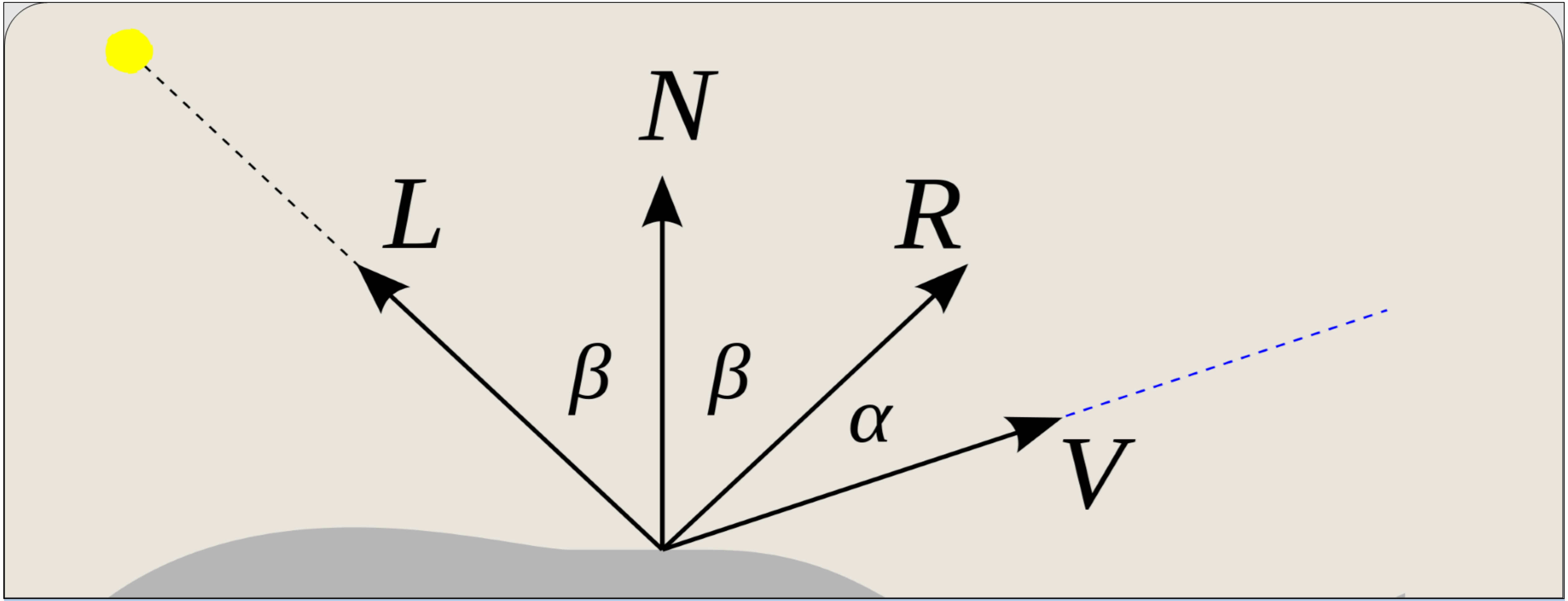
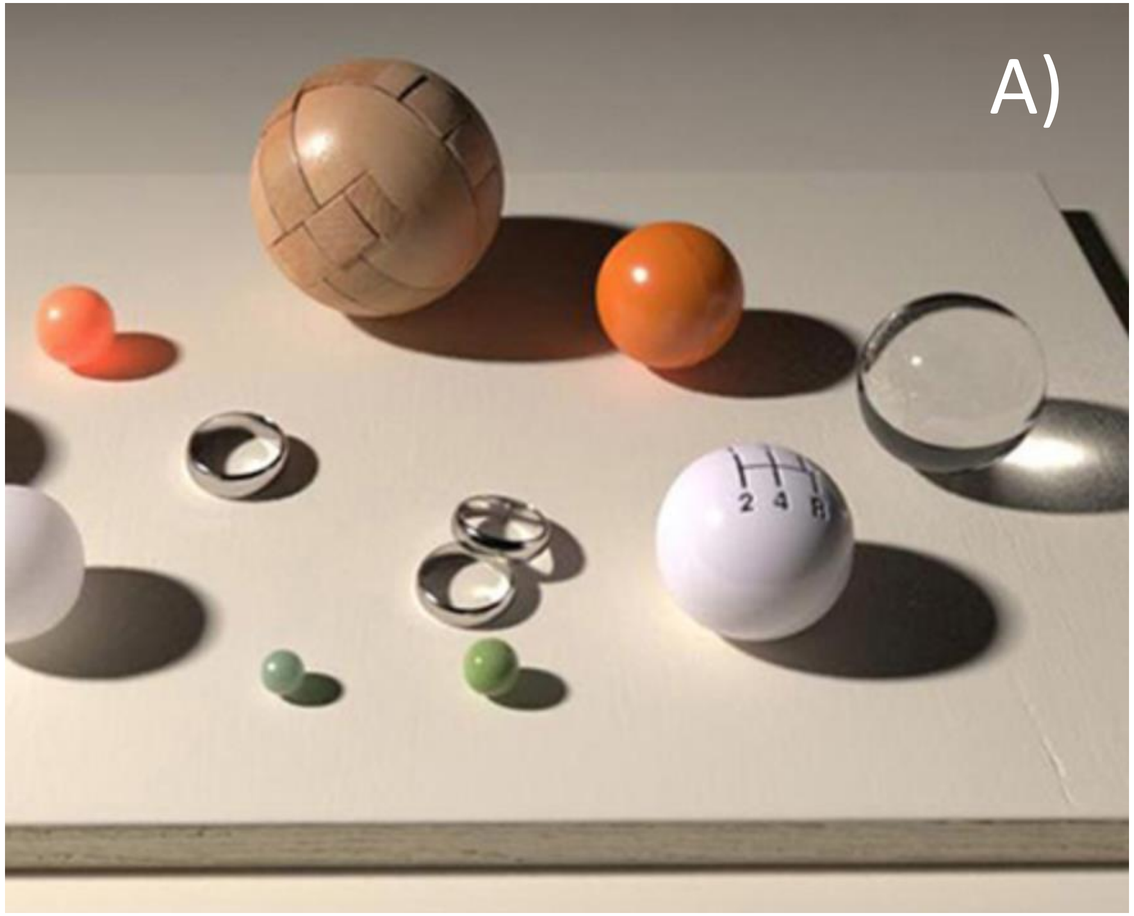


Computer Graphics

Local Illumination

Andreas Aristidou
andarist@ucy.ac.cy
http://www.andreasaristidou.com

Clicker Question 1: *Which image is real?*



Source: Hyperion Renderer

Elements for calculation of lighting

Photo credit: UCSD

Scene rendered using photon mapping

Elements for calculation of lighting

1. Light Sources
   - in which spectrum they emit (color)
   - geometry (shape, position, direction)
   - angular attenuation (falloff)

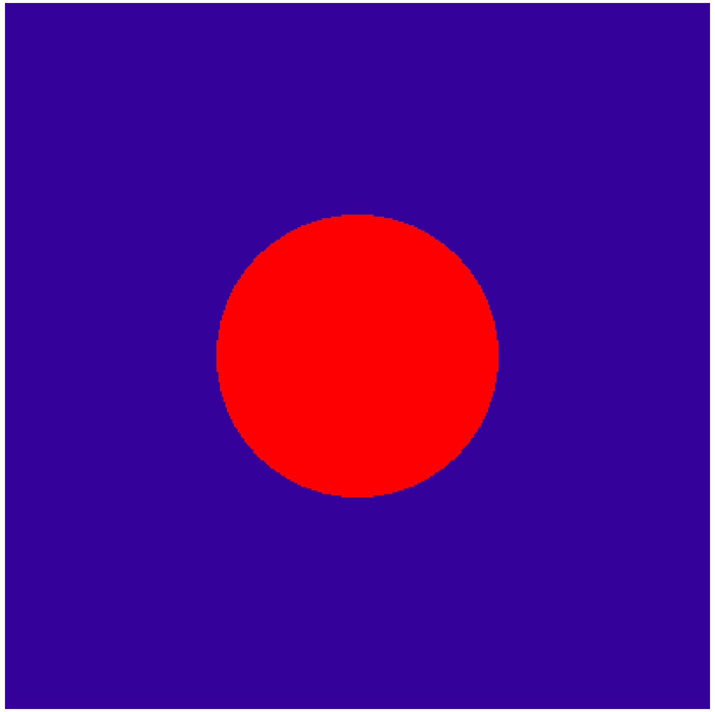
2. Material Properties
   - In which range they emit and reflect
   - geometry (position, direction, micro-structure)
   - absorption

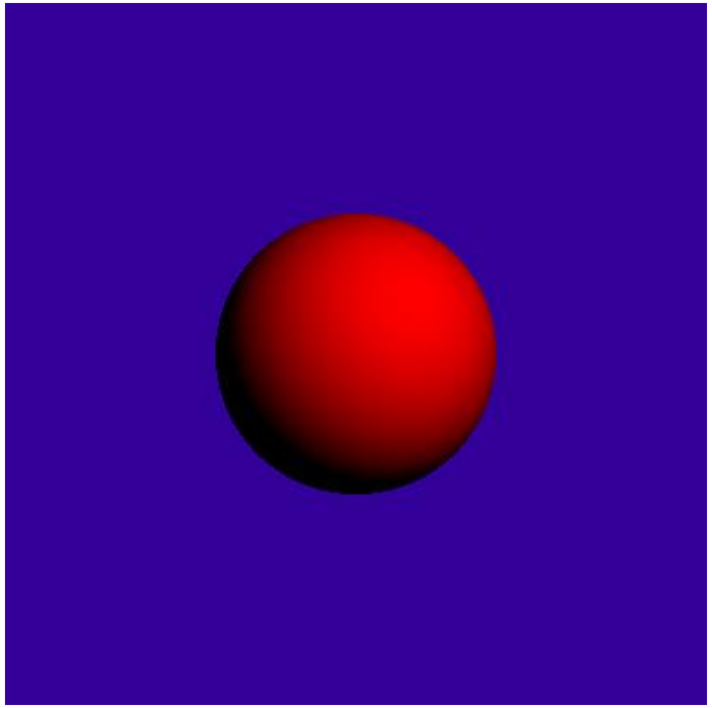
3. **Illumination Model**

Photo source : https://www.overclock.net/forum/234-art-graphics/251218-kerkythea-shaded-lightsource-test.html

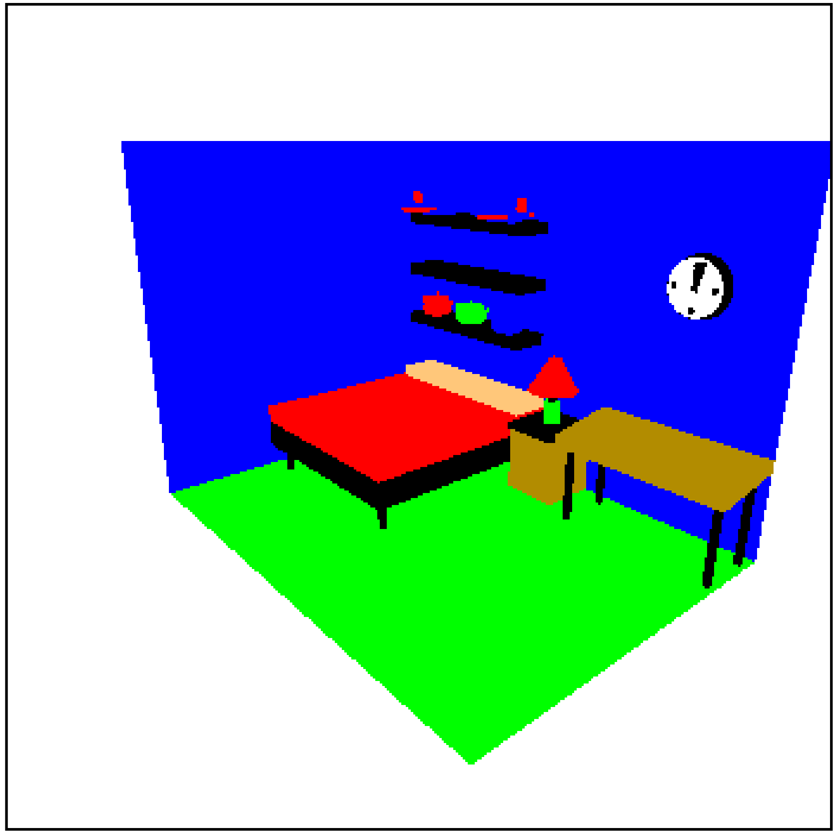
Why Lighting?

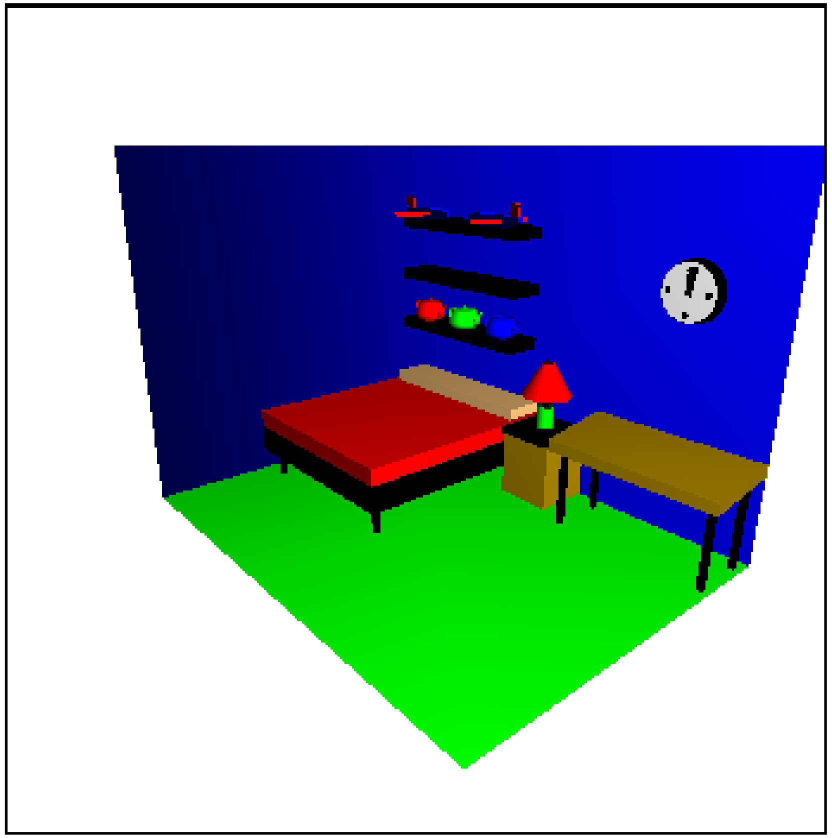
- If we don’t have lighting effects nothing looks three dimensional!



