CSC4140 Assignment VII

Computer Graphics

April 30, 2022

Ray Tracing II

This assignment is 8% of the total mark.

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

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

Signature:

1 Overview

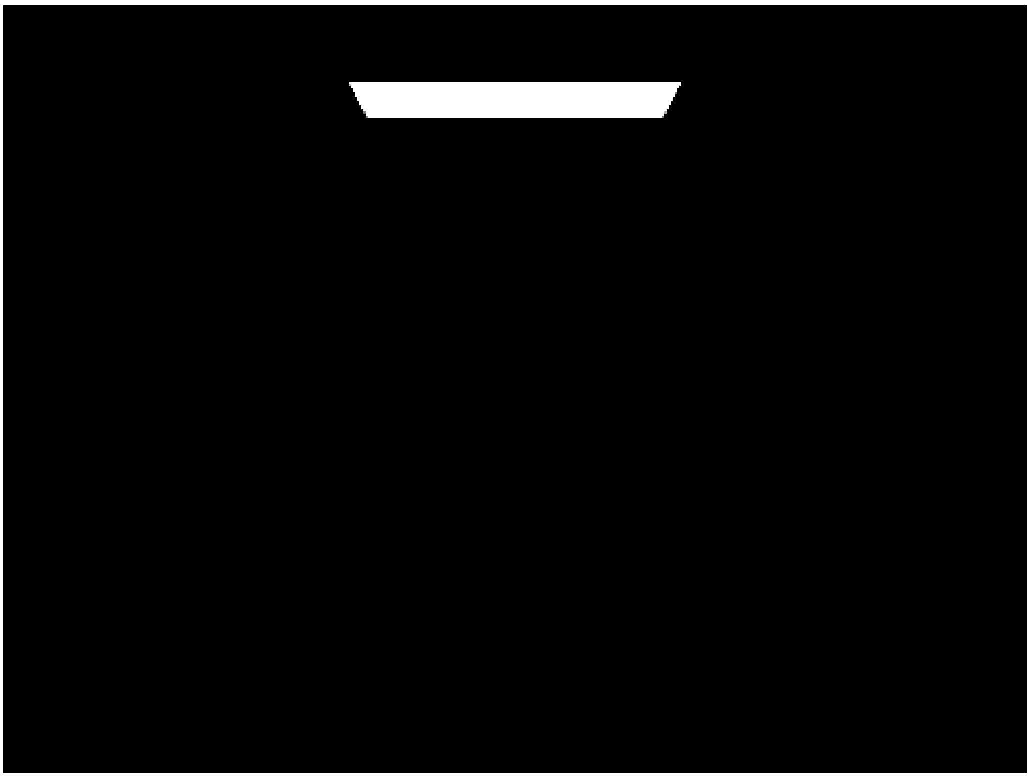
In this assignment, we implement advanced materials including mirror (reflection), complete refraction material (refraction), glass (refraction and reflection), as well as microfacet materials.

In addition, we implement environment lighting where the lighting information is stored in a texture.

Lastly, we achieve the depth of field effect by implementing a thin lens camera model.

2 Part 1: Mirror and Glass Materials

2.1 max_ray_depth = 0



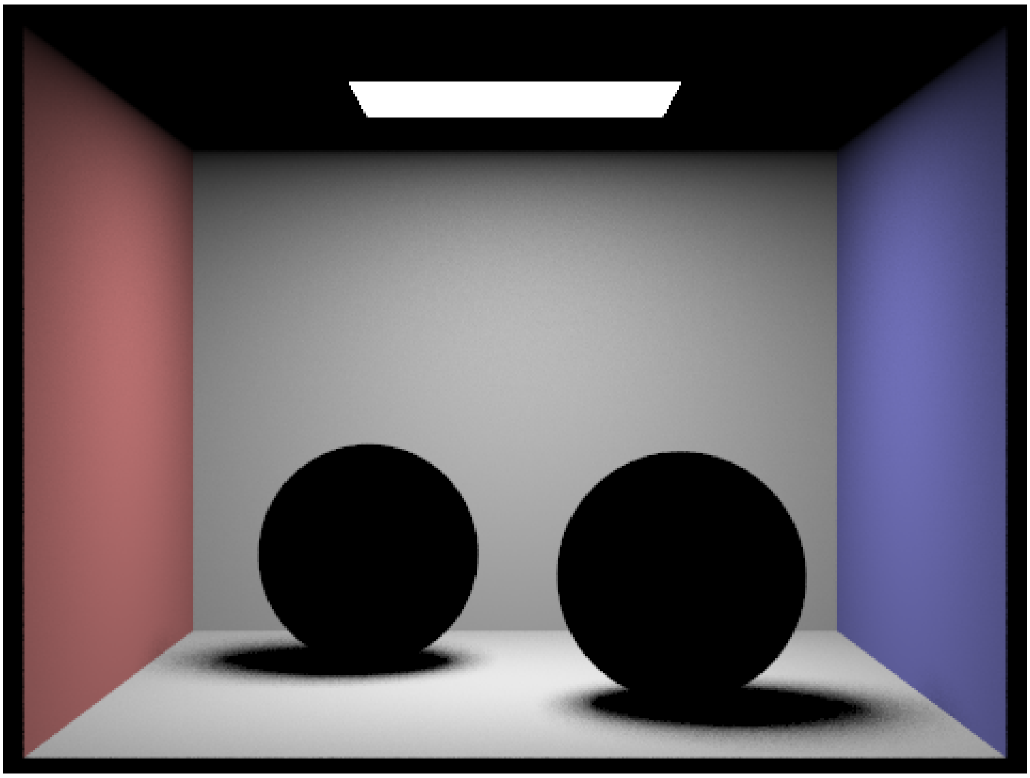
Effects:

Only emission can be seen.

Reasons:

We only consider the emission when sampling the pixels.

2.2 max_ray_dept = 1



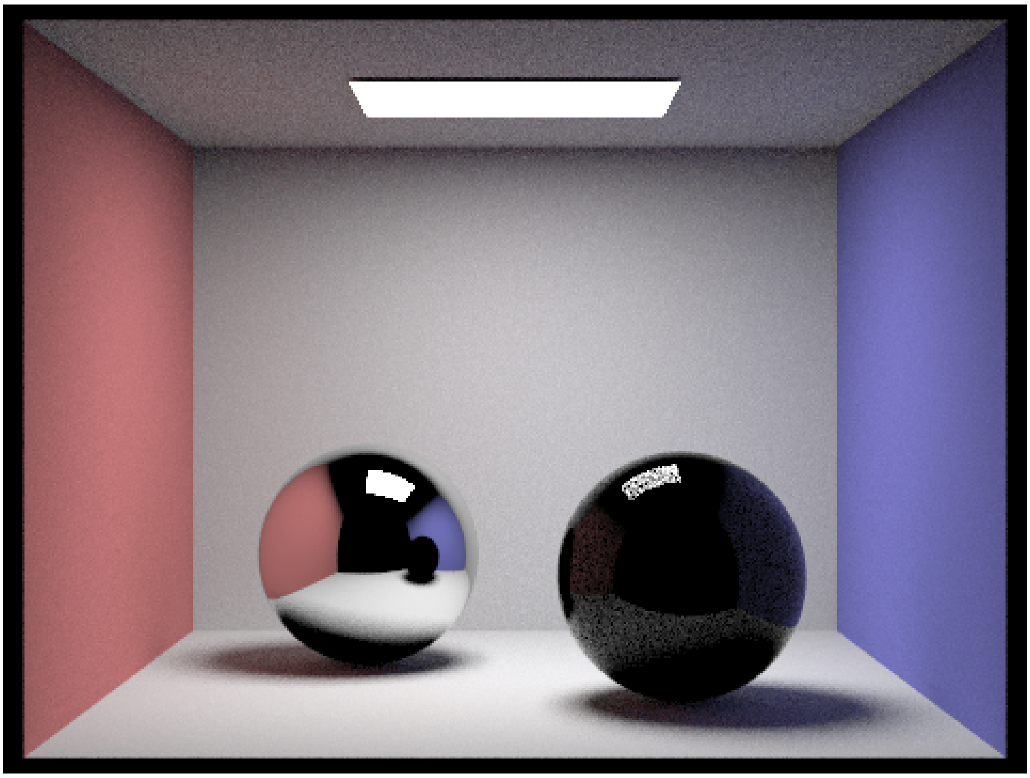
Effects:

Direct lighting effects can be seen. The mirror and the glass are totally dark.

