

# Computer Graphics, Autumn 2019

## Assignment 3

### Benchmarking in PBRT

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**Due date: 29/11/19 (5pm)**

In the first assignment you used *PBRT* as a ‘black box’ to render images of objects which you then composited onto a photograph of a real environment. In the second assignment you were required to build your own renderer, via ray tracing. In this **third and final assignment for the course**, you will need to delve deeper into the workings of PBRT, *expand its arsenal of materials and sampling methods* and perform a comprehensive comparison of different integrators and sampling strategies. The goal of the analysis is to identify the configuration parameters that offer the best settings for your newly created material. In addition to a report, you will also be evaluated based on a *five-minute presentation* of your implementation and experimental results in class.

## Part I

# Implementation Details

For the third assignment, you are asked to augment *PBRT* with the following features. The course textbook [www.pbr-book.org](http://www.pbr-book.org) provides all the interface information required to implement your new `Sampler` and `Material/BxDF`.

- Implement the basic *dart throwing Poisson disk* sampling method. Subsequently, implement a relaxed version of *Poisson disk sampling*, proposed by M.McCool et al. [1], as a `PixelSampler` within *PBRT*. The proposed method consists of two steps, the *relaxed Poisson disk sampling* method, and *Lloyd’s relaxation*. You are asked to implement either. Suggested reading:
  - Chapter 7: SAMPLING AND RECONSTRUCTION [2].
- Implement the “*anisotropic Phong BRDF*” model, proposed by M. Ashikhmin et al. [3], as a new `Material` and accompanying `BxDF` within *PBRT*. The paper defines the material function and a method for performing importance sampling. You are asked to implement both. Suggested reading:

- Chapter 8: REFLECTION MODELS [4].
- Chapter 9: MATERIALS [5].
- Chapter 14: LIGHT TRANSPORT I: SURFACE REFLECTION [6].

## Part II

# Experimental Evaluation Details

For the experimental part of the assignment you are asked to model scenes that will show the benefits of different samplers as well as integrators. In order to do this effectively, you will first need to understand how they operate (and therefore what types of scenes they might outperform other integrators in). You will need to model **four** original scenes with each using the “*anisotropic Phong*” material on at least one of the visible objects. Each scene should be rendered with **three** different integrators, and **four** different samplers – one of which must be Poisson disk sampling – using **three** increasing sample counts. i.e.  $4 \times 3 \times 4 \times 3 = 144$  combinations.

## 1 Qualitative comparison

Since it might not be feasible to render full images of all combinations, you will only need to show three images of each scene (i.e. 12 full images). Use the same three different integrators for each image and all images must be rendered use the Poisson disk sampler that you have implemented. Compare and contrast different integrators visually, showing cropped regions of interest.

## 2 Quantitative comparison

Your quantitative comparison must include all 144 combinations but you do not need to render high resolution images for this. You may either choose a random subset of pixels or within the crop windows selected for qualitative comparison. For each combination, plot error convergence using the *Mean Squared Error* (MSE) metric that you have used previously in this course:

$$\frac{1}{N} \sum_i [|R_{i_{ref}} - R_{i_{test}}|^2 + |G_{i_{ref}} - G_{i_{test}}|^2 + |B_{i_{ref}} - B_{i_{test}}|^2],$$

where  $i$  is the index of pixels contained within an  $N$ -pixel region.  $R_{i_{ref}}, G_{i_{ref}}, B_{i_{ref}}$  and  $R_{i_{test}}, G_{i_{test}}, B_{i_{test}}$  indicate the *linear RGB* values of the  $i$ -th pixel in the reference image and the test image, respectively. Plot the MSE against the increasing number of samples in log-log scale. The reference image should be rendered with a high sample count (at least two orders of magnitude higher than the largest sample count selected for the experimental setup) and an unbiased sampler as the sampler of choice. Present your results

in a  $4 \times 3$  grid of images for each scene, with different sampling methods along rows and integrators across the columns.

### Tips:

- implement and test the Poisson disk sampler independently first before trying it within PBRT's software framework.
- take advantage of `pbrt`'s `cropwindow` and `nthreads` options to speed up rendering.
- Identify cases where integrators and samplers might exhibit different performance, and model your scenes based on these observations.
- use the `imgtool` tool bundled with PBRT to retrieve the linear RGB values of the `.exr` renderings.

## Part III

# Submission and marking

Your submissions will be marked based on a report and a five-minute presentation in class. For the presentation, use slides to highlight your implementation of Poisson disk sampling and the Ashikmin-Shirley anisotropic Phong material. Also highlight the results of your quantitative analysis. The presentation schedule will be announced soon.

