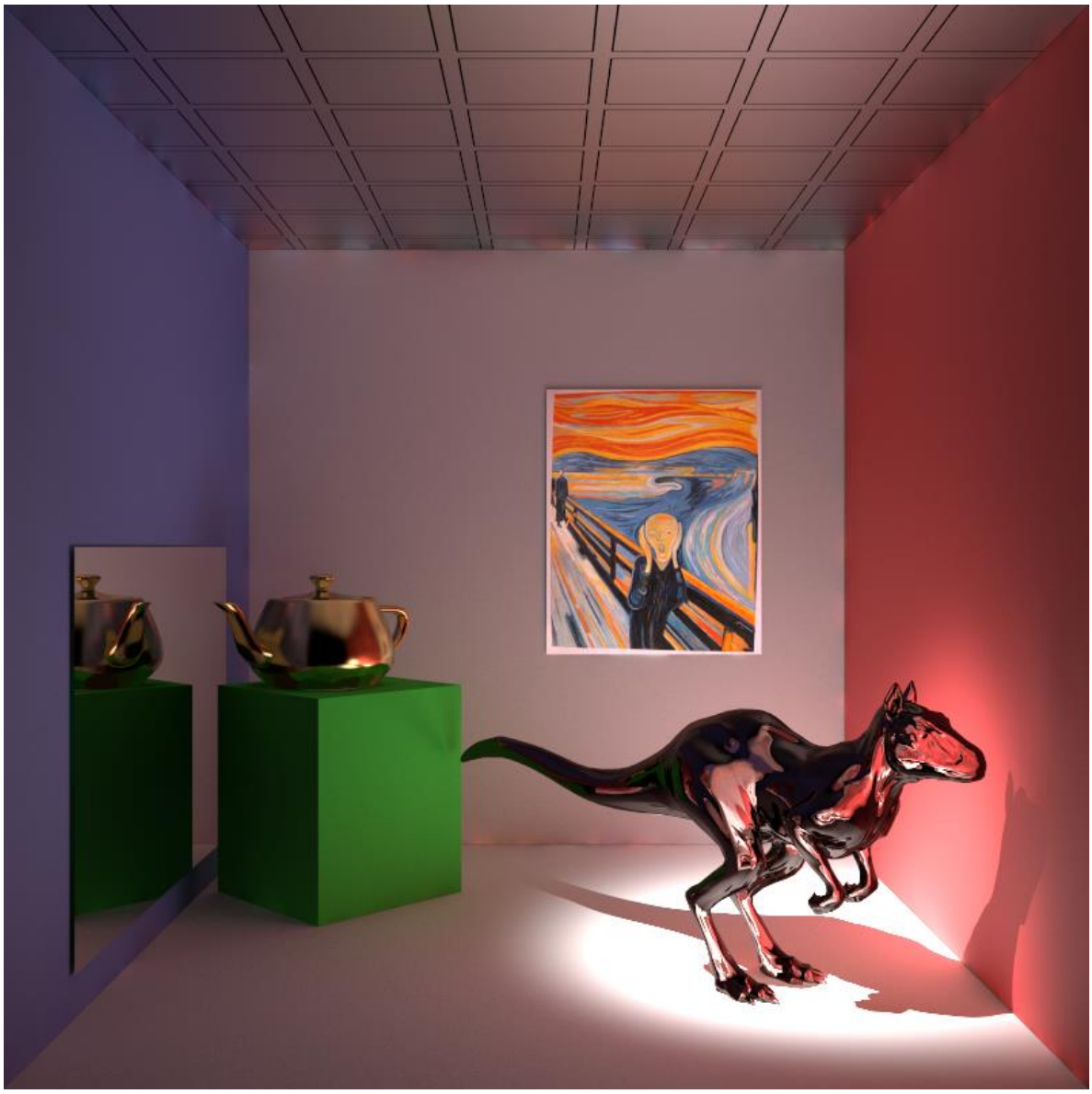


Figure 10. Scene rendered with photon mapping and a best candidate sampler.

