CSC4140 Assignment 7

Computer Graphics

May 1, 2022

Ray Tracing 2

This assignment is 8% of the total mark.

Strict Due Date: 11:59PM, May 1^{th}th , 2022

Student ID: 119010344

Student Name: Xiao Nan

This assignment represents my own work in accordance with University regulations.

Signature: Xiao Nan

Contents

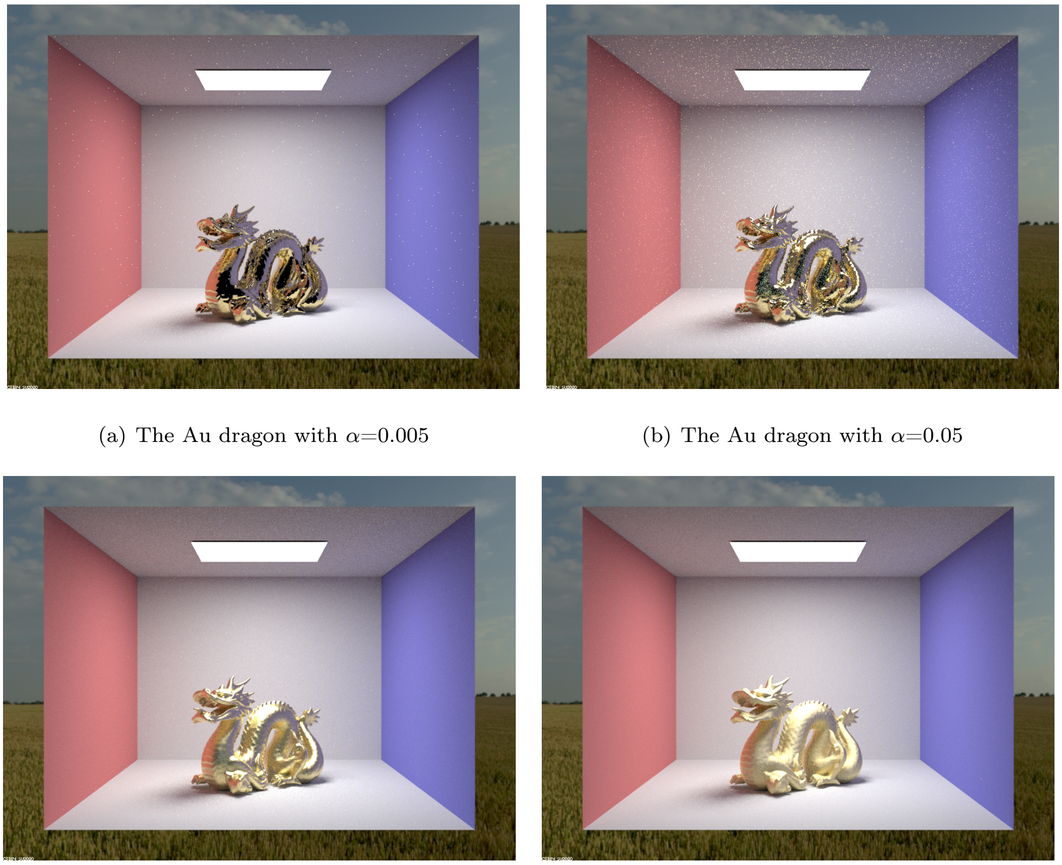
1 Overview

This assignment consists of in total three parts: In the first part I implemented the light reflection and refraction simulation (using the microfacet BRDF) on isotropic rough conductors (microfacet material), using both importance sampling and hemisphere sampling for the BSDF of the microfacet material. In the second part I implemented the environmental light simulation, where the environmental light source is regard as a light source infinitely far away and the methods for sampling from the source includes uniform sphere sampling and importance sampling. In the third part I implemented the thin-lens camera model supporting the adjustment of the aperture size and the focal distance.

