Computer Graphics - Lab 2
Materials (Reflection models)

Nov 22, 2016

Introduction

This lab will introduce the use of lighting shaders and how to apply them for simulating different objects and materials. Using BRDF functions, the fragment shader will be heavily programmed to be able to recreate some of the more known reflection models named as Phong, Blinn-Phong, Oren-Nayar and Cook-Torrance.

2.1 Phong shader

Ambient illuminance (Ia)

Ia sets the simulation of ambient lightning for an object. It is sometimes used as a performance-cheap way to make shadows appear more realistic instead of completely dark when no light is reflected. This illumination is not depended on the direction. It is constant over the entire object and if the value of **Ia** is increased, this simulated environment light is intensified.

Diffuse illuminance (Id)

Id decides the intensity of diffuse illuminance. More than this intensity factor, the diffuse illuminance depends on the incident angle of all the directional lights. The incoming light is reflected from the surface, so that the incident beam is reflected at different angles instead of a single one, like situations with specular reflection. If the light hits perpendicular to the surface, it will be more intense than if it would hit at a more narrow angle. It depends on the normal vector and the light direction but also the color of the material and the light.

Specular illuminance (Is)

Is sets the shininess of an object. This is appears as a bright white spot, positioned with respect to the viewer and all defined light sources in the room. The higher value of **Is**, the shinier the object will appear.

If **Ia** is set to zero, the only light that exists, consists of the defined light sources. In task 2.1 this looks fine since there are sufficient light from the four sources to give a representation of the icosahedron like the one in the lab instructions.
If **Is** also is set to zero, the only reflection illuminance is the diffuse one. This makes the model surface appear more matte, but can still represent a geometric figure.
If the **Ia** is set to some intermediate value and the rest is zero, the figure completely lack depth and has only one solid colour.

2.2 First BRDF

A bidirectional reflectance distribution function decides how light is reflected from a point on a surface towards a defined viewer. This is based on the position of the point and the direction from this surface point to the viewer and the light.

The BRDF function (lambertian) returns a vector with the values set to the fraction of a reflectivity constant divided by PI across all axes. The vector is then inserted into the rendering equation which will give the same result for each point in a polygon. This gives the figure a very matte (lambertian) surface.

The surface of the icosahedron is more matte compared to the previous version in Task 2.1. This is because merely a lambertian (diffuse) BRDF is used in the fragment shader. No specular BRDF is used so the reflection of the lights modelled as bright white spots are not visible as in Task 2.1.
If the specular illuminance factor **Is** is set to zero in task 2.1, the same result can be achieved.

2.4 Physically-based reflectance models

For a physically-based reflectance model the lightning equation requires that besides using the BRDF, we will need to multiply it with the dot product of the normal vector and the light vector, along with the light colour as previous.

Each reflection model contains ambient, diffuse or specular components (often combined). There are more components to be used, but in this lab only the three aforementioned components will be used to compute the lighting equation for an object.

The specular component is narrow and reflects only a small part of the light, giving some narrow highlights on the object, making it seem like the light is reflecting directly back at the viewer. The diffuse reflection depends on the direction of the surface and the incoming light. This gives a more rough and matte color of the surface. Ambient “reflection” is not really a reflection of the light, since it’s a constant illuminance over the entire object. This simulation is mostly used to make some unrealistic shadows on the object seem more natural. Since it is a constant, it won’t be implemented in the lighting equation unless it’s necessary for our model. Also during this task, four light sources was used which made the object appear more illuminated, one of the reasons why eliminating the need to use ambient light was decided.

Phong

This BRDF is well-known and has been implemented into many games over the previous decades. It is not a physical-based reflection model however and is only mentioned shortly here. It has a specular part and a diffuse part (*lambertian*). The specular component is calculated by using the dot product of, the incident between the light direction and the normal, and the camera view. This is all powered up to a parameter called *shininess* which focuses the specular reflection more on a specific point to make it more concentrated. This BRDF is mostly used for objects to replicate a surface resembling plasticity because the highlight controls are decided by the color of the light source and not the material of the object. Hence, not making it a physical-based reflection model.

Blinn-Phong

Blinn-Phong BRDF is very similar to Phong. Though it can be seen as an improvement of the Phong shader since the calculation is faster. One difference is that Blinn-Phong uses the halfway vector instead of the "direction of reflection" vector. In the BRDF there are a few parameters which as previous decides the intensity of the diffuse component (*kL*) and the specular component (*kG*) and another parameter named *smoothness* which decides how much specular light should be reflected. To make it linear the calculation $8192^{(1-smoothness)}$ was done. If it's a low number (around 0.1), the reflections will be sharper and higher numbers (0.9) produces broader highlights.