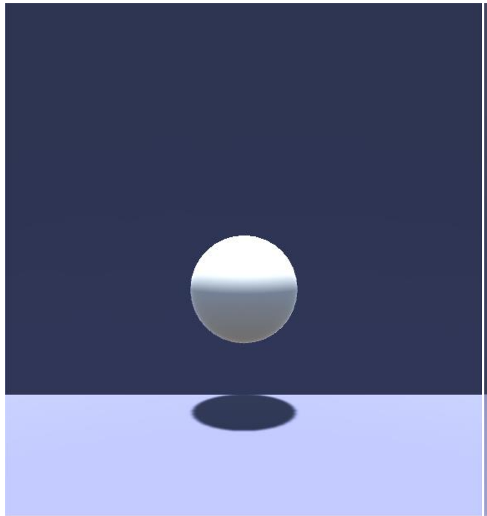


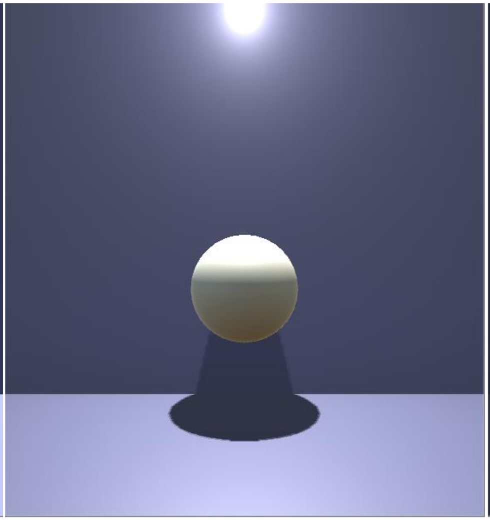
Why Lighting?

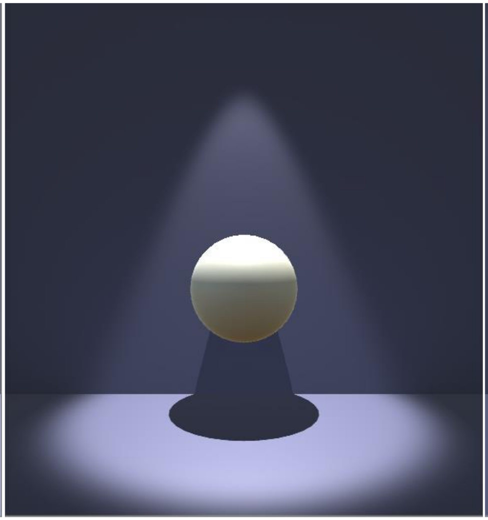


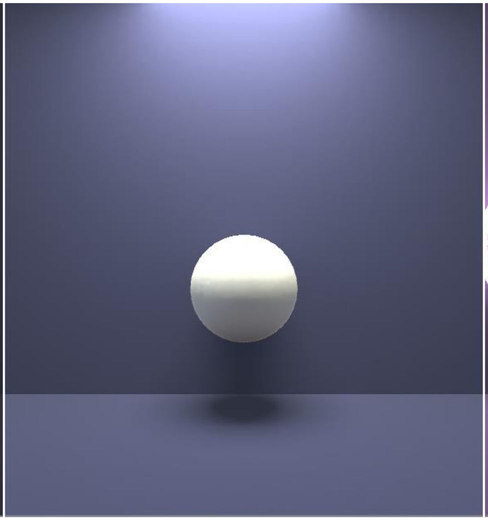


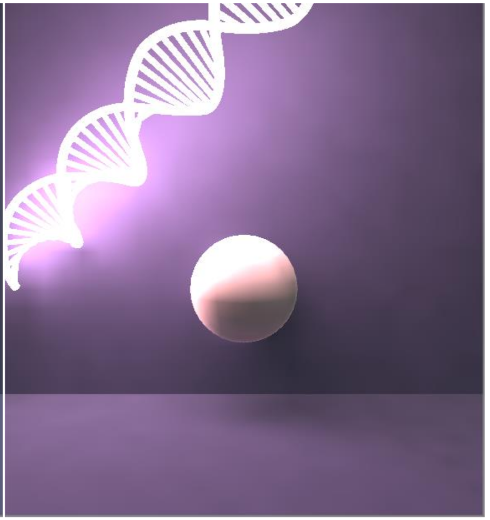
Light Sources


Directional


Point Light

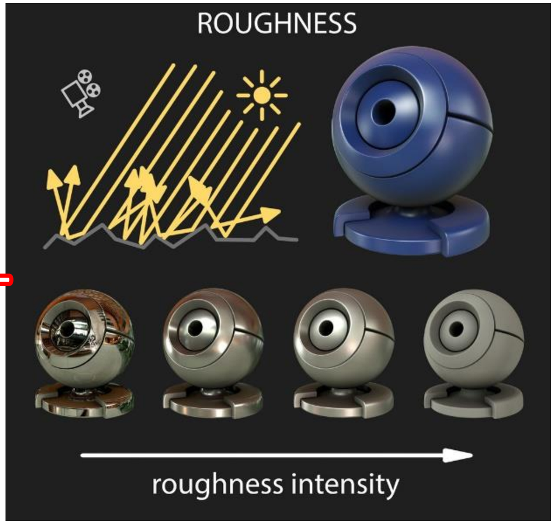

Spotlight

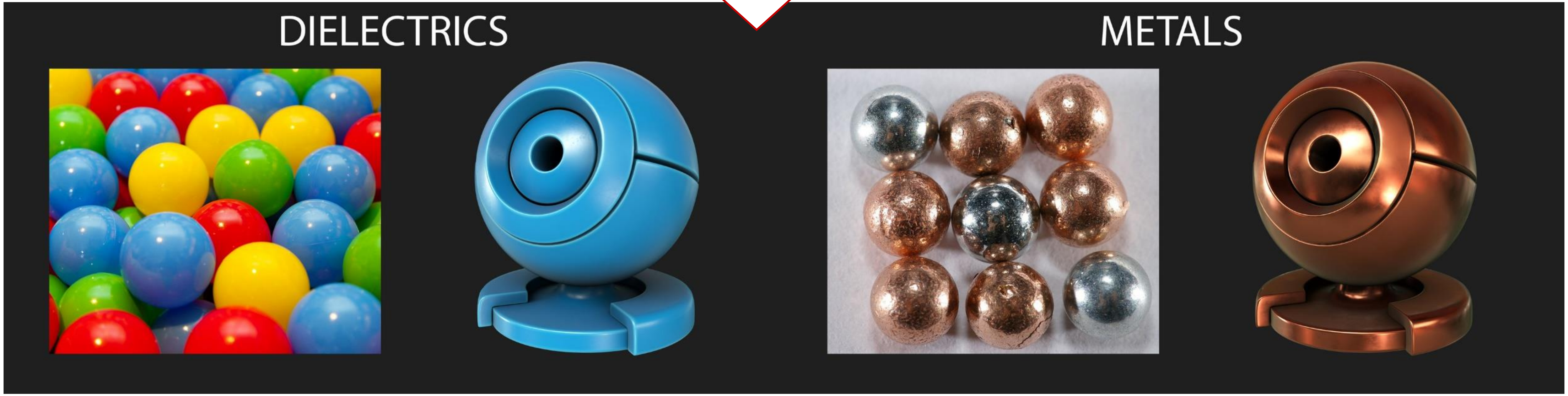

Area Light


Mesh Light

Materials

BRDF: Bidirectional Reflectance Distribution Function



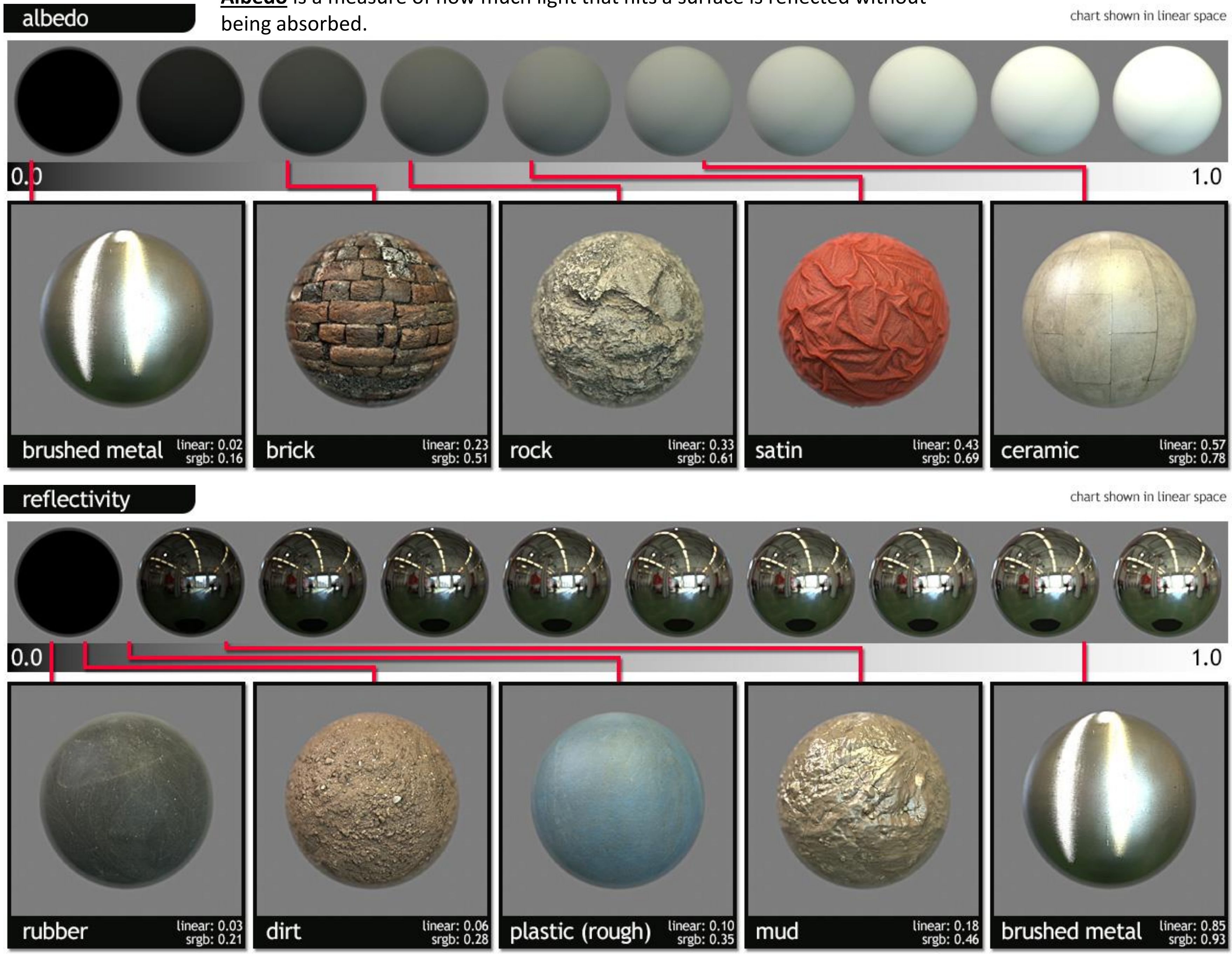


Images from: https://3dcoat.com/pbr/

Materials

Your imagination is the limit

Albedo is a measure of how much light that hits a surface is reflected without being absorbed.



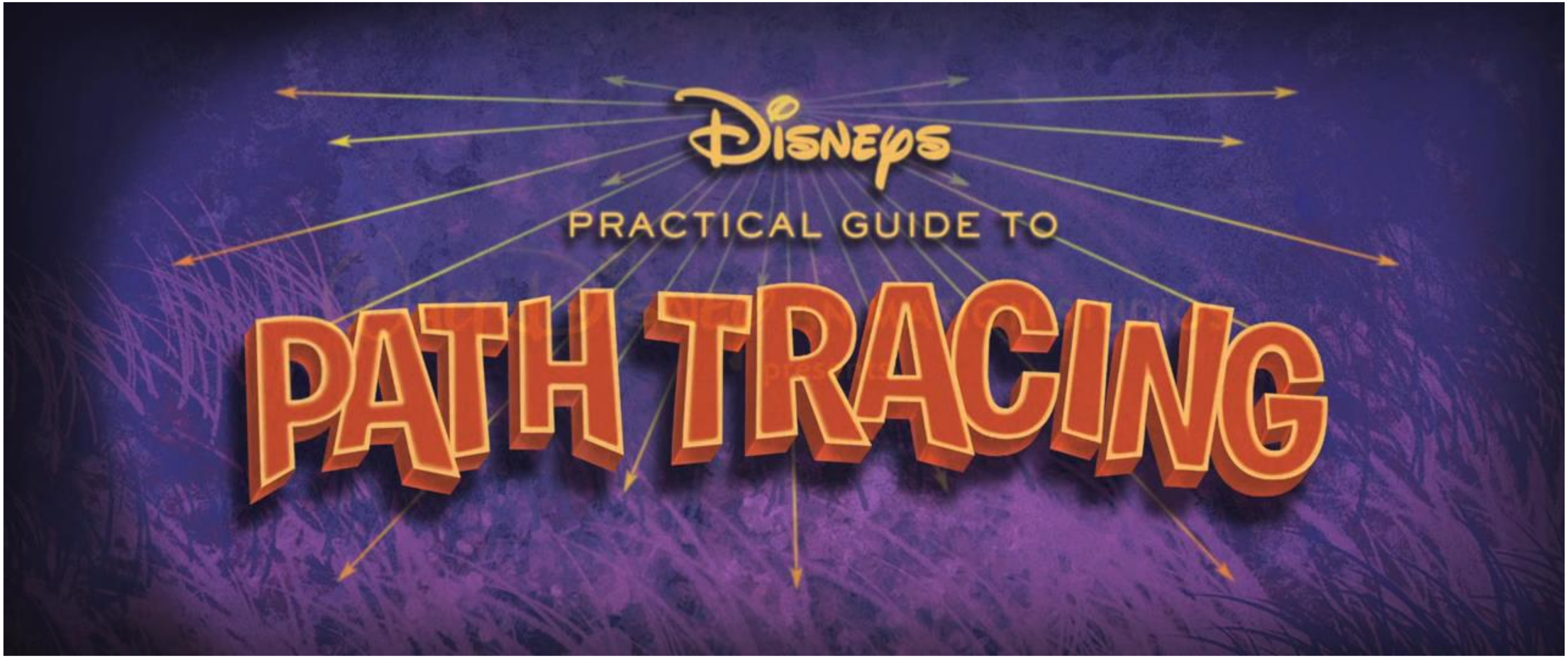
Illumination models

- In the real world, light starts from the light source bounces on the different surfaces of the environment, is absorbed or dispersed by any particles in the atmosphere, is reflected, etc. until it reaches our eye