2 Microfacet BSDF

2.1 Results for different αs

The results of the four images of *CBdragon-microfacet-au.dae*, with α set to 0.005, 0.05, 0.25 and 0.5, as well as 128 samples per pixel, 1 samples per light and maximum ray depth=5, are shown in figure 1. Where we may observe that the higher α is, the more likely that the dragon tends to diffuse the lights (showing almost no biased reflection from a particular incident direction and uniformly reflecting lights from all directions), and on the other hand, the smaller α is, the dragon tends to be more glossy and show stronger ability of aggregating lights from a given direction, resulting in a more mirror-like reflection effect.



(a) The Au dragon with α=0.005

(b) The Au dragon with α=0.05

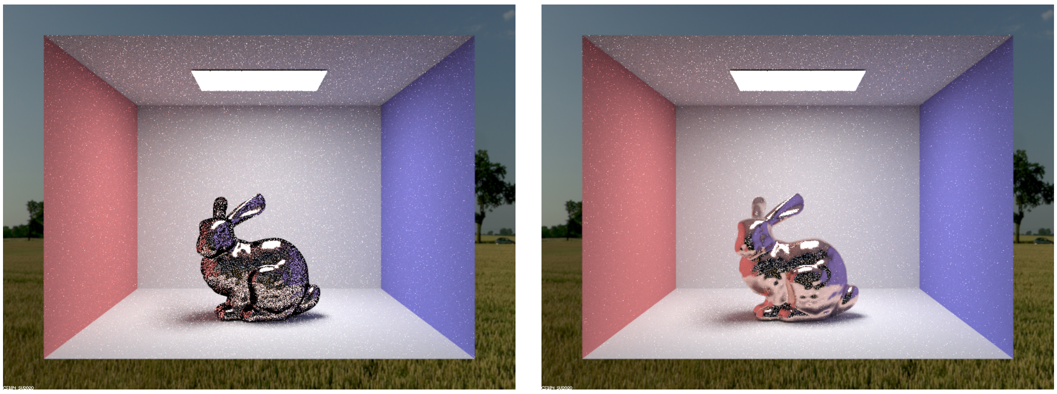
(c) The Au dragon with α=0.25

(d) The Au dragon with α=0.5

Figure 1: Results with different α values

2.2 Results for different sampling methods

The results of the two images of *CBbunny-microfacet-cu.dae* rendered using cosine hemisphere sampling and importance sampling are shown in figure 2, where we may observe that the cosine hemisphere sampling gives a more noisy results in that more black dots, in which the lights from the half-vector symmetric direction are not sampled adequately, are involved in the image, and hence the sampling direction doesn't match the Beckmann NDF for the microfacet surface well. The importance sampling, on the other hand, provides a more saturated illumation result because of the well-chosen incident light directions.



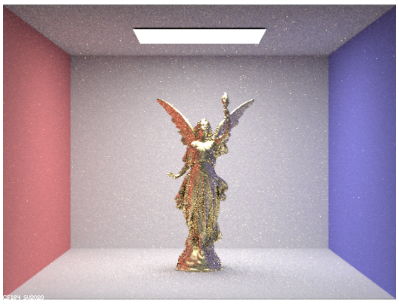
(a) *CBbunny-microfacet-cu.dae* with cosine hemisphere sampling

(b) *CBbunny-microfacet-cu.dae* with importance sampling

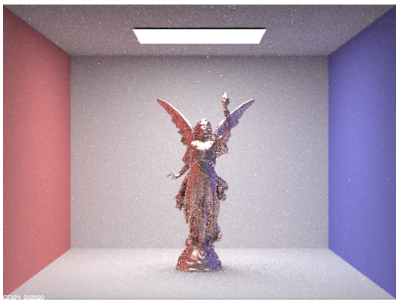
Figure 2: Results with different sampling methods

2.3 Results for other conductor materials

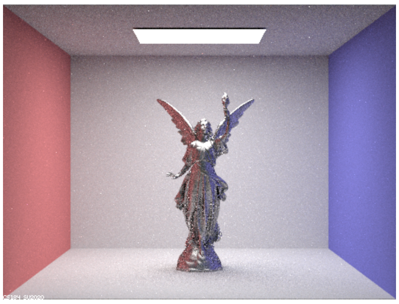
The results for the *CBlucy.dae*, with the indices of refraction for conductors (n and k) being set to different values, are shown in figure 3. Specifically, 2.3, 2.3 show the Lucy rendered with gold and copper as its surface material (corresponding to the groups of refraction indices for gold and copper, respectively). 2.3, 2.3 show the Lucy rendered with iron and its oxide, where we see clearly that the iron is more likely to diffuse light, whereas the iron oxide appears with a higher contrast. 2.3 shows the Lucy rendered with the mercury, where the diffuse of light is stronger (i.e. more lights are diffused from the surface) than that given by the iron surface. 2.3 gives the refraction indices with which the above images are rendered.