Reasons:

We only consider one bounce radiance. When a ray from the camera hits the scene, it terminates without bouncing. That is, there is no ray from the scene to the mirror or the glass.

2.3 max_ray_dept = 2



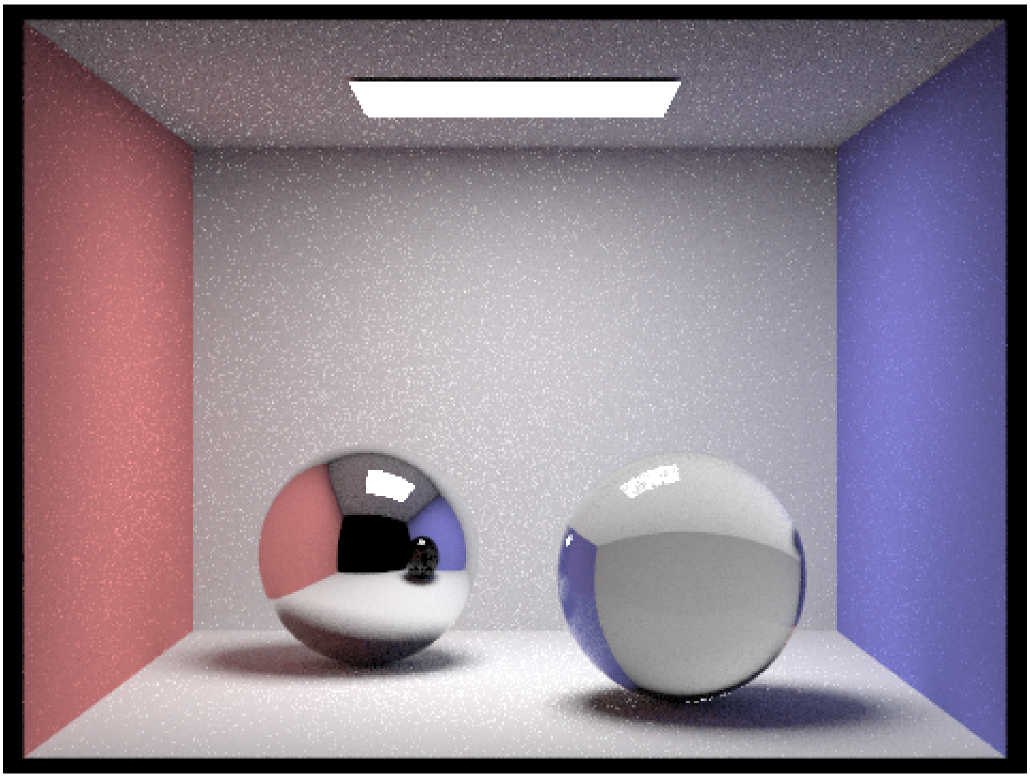
Effects:

Partial reflections on the mirror and the glass can be seen. There is no refraction on the glass, therefore, it looks dark. In the reflection, the ceiling is dark.

Reasons:

A ray needs at least three bounces to refract through the glass sphere and reach the scene. Also, a ray needs at least three bounces to reflect on the glass and then reach the ceiling.

2.4 max_ray_dept = 3



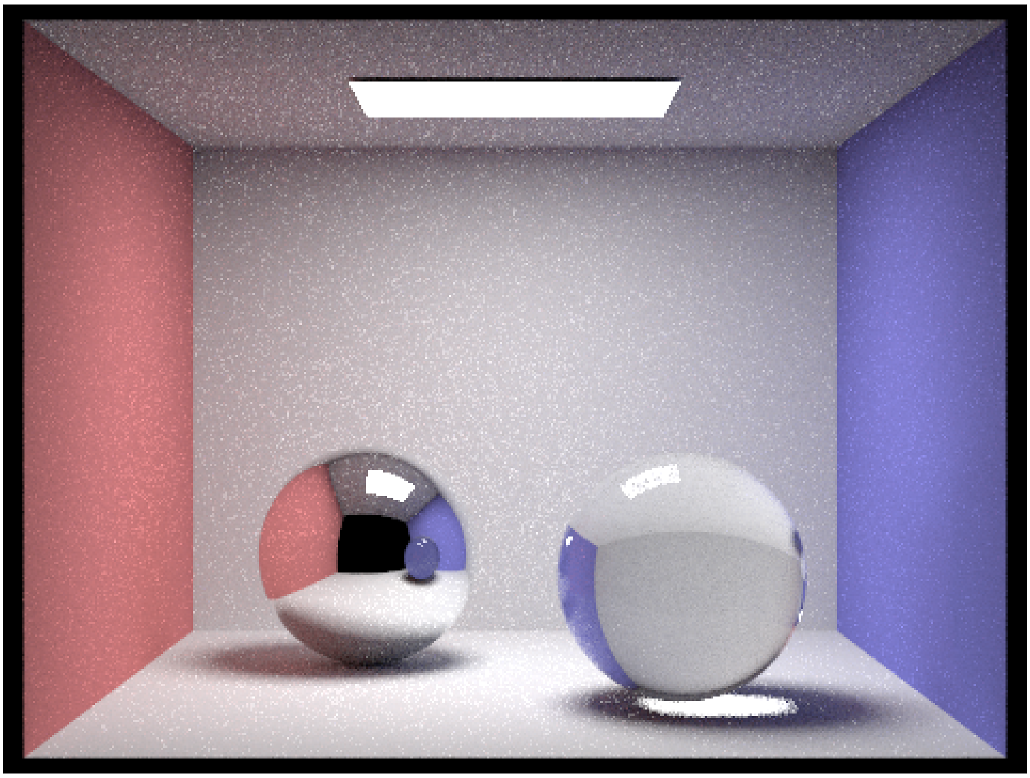
Effects:

Refraction on the glass can be seen. In the reflection, the ceiling becomes illuminated.

Reasons:

A ray has enough bounces to refract through the glass sphere and reach the scene. Also, a ray has enough bounces to reflect on the glass and then reach the ceiling.

2.5 max_ray_dept = 4



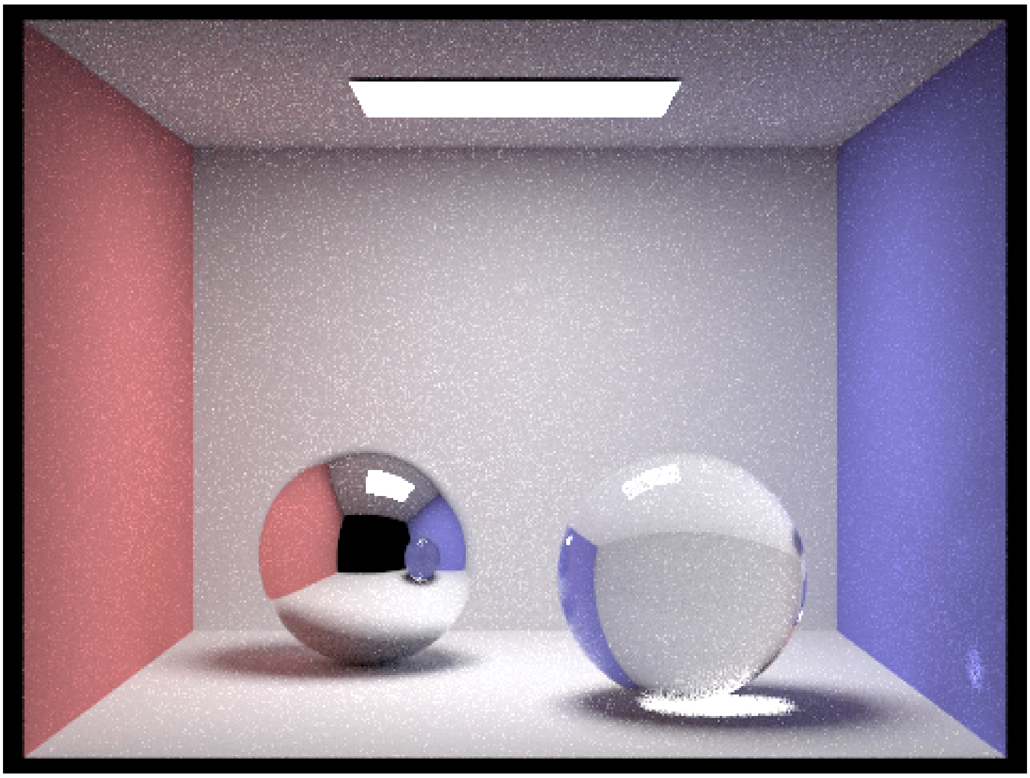
Effects:

Refraction on the glass can be seen. In the reflection, the ceiling becomes illuminated. The light refract through the glass sphere and illuminate the floor below it.