Halton

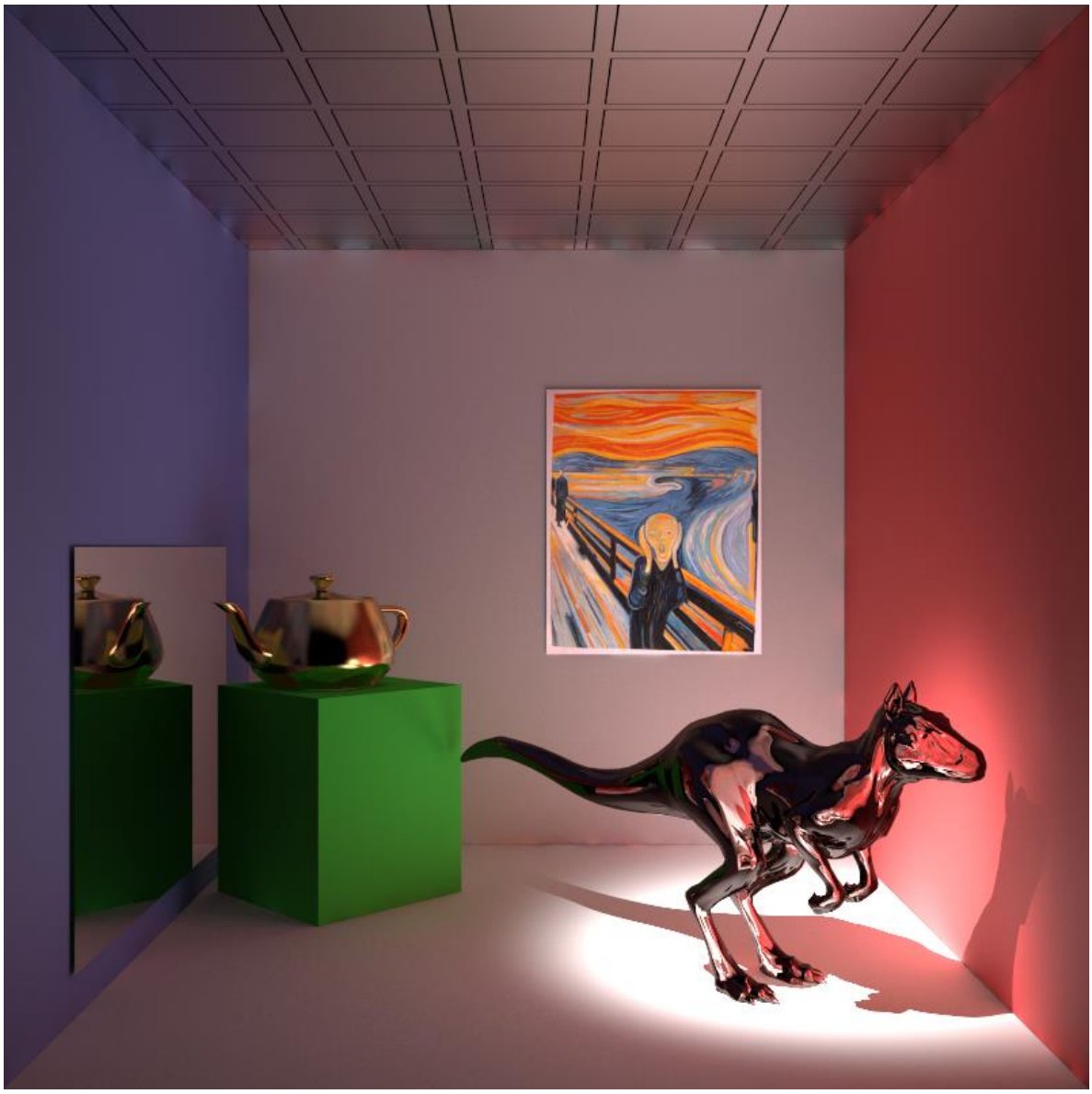


Figure 11. Scene rendered with photon mapping and a halton sampler.

Low Discrepancy

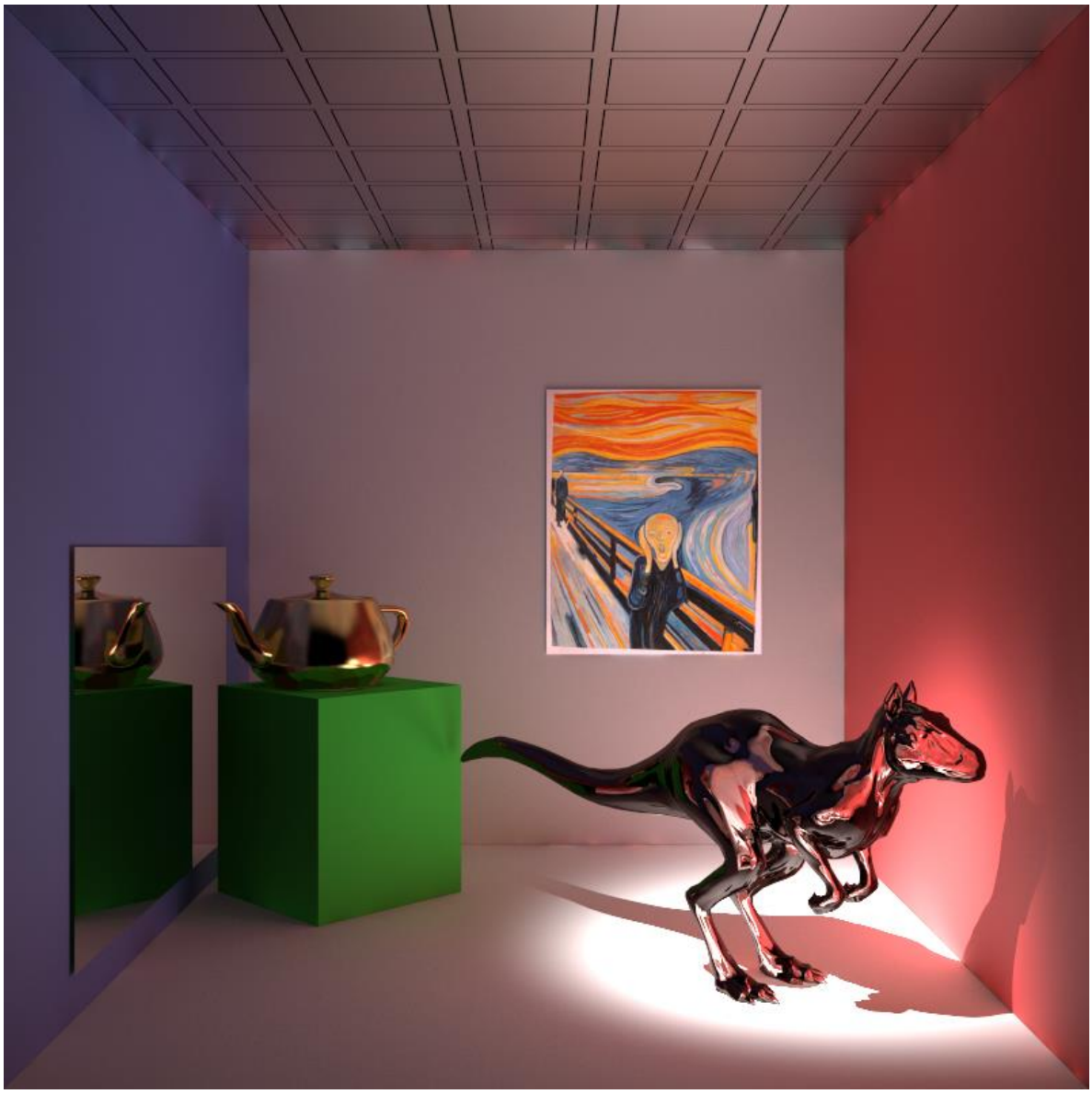


Figure 12. Scene rendered with photon mapping and a low discrepancy sampler.