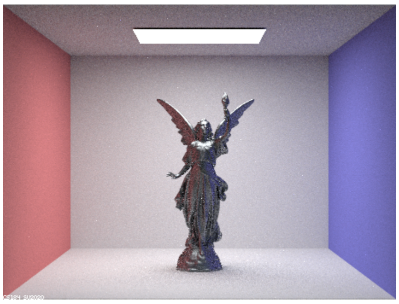
(a) *CBlucy.dae* with gold (Au)



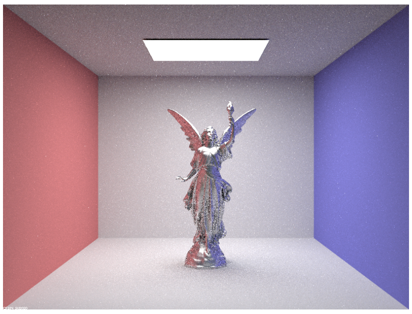
(b) *CBlucy.dae* with copper (Cu)



(c) *CBlucy.dae* with iron (Fe)



(d) *CBlucy.dae* with Hematite (Fe_2O_3)



(e) *CBlucy.dae* with Mercury (Hg)

```
<microfacet>
  <alpha>0.25</alpha>
  <!-- Hg -->
  <eta>1.8795 1.5472 1.1353</eta>
  <k>5.1076 4.6437 3.9980</k>
  <!-- Cu  -->
  <eta>0.33228 1.0162 1.2474</eta>
  <k>3.1646 2.5785 2.4603</k>
  <!-- Au  -->
  <eta>0.21646 0.42833 1.3284</eta>
  <k>3.2390 2.4599 1.8661</k>
  <!-- Fe2O3 -->
  <eta>3.2008 3.3148 3.2320</eta>
  <k>0.10400 0.50200 0.90160</k>
  <!-- Fe -->
  <eta>2.8851 2.9500 2.6500</eta>
  <k>3.0449 2.9300 2.8075</k>
</microfacet>
```

(f) Different refraction indices for different materials rendered for *CBlucy.dae*

Figure 3: Results with different refraction indices (materials)

3 Environmental lighting

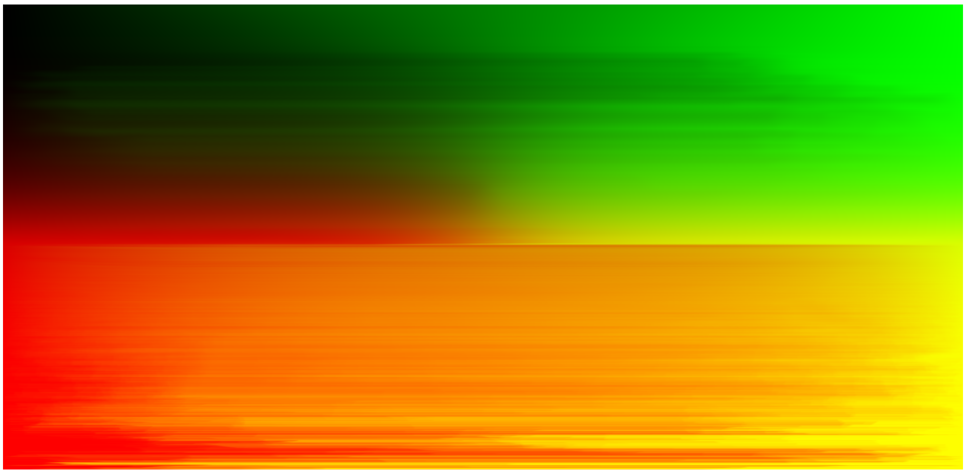
3.1 The ideas for environmental lighting

Environmental lighting refers to the lighting we perform to simulate the effect of the scene's lighting on the target object. It works by mapping an environmental texture, referred to as the HDRI (High Dynamic-Range Image) map containing illumation information on every texel, to the lighting sphere around the object in order to simulate the lighting effects from the environment, such as reflection, refraction and bouncing, on the target object. We perform the environmental lighting in order to render a more photo-realistic surface lighting (reflection and refraction) on the target object under the illumation influence of a given environment.

