COMP30019 Graphics and Interaction Illumination Models

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Lecture outline

Introduction to illumination

How does light interact with object surfaces?

Aim: understand illumination models and surface properties for realistic shading.

Shading and illumination

In real scenes, there is a variation of *shading* over object surfaces caused by

- surface material properties,
- orientation of surfaces,
- nature and direction of light sources,
- view direction and
- shadows.

Surface types

In order to create realistic renderings by computer graphics, we need to attempt to simulate this shading for different kinds of surfaces:

- self-luminous,
- transparent refractive,
- transparent translucent,
- reflective,
- diffuse (also body reflection or matte),
- specular (aka surface reflection or gloss),
- textured (macrotexture versus microtexture).

Surface types

In order to create realistic renderings by computer graphics, we need to attempt to simulate this shading for different kinds of surfaces:

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- textured (macrotexture versus microtexture).

Surface examples

- Self lunious example is some kinds of jelly fish that glow in dark or radioactive isotopes
- Transparent refractive, – glass or water
- Transparent translucent – light interacts in more complex way, e.g scatters.
- reflection, either
  - diffuse (body reflection), e.g. carpet
  - specular (surface reflection), e.g. polished steel.
- These shading patterns can provide useful perceptual clues about the 3D structure of the scene.

Isotropic surfaces

In isotropic surfaces the relationship between the incoming (or incident) and outgoing (or reflected) direction of light is the same over the whole surface (otherwise anisotropic).

Illumination models generally most often consider isotropic surfaces only, however:

- Certain kinds of material (such as velour) and certain rock or stone faces (look different depending on angle that you view them).
- As a result of asymmetric microtexture.

Shading model versus illumination model

There is a difference between the *shading model* and the *illumination model* used in rendering scenes,

- the illumination model captures how light sources interacts with object surfaces, and
- the shading model determines how to render the faces of each polygon in the scene.

The shading model depends on illumination model, for example

- some shading models invoke an illumination model for every pixel (such as ray tracing),
- others only use the illumination model for some pixels and the shade the remaining pixels by interpolation (such as Gouraud shading).

- The illumination model is about determining how light sources interacts with object surfaces
- Whereas shading is about how to interpolate over the faces of polygons, given the illumination.

The choice of illumination model is a compromise between modelling the physics fully, and the computational cost.

- Simple illumination models do not consider shadows, reflections or photon-based effects (such as radiosity).
- In full ray tracing one considers *all* rays of light and their recursive interaction between each object —very computationally complex!
- In limit can't model exactly since (ray tracing is undecidable: not Turing computable), so have to make decision about model limitations no matter what, e.g. how many time will we recurse (in other words how many times will we allow for re-reflection) ?

Ambient illumination

The simplest kind of shading is that from *ambient* illumination, that is, light that comes uniformly from all directions.

The radiated light intensity I at a point on a surface depends on the intensity of the illumination I_a, and on the *reflectivity* k_a (or *albedo*) of the surface—the fraction of the incoming light which the object reflects, near zero for black objects, near one for white objects. Thus

$$I = I_a k_a$$

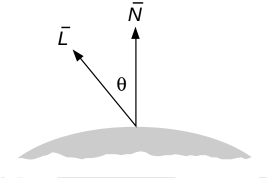
Ambient illumination is mathematically an extended form of Lambertian reflection, integrating contributions from an infinite number of infinitesimal point light sources in all directions, instead of a single point light source.

In ambient shading assume that light comes uniformly from all directions (average of full rendering case).

- Involves integrating contributions from an infinite number of infinitesimal point light sources in all directions.
- Radiated light intensity I at a point on a surface depends on the intensity of illumination $\mathbf{I_a}$ and reflectivity, or albedo, of the surface $\mathbf{k_a}$.