- In computer graphics we approach it

- We make use of simplified models which we call lighting models

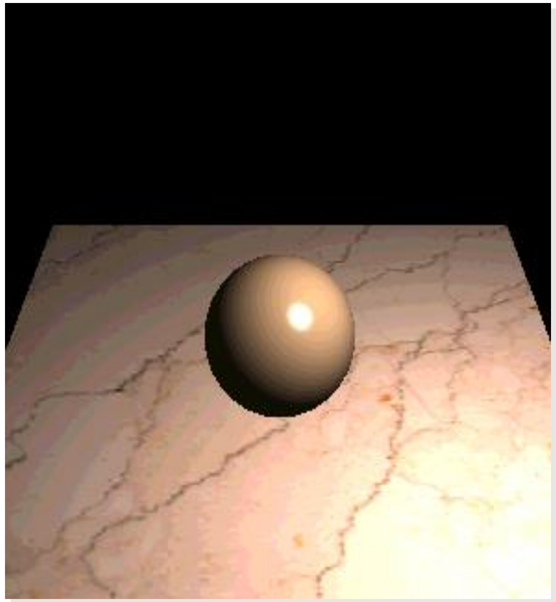
How light works



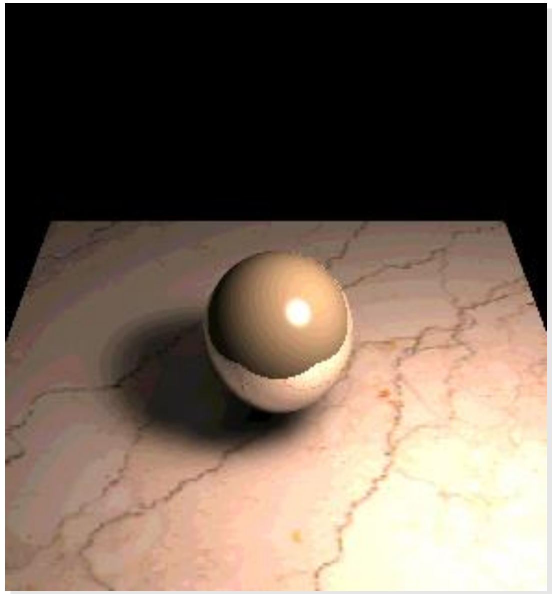
https://youtu.be/frLwRLS_ZR0

Lighting models – 2 general categories

- Local illumination
  - Light comes to objects directly from light sources and is reflected in the eye



- Global illumination
  - light that bounces from other surfaces before it is reflected from the object in our eye is also taken into account



Diffuse Interreflection

Direct illumination

Diffuse Interreflection

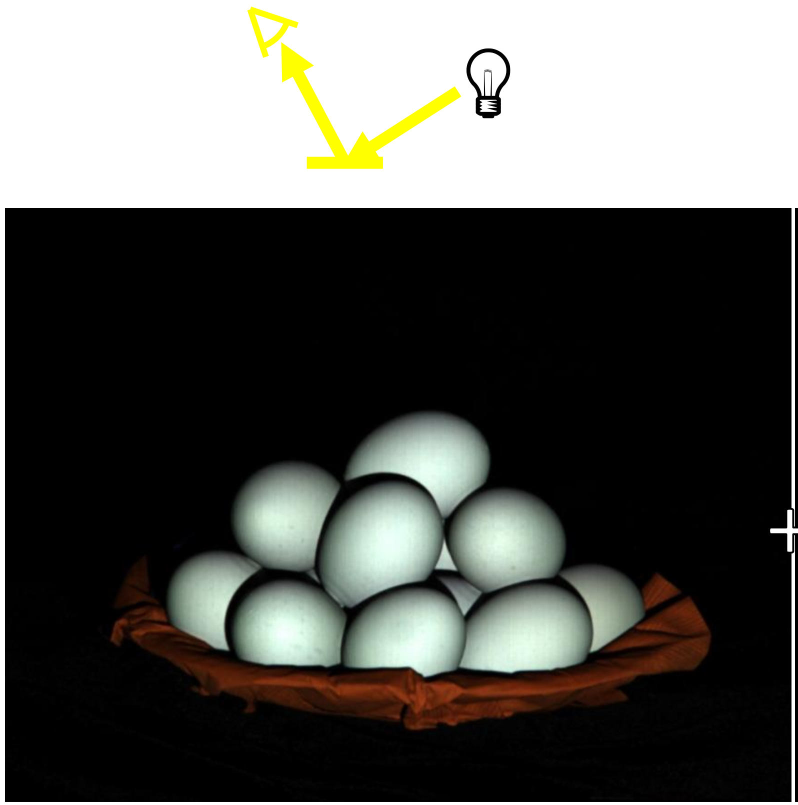
Indirect illumination

Diffuse Interreflection is Surprisingly Important

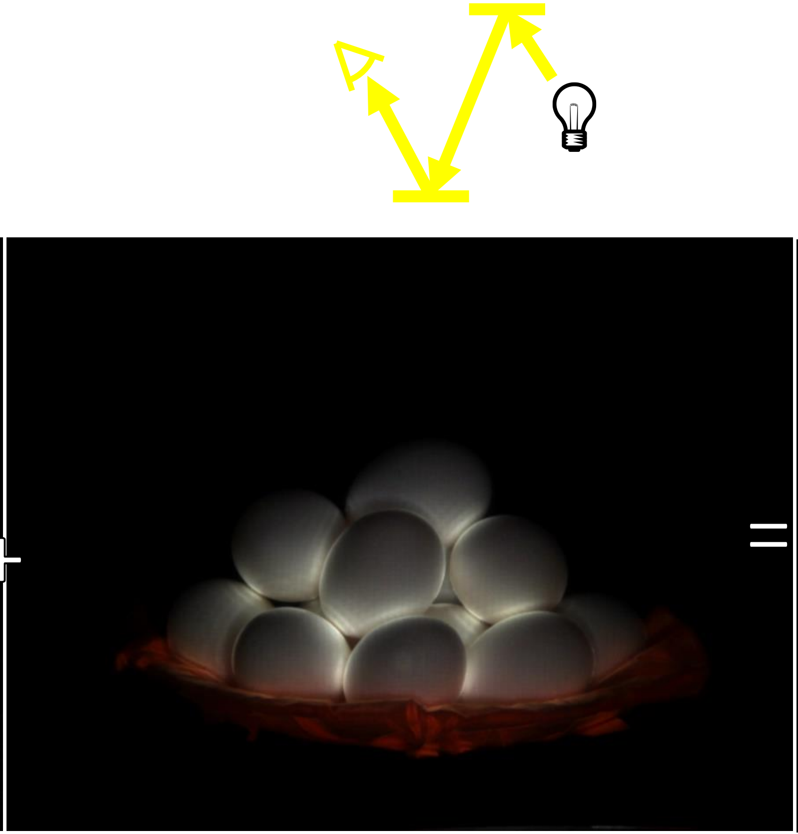
Total illumination
(normal image)

Total illumination

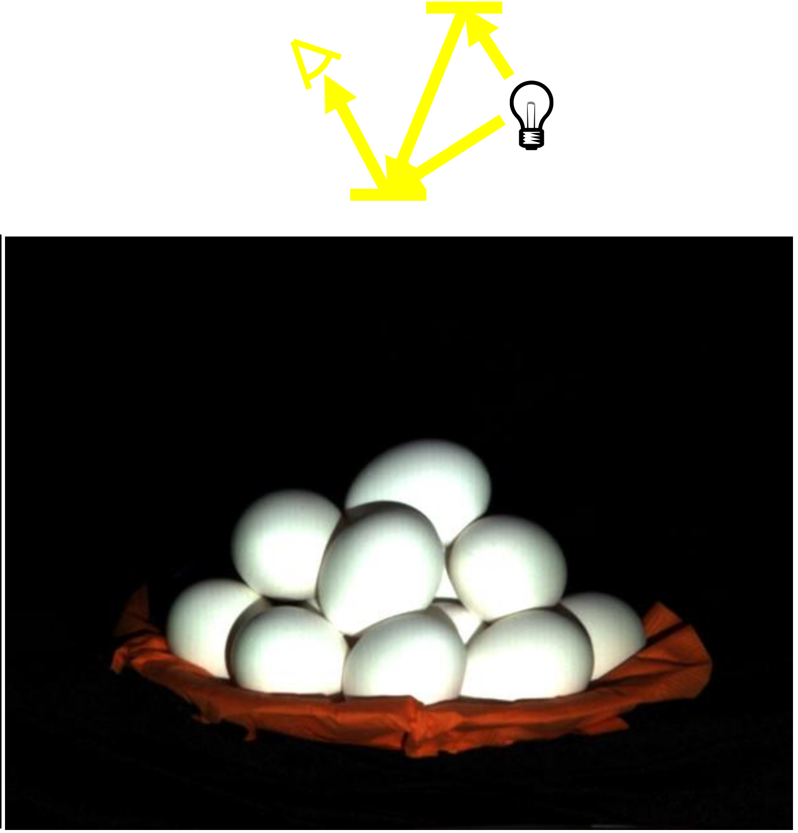
Imaging algorithms divide lighting into several parts



Direct Illumination

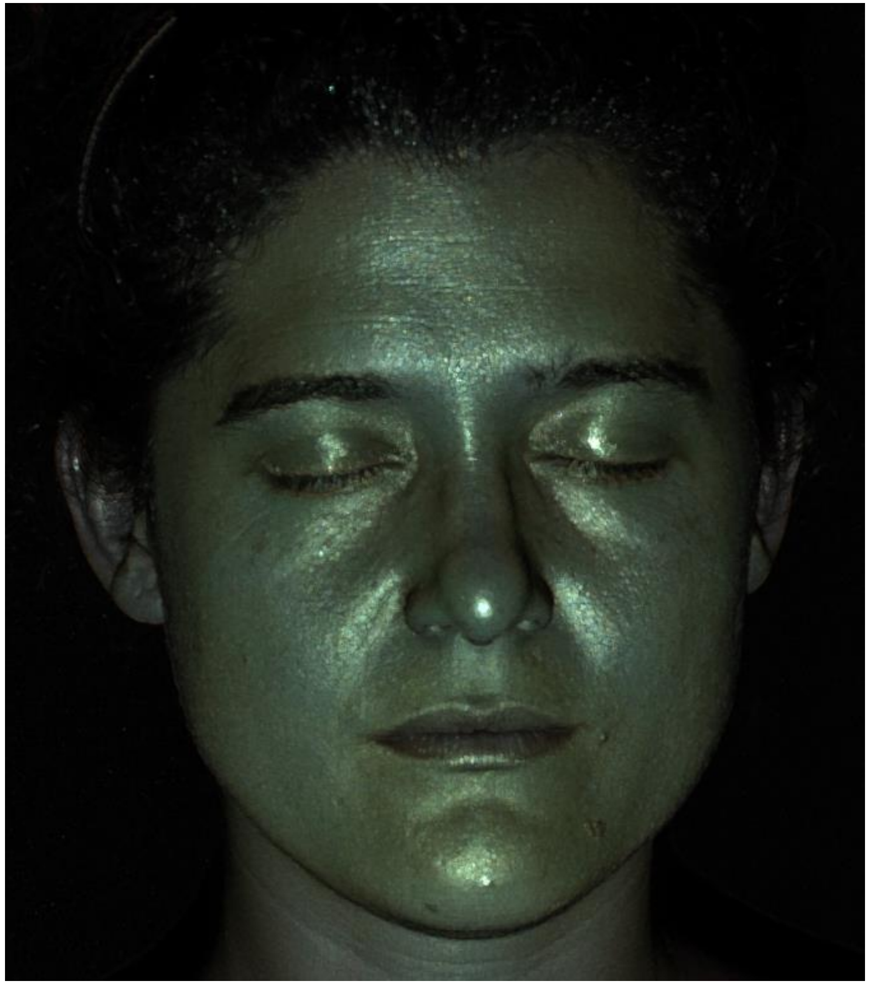


Indirect Illumination



Full Illumination

Human face



Direct illumination

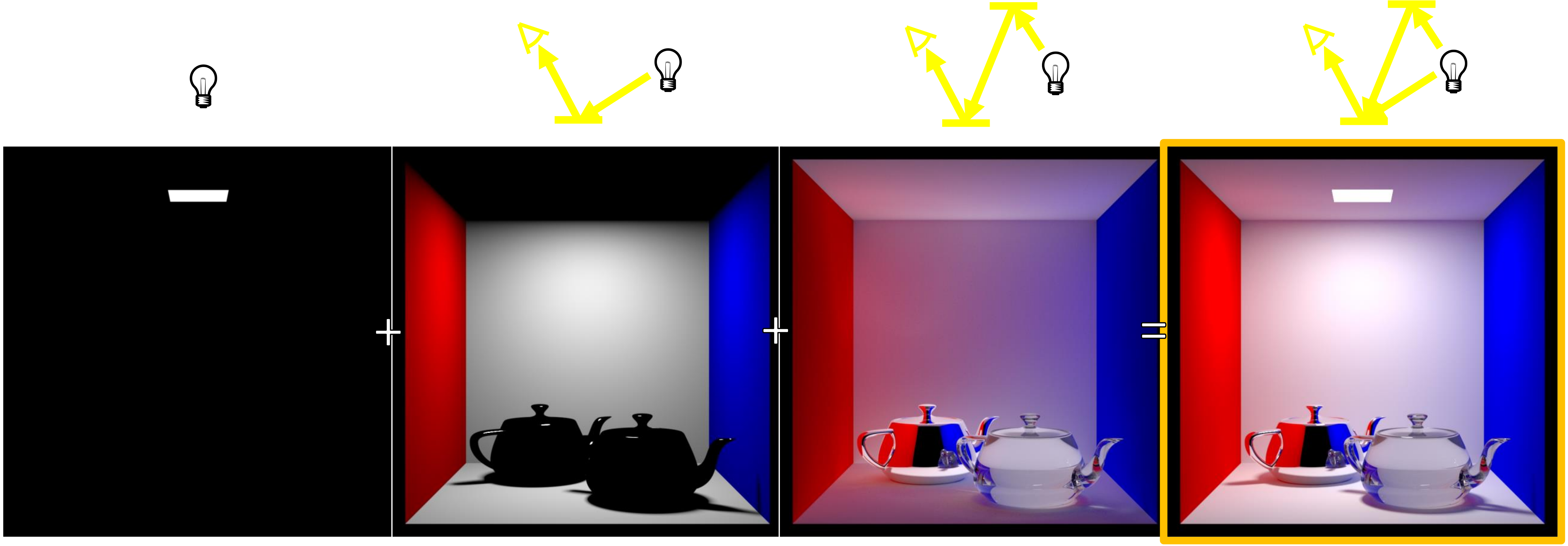
Human face

Indirect illumination

Human face

Total illumination
(normal image)

Global Illumination



Light Source

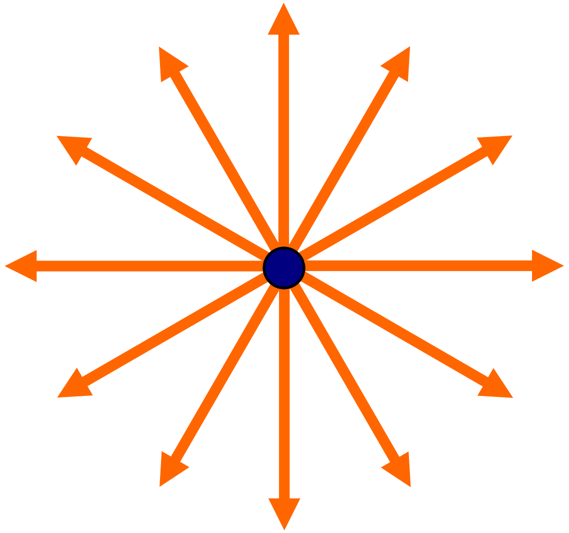
Direct Illumination

Indirect Illumination

Full Illumination

Point Light Sources

- A point source is the simplest model we can use for a light source
- We simply define:
  - The position of the light
  - The RGB values for the colour of the light
- Light is emitted in all directions
- Useful for small light sources



Radial Intensity Attenuation

- As light moves from a light source its intensity diminished
- At any distance d_l away from the light source the intensity diminishes by a factor of $1/{d_l}^2$
- However, using the factor $1/{d_l}^2$ does not produce very good results so we use something different