Random

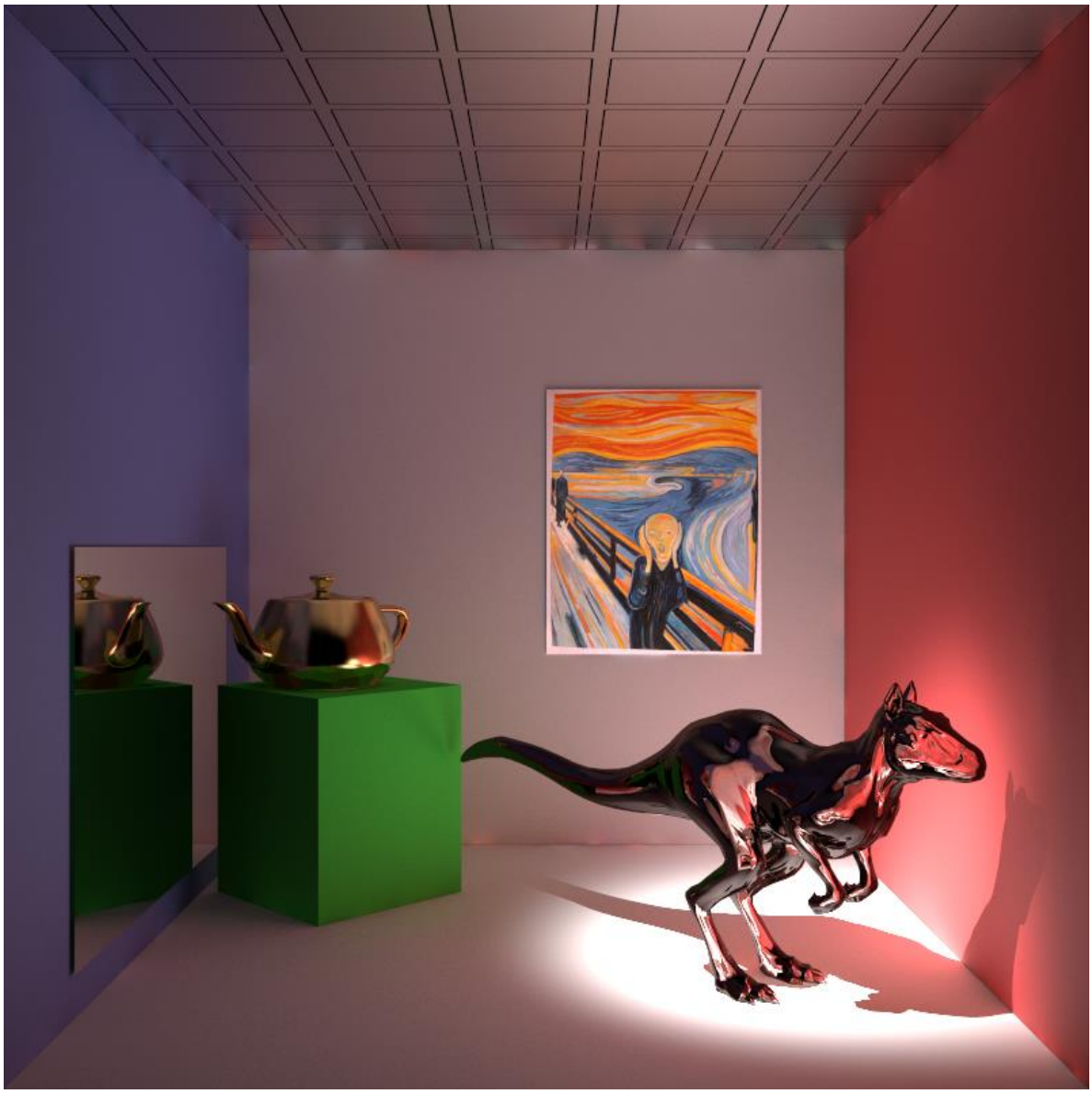


Figure 13. Scene rendered with photon mapping and a random sampler.

Stratified

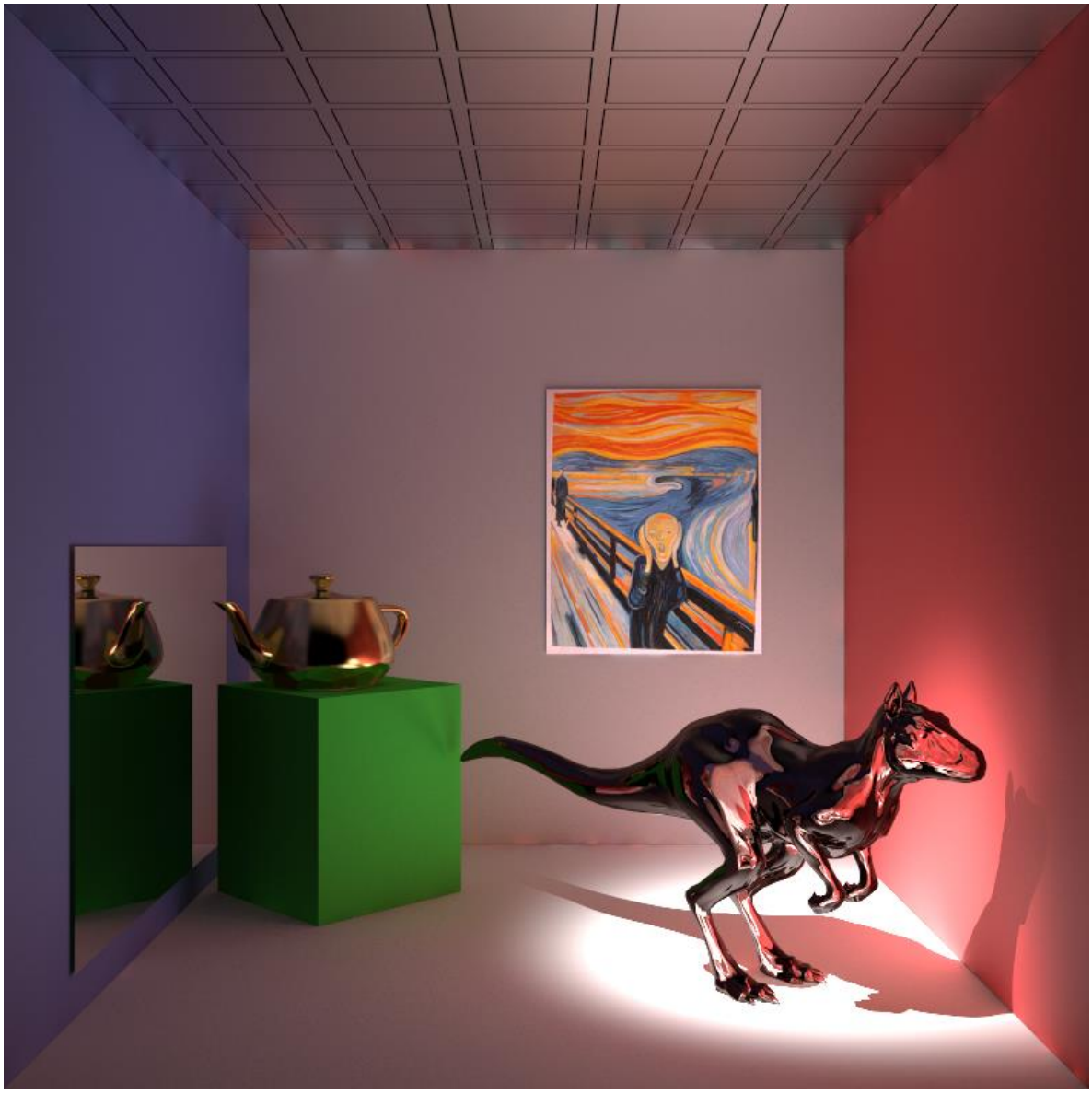
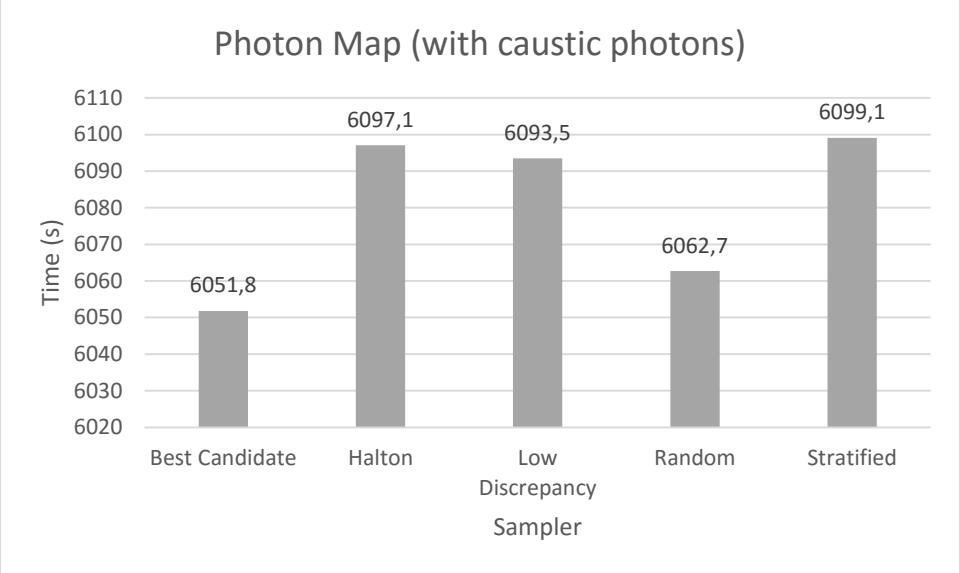


