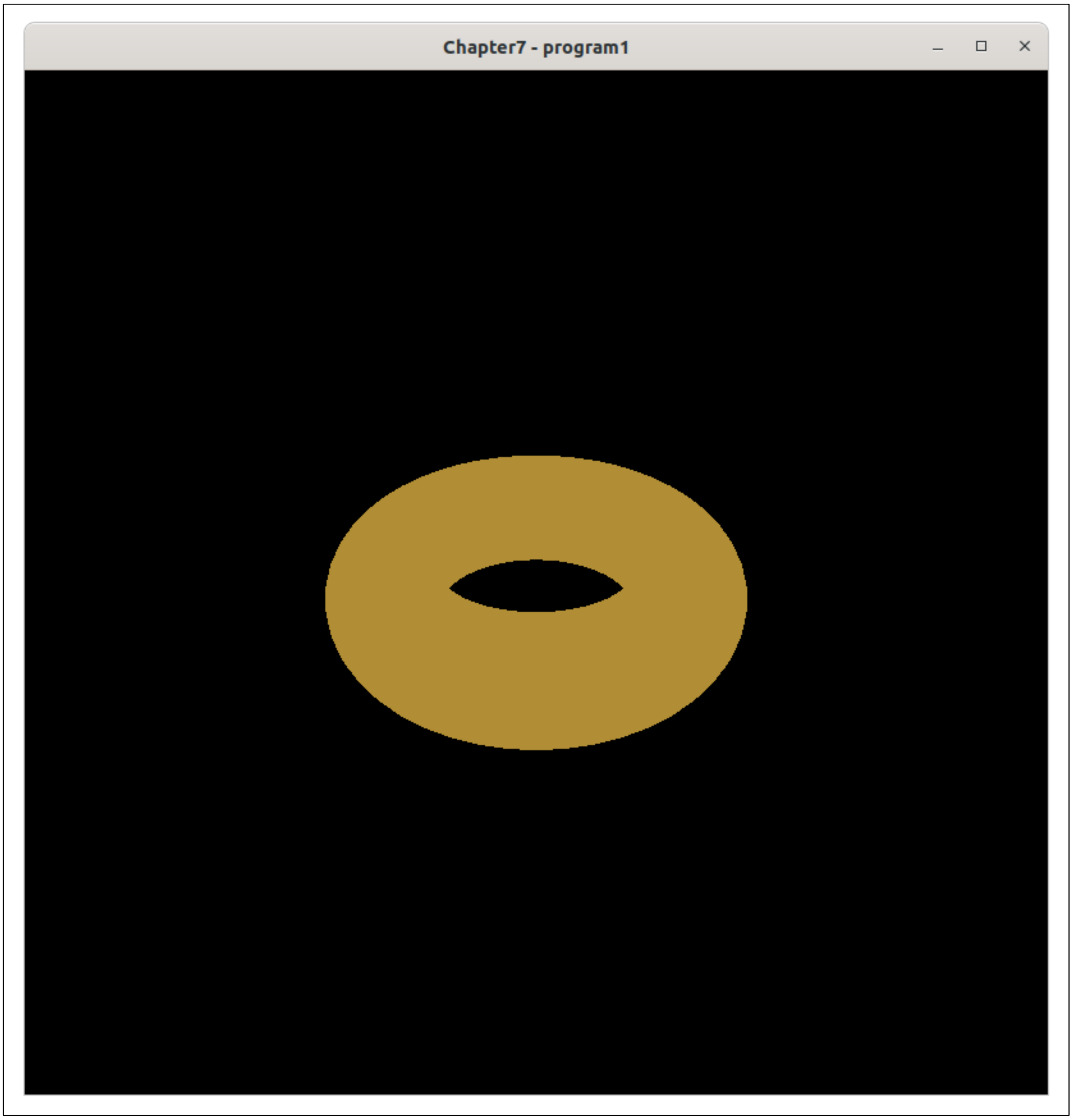