## What to Submit

The submitted `.zip` file should contain:

- A folder structure mimicking that of `pbrt` and containing **all the necessary .h and .cpp files that contain your implementations** of the *Poisson disk* sampler and the *“anisotropic Phong”* material, as well as **all the modified pbrt header and source files** that are needed for your code to run. Copying your files in the respective `pbrt` locations should allow `pbrt` to compile and run seamlessly. Please only submit source files (including config files/makefiles).
- A comprehensive **report** containing implementation details, how-to-use manual (`pbrt` input file parameter description), documentation of implemented functions, and the experimental evaluation.

Implementation details should specify how you implemented the new sampler and material within the code context of `pbrt`, which code snippets included, if required (Please avoid copy-pasting the whole code in the report, just the source lines needed for explaining your implementation). Furthermore, provide examples that showcase

your methods. Regarding the *Poisson disk sampler*, provide an example visualization of the samples, starting with the basic *dart-throwing* method, and continuing with the relaxed *Poisson disk* sampling of McCool [1], with and without *Lloyd's relaxation*. Compare the performance of the samplers with each other, and against a baseline sampler, such as *uniform sampling*, for an example scene that exhibits a challenging integration problem, such as soft shadows, or depth-of-field. Identify and comment on the advantages and disadvantages of each method in the report. Regarding the “*anisotropic Phong*” material, showcase the difference between uniform and importance sampled BSDF, as well as how parameters of the model influence the appearance of a synthetic object equipped with this material, by recreating the grid of Figure 1 from the referenced paper [3]. An example `.pbrt` input file to generate a single instance of this grid can be found at the end of problem sheet. How-to-use manual should specify how to define your new sampler and material in the `pbrt` input file, along with a definition and description of the parameters of each method.

The experimental evaluation part of your report should describe in detail the experimental process, experimental decisions, and results, with inline figures and plots that are numbered, annotated, referenced, and easily readable. Critical qualitative and quantitative assessment of the findings is required, along with experimental results supporting them (figures, plots, etc.).

- Example renderings, in `.exr` format, showcasing the implemented methods, along with the `.pbrt` input files used to generate them. Copying your implementation files in a fresh installation of `pbrt`, and specifying the supplied `.pbrt` as input files should produce the exact same renderings as the ones included in your deliverable. Examples of the **four** (4) modelled scenes, alongside the `.pbrt` files used to generate them.

A submission of only the final output without explanations and intermediate steps will only receive half the credit. **Plagiarism is considered a serious offence**, so please make sure that you supply original code, or clearly reference the sources from which your code originates.

Please name your submission file as `<your UUN>_A3.zip`, and upload it on the *Learn* platform (<https://learn.ed.ac.uk>) as the third assignment for the course.

## Marking Scheme

A total of 100 points are assigned for this project, which will then be halved, i.e. its final contribution to your grade will be at most 50%, depending on the marks on your past two assignments. See the course website for clarification. The marking scheme is described below. Numbers in parentheses indicate points of the specific task. Each student is expected to design unique scenes illustrating the abilities of the implemented sampler and material. Provide evidence of having achieved each of the following milestones in your

report. Part of the marks of each milestone are attributed to the respective section in the submitted report.

1. Implementation (total 44)
  - (a) *Poisson disk sampling* (total 22)
    - i. Dart-throwing Poisson disk sampling (5)
    - ii. Relaxed Poisson disk sampling [1] OR Loyd’s relaxation [1] (12)
    - iii. Example renderings (on one scene) depicting observable differences between Poisson disk sampling and any other (baseline) sampler (5)
  - (b) “*anisotropic Phong BRDF*” [3] (total 22)
    - i. anisotropic Phong material (7)
    - ii. Importance sampling the anisotropic Phong material (9)
    - iii. Example renderings demonstrating the difference between rendering with and without importance sampling (2)
    - iv. Grid of renderings showcasing the behaviour of different parameters, similar to Figure 1 of [3]. An example `.pbrt` input file is provided at the end of the problem sheet. Crop the image as necessary to arrange in a grid. (4)
2. Experimental evaluation (total 44)
  - (a) Qualitative comparison (12) (1 per sampler-integrator-scene image)
  - (b) Convergence plots (12) (0.25 per sampler-integrator-scene combination convergence plot)
  - (c) Description, assessment and discussion of the results. This should include justification for why certain combinations appear better than others (20)
3. Five-minute presentation (12)

## Pbrt input file example (Task 1 (b) iii)

Use the input file of Figure 2 to generate the example scene of Figure 1. The sphere is rendered with the “*anisotropic Phong*” material, with  $R_d = 0.01$ ,  $R_s = 0.5$ ,  $n_v = 10$ ,  $n_u = 10000$ . For *Task 1 (b) iii* alter the parameters of the `anisotropicPhong` material to generate a grid similar to Figure 1 from [3].