3.2 The environmental map being used, and the *probability-debug.png* file

The environmental map used is shown in figure 4, where the first sub-figure shows the *.env* file that I used and the second sub-figure shows the *probability-debug.png* file dumped for the environmental map.

(a) The environmental map I used (*field.exr*)

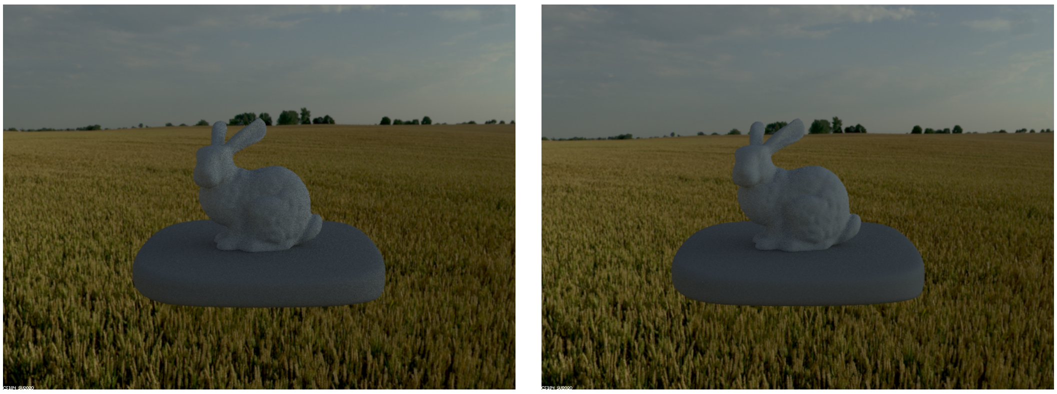


(b) *probability-debug.png* file

Figure 4: The environmental map I used, and the probability map

3.3 Results for different sampling methods with *bunny-unlit.dae*

The results for rendering *bunny-unlit.dae* with *field.exr* using 4 samples per pixel and 64 samples per light, one using the uniform sampling and the other using the importance sampling, are shown in figure 5. We may observe that the uniform hemisphere sampling gives a result with a higher noise level (since more black dots appear on the rabbit), whereas the importance sampling gives a results having lower noise level (with the rabbit's surface being smoother and having less black dots).

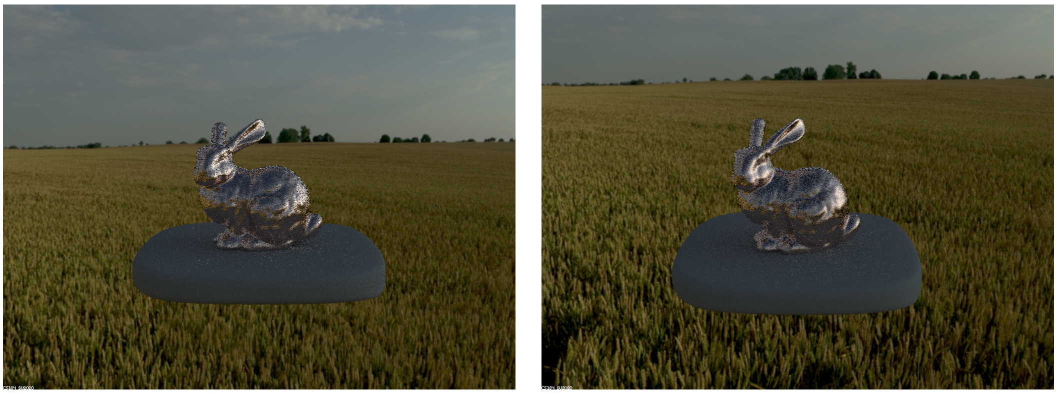


(a) Uniform sampling for the environmental light (b) Importance sampling for the environmental light