Reasons:

A ray has enough bounces to refract through the glass sphere and reach the scene. Also, a ray has enough bounces to reflect on the glass and then reach the ceiling.

2.6 max_ray_dept = 5



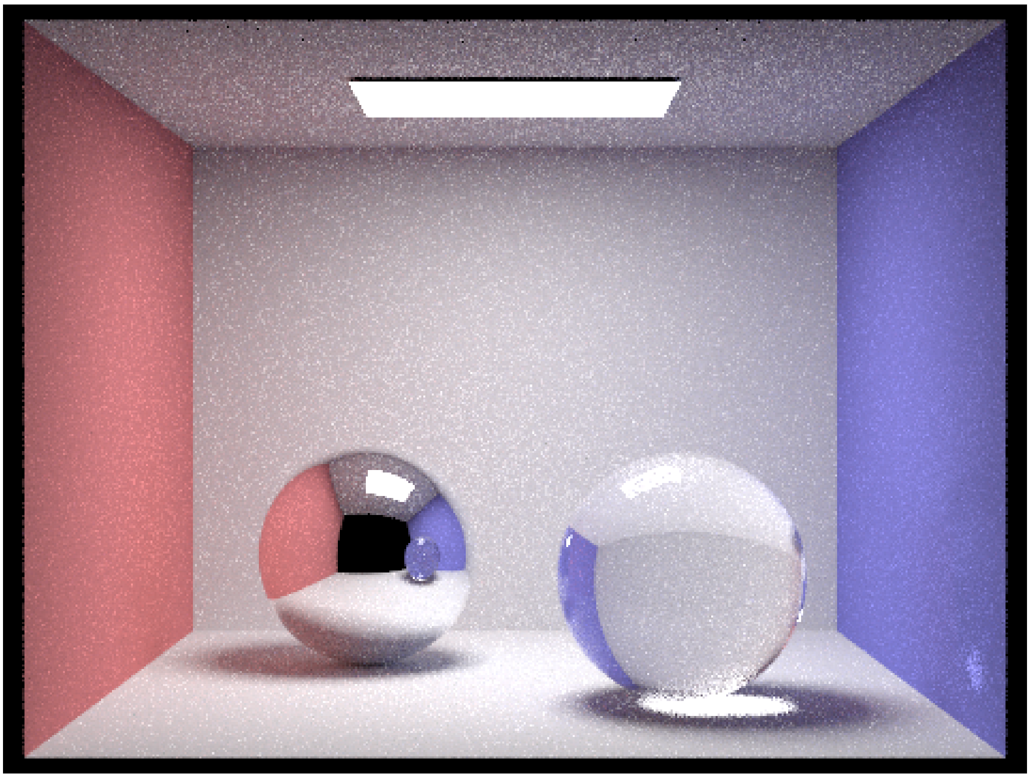
Effects:

The bottom of the glass sphere becomes illuminated. Also, there is a bright spot on the blue wall.

Reasons:

The bottom of the glass sphere and the spot on the blue wall are illuminated by the light reflected on the floor. The reason why there is a small bright spot on the blue wall is that the irradiance is higher when the incident light is more perpendicular to the surface.

2.7 max_ray_dept = 100



Effects:

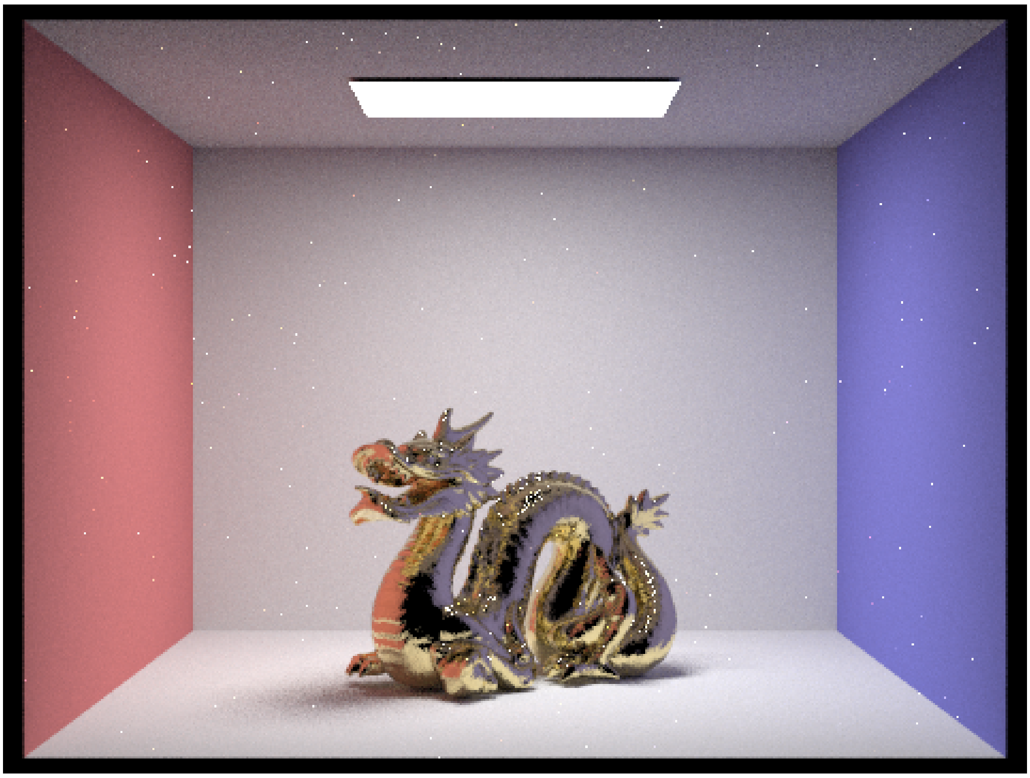
The scene becomes slightly brighter. However, there is no significant difference.

Reasons:

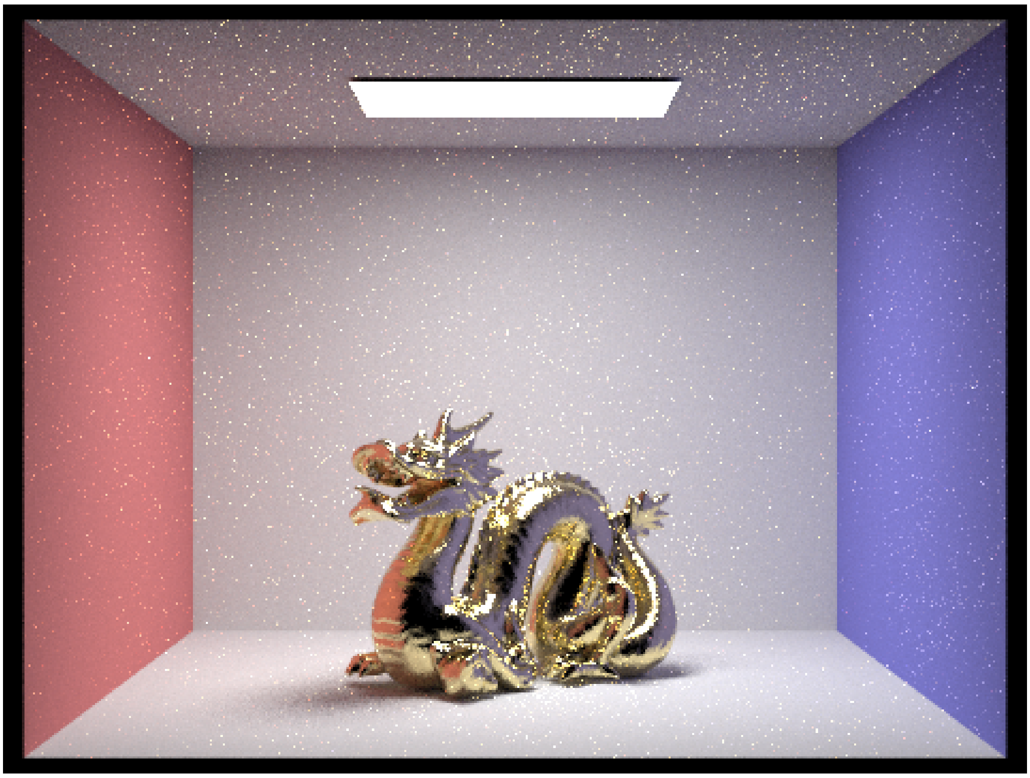
The radiance decreases exponentially as the number of bounces increases.