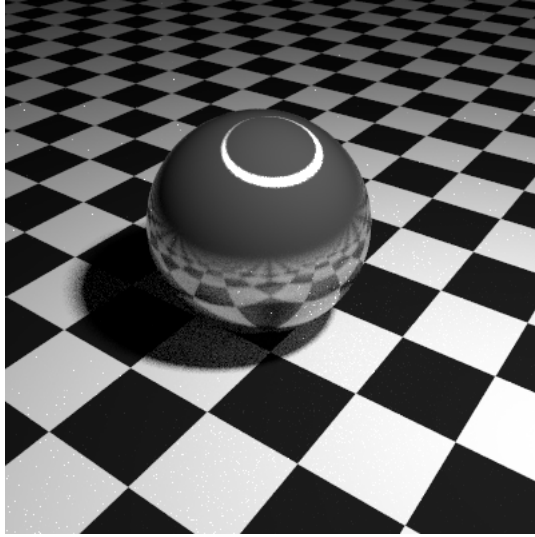


Figure 1: Output of Figure 2.

```

1 LookAt 3 4 3 # eye
2     .5 .5 0 # look at point
3     0 0 1   # up vector
4 Camera "perspective" "float fov" 45
5
6 Sampler "random" "integer pixelsamples" 50
7 Integrator "path" "integer maxdepth" [5]
8 Film "image" "string filename" "simple.png"
9     "integer xresolution" [400] "integer yresolution" [400]
10
11 WorldBegin
12
13
14 AttributeBegin
15     AreaLightSource "diffuse" "rgb L" [ 500.0 500.0 500.0 ]
16     Translate 3 0 5
17     Shape "sphere" "float radius" [.30]
18 AttributeEnd
19
20 AttributeBegin
21     Material "anisotropicPhong" "rgb Rd" [ 0.01 0.01 0.01 ] "
22         rgb Rs" [.5 .5 .5 ] "float nv" [10.0] "float nu" [10000.
23         0]
24     Shape "sphere" "float radius" 1
25 AttributeEnd
26
27 AttributeBegin
28     Texture "checks" "spectrum" "checkerboard"
29         "float uscale" [45] "float vscale" [45]
30         "rgb tex1" [.01 .01 .01] "rgb tex2" [.8 .8 .8]
31     Material "matte" "texture Kd" "checks"
32     Translate 0 0 -1
33     Shape "trianglemesh"
34         "integer indices" [0 1 2 0 2 3]
35         "point P" [ -20 -20 0   20 -20 0   20 20 0   -20 20 0 ]
36         "float st" [ 0 0   1 0   1 1   0 1 ]
37 AttributeEnd
38
39 WorldEnd

```

Figure 2: Pbrt input file example

## References

- [1] Michael McCool and Eugene Fiume. Hierarchical poisson disk sampling distributions. In *Proceedings of the Conference on Graphics Interface '92*, pages 94–105, San Francisco, CA, USA, 1992. Morgan Kaufmann Publishers Inc.
- [2] Matt Pharr, Wenzel Jakob, and Greg Humphreys. 07 - sampling and reconstruction. In Matt Pharr, Wenzel Jakob, and Greg Humphreys, editors, *Physically Based Rendering (Third Edition)*, pages 401 – 504. Morgan Kaufmann, Boston, third edition edition, 2017. Available at [www.pbr-book.org](http://www.pbr-book.org).
- [3] Michael Ashikhmin and Peter Shirley. An anisotropic phong brdf model. *J. Graph. Tools*, 5(2):25–32, February 2000.
- [4] Matt Pharr, Wenzel Jakob, and Greg Humphreys. 08 - reflection models. In Matt Pharr, Wenzel Jakob, and Greg Humphreys, editors, *Physically Based Rendering (Third Edition)*, pages 507 – 568. Morgan Kaufmann, Boston, third edition edition, 2017. Available at [www.pbr-book.org](http://www.pbr-book.org).
- [5] Matt Pharr, Wenzel Jakob, and Greg Humphreys. 09 - materials. In Matt Pharr, Wenzel Jakob, and Greg Humphreys, editors, *Physically Based Rendering (Third Edition)*, pages 571 – 594. Morgan Kaufmann, Boston, third edition edition, 2017. Available at [www.pbr-book.org](http://www.pbr-book.org).
- [6] Matt Pharr, Wenzel Jakob, and Greg Humphreys. 14 - light transport i: Surface reflection. In Matt Pharr, Wenzel Jakob, and Greg Humphreys, editors, *Physically Based Rendering (Third Edition)*, pages 805 – 885. Morgan Kaufmann, Boston, third edition edition, 2017. Available at [www.pbr-book.org](http://www.pbr-book.org).