Radial Intensity Attenuation

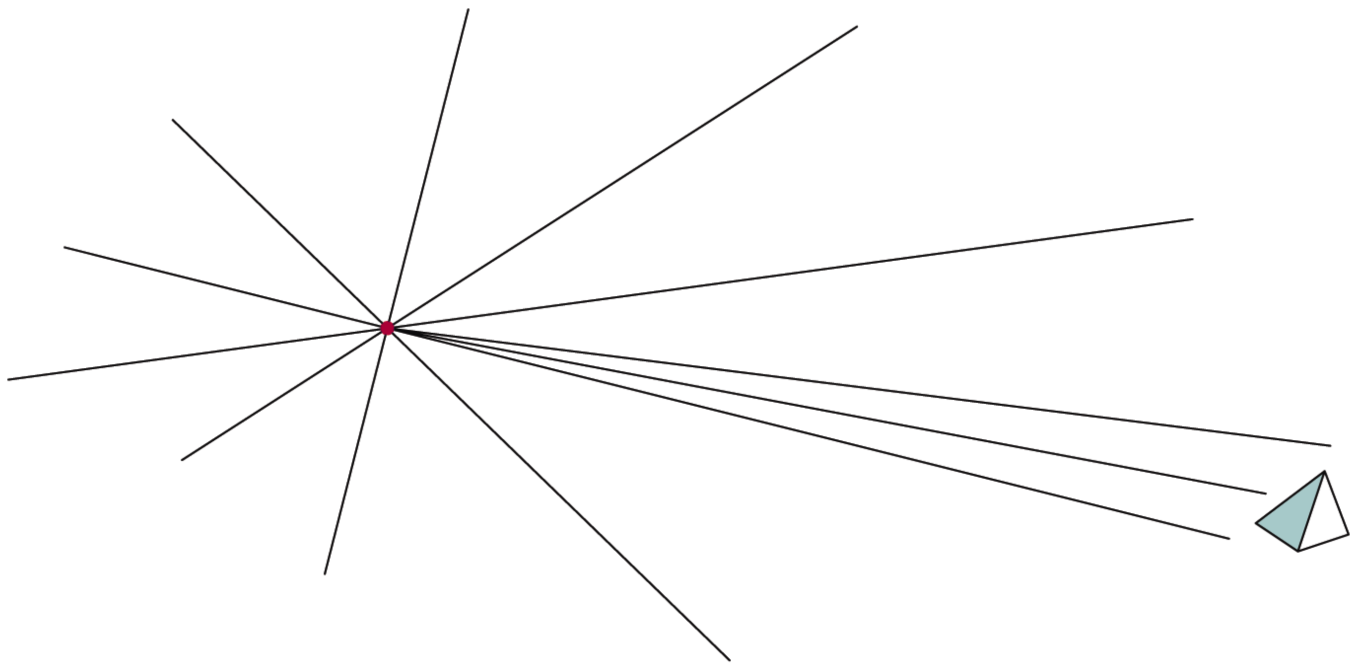
- We use instead in inverse quadratic function of the form:

$$f_{radatten}(d_l) = \frac{1}{a_0 + a_1 d_l + a_2 {d_l}^2}$$

- where the coefficients a_0, a_1, and a_2 can be varied to produce optimal results

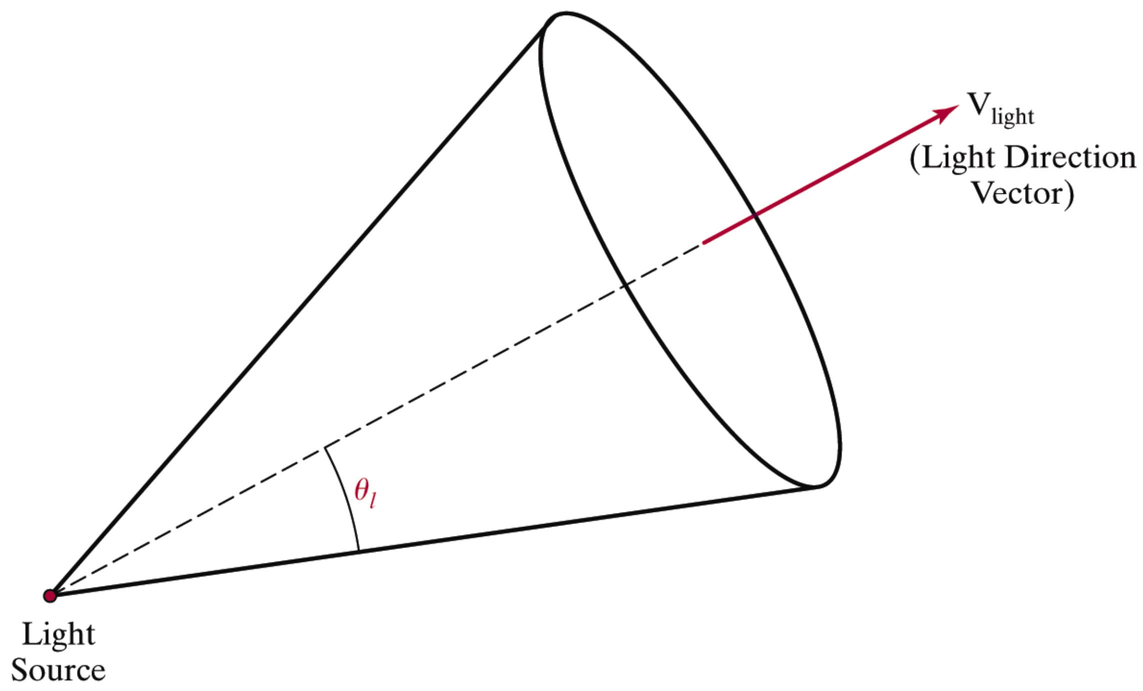
Infinitely Distant Light Sources

- A large light source, like the sun, can be modelled as a point light source
- However, it will have very little directional effect
- Radial intensity attenuation is not used!



Directional Light Sources & Spotlights

- To turn a point light source into a spotlight we simply add a vector direction and an angular limit θ_l

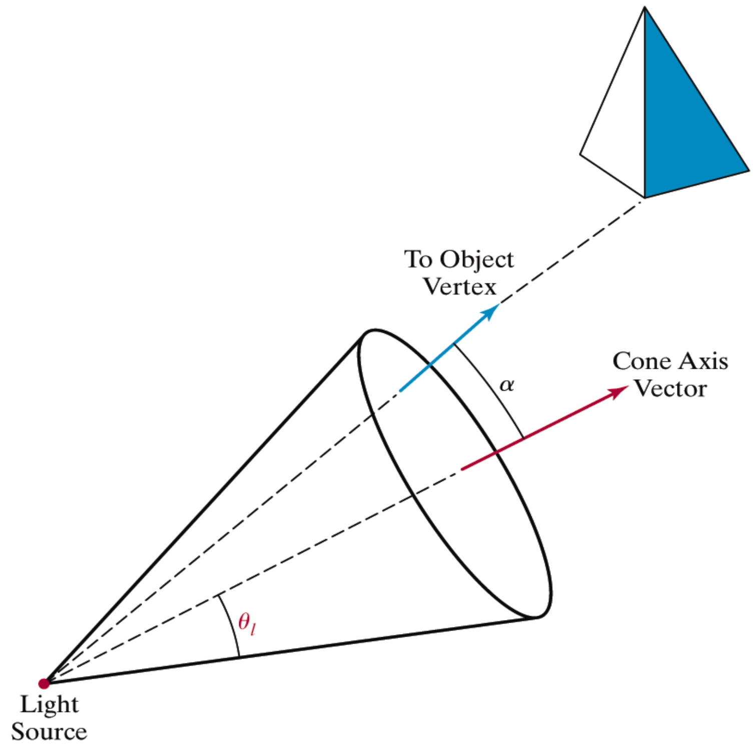


Directional Light Sources & Spotlights

- We can denote V_{light} as the unit vector in the direction of the light and V_{obj} as the unit vector from the light source to an object
- The dot-product of these two vectors gives us the angle between them

$$V_{obj} \cdot V_{light} = \cos\alpha$$

- If this angle is inside the light's angular limit then the object is within the spotlight



Angular Intensity Attenuation

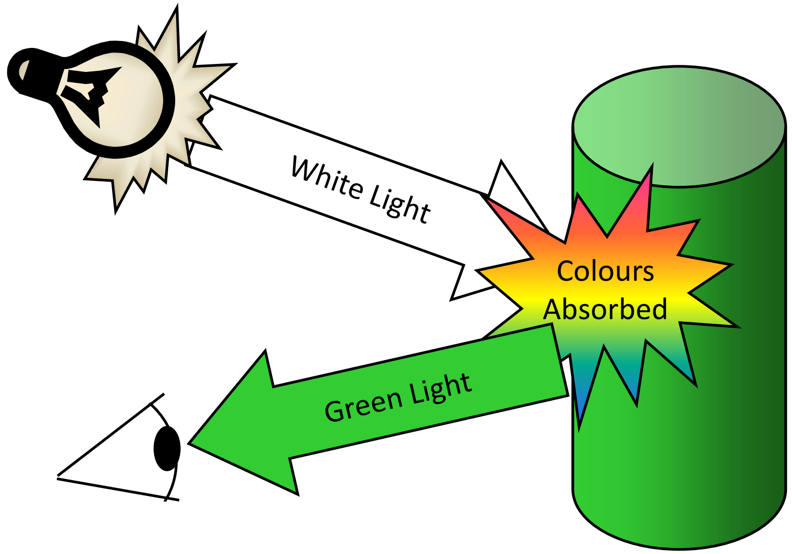
- As well as light intensity decreasing as we move away from a light source, it also decreases angularly
- A commonly used function for calculating angular attenuation is:

$$f_{angatten}(\phi) = \cos^{a_l} \phi \qquad\qquad 0^\circ \le \phi \le \theta$$

- where the attenuation exponent a_l is assigned some positive value and angle ϕ is measured from the cone axis

Reflected Light

- The colours that we perceive are determined by the nature of the light reflected from an object
- For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object

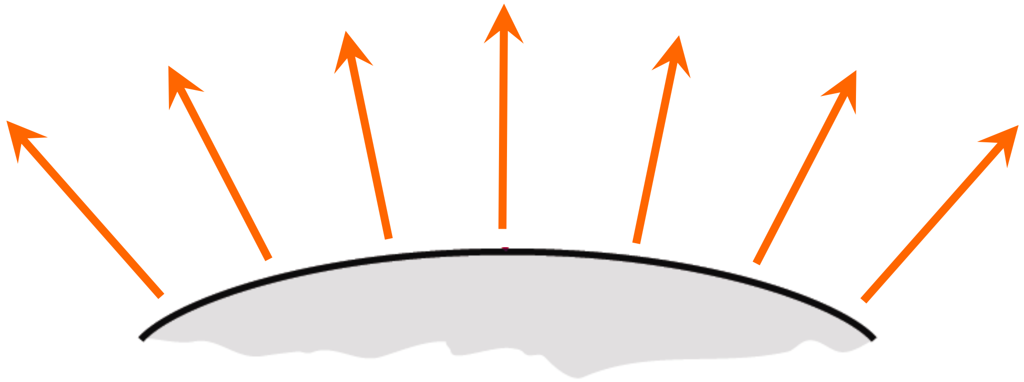


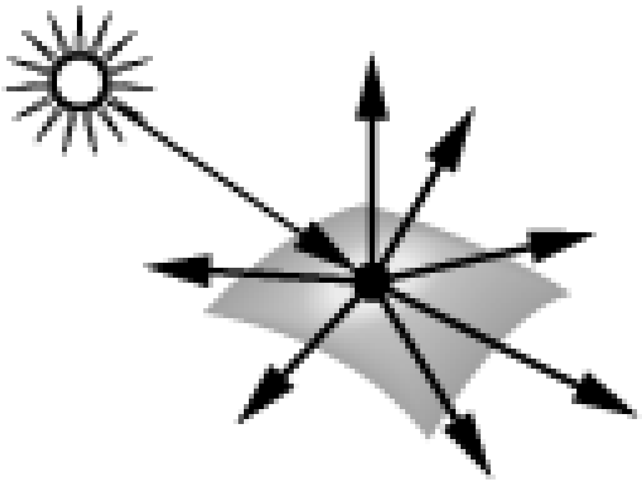
Surface Lighting Effects

- The amount of incident light reflected by a surface depends on the type of material
- Shiny materials reflect more of the incident light and dull surfaces absorb more of the incident light
- For transparent surfaces some of the light is also transmitted through the material

Diffuse Reflection

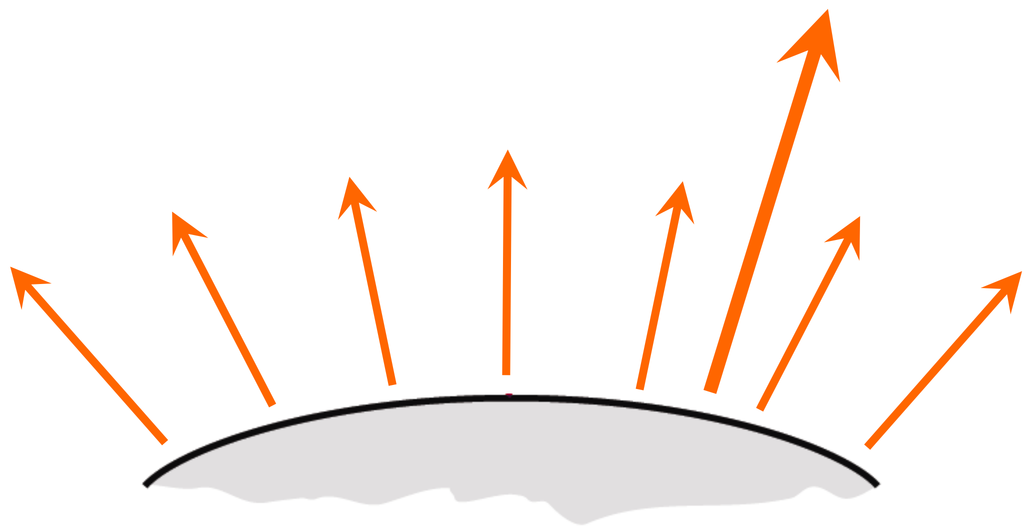
- Surfaces that are rough or grainy tend to reflect light in all directions
- This scattered light is called **diffuse reflection**