3 Part 2: Microfacet Material

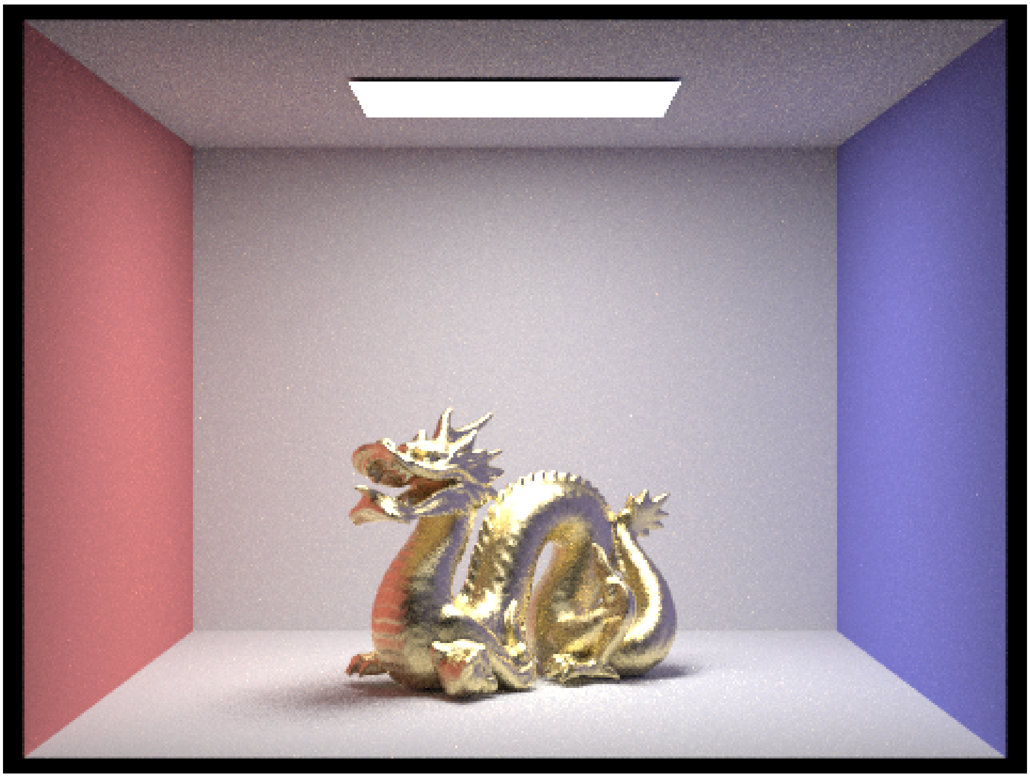
3.1 alpha = 0.005



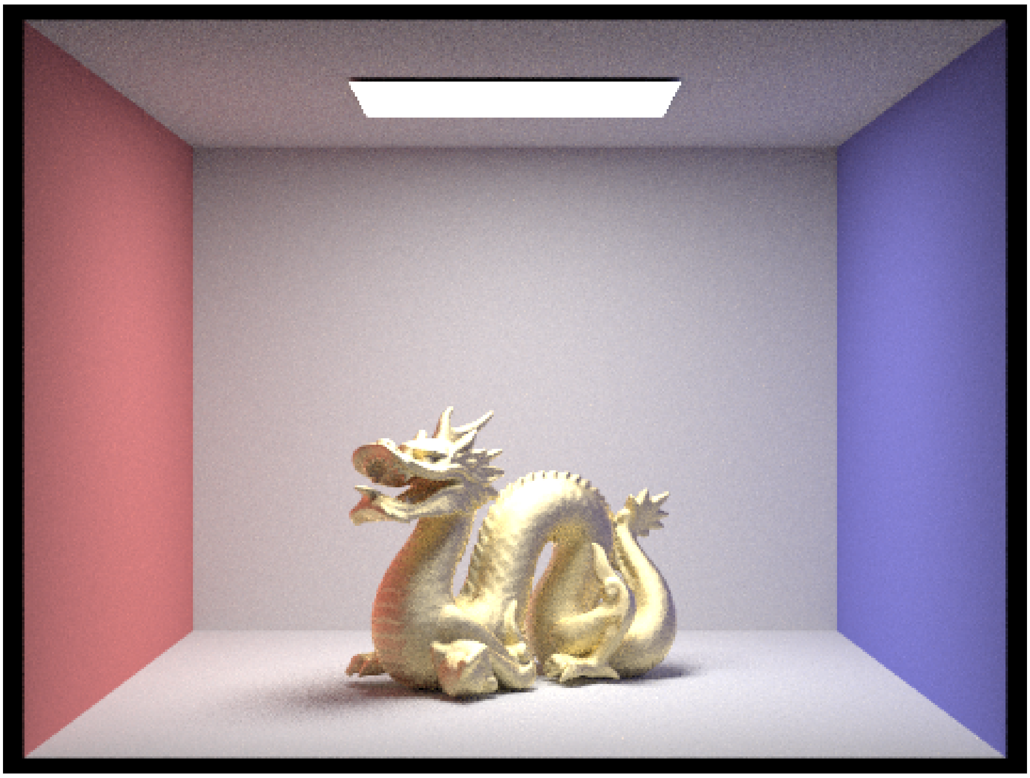
3.2 alpha = 0.05



3.3 alpha = 0.25

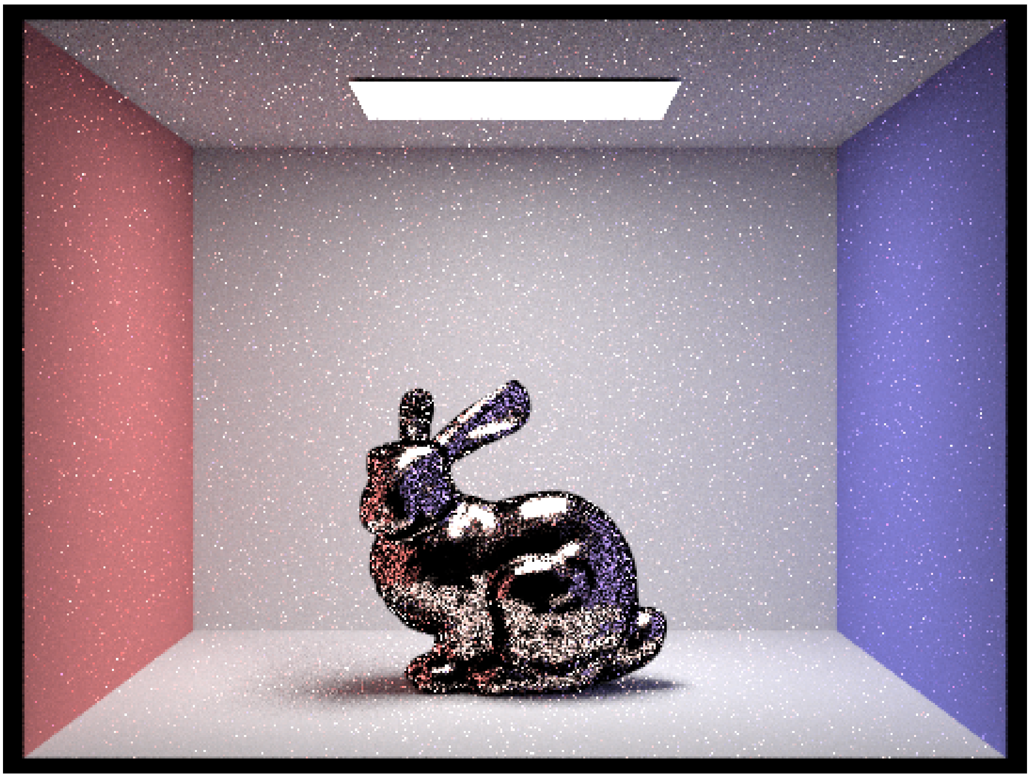


3.4 alpha = 0.5



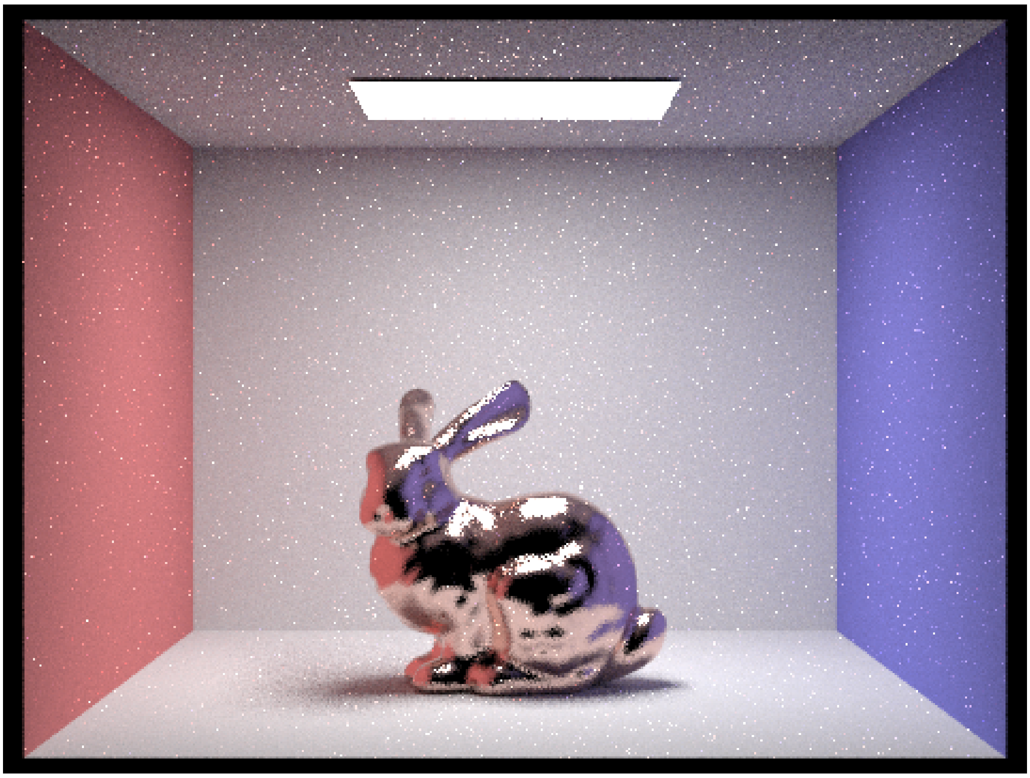
As alpha increases, the material becomes rougher. Therefore, the surface becomes brighter and the area of highlight becomes larger. Meanwhile, the surface becomes less reflective, in other words, less shiny.

3.5 Cosine hemisphere sampling



In cosine hemisphere sampling, the bunny is very dark and noisy. This is because cosine hemisphere sampling is not efficient as we randomly sample over the entire hemisphere. As such, the sampling rays are likely to contain very low radiance. Hence, the bunny looks dark and noisy.

3.6 Importance sampling