Figure 14. Scene rendered with photon mapping and a stratified sampler.

Photon Map With Caustic Photons

With the insertion of the Caustic Photons the final images get even better look, nearly what we pretend from it. Yet, like it was expected, we there was another increase on the rendering time, which was approximately three times bigger comparing with the last implementation (Photo Map Without Caustic Photons) and almost 100 times bigger associating with Path Tracing. Graph 4 shows that the times are very similar for any Sampler, not differing more than 1 minute.

Finally, the rendered image has caustics shadows, although they are not as we were guessing. According with the reference image, the caustic shadows must be much more well-defined, and not so glossy. Maybe this problem can be solved by changing the values of the variables that we considered as static. The previous problems related with the intersection of the planes, still persist, even on the reference image.



Graph 4. Rendering time comparison between samplers using the photon map tracing surface integrator with 10.000 caustic photons.

Best Candidate

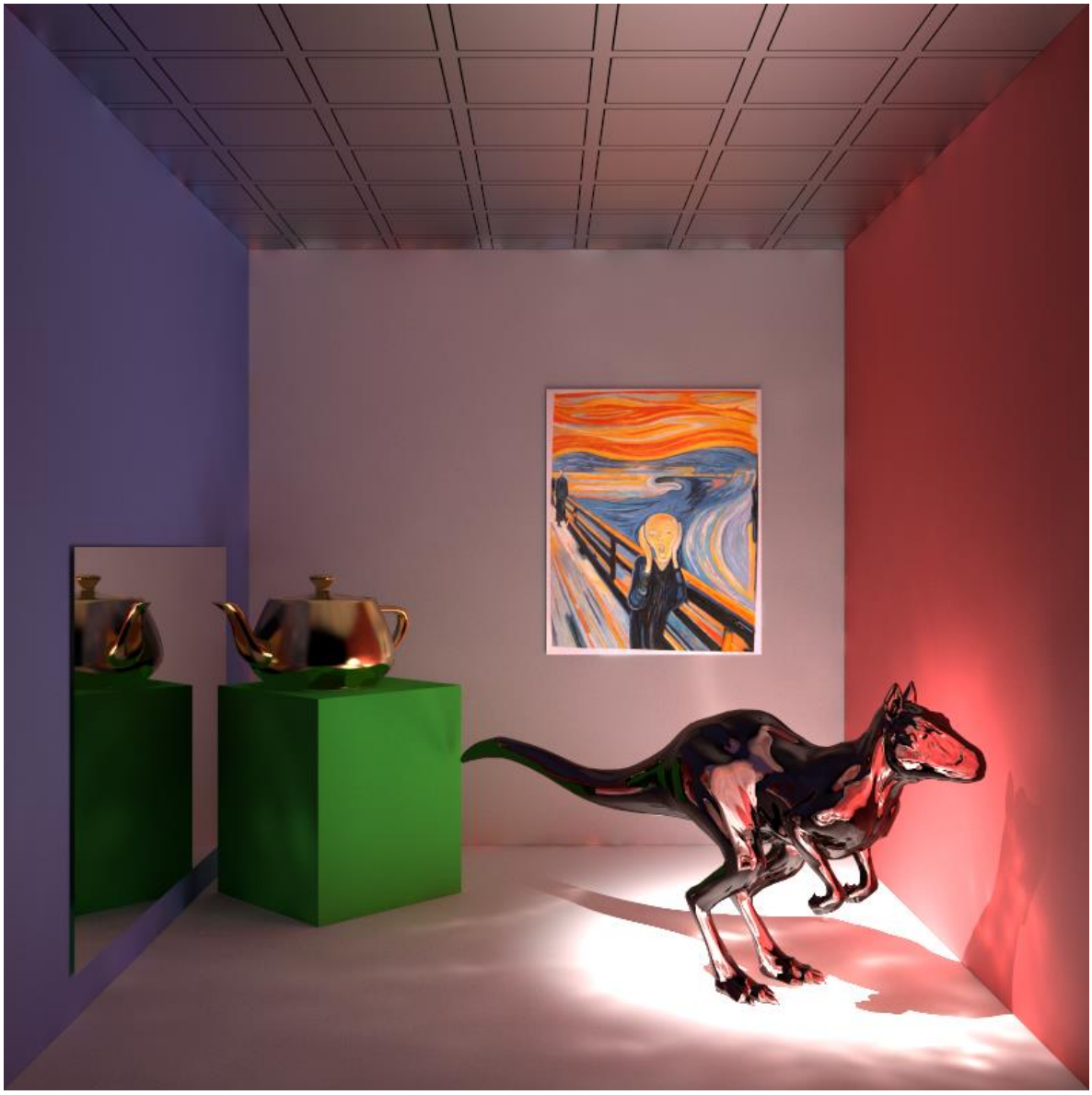


Figure 15. Scene rendered with photon mapping (with caustic photons) and a best candidate sampler.