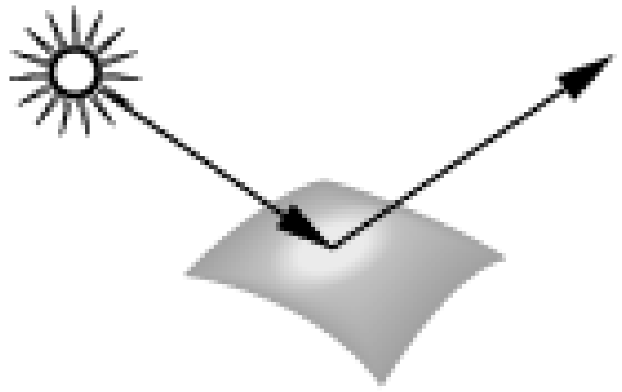




Specular Reflection

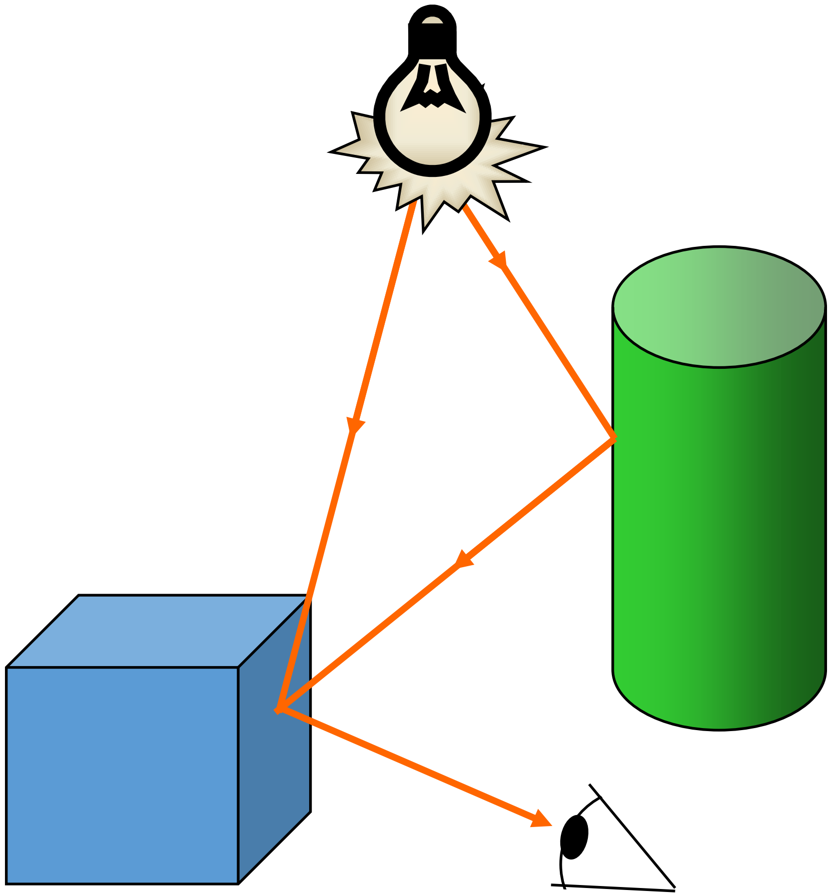
- Additionally to diffuse reflection some of the reflected light is concentrated into a highlight or bright spot
- This is called **specular reflection**



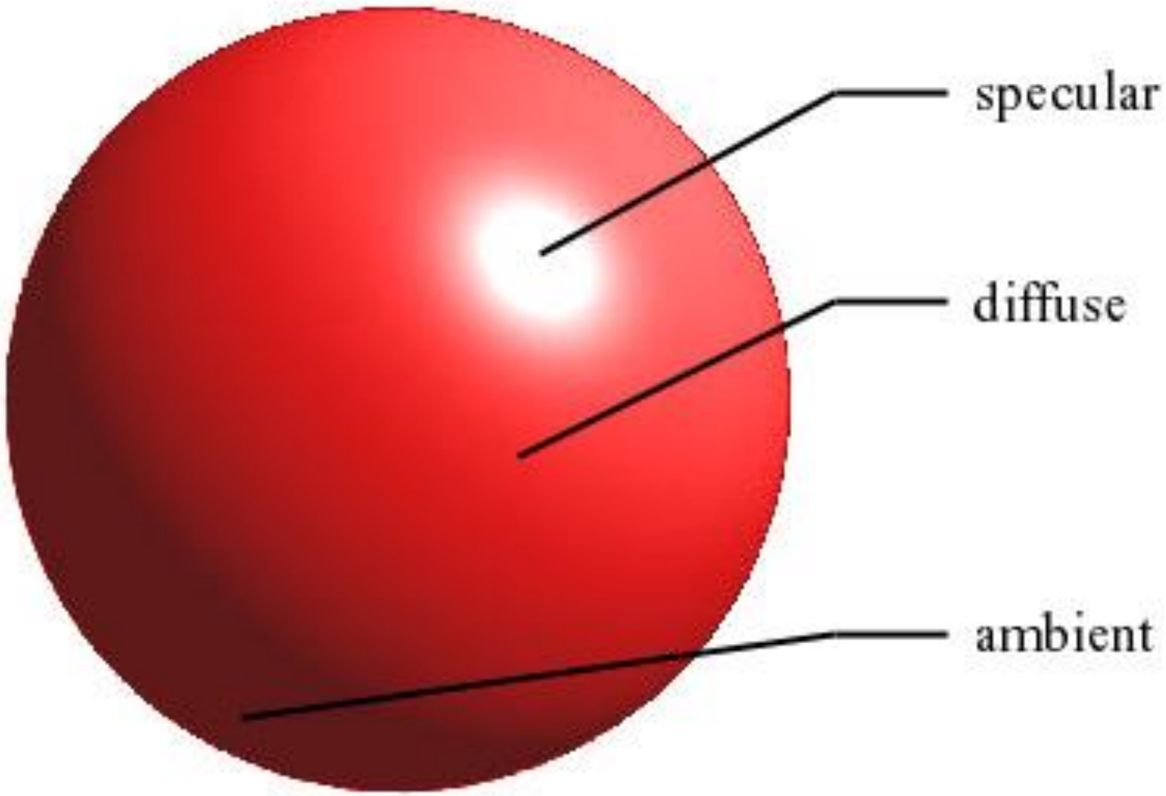


Ambient Light

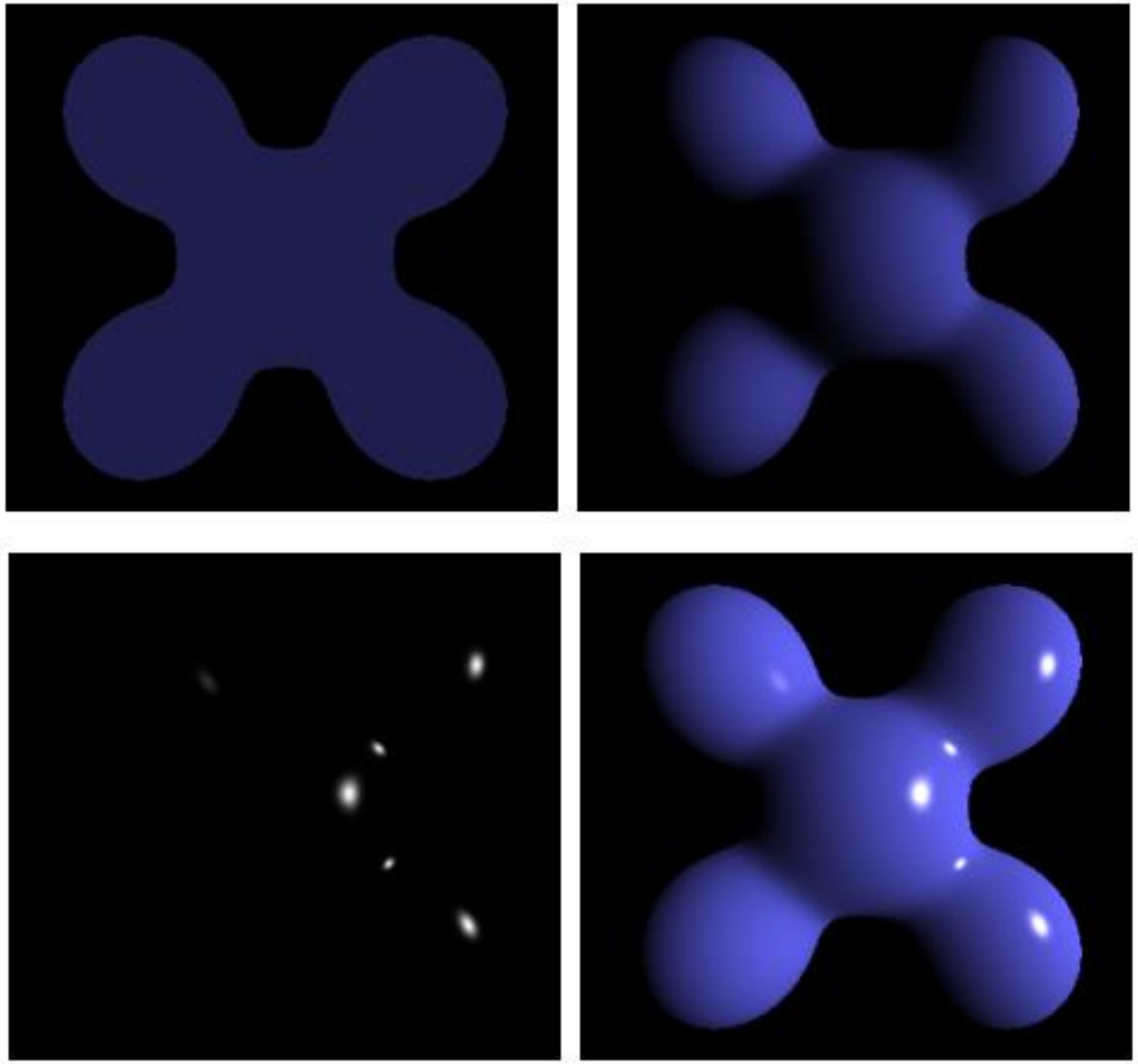
- A surface that is not exposed to direct light may still be lit up by reflections from other nearby objects – **ambient light**
- The total reflected light from a surface is the sum of the contributions from light sources and reflected light



Example



Example



Ambient

Diffuse

Specular

Final Image

Basic Illumination Model

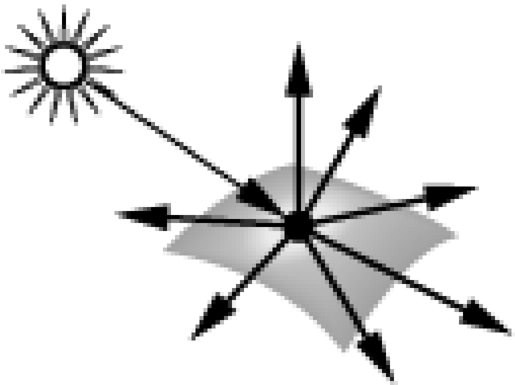
- We will consider a basic illumination model which gives reasonably good results and is used in most graphics systems
- The important components are:
  - Ambient light
  - Diffuse reflection
  - Specular reflection
- For the most part we will consider only monochromatic light

Diffuse Reflection

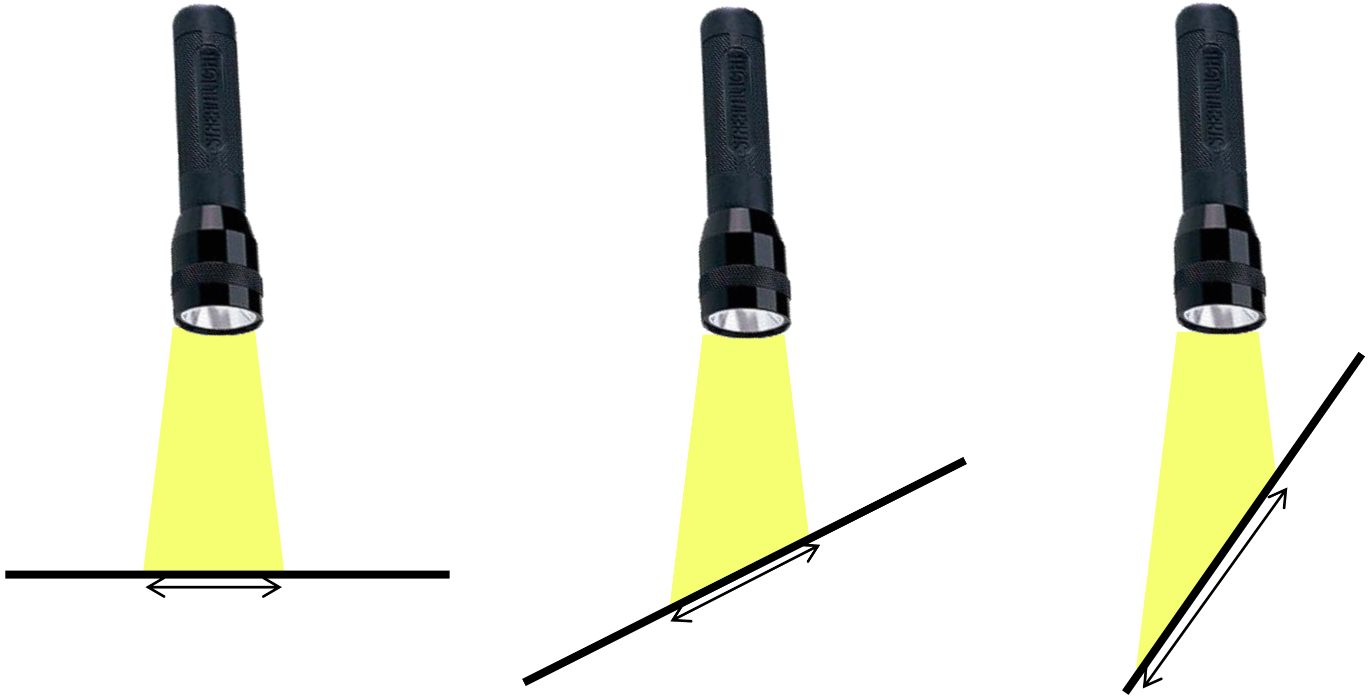
- On diffuse surfaces the light is reflected equally **in all directions**

- Light is reflected according to the law of **Lambert**

- The percentage of light reflected diffusely depends on the
  1. Diffuse-reflection coefficient $\mathbf{k_d}$
  2. Direction and intensity of the incoming light



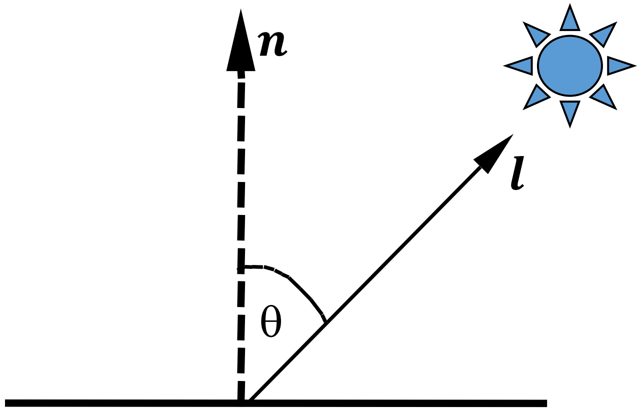
Diffuse reflection

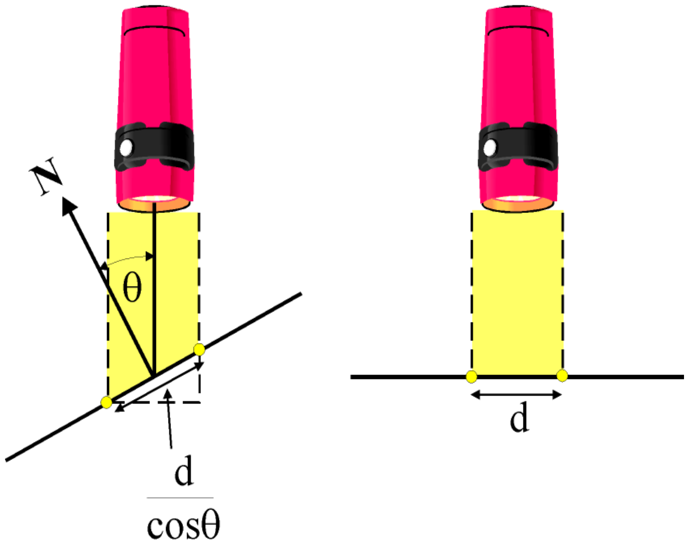


However, the intensity of light reflected **IS** dependent on light direction

Lambert’s cosine law

- Reflection is analogous to $\cos\theta$





- $\boldsymbol{l}$ is the direction of the light source
- $\boldsymbol{n}$ is the normal for a surface
- $\boldsymbol{I}$ is the intensity of the light source

$$\boldsymbol{I_r} = \boldsymbol{I k_d} \cos\theta$$

Lighting equation #1

- k_d depends on the wavelength

$$\boxed{I_r = I k_d (n.l)}$$

- Which is of course 3 equations, one for each of the RGB*

$$I_{r,red} = I_{red} k_{d,red} (\boldsymbol{n}.\boldsymbol{l})$$
$$I_{r,green} = I_{green} k_{d,green} (\boldsymbol{n}.\boldsymbol{l})$$
$$I_{r,blue} = I_{blue} k_{d,blue} (\boldsymbol{n}.\boldsymbol{l})$$