Lambertian (diffuse) reflection

When a ray of light hits a surface, some fraction of it penetrates some way into the body of the object, where it is scattered (and may interact with coloured pigment particles). Eventually, some of the light is reradiated more-or-less uniformly in all directions. For a given surface, the brightness depends only on the angle θ between the direction $\bar{L}$ to the light source and the surface normal $\bar{N}$ (Foley Figure 14.01).



- The brightness depends only on the angle θ between the direction $\bar{L}$ to the light source and the surface normal $\bar{N}$.
- This is the so-called *Lambertian* reflection (or *matte*, or *diffuse* or *body* reflection—all these terms are used.)
- In Lambertian reflection light is re-radiated uniformly in all directions.

We assume that *the light source is a point*, so that over a tiny patch of surface, all the incident light rays are effectively parallel. (This will be approximated, in practice, by a small light source, like a light globe, which is reasonably far away.)

The intensity of light re-radiated from a tiny patch of surface depends on the intensity I_p of the incoming light from the point light source, on how much of this light is intercepted by the surface patch, and on the reflectivity k_d (or albedo) of the surface.

If the surface patch is facing full-on to the light source, then it will intercept the maximum amount of light. *As the patch turns away from the light*, it will intercept less of the light, following a cosine law, $\cos\theta$, where θ is the angle between the local surface normal, and the direction to the light source.

The diffuse (or Lambertian) illumination equation is therefore

$$I = I_p k_d cos\theta$$

This cosine can be expressed as a scalar product, thus the Lambertian contribution to the total intensity is

$$I = I_p k_d (\bar{N} \cdot \bar{L})$$

where $\bar{L}$ and $\bar{N}$ are unit vectors in the directions, respectively, of the light source and of the surface normal.

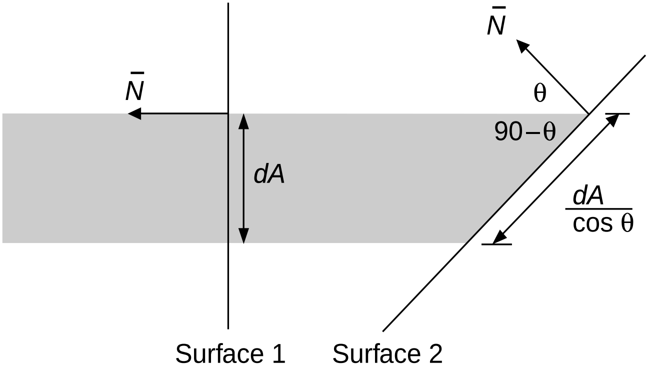
Independence of surface orientation

For a given small surface patch, the amount of light radiated towards the viewer is greatest when the surface normal is pointing straight at the viewer, and falls off according to a cosine law as the surface slants away from the viewer.

However, at the same time, for a given visual angle subtended at the viewer, more of the surface is seen within that angle as the surface slants away from the viewer, again according to a cosine law.

These two effects exactly compensate, so, overall, Lambertian reflection is independent of surface orientation with respect to the viewer.

Light beam shown in 2D cross-section (Foley Figure 14.02).



- At angle of incidence of θ, less light is radiated towards the viewer, according to $I = I_p k_d cos\theta$, however,
- a greater area is intercepted according to $\frac{dA}{cos\theta}$.

Independence of distance of viewer from surface

Likewise, as the surface moves further away from the viewer, the received light intensity falls off as an inverse-square law in distance.

However, for a given angle subtended at the viewer, the amount of surface included grows in proportion to the square of the distance.

These two effects *also* compensate, so that intensity of Lambertian reflection is independent of the distance of the surface from the viewer.

Dependence of distance of light source from surface

The intensity of the incoming light (and therefore of the reflected light) *does* depend on the distance of the surface from the light source.

Physically, for a point light source, this dies off in inverse proportion to the square of the distance.

However, if this physical law is followed in rendering, the intensity seems to go down unrealistically fast. (This is because most real lighting is not from a single, ideal point source.)