Figure 5: Results for different sampling methods on *bunny-unlit.dae*

3.4 Results for different sampling methods with *bunny-microfacet-cu-unlit.dae*

The results for rendering *bunny-microfacet-cu-unlit.dae* with *field.exr* using 4 samples per pixel and 64 samples per light, one using the uniform sampling and the other using the importance sampling, are shown in figure 6. We may observe that the uniform hemisphere sampling gives a result with a higher noise level (more black dots appearing on the rabbit), whereas the importance sampling gives a results having lower noise level (with the rabbit's surface having less black dots) and hence more smooth (metal-like) illuminance on the microfacet surface.



(a) Uniform sampling for the environmental light (b) Importance sampling for the environmental light

Figure 6: Results for different sampling methods on *bunny-microfacet-cu-unlit.dae*

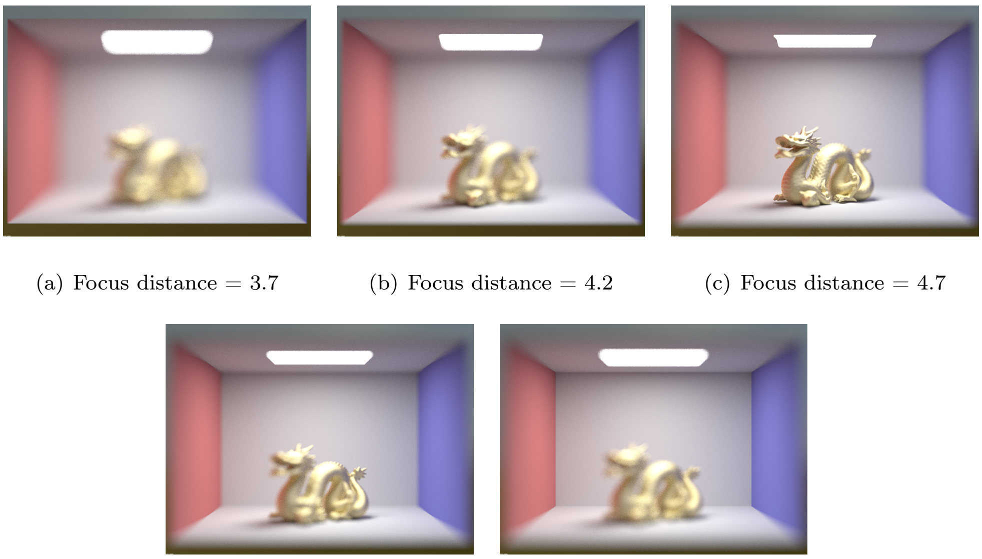
4 Focus distance and aperture size adjustment

4.1 Differences between the pin-hole camera model and the thin-lens camera model

The pin-hole camera model refers to the camera model where the lights shooting on the sensor all come from a pin-hole with negligible aperture size, and the thin-lens camera model refers to the camera model that is too "thin" to have any depth, hence not resulting in any bent on the light passing through the lens. The thin-lens camera model has a finite aperture size controlling the amount of light coming in to the sensor, hence affecting the depth of field and the illuminance of the image. Because of this, a pinhole camera can be regarded as an idealization of the thin-lens camera as aperture shrinks to zero, where the lights travel along a single and straight path through a pinhole onto the view plane, resulting in an upside-down image on the plane.

4.2 The focus stack

The results with focus distance equaling to 3.7, 4.2, 4.7, 5.2, 5.7, given the aperture size=0.25 and rendered with 1920*1440 resolution, 64 samples per pixel and 5 max ray depth, are shown in figure 7. We may observe that the focusing effects on different objects (the artificial light source, the background room, etc) are distinguished when the focal distance varies, and when focus distance = 4.7 the golden dragon is seen clearly, indicating the most suitable focal distance for capturing the dragon object.