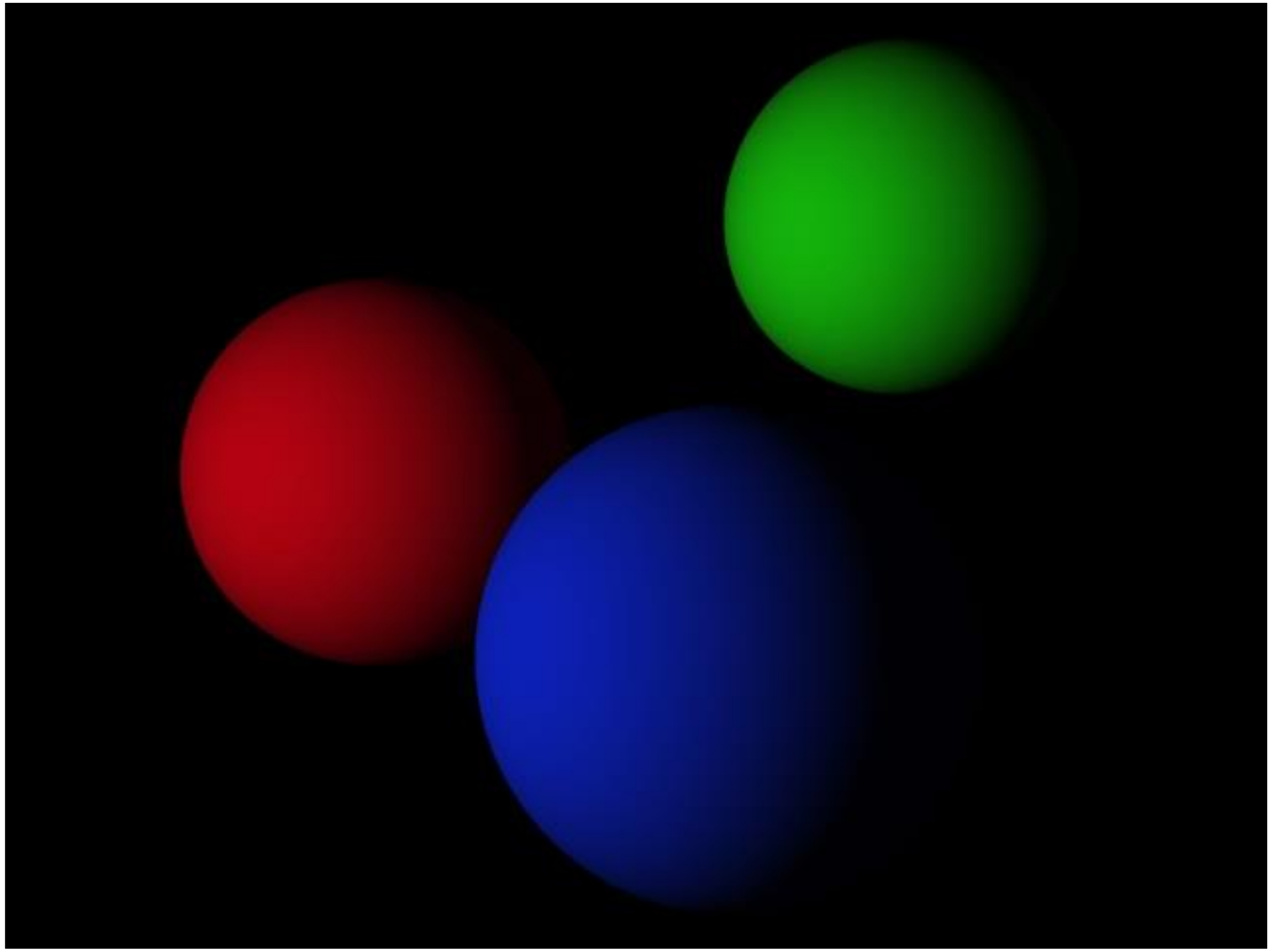
Multiple light sources

- We have diffused lighting from every source:

$$I_r = \sum_{j=1}^{p} I_j k_d (n.l_j)$$

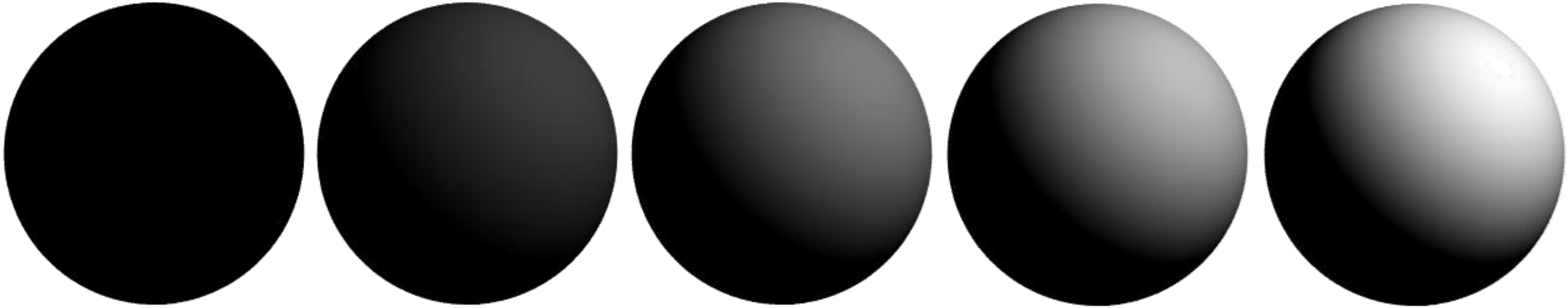
- The $\boldsymbol{I_j}$ is the incoming light from the source $\boldsymbol{j}$ (the intensity of the source j)
- The $\boldsymbol{l_j}$ is the vector to the source $\boldsymbol{j}$
- **p** is the number of light sources

The image – only diffuse



Diffuse reflection

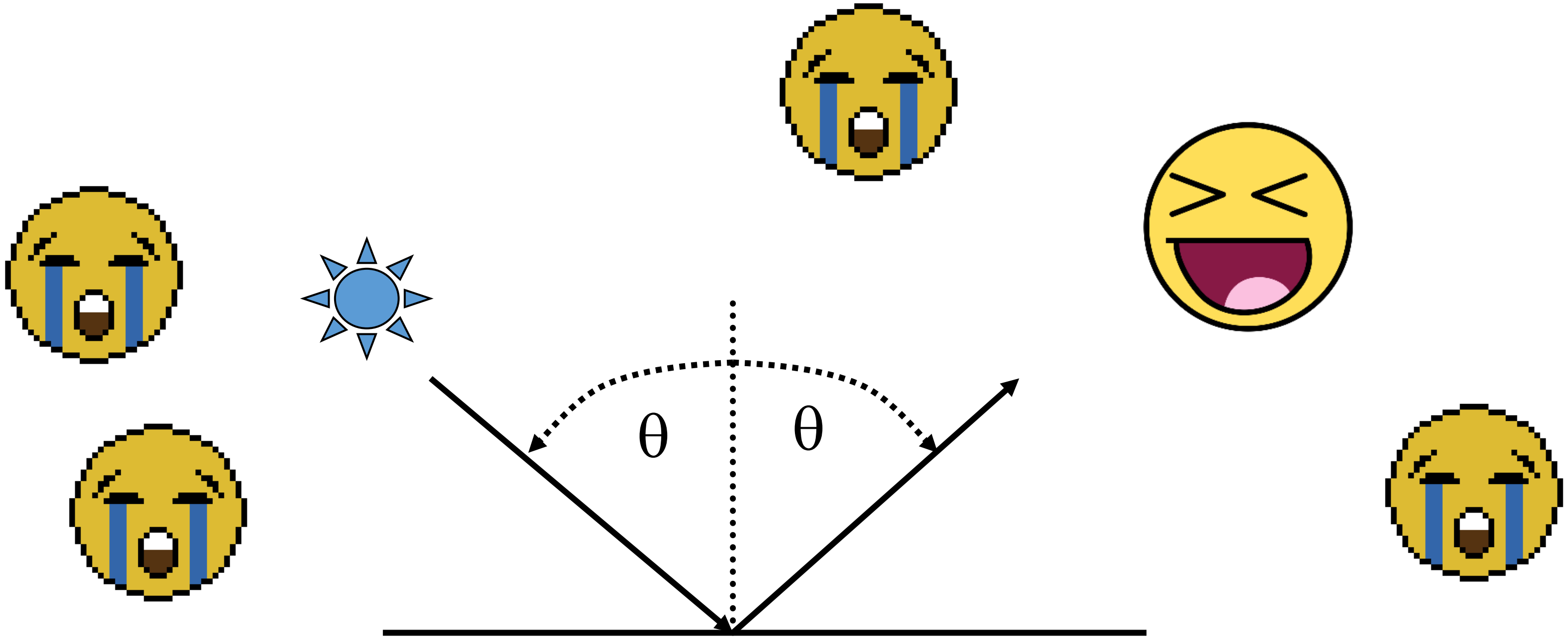
$k_d = 0.0$ $k_d = 0.25$ $k_d = 0.5$ $k_d = 0.75$ $k_d = 1.0$



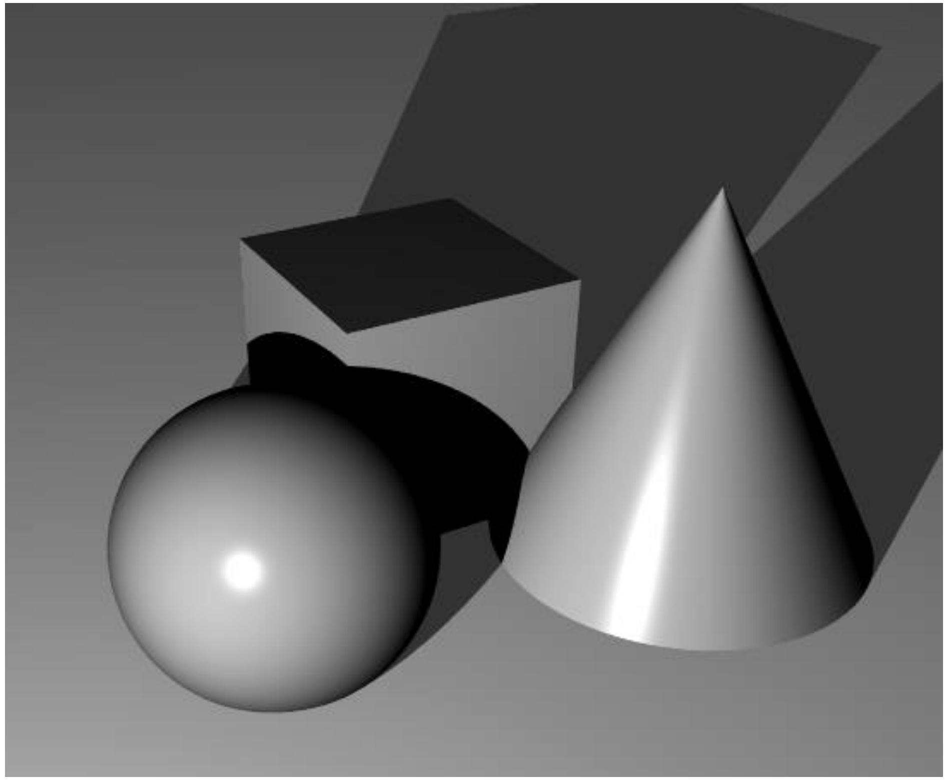
- The spheres above are lit by diffuse (k_d) values of 0.0, 0.25, 0.5, 0.75, 1 respectively

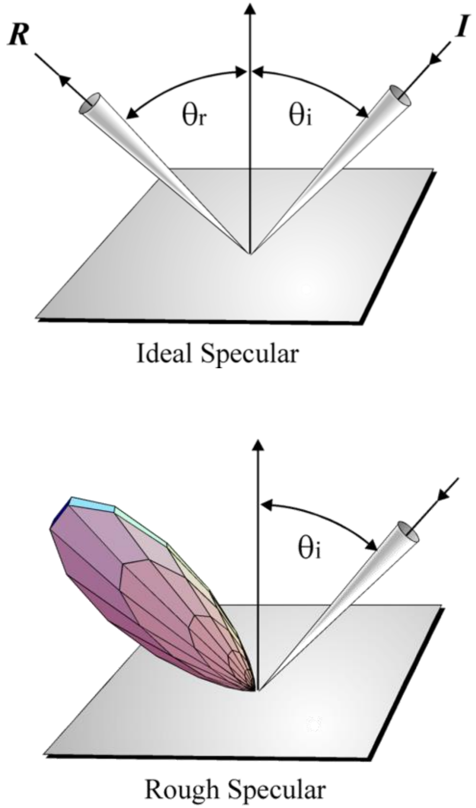
Perfect Specularity

- We would almost never see the highlight
-



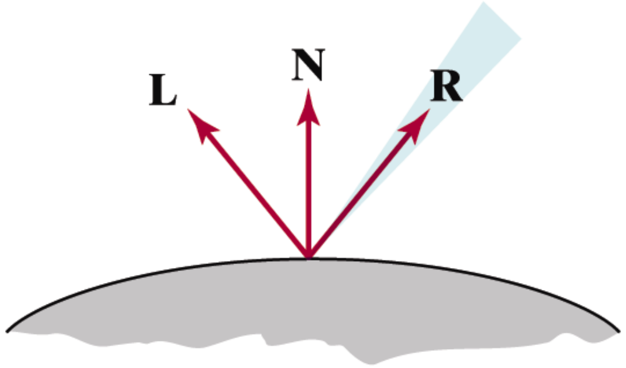
Specular Highlights



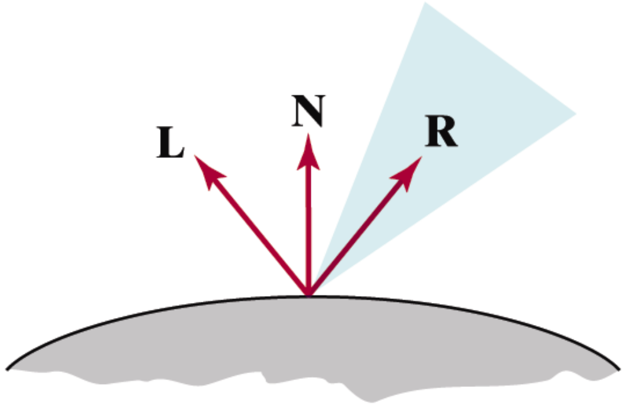


Specular Reflection

- A perfect mirror reflects light only in the specular-reflection direction
- Other objects exhibit specular reflections over a finite range of viewing positions around vector R



Shiny Surface
(Large m_s)

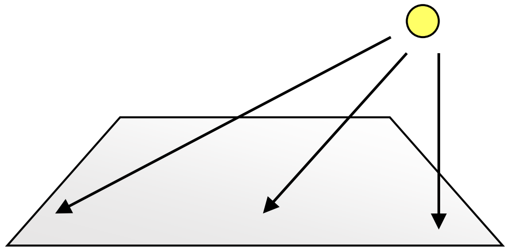


Dull Surface
(Small m_s)

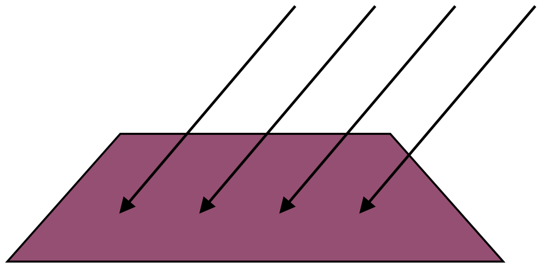
Phong Shading

Phong, B. T. (1975). Illumination for computer generated pictures. Communications of the ACM, 18(6), 311-317.