Halton

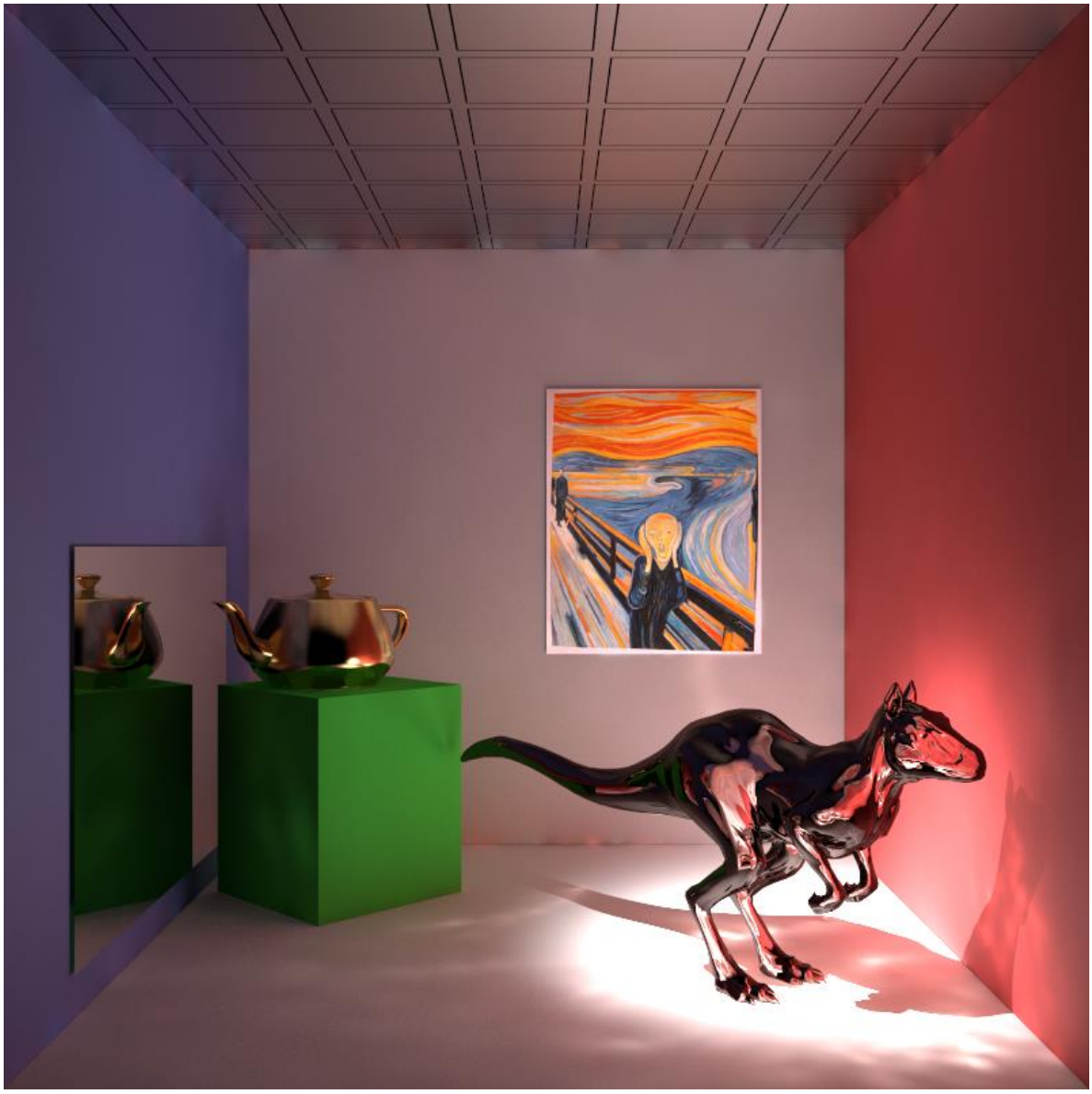


Figure 16. Scene rendered with photon mapping (with caustic photons) and a halton sampler.