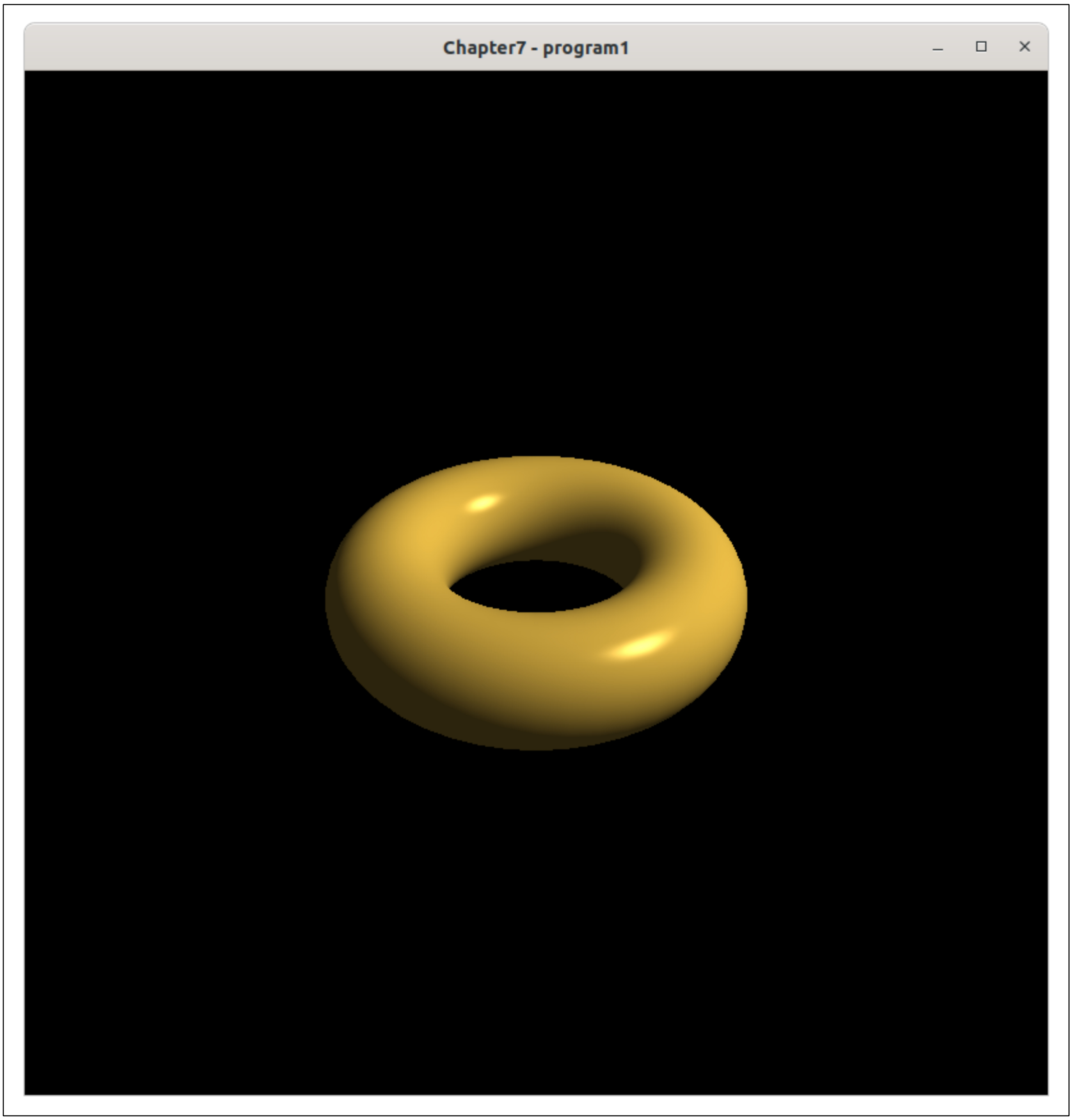
The effect of lighting