In importance sampling, the bunny appears much brighter and cleaner. This is because importance sampling focuses on normals with higher probability according to the distribution of normals. Therefore, the lighting and reflection are better approximated.

4 Part 3: Environment Light

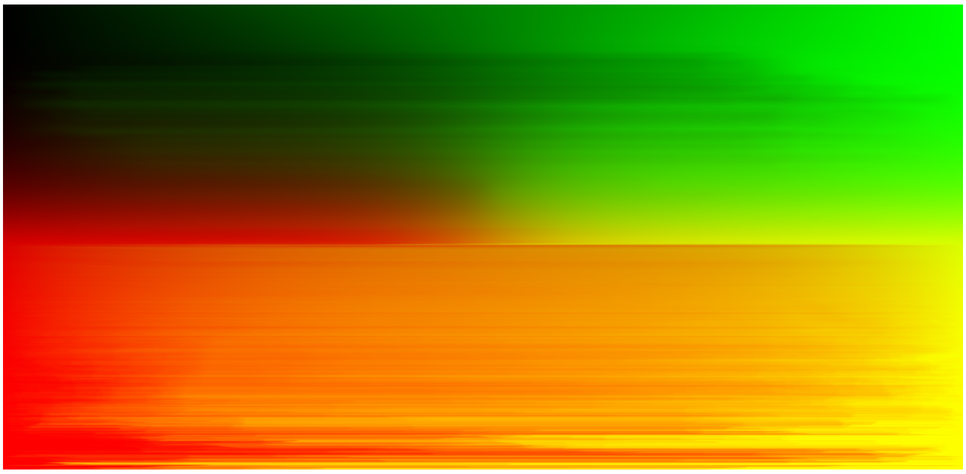
Previously, we define light sources in the scene. In environment lighting, alternatively, we use a texture to express a sphere of light. The environment lights are regarded as infinitely far away from the primitives in the scene.

In real-world scene, there are infinitely many direct and indirect light sources, which is computationally prohibited to simulate. However, when we use a texture to store the environmental radiance information, we can achieve both a high degree of photo-realism and efficient computation.

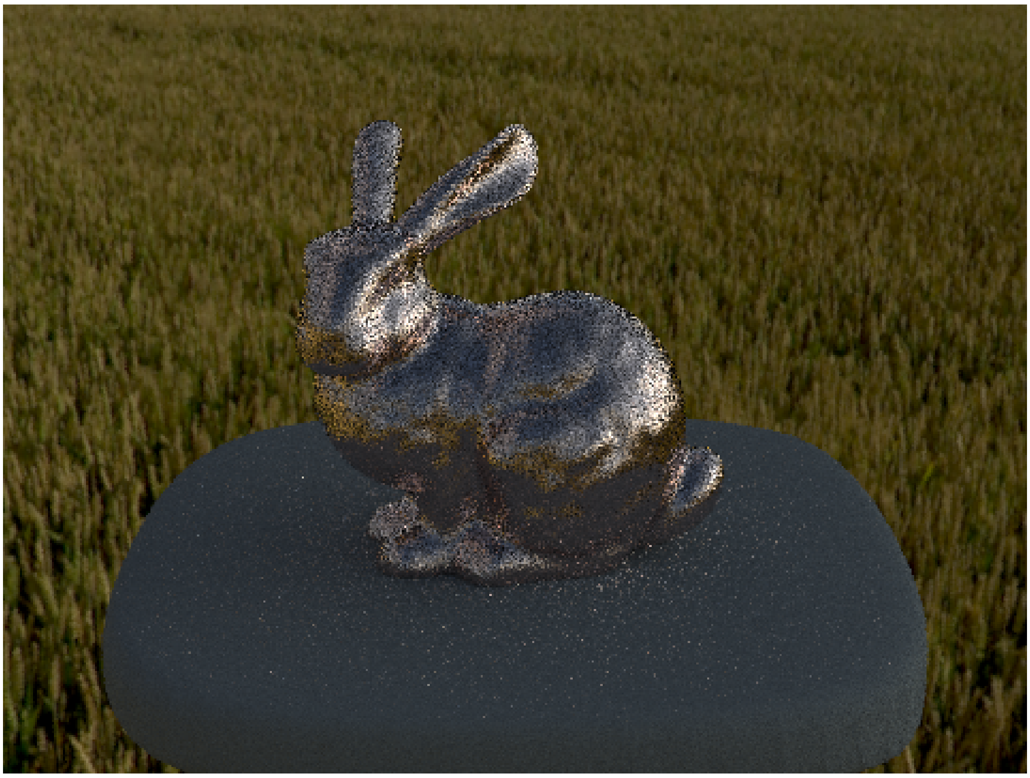
The environmental map used in this report is field.exr, which is shown below.