Low Discrepancy

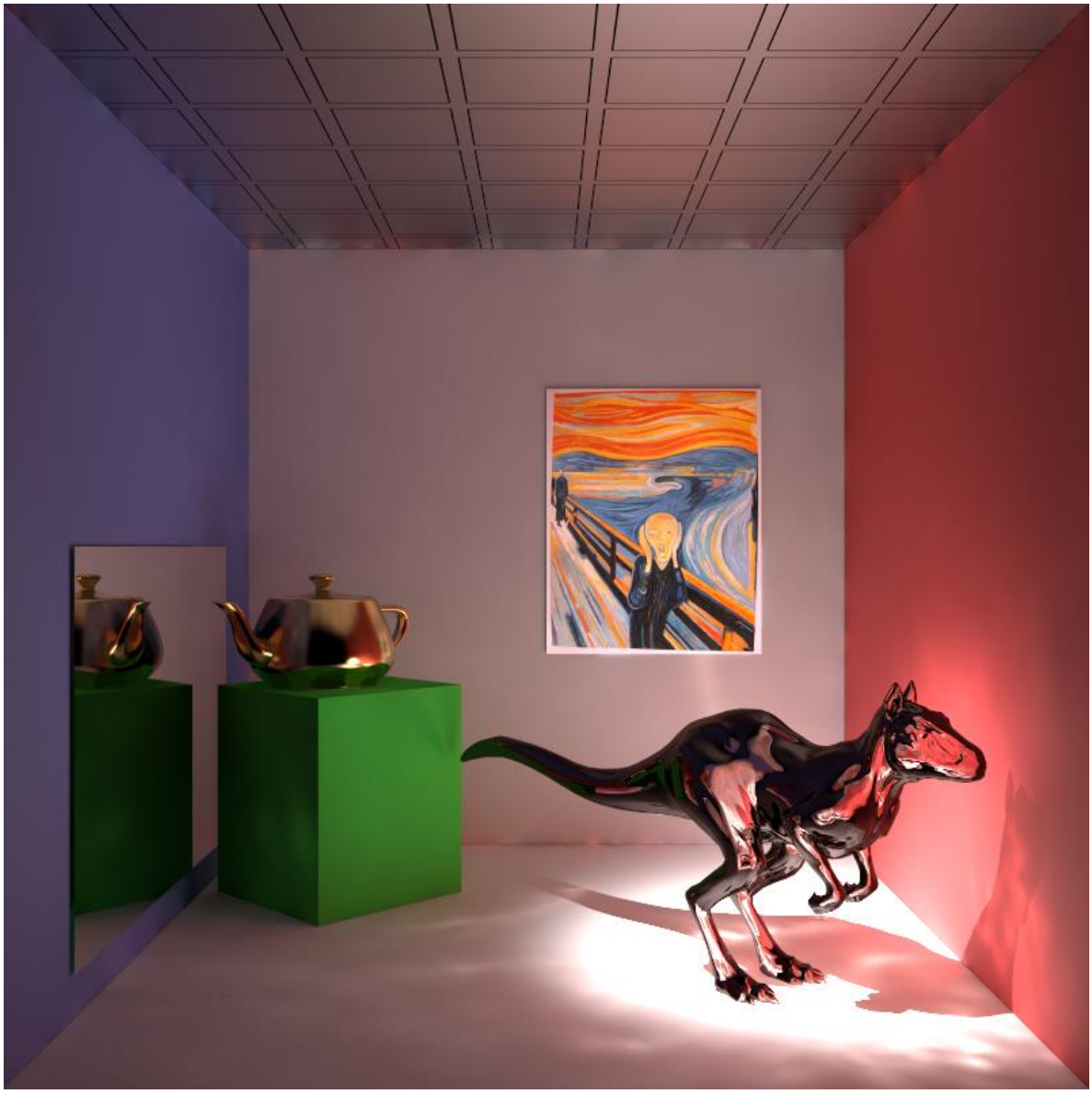


Figure 17. Scene rendered with photon mapping (with caustic photons) and a low discrepancy sampler.

Random

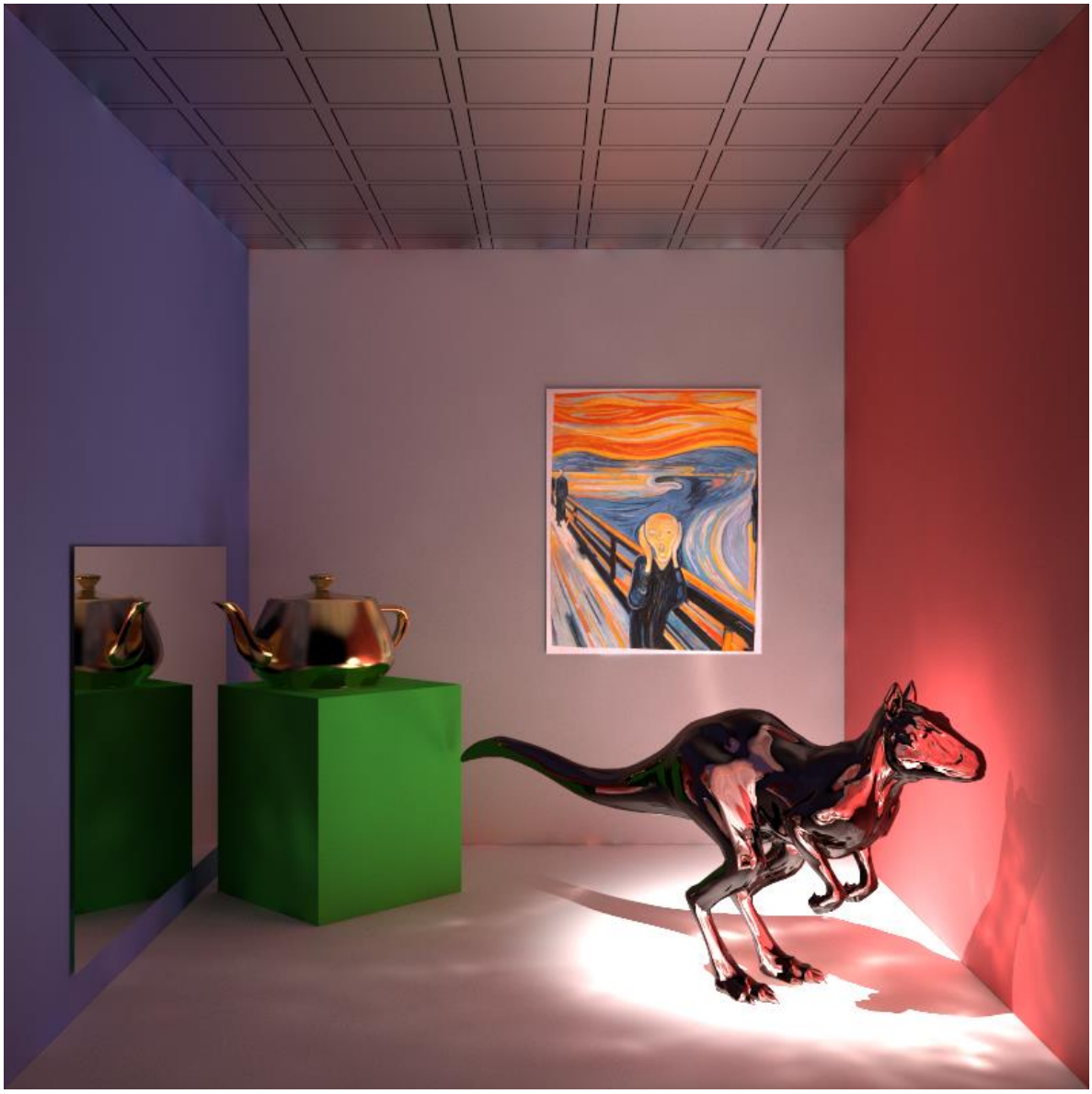


Figure 18. Scene rendered with photon mapping (with caustic photons) and a random sampler.