In chapter seven we are going to study lighting models. Modeling the way that light interacts with three dimensional objects can greatly improve our perception of those objects as three dimensional objects.

For example, here is the author's torus rendered without the use of a lighting model. In this version of the program we simply apply the same color to every point on the surface of the torus.



Here now is the same shape rendered with one of the lighting models we are going to study in chapter seven.



This is a huge improvement! By correctly modeling the way that light interacts with a three dimensional object we trigger the part of our visual system that uses lighting clues to reconstruct three dimensional objects from two dimensional pictures.

Illumination and color

The color of objects is the result of light from a light source bouncing off of the object. Both the light source and the material of an object have colors. As usual in computer graphics, we represent all colors as a combination of red, green, and blue values.

The light reflected off of an object is the product of the light intensity and the color of the object. The reflected light has three components:

$$reflected_{red} = light_{red} * material_{red}$$

$$reflected_{green} = light_{green} * material_{green}$$

$$reflected_{blue} = light_{blue} * material_{blue}$$

The light values we use here represent how much light strikes the surface of the material. That factor in turn in the result of many other factors.

Kinds of light sources

In computer graphics we recognize three types of light sources.

1. *Ambient light* is the result of light from all light sources combined bouncing around in the scene. Ambient light has only an intensity. If there are multiple light sources in the scene, each will contribute a certain amount to this term.
2. *Diffuse light* is the result of what the authors call *distant lighting*. This type of light source has both an intensity and a direction.
3. *Specular lighting* is produced by direct reflections of light sources. The authors say that specular lighting is produced by *positional* light sources. Positional light sources have a location and an intensity.

These categories are not pure. In the lighting model that the authors use a given light source can have ambient, diffuse, and specular components all at the same time.

Material properties

In the simplest model of a material, a material simply has a color.

This simplistic model is too simplistic to capture all of the aspects of materials. In particular, this model ignores factors such as *roughness* that have an impact on how light interacts with a given material.

In a more sophisticated material model, we assign different color values to a material for use with different light contribution. In this model a material can have separate ambient, diffuse, and specular color values. This system allows us to better model material properties. For example, a smooth material would have a correspondingly larger specular color value, while a rough material would have a very small specular color value.

A model for lighting

The textbook uses the ADS lighting model. In this model the color of a point on the surface of an object is the result of three different contributions.

$$\text{color} = \text{ambient} + \text{diffuse} + \text{specular}$$

Each of these contributions in turn can itself be a sum of contributions from distinct light sources in the scene.

Ambient contribution

Ambient light is the simplest to model. This type of illumination is simply the product of the light's ambient intensity and the material's ambient color value.

$$ambient_{red} = ambient\text{-}light_{red} * material\text{-}ambient_{red}$$

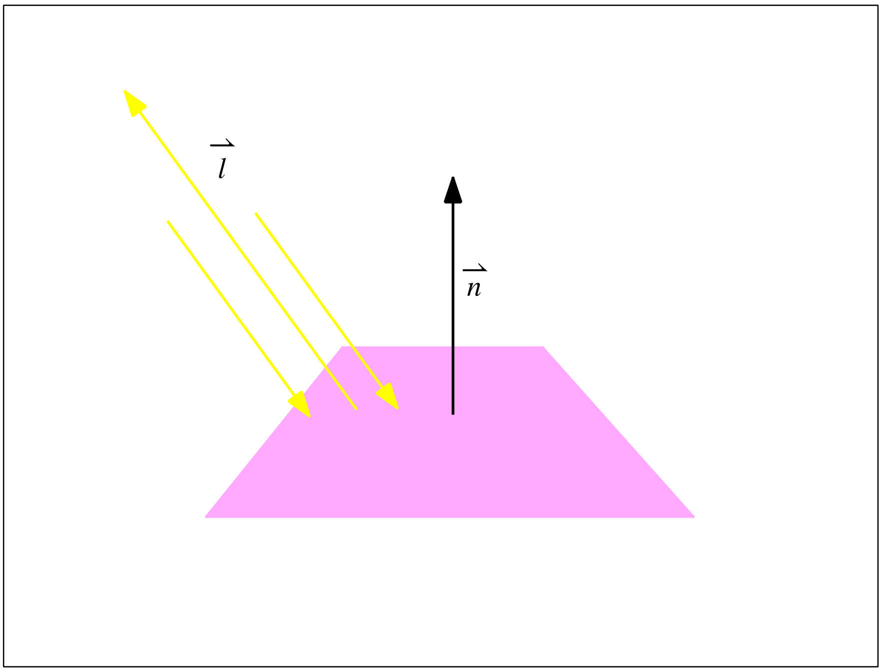
$$ambient_{green} = ambient\text{-}light_{green} * material\text{-}ambient_{green}$$

$$ambient_{blue} = ambient\text{-}light_{blue} * material\text{-}ambient_{blue}$$

Diffuse illumination

Diffuse illumination comes from distant, or directional light sources. These light sources has an intensity and a direction. We usually describe this direction via a light direction vector $\vec{l}$.