4.1 Environmental map

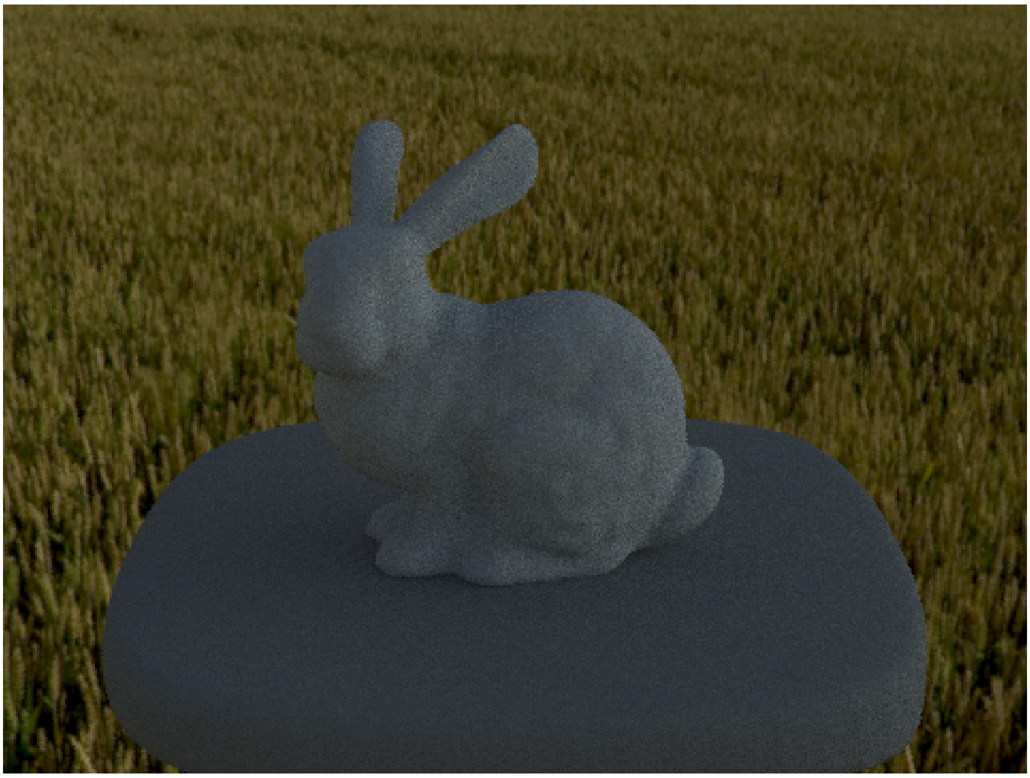
4.2 Probability map



4.3 Hemisphere sampling - bunny_microfacet_cu_unlit

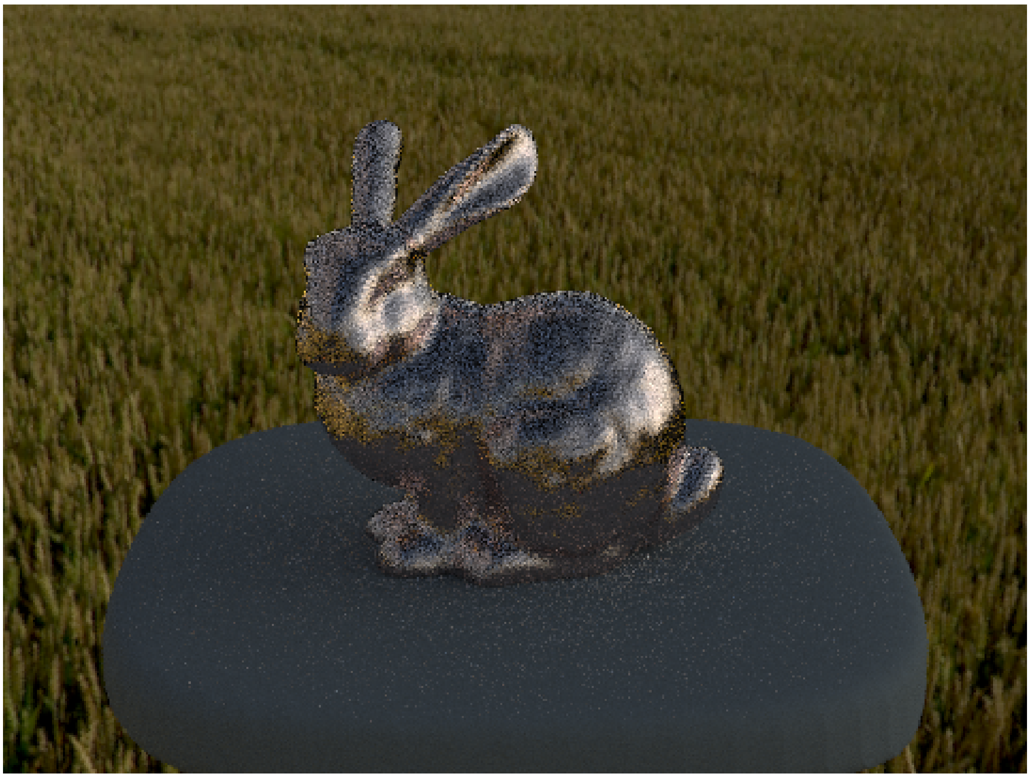


4.4 Hemisphere sampling - bunny_unlit

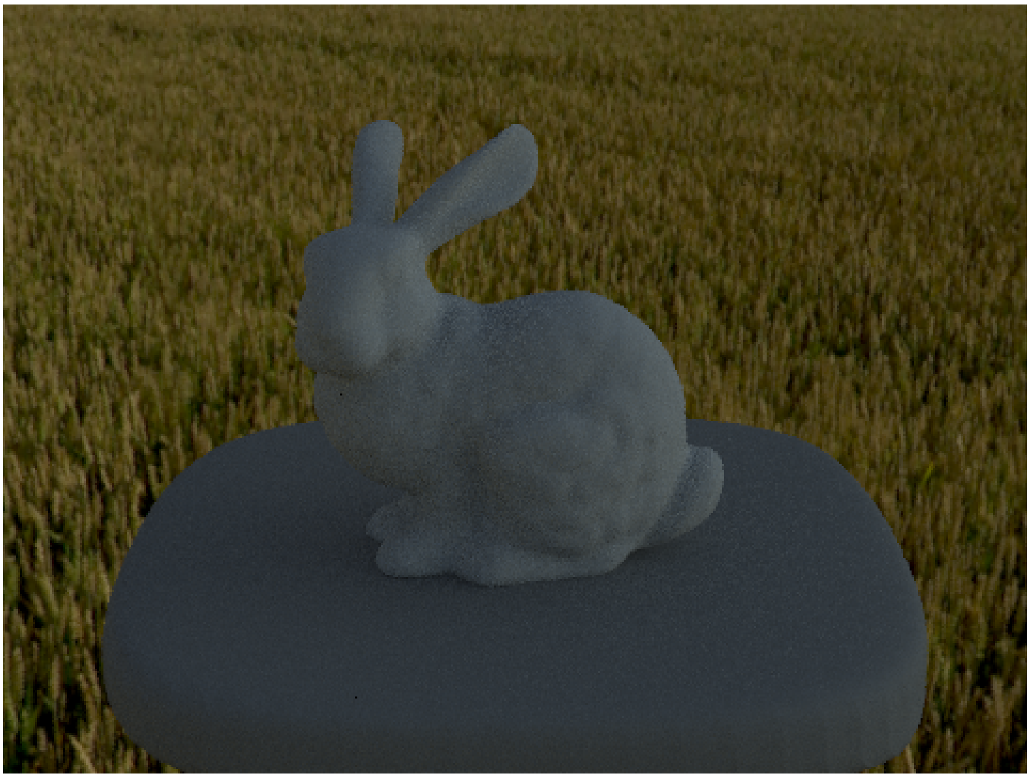


In hemisphere sampling, the bunny is noisy and dark. This is because when we uniformly sample over the hemisphere, most of the rays have very low radiance. The high-radiance part of the environmental map may not be well sampled. Although the expectation of the result is correct, the variance is high, which makes the bunny dark and noisy.