Cook-Torrance

The Cook-Torrance model is one of the most expensive ones to calculate and models the light behaviour into a diffuse and specular reflection depending on the material of the object. The coefficient variables that are used are *kD* (Diffuse), *kS* (Specular), *IOR* (Indices of refraction) and *roughness*. These parameters are tuned with energy preservation in mind, meaning that the surface shouldn't emit more light than is received, so the sum of *kD* and *kS* should be 1. *IOR* variable describes the refraction of the light when it hits the object. Sensible values can be between 1 - 4, since the Germanium metal is the highest material with index of refraction at 4.05. However, it probably is not used as much, but ultimately it depends on the material used itself.

The Cook-Torrance BRDF is made up of several components: Fresnel, which was implemented with the Shlick approximation and decides what fraction of the light is reflected and which is transmitted; Microfacet model with Beckmann distribution; Geometric attenuation, which calculates the remaining light from the microfacets that block the light. They all describe how the light should behave depending on the surface it enters, making up the specular reflection of the model.

Oren-Nayar

The Oren-Nayar model can be used to model diffuse reflection from rough surfaces. It has been shown to do this more precise than for instance the Lambertian model. The parameters that are used for this model are *albedo* and *roughness*. *Albedo* measures the intensity of the diffuse reflection and should not be ≥ 1 to make sure of energy conservation. *Roughness* decides the roughness of the surface, 0 is for a smooth surface, 1 is for a matte surface. Since this is primarily a diffuse model, it will not contain a specular reflection, meaning the produced reflection will be of matte colour. The *roughness*^{2} parameter are said to be in the interval [-3 * *roughness*, 3 * *roughness*] as a rule of thumb. This means that if the roughness is set to more than 3.0 (*roughness* = 3.0, *roughness*^{2} = 3 * *roughness* = 9.0), further additions will almost have no impact on the visual result. Because of this "soft" limit, very rough materials are hard to represent according to tests that were made.

2.4.1 Comparing the models

Here there will be comparisons between the different models and how each can mimic an object in the real world. Four light sources was used during the tests. They were positioned at *(0, 0, 1), (0, 1, 1), (1, 0, 1)* and *(-1, 0, 1)* and the camera was positioned at *(0, 0, 0)* in world frame. No ambient light will be used in the comparisons.

Since the images are static, it may be difficult to see the form of the object, it would be much better to have an animation which would rotate it around but alas, one can't have all the good things in life.

Tin

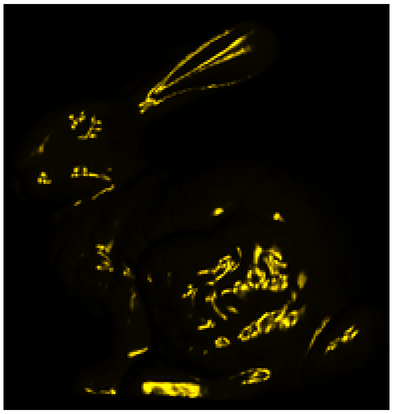
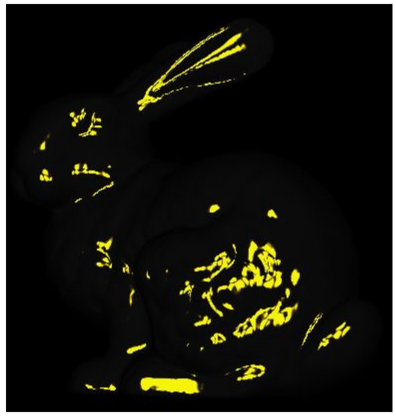
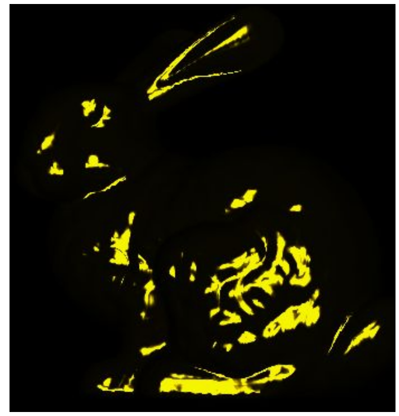
Used RGB-color: Tin = (0.827, 0.83, 0.835)

		
Phong	**Blinn-Phong**	**Cook-Torrance**
Diffuse intensity = 0.10 Specular intensity = 0.8 Shininess = 15.0	Diffuse intensity = 0.1 (kL) Specular intensity = 1.0 (kG) Smoothness = 0.40;	Diffuse intensity = 0.1 (kD) Specular intensity = 0.9 (kS) Roughness = 0.2 IOR = 2.16 (Tin)

This test is for representing a smooth but not too glossy tin surface. The differences between the models show that Cook-Torrance may be best suitable for a metal material, because of the more accurate representation of Tin. Perhaps even Phong might be suitable if one wants a bit more reflective metal surface. However it was hard to tune Blinn-Phong to appear the same as the others and it ended up looking too shiny.