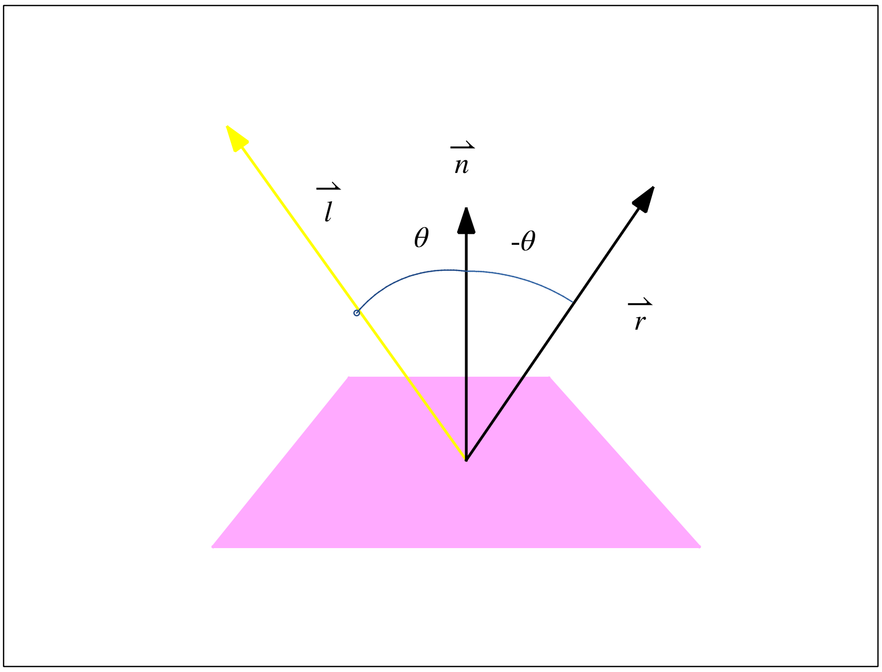
If this type of light strikes a surface at an angle, the light from this light source will get spread over a wider area on the surface. This fall-off in illumination can be modeled via a term that is proportional to the cosine of the angle between the light vector and the *surface normal vector*, $\vec{n}$. This cosine term in turn can be computed by simply taking the dot product of the two vectors.