4.5 Importance sampling - bunny_microfacet_cu_unlit



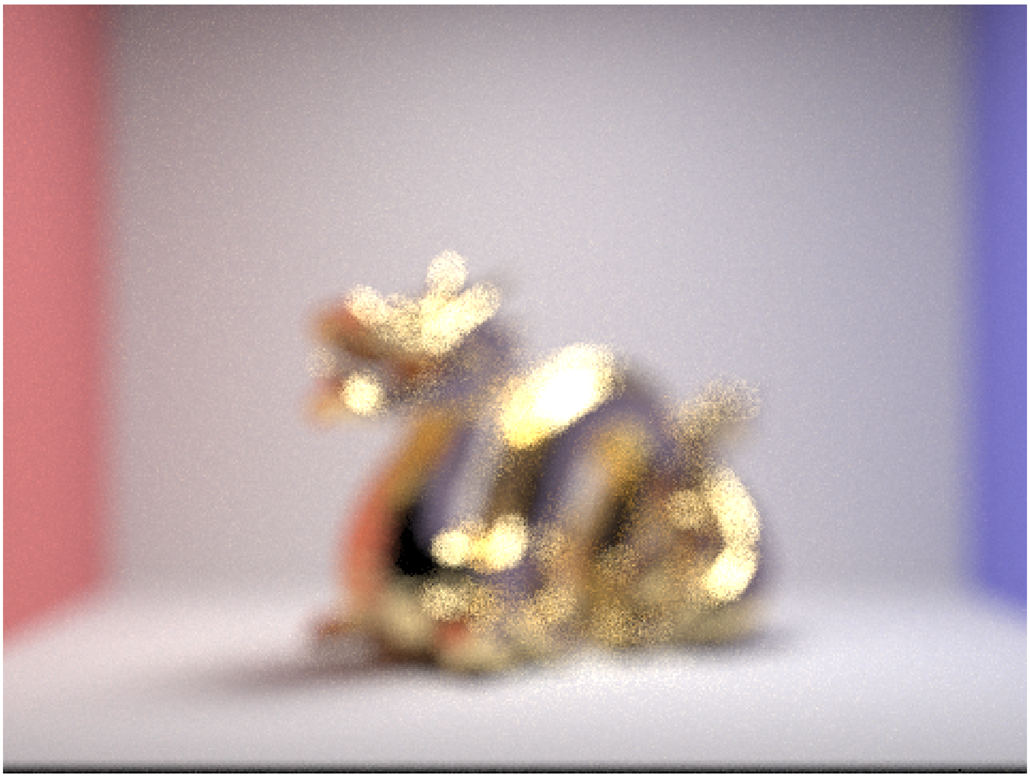
4.6 Importance sampling - bunny_unlit



In importance sampling, we focus on parts of the texture that has higher radiance. The majority of the sampling rays have higher radiance, effectively reducing the variance of the result. By using Monte Carlo integration, our result has the same expectation as the ground truth.