Gold

Used RGB-color: Gold = (1.0, 0.843, 0.0)

		
Phong	**Blinn-Phong**	**Cook-Torrance**
Diffuse intensity = 0.1 Specular intensity = 1.0 Shininess = 100.0	kL = 0.04 kG = 0.96 Smoothness = 0.25	kS = 0.97 kD = 0.03 Roughness = 0.7 IOR = 0.166 (Gold)

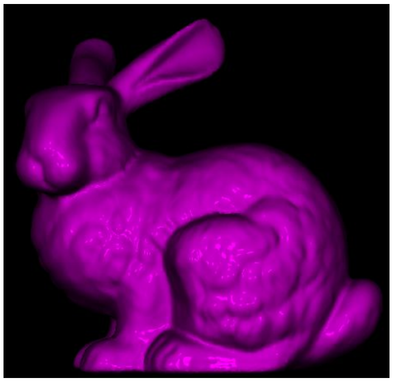
The test comparisons for the metal material above shows that the different reflection models produce similar results. There are some differences in the intensity of the specular reflection. Cook-Torrance probably produced the most realistic version of the metal in this case. It can be hard to tell from only these images, but while animated it was easier. The problem is to represent shiny gold-like materials like this, without having other reflecting objects nearby. If for instance the the *diffuse intensity / kL / kD* would be increased, the surface would only look like it was painted in glossy brown/yellow metallic.

Oren-Nayar was intentionally not tested since this material requires specular reflection which is not included in the Oren-Nayar model. It would not be possible to achieve the same specular reflection as the other models without combining the Oren-Nayar model with a specular BRDF.

The reason the object might be too dark is because there are no other lights than the ones in front of it, and since the room is dark, the object won't have anything else to reflect from the sides.

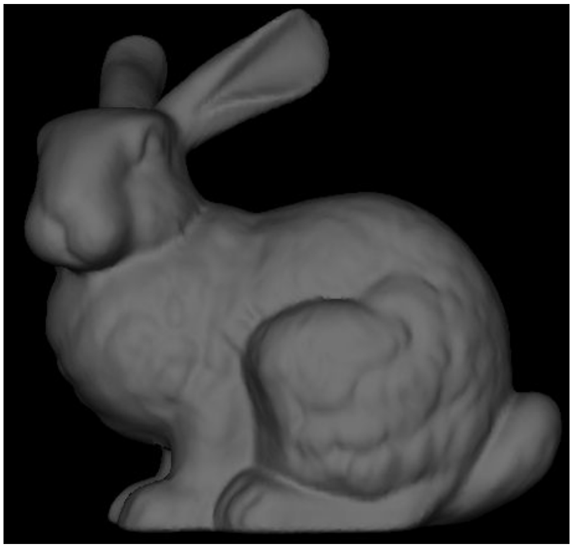
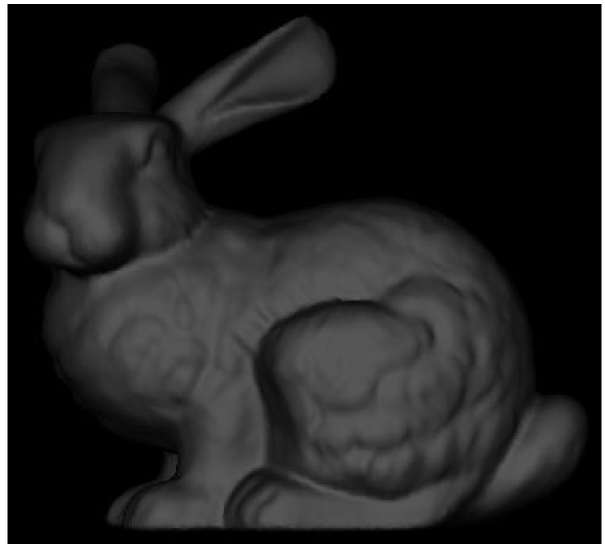
Glazed ceramic

Used RGB-colour: (0.9, 0.0, 0.9)

		
Phong	**Blinn-Phong**	**Cook-Torrance**
Diffuse intensity = 0.25 Specular intensity = 1.0 Shininess = 550.0	Diffuse intensity = 0.7 (kL) Specular intensity = 0.3 (kG) Smoothness = 0.15	Diffuse intensity = 0.6 (kD) Specular intensity = 0.4 (kS) Roughness = 0.03 IOR = 1.504 (Porcelain)

Glazed ceramic was also tested to see how the different models would handle it. This time more of diffuse reflection was used, giving a brighter image of the bunny. As one can see, comparing the images above, all the models produce more or less the same result. In this case Blinn-Phong gives a better representation of the material, however the other models also simulate the material well.

Granite

	
Oren-Nayar	**Phong**
Albedo = 0.96; Roughness = 0.05;	Diffuse intensity = 0.25 Specular intensity = 0.0 Shininess = 1.0

This time Oren-Nayar model was tested to resemble the material granite with a more rough/matte surface than in the previous tests. Since Oren-Nayar is only a diffuse model, it doesn't have any specular reflections which is why the surface is very matte and rough. The result was compared to the Phong model with the same purpose, as can be seen in the images above. This can tell that Oren-Nayar is more fit for reaching this rough/matte kind of result, while Phong gives a harder/glossier surface with more darkening at grazing angles.