Dependence of distance of light source from surface

Therefore, many graphics systems use a factor of the form

$$\frac{1}{C + U}$$

where U is the light-source distance, and C is some constant offset. This is ad-hoc, but gives reasonable results.

If the light source is sufficiently “distant”, then all parts of the object can be regarded as equally far from the light source, and therefore no such correction need be made.

The effect of distance, the same for all points, can essentially be absorbed into the light-source intensity factor I_p.

Specular reflection

When a ray of light hits a surface, some fraction of it is also reflected immediately at the outer boundary of the surface. This is the *specular* reflection and leads to highlights and glossiness.

If the surface were a perfect mirror, then the reflection would follow the law of perfect reflection: For an incident ray of light from the light source, the emergent reflected ray would lie in the plane defined by the incident ray and the surface normal, and make the same angle with the surface normal as the incident ray.

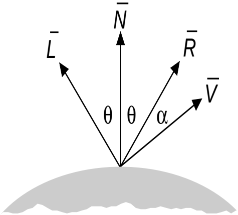
(This direction of perfect reflection can be derived using a little vector geometry.)

For most glossy surfaces, however, the reflected light is spread out (e.g. scratches in steel of texture in plastic), to a greater or lesser degree, from the direction of perfect reflection. This is caused by microscopic unevenness of the surface: there are a lot of little reflecting facets, whose normals vary from the overall surface normal.

The reflection is strongest in the direction of perfect reflection, and becomes weaker for directions away from this.

Specular reflection as a function of angle

This spread of reflection is modelled by looking at the angle α between the direction of perfect reflection and the viewer direction, and modify the reflected intensity by the factor $(\cos\alpha)^n$ (Foley Figure 14.08).



$(cos\alpha)^n$ is at its maximum, 1, when the viewer direction coincides with the direction of perfect reflection, and becomes less for directions away from this.

Specular reflection exponent

The exponent n is the *specular reflection exponent* and controls the degree of spread.

- High values of n (maybe as much as 100 or 200) lead to a rapid fall-off and sharp highlights, corresponding to a very glossy surface, almost like a mirror.
- Low values (as low as 1 or 2) lead to a slow fall-off and spread-out, more diffuse highlights, a more matte surface appearance.

- High values of specular reflection exponent correspond to very glossy surfaces, such as Steel.
- Low values of specular reflection exponent correspond to very glossy surfaces, such as carpet.

Specular reflection is independent of material colour

Notice that specular reflection, being from the outer surface, does not involve interaction with the body of the material, and so is independent of Lambertian reflectivity.

This is particularly important in dealing with colour.

The colour of a specular reflection depends only on the colour of the incoming light, not on the colour of the material.

Example: coloured reflections on surface of steel.

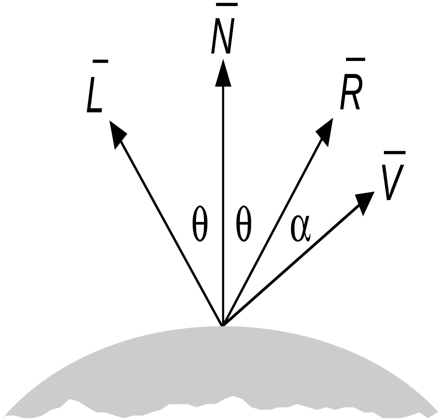
- The colour of a specular reflection depends only on the colour of the incoming light, not on the colour of the material.

Phong illumination model and specular reflection

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + f_{att} I_{p\lambda}[k_d O_{d\lambda} cos\theta + W(\theta) cos^n \alpha]$$

$$I_\lambda = I_{a\lambda} k_a O_{d\lambda} + f_{att} I_{p\lambda}[k_d O_{d\lambda}(\bar{N}.\bar{L}) + k_s(\bar{R}.\bar{V})^n]$$

where $I_{a\lambda}$ is the ambient light (as a function of wavelength), $I_{p\lambda}$ is the point light source, $O_{d\lambda}$ is objects diffuse colour, $W(\theta)$ is the fraction of specularly reflected light, k_d is the diffuse-reflection coefficient, k_s is the specular reflection coefficient, n is the specular-reflection exponent and f_{att} is the light source attenuation factor (a function of distance).