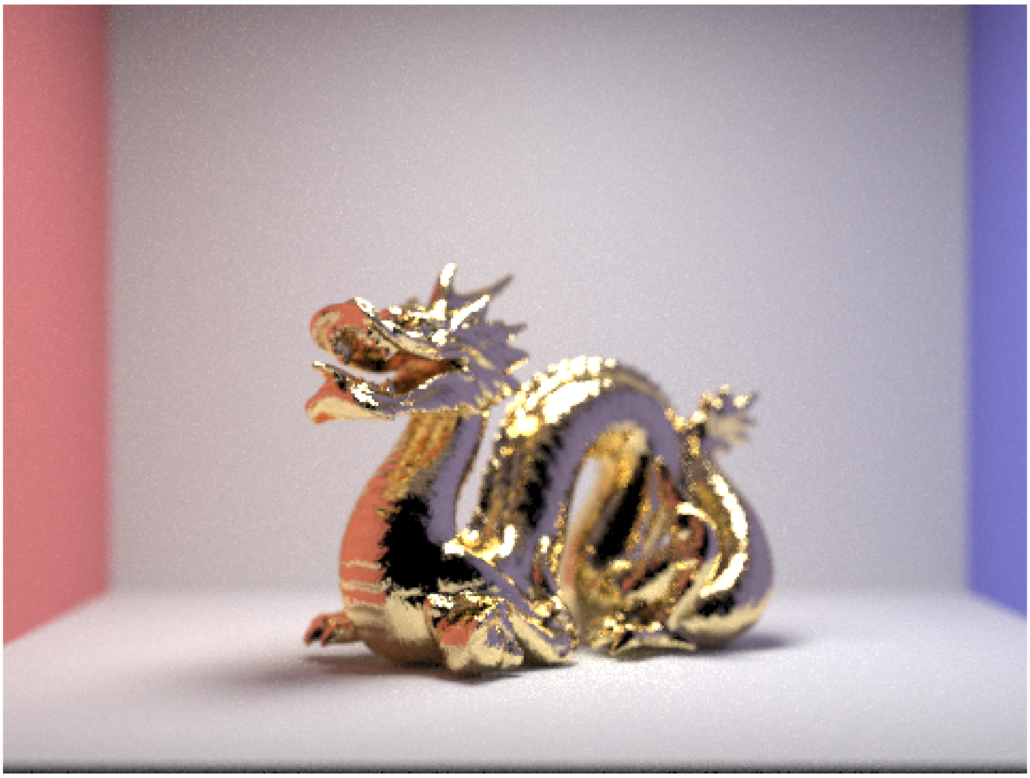
5 Part 4: Depth of Field

5.1 aperture = 0.05, focal length = 2

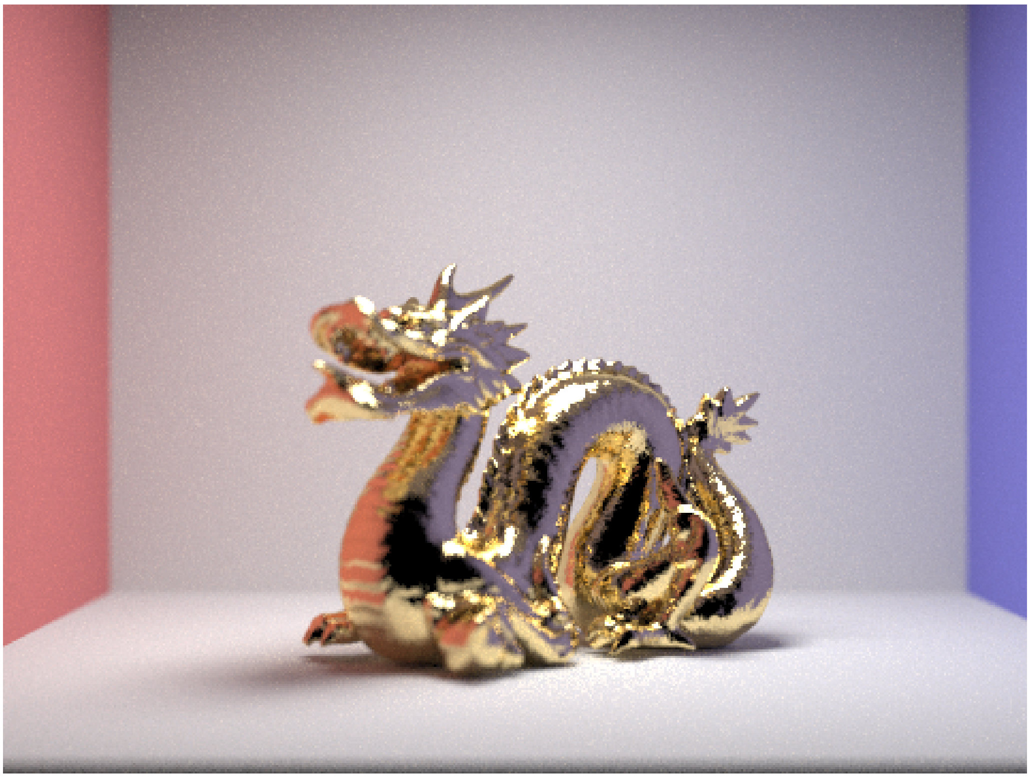


5.2 aperture = 0.05, focal length = 2.5

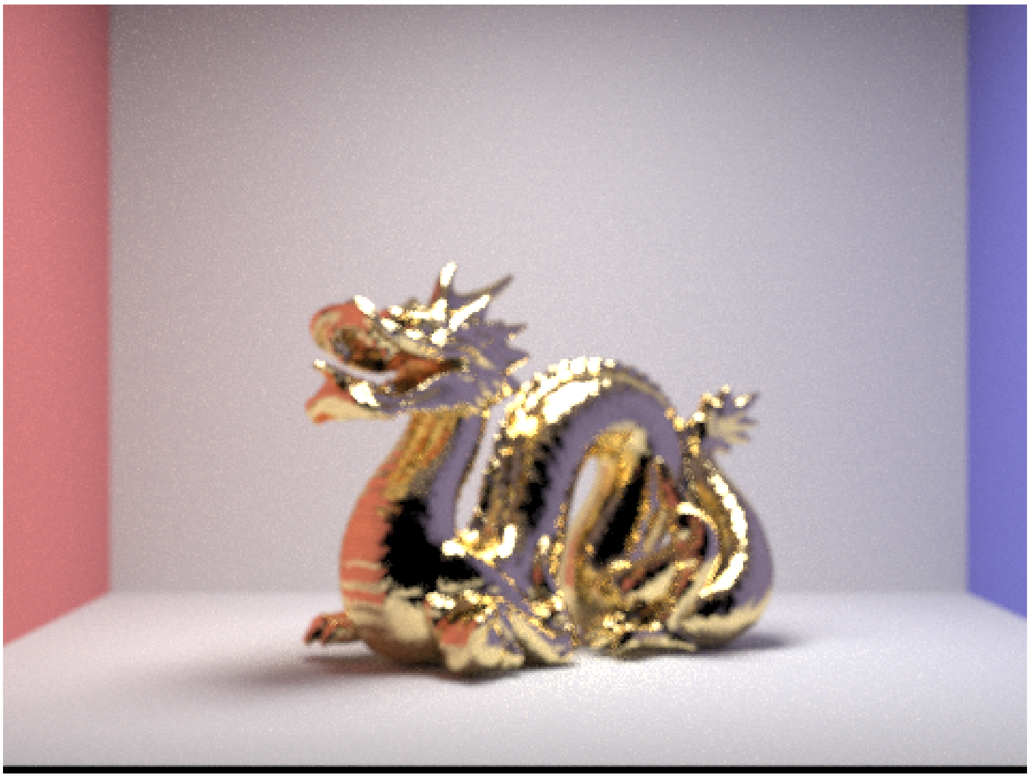
5.3 aperture = 0.05, focal length = 3



5.4 aperture = 0.05, focal length = 3.5

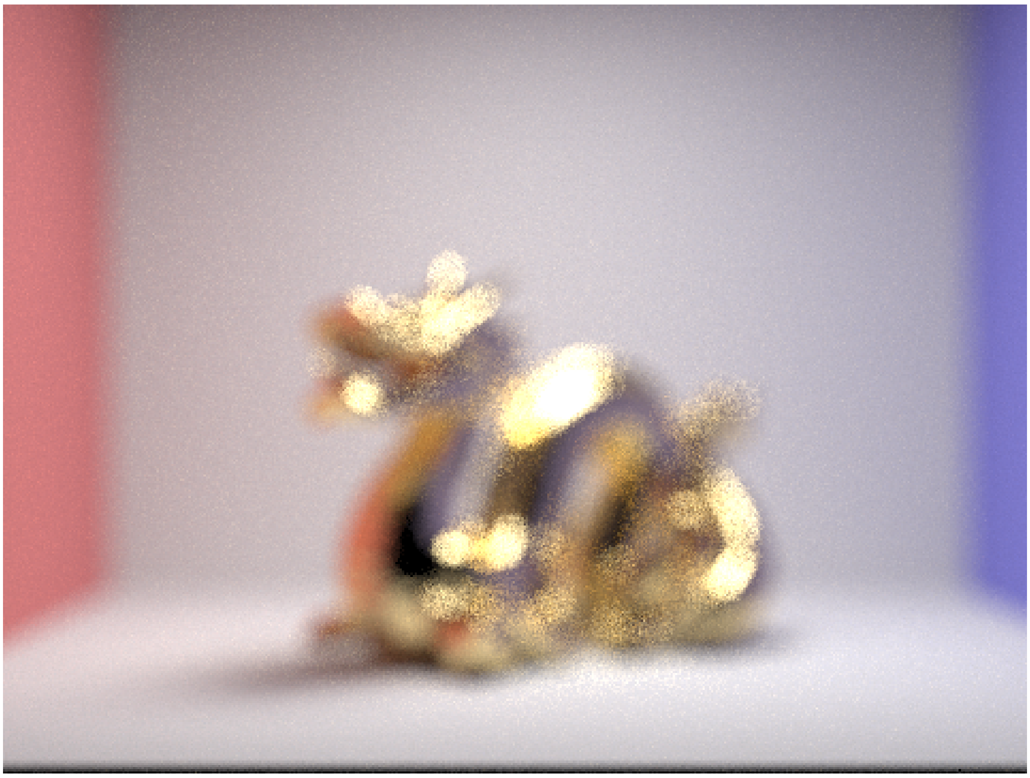


5.5 aperture = 0.01, focal length = 2

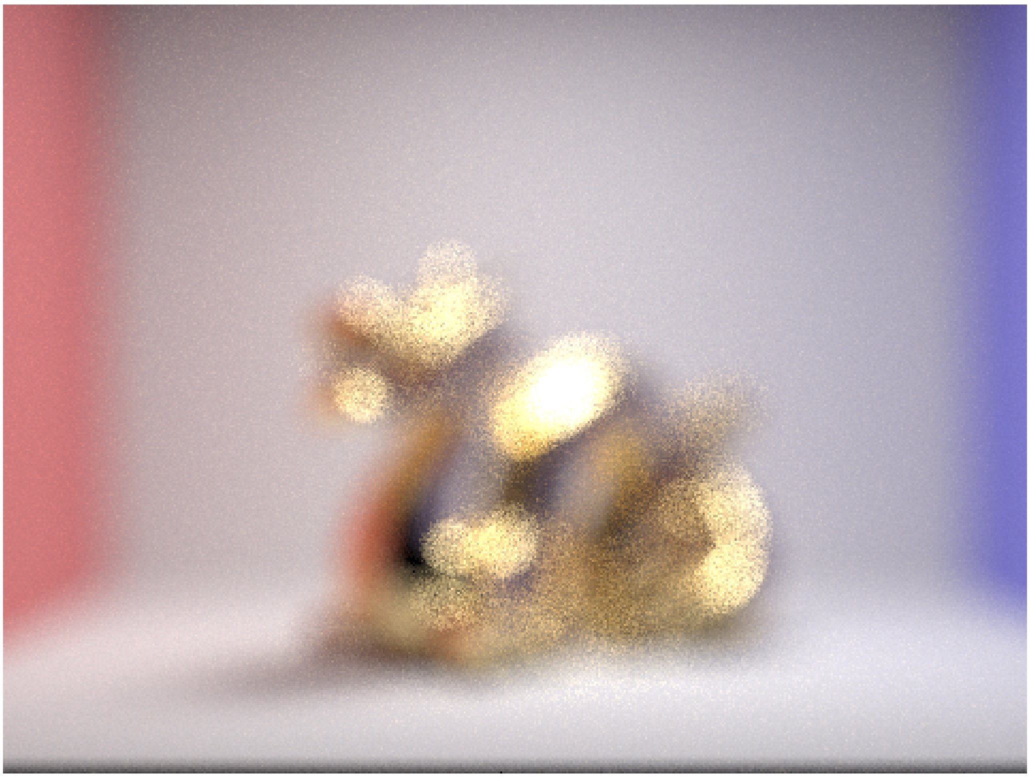


5.6 aperture = 0.03, focal length = 2

5.7 aperture = 0.05, focal length = 2



5.8 aperture = 0.08, focal length = 2



Most modern cameras use a lens to focus light onto the view plane. This is done so that one can capture enough light in a sufficiently short period of time that the objects do not move appreciably, and the image is bright enough to show significant detail over a wide range of intensities and contrasts. Every ray from a point on the focal plane goes to the same point on the view plane. However, every ray from a point off the focal plane goes to a range of points on the view plane, which makes the image blurred.

A pinhole camera is an idealization of the thin lens as aperture shrinks to zero.