- Model Assumptions
  - A point (or directional) light source
    - Position defined by a point in space, radiating light equally in all directions
    - Repeat and accumulate results if we wish to model more than one light source
  - A viewer
    - Position defined by a point in space, the centre of projection or camera positions



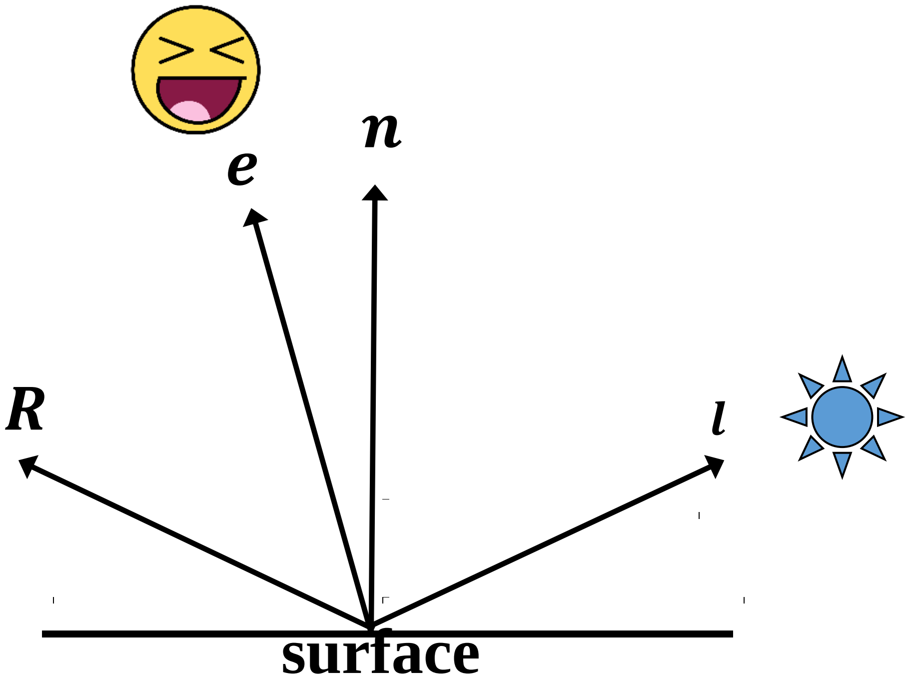
positional



directional

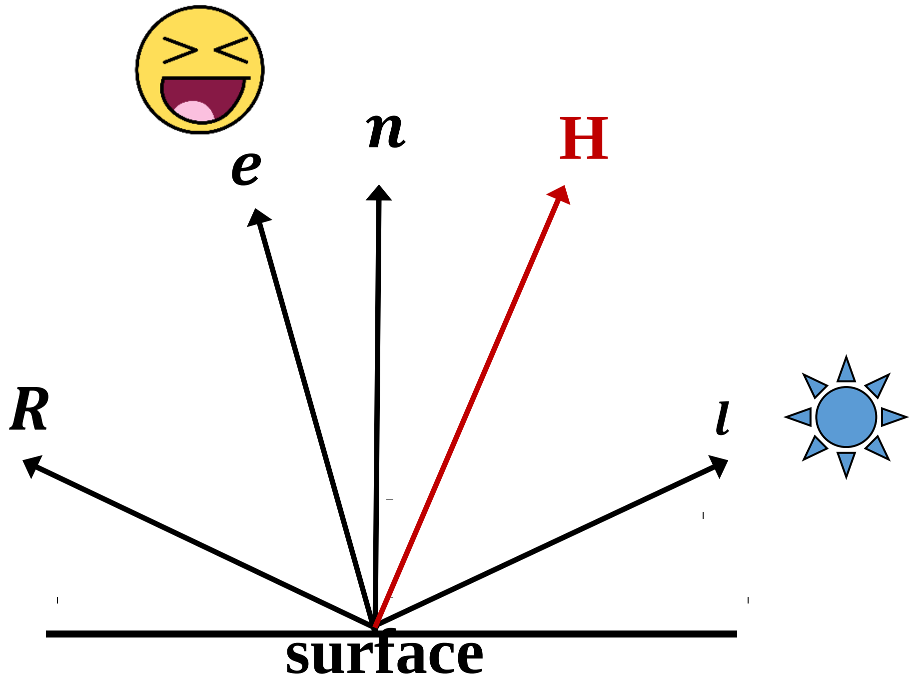
Imperfect Specularity

- $\boldsymbol{e}$ is the direction to the eye
- $\boldsymbol{n}$ is the normal of the surface
- $\boldsymbol{l}$ is the direction to the light source



Imperfect Specularity

- $\boldsymbol{e}$ is the direction to the eye
- $\boldsymbol{n}$ is the normal of the surface
- $\boldsymbol{l}$ is the direction to the light source
- **H** is the dichotomy of $\boldsymbol{e}$ and $\boldsymbol{l}$

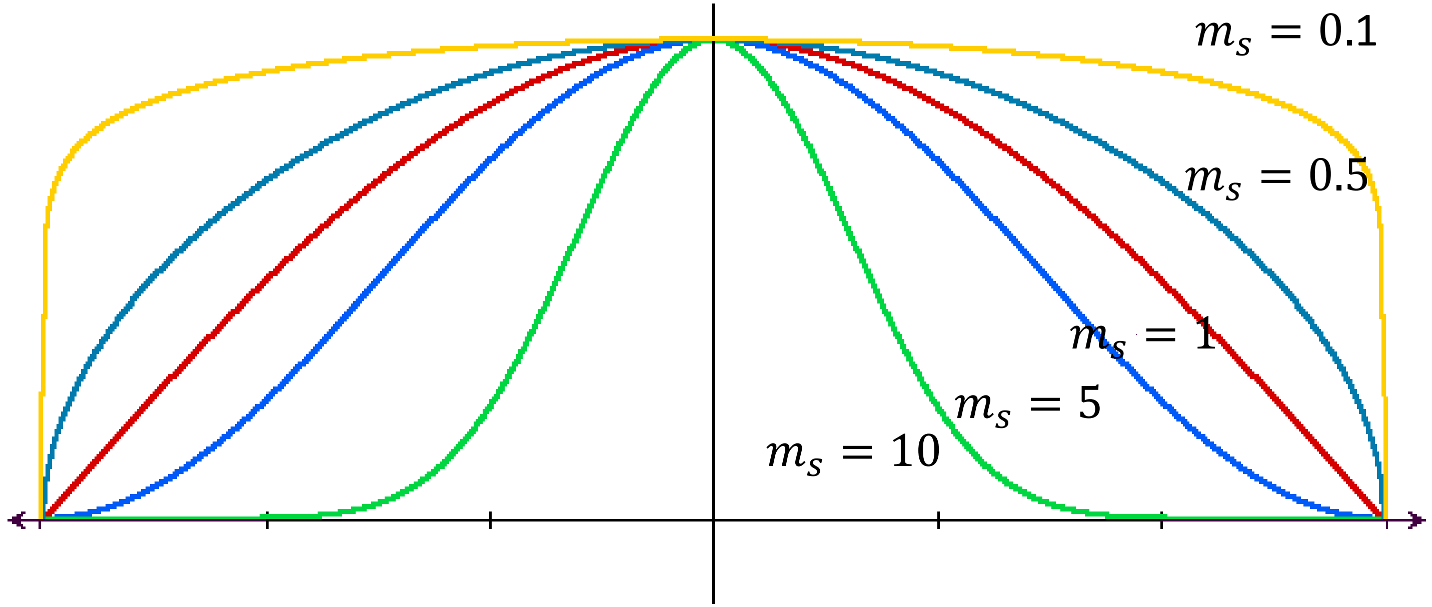


The Phong Specular Reflection Model

- So, the specular reflection intensity is proportional to $\cos^{m_s} \varphi$
- The angle φ can be varied between 0° and 90° so that cosφ varies from 1.0 to 0.0
- The **specular-reflection exponent**, m_s is determined by the type of surface we want to display
  - Shiny surfaces have a very large value (>100)
  - Rough surfaces would have a value near 1

Phong Lighting: The m_{shiny} Term

- The graphs below show the effect of m_s on the angular range in which we can expect to see specular reflections



What does this term mean, visually?

The Phong Specular Reflection Model

- For some materials the amount of specular reflection depends heavily on the angle of the incident light
- *Fresnel's Laws of Reflection* describe in great detail how specular reflections behave
- However, we don't need to worry about this and instead approximate the specular effects with a constant specular reflection coefficient k_s

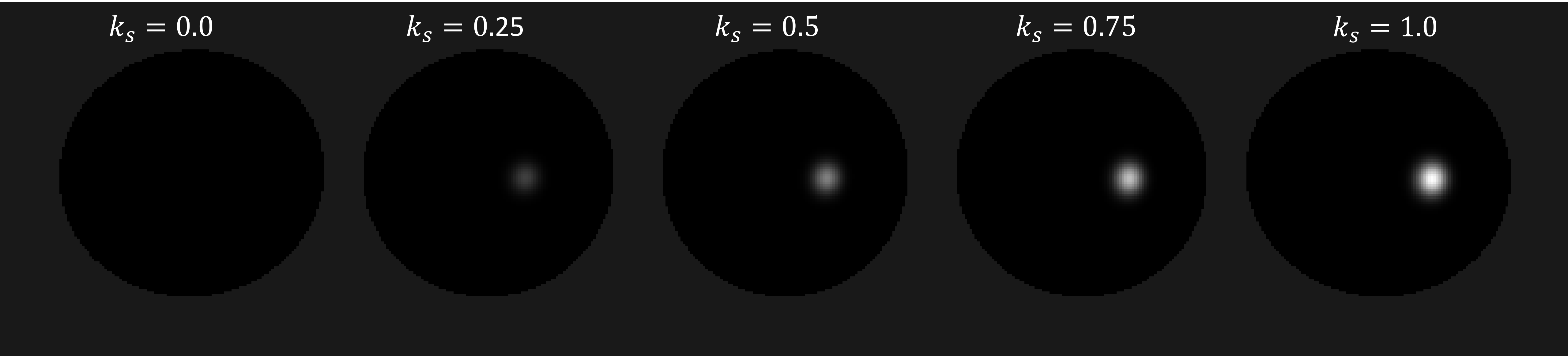
Specular Reflections

$$\boxed{I_s = Ik_s(h.n)^m}$$

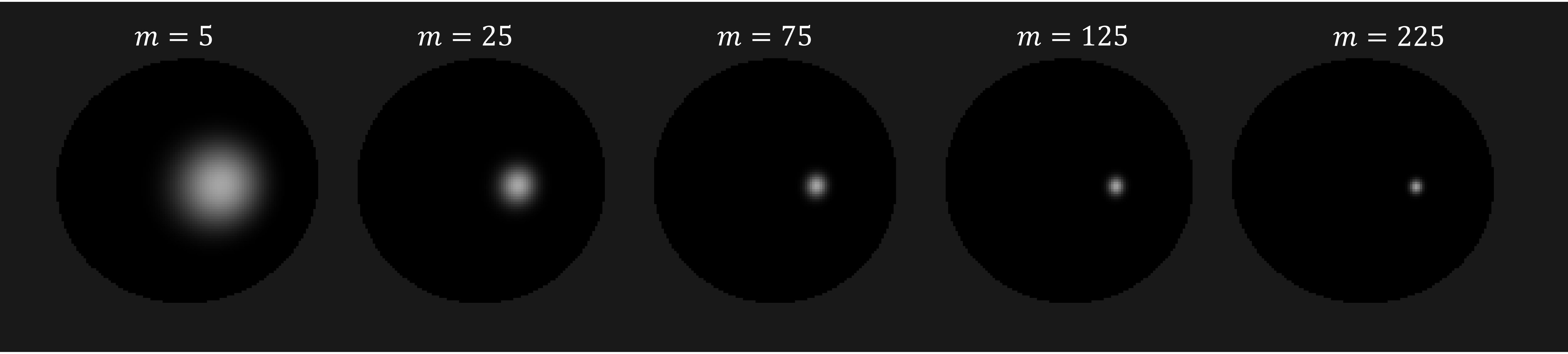
- where m is *shininess*
  - determines its characteristics highlight
    - High m implies highlight concentrated around the reflected
    - Small m makes the highlight wider and more hazy

Imperfect Specularity

specularity (k_s)



shininess (m) – For $k_s = 1.0$



Lighting equation #2

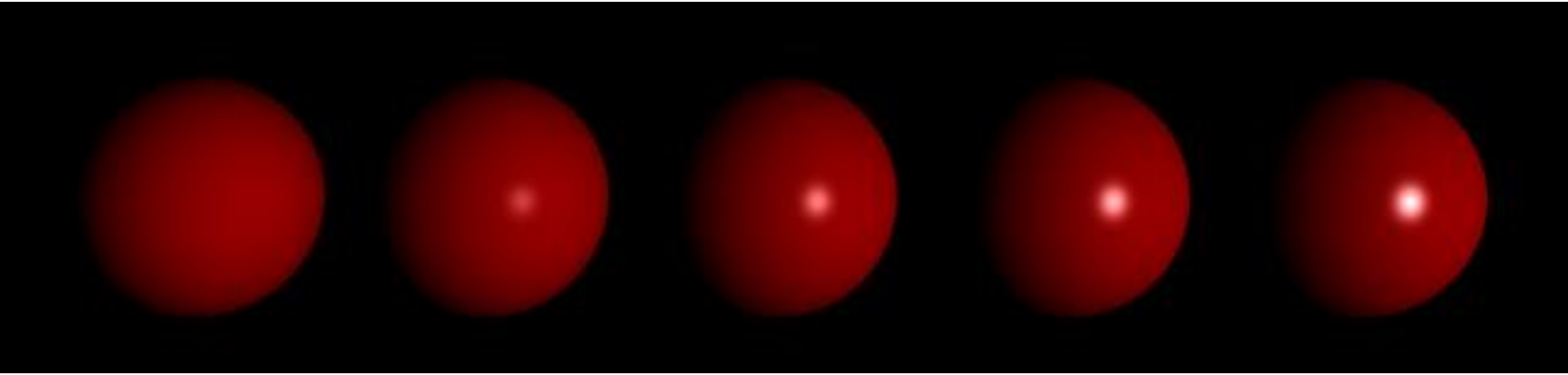
$$\boxed{I_r = I(k_d(n.l) + k_s(h.n)^m)}$$

- With 2 terms: diffused & specular
- Again, if we have more than one light source, add all the diffused and speculars from each source.