$$\text{diffuse} = \text{light} * \left(\vec{n} \cdot \vec{l}\right)$$

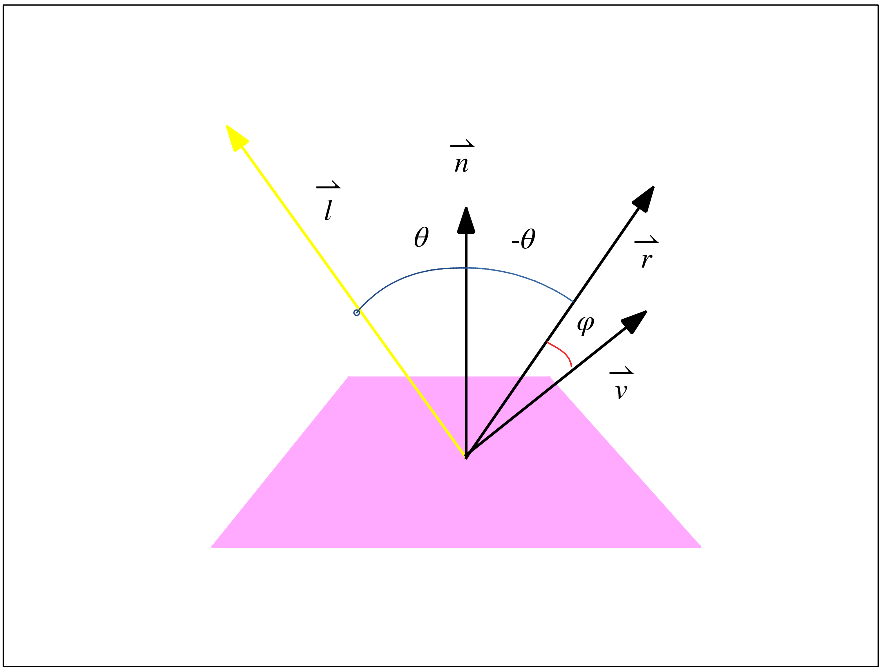
Specular illumination

Specular illumination is the result of light from a light source being reflected off of a surface. When light from a light source strikes a flat, smooth surface, that light gets reflected from the surface. If the vector from the surface point to the light source is $\vec{l}$, light reflected from the surface bounces off in the direction of the *reflected vector* $\vec{r}$.



The reflected vector forms an equal and opposite angle with the angle between the light vector and the surface normal.

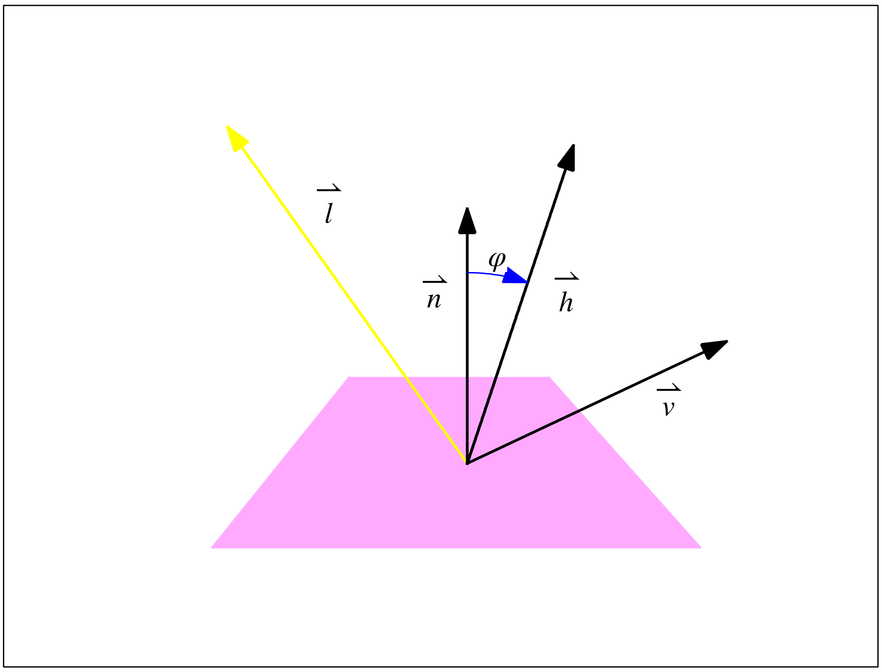
The intensity of the illumination that a view experiences is a result of the angle between the observer's *view vector,* $\vec{v}$, and the reflected vector. The view vector is a vector that runs in the direction from the point on the surface to the observer's location.



Specular reflections die off very quickly as the view vector moves away from the reflected vector. In *Phong Shading* we compute the strength of the specular reflection by computing the cosine of the angle φ between the $\vec{r}$ and $\vec{v}$ vectors and then raising that term to a power n. Once again, we can easily compute this cosine term by normalizing both of the vectors and taking their dot product.

By raising or lowering the exponent n we can either sharpen or dull this effect. In computer graphics we commonly refer to this n factor as the material's *shininess*.

One problem with Phong shading is that computing the reflected vector is computationally expensive. Since we need to first compute the $\vec{r}$ vector to compute the angle φ, this makes computing the specular term expensive. Blinn introduced an approximation that is easier to compute. Blinn instead computed a *halfway vector* $\vec{h}$ that is the simple average of the light vector $\vec{l}$ and the view vector $\vec{v}$. The angle between this halfway vector and the surface normal approximates the angle φ between $\vec{r}$ and $\vec{v}$, and is much cheaper to compute.



$$\vec{h} = \frac{1}{2}\left(\vec{l} + \vec{v}\right)$$

$$\cos\varphi \approx \frac{\vec{h} \cdot \vec{n}}{\left|\vec{h}\right|\left|\vec{n}\right|}$$

$$\text{specular} = (\cos\varphi)^n$$