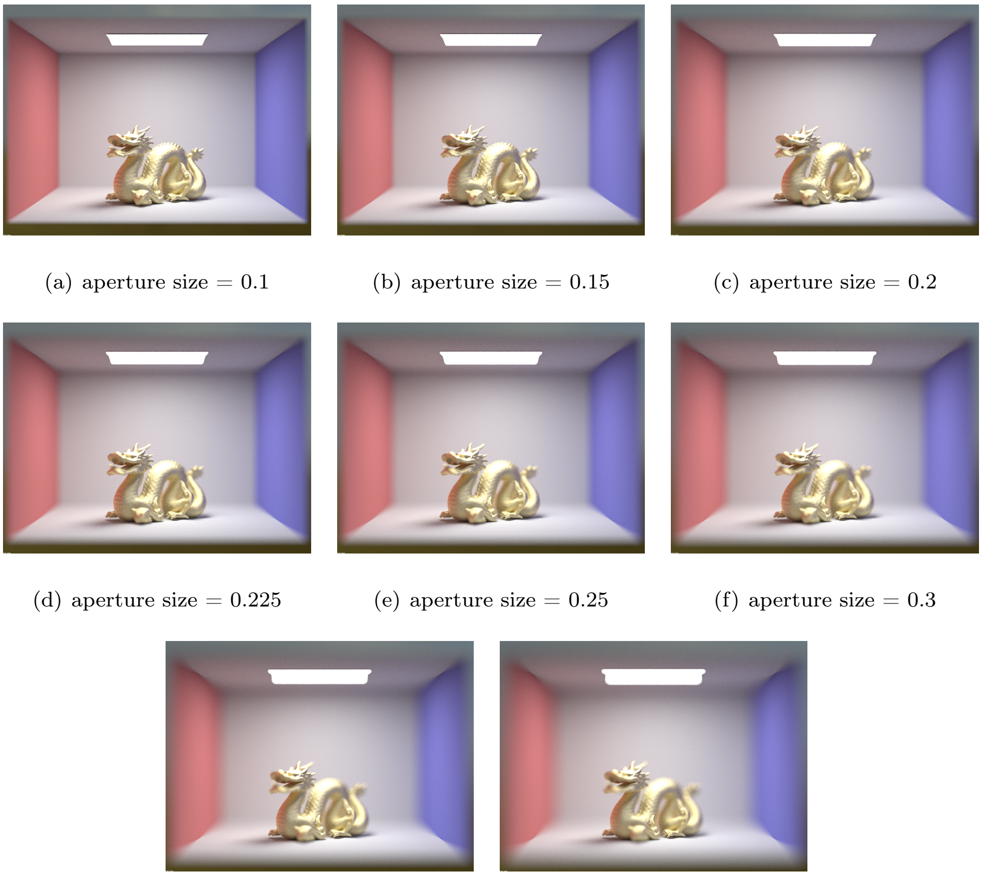
(a) Focus distance = 3.7 (b) Focus distance = 4.2 (c) Focus distance = 4.7

(d) Focus distance = 5.2 (e) Focus distance = 5.7

Figure 7: Results for different focus distances, given aperture size=0.25

4.3 Results with different aperture sizes

The results with aperture size equaling to 0.1, 0.15, 0.2, 0.225, 0.25, 0.3, 0.4, 0.5, given the focal distance=4.7 and rendered with 1920*1440 resolution, 64 samples per pixel and 5 max ray depth, are shown in figure 8. We may observe that as the aperture size increases, the illumation of the whole image is improved (that is, the image becomes brighter), but at the same time the depth of field decreases (that is, the range in which the objects can be observed clearly decreases). Hence, we may conclude that the increase of the aperture size involves the tradeoff between improving the overall brightness as well as reducing the depth of field (that is, reducing the range in which objects can be seen clearly).



(a) aperture size = 0.1
(b) aperture size = 0.15
(c) aperture size = 0.2
(d) aperture size = 0.225
(e) aperture size = 0.25
(f) aperture size = 0.3
(g) aperture size = 0.4
(h) aperture size = 0.5

Figure 8: Results for different aperture sizes, given focus distance=4.7