Stratified

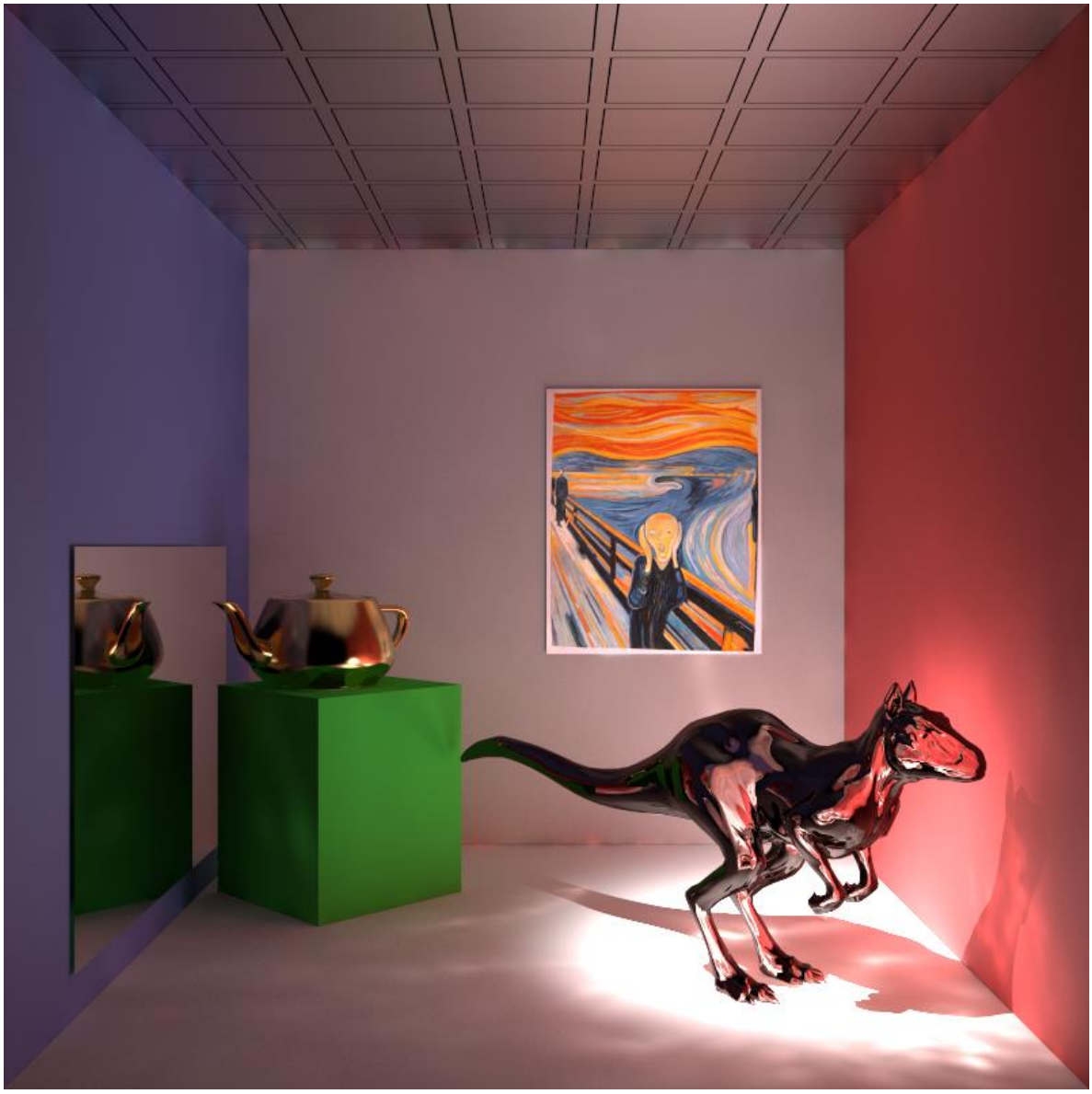


Figure 19. Scene rendered with photon mapping (with caustic photons) and a stratified sampler.

Reference Image

To generate the reference image we used the photon map surface integrator with 1.000.000 caustic photons and 20.000 indirect photons, and the random sampler with 256 pixel samples; both the surface integrator and the sampler were chosen based on the best results we had achieved by the time. With the values used we can have a clear image and are able to see high quality caustics for comparison with the rest of the scenes rendered.