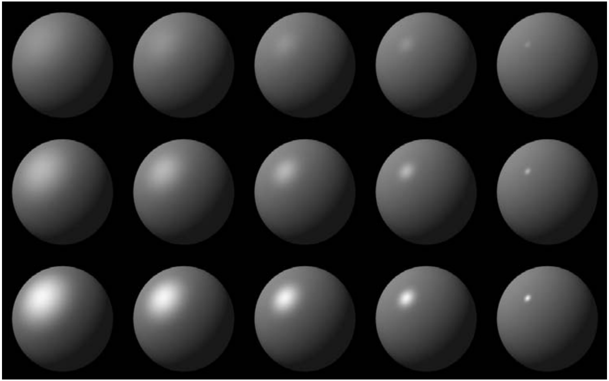


(Foley Figure 14.08)

Phong developed this popular model in 1975 — assures a maximum specular reflection occurs when α is zero and falls off sharply as α increases.

- Need to first identify that amount of incident light specularly reflected depends on the angle of incidence θ.
- If $W(\theta)$ is the fraction of specularly reflected light, then Phong's model is.
- Note that $W(\theta)$ is equivalent to k_s, the specular reflection coefficient ($W(\theta)$ is set to a constant k_s, the mateiral's specular-reflection coefficient which ranges between 0 and 1).
- Then point out that *if* the direction of reflection $\bar{R}$ and the viewpoint direction $\bar{V}$ are normalised, *then* $cos\alpha = \bar{R}.\bar{V}$.

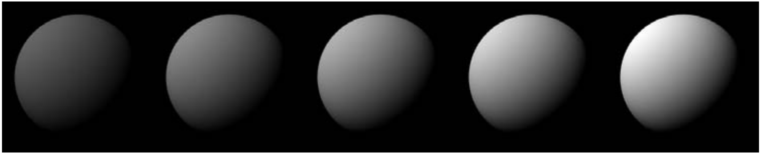
Spheres shaded using Phong's illumination model for increasing values of n (higher specular reflection exponent from left to right) and k_s (higher specular reflectivity coefficient, albedo, from top to bottom) (Foley Figure 14.10).



Combined lighting models

The combination of the above three components, ambient illumination, Lambertian reflection, and (simple) specular reflection is adequate to give reasonably realistic renderings. There are also effects of incident or reflected light being blocked by small-scale surface roughness. However, these effects can usually be ignored (assume isotropic surfaces).

Lambertian (top) versus Lambertian *and* ambient (bottom)



(Foley Figures 14.03 and 14.04).

The mixing of ambient reflection (light from all directions) with Lambertian (light from a point light source) can lead to reasonably realistic effects.

- Ambient light is a bit like *averaging* all rays coming from all directions together with a dominant source.
- This example corresponds to something rather like Styrofoam balls from a bean bag.

Multiple Light Sources

If there are multiple light sources, then their contributions at any point on a surface add together, less any shadowing.

Refractive index

In certain circumstances - such as at uniform planar interfaces of materials with different refractive index - greater realism can be achieved (at greater computation cost), by taking into account how the fraction of incident light reflected (versus what enters the body of the surface) depends somewhat on the angle of incidence.

This is governed by the *Fresnel* equation.

Summary

- Lambertian surfaces exhibit body reflection (or re-radiation), independent of orientation and distance from viewer but not light source, leading to matte appearance.
- Specular surfaces exhibit surface reflection, dependent on orientation and distance of both viewer and light source, leading to glossy appearance with highlights.
- The Phong illumination model captures a combination surface properties including
  - diffuse (Lambertian with point light source),
  - ambient (special case of Lambertian with uniform light), and
  - specular reflection

  as a function of wavelength.