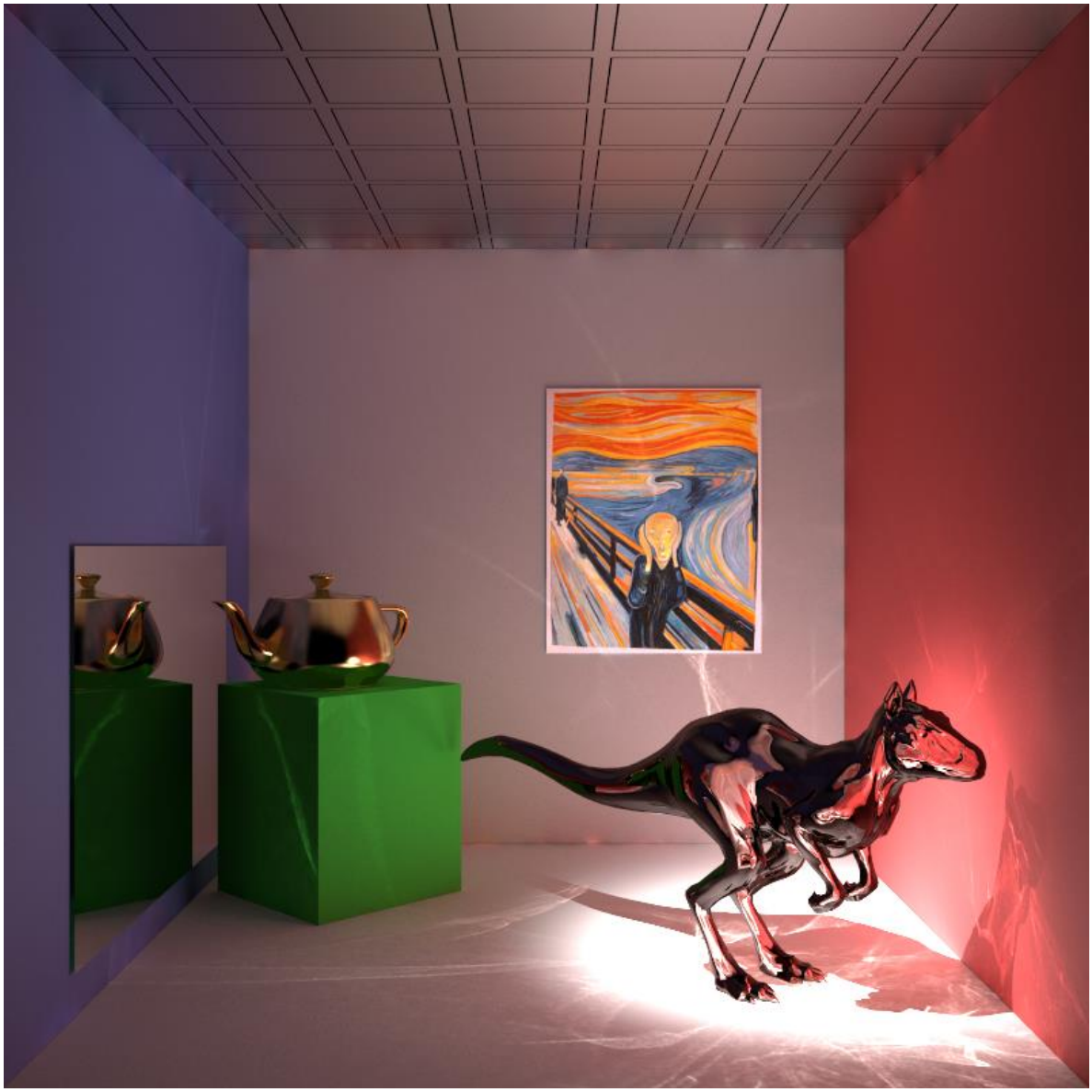


Figure 20. Reference scene.

Conclusion

After observing and comparing all the resultant images from the various studied algorithms, the most immediate conclusion is that there is little difference between the considered samplers, but there is a noticeable variance between the surface integrators. Graph 5 presents the results obtained when the numerous final imagens were compared with the reference image through the "rmse.exe" program from PBRT project. This graph proves just this point, were between samplers the RMSE variance is insignificant, but between surface integrators it is not.

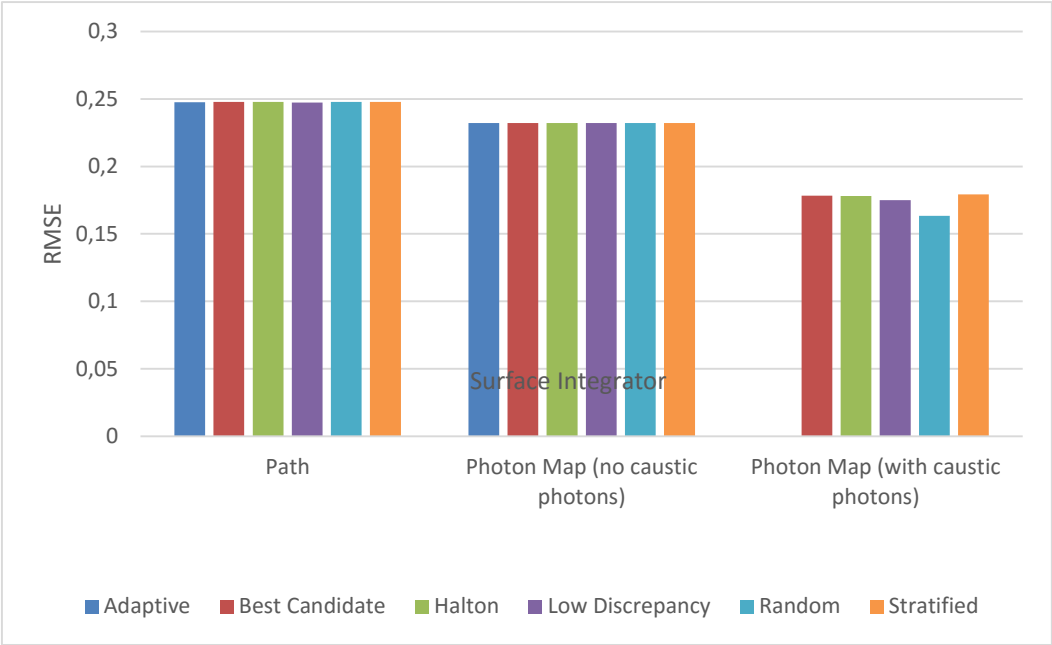
From the beginning we set as an objective to find the best relation between image quality, in terms of realism (this is under the subject of Photorealism, after all), and time spent on the rendering. Of course, according to the obtained results, our final choice will be much more influenced by the image quality then the rendering time, mainly because we are dealing with not real time graphics. So, our focus goes immediately to the Photon Map surface integrator. Even by analyzing the Graph 5, we conclude that those images are the closest ones to the reference.

With Path Tracing we noticed that was a lot of noise in all images. Besides the rendering time was very low, the image quality would never compensate that. Although we haven't tried, it would be perfectly acceptable to compare Path Tracing with Photon Map but on conditions where the time consumed on the rendering was most similar, as possible, on both. A relevant question associated with Path Tracing is that, as long as it creates more rays, we gave exponentially less importance to them and consequently the time grows steeply. From this perspective, we consider it this would be a good start point for a future work.

When we tried the Photon Map Integrator Without Caustic Photon there was a huge gain not only on the images' quality but also on the rendering time. The problems related with the Path Tracing were gone and everything looked considerably smoother. Still, there wasn't caustics shadows and for that reason we were forced to add the caustic photons.

Now we have the surface integrator choice justified, remains the choice of sampler. Just like we said before, on Photon Map With Caustic Photons, the rendering times are very close to each other, not exceeding 1 minute of difference. So, admitting they are all equal, the decision stands for Graph 5, where we see that the Random Sampler is the one that produces better results. However, we are aware that the obtained caustics aren't defined as they should be.

At last, we would like to mention that SeARCH killed the job responsible to the Adaptive sampler on Photo Map and that's the reason why we have this gap on the results. Also, we would like to try some others Surfaces Integrators that are only available on PBRT-v3 such as Metropolis Light Transport (MLT) and Stochastic Progressive Photon Mapping (SPPM). Stays as another viewpoint or a future work.



Graph 5. RMSE comparison between surface integrators and samplers.