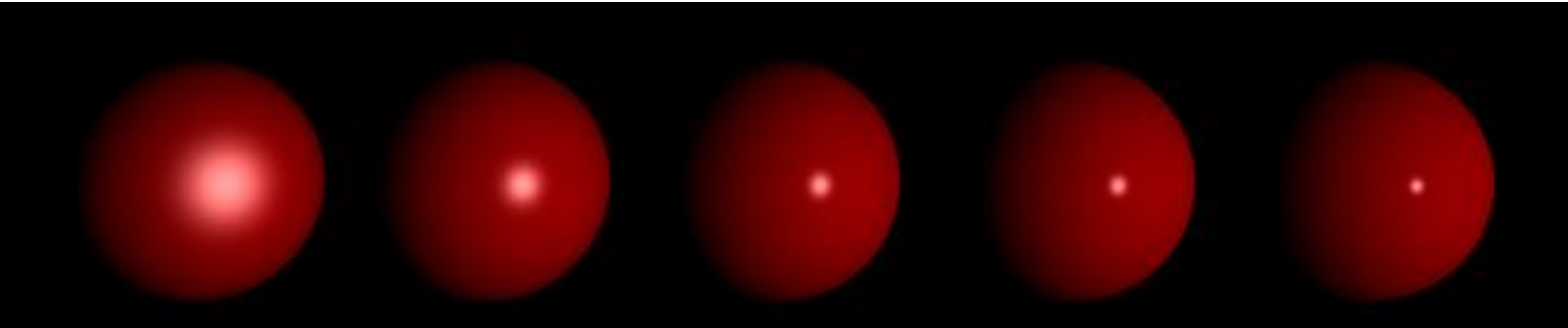
$$\boxed{I_r = \sum_{j=1}^{p} I_j \left(k_d(n.l_i) + k_s(h_j.n)^m\right)}$$

- If I_r give values > 1.0 then we will have to cut off, to stay within the limits of what our screen can show
- We use three values $k_{d,red}$ $k_{d,green}$ and $k_{d, blue}$

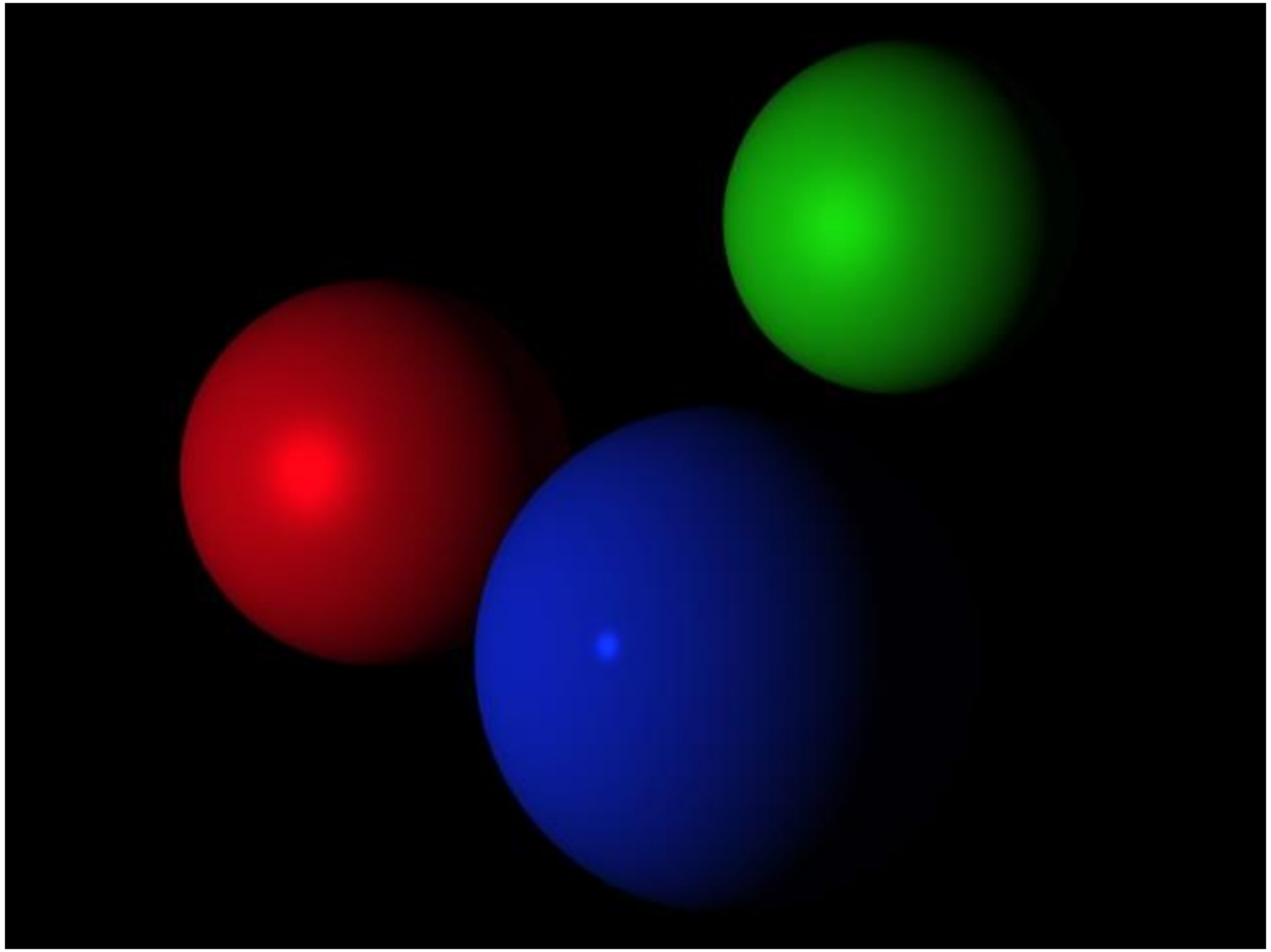
Imperfect Specularity



Combined with a constant diffuse red component



The image – diffuse and specular



$$I_r = I(k_d(n.l) + k_s(h.n)^m)$$

Έμμεσος φωτισμός (Ambient Light)

- Προσέγγιση του γενικού φωτισμού
  - Κάθε αντικείμενο φωτίζεται ως ένα βαθμό από “αδέσποτο” φως
  - Σταθερό (εξίσου) σε ολόκληρη την επιφάνεια κάθε αντικειμένου
- Συχνά χρησιμοποιείται απλά για να σιγουρευτούμε ότι όλα φωτίζονται, ακόμα και σε περίπτωση που δεν λαμβάνουν κατευθείαν φως από μια πηγή φωτός

Ambient Light

- Ambient lighting is usually defined the same for the entire scene
- Intensity of the ambient lighting
  - $I_a = [I_{a,red}, I_{a,green}, I_{a,blue}]$

- Each object reflects a percentage of that light
- Ambient-reflection coefficient
  - $k_a = [k_{a,red}, k_{a,green}, k_{a,blue}]$

Lighting equation #3

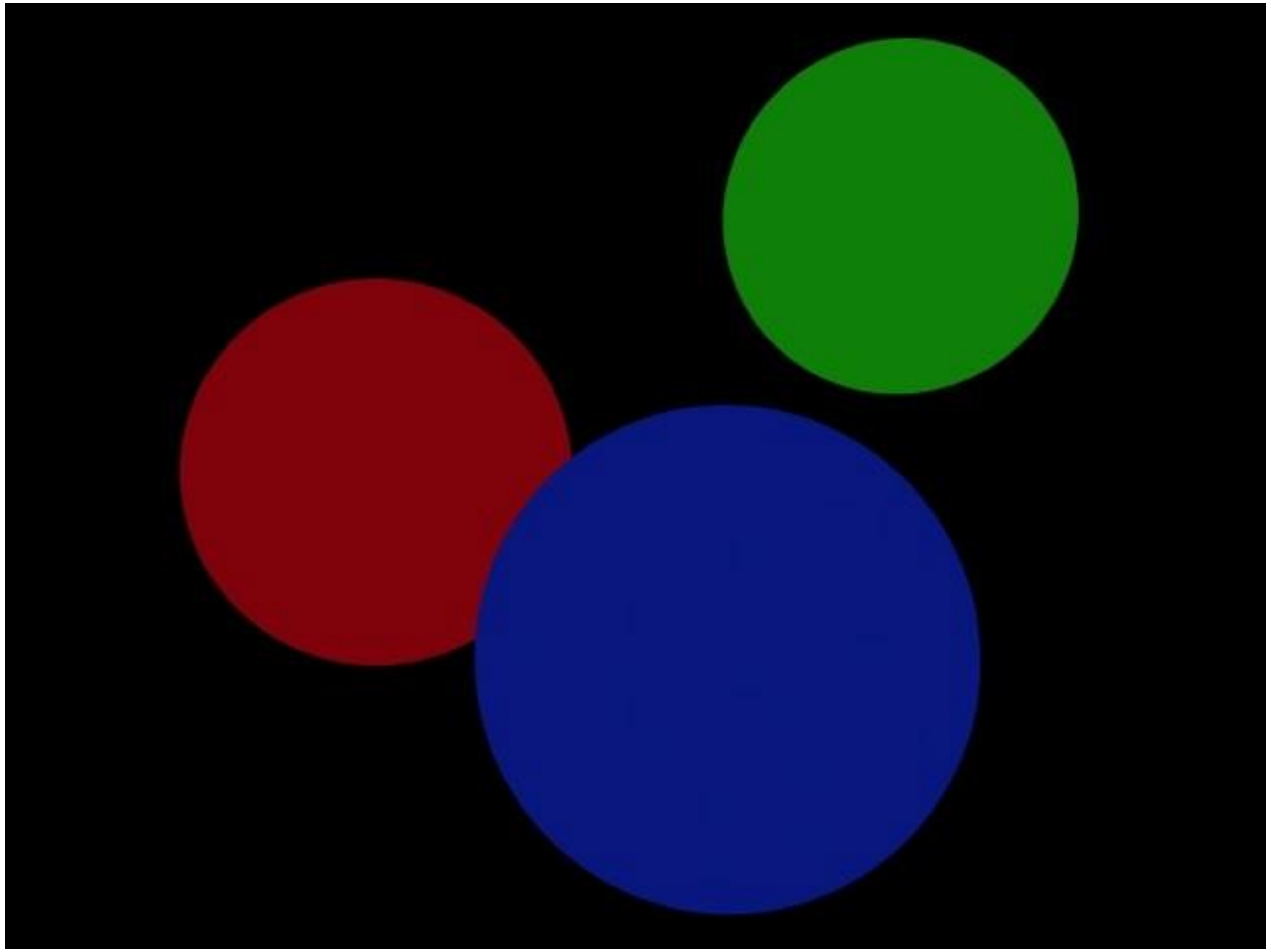
- So, so far we have:
-

$$\boxed{I_r = k_a I_a}$$

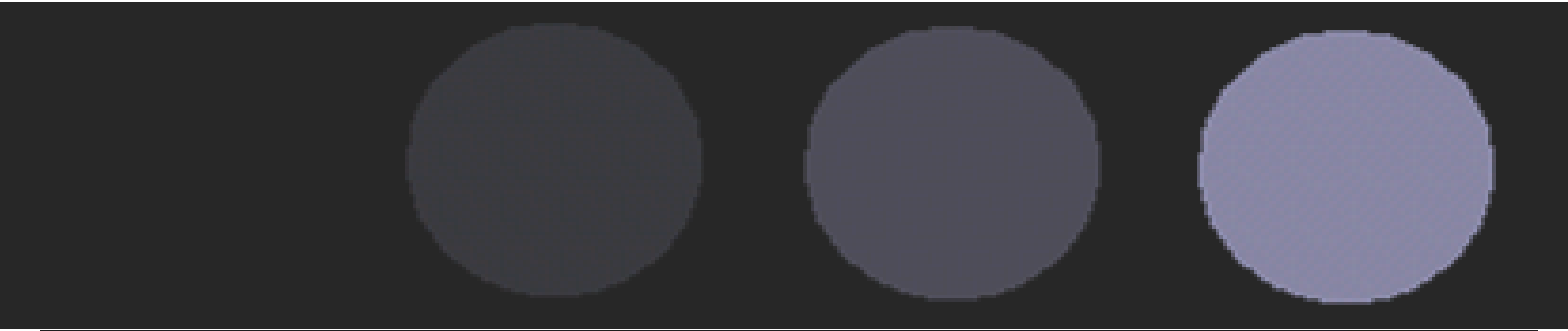
- Which is of course 3 equations, one for each of the RGB

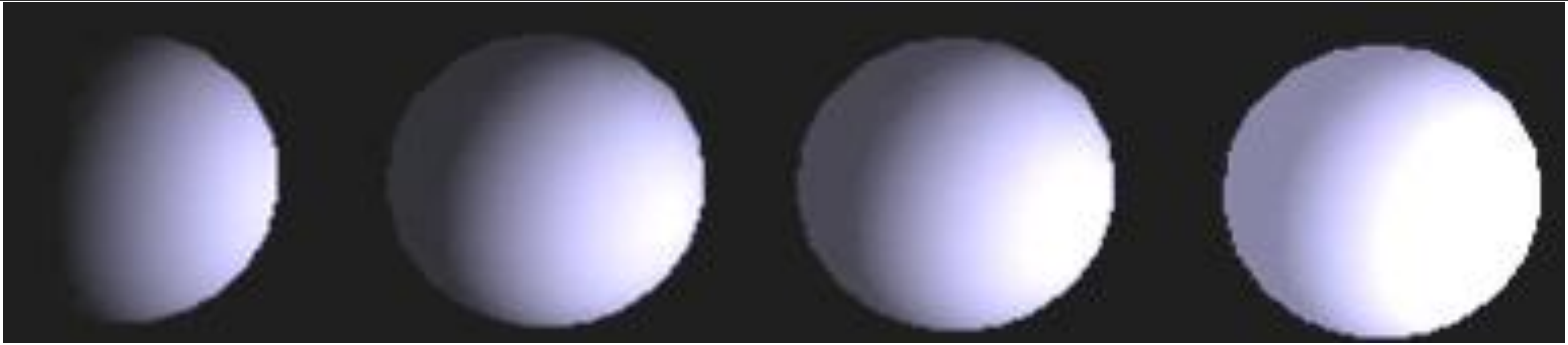
$$I_{r,red} = k_{a,red} I_{a,red}$$
$$I_{r,green} = k_{a,green} I_{a,green}$$
$$I_{r,blue} = k_{a,blue} I_{a,blue}$$

The image – only ambient



Ambient Light





Phong's lighting model

- The most common lighting model in real-time graphics.

- Lighting equation with 3 components: **Ambient, diffused & specular**

$$\boxed{I_r = k_a I_a + \sum_{j=1}^{p} I_j \left(k_d (n.l_i) + k_s (h_j.n)^m\right)}$$

- Each of the 3 elements of the equation could be used on its own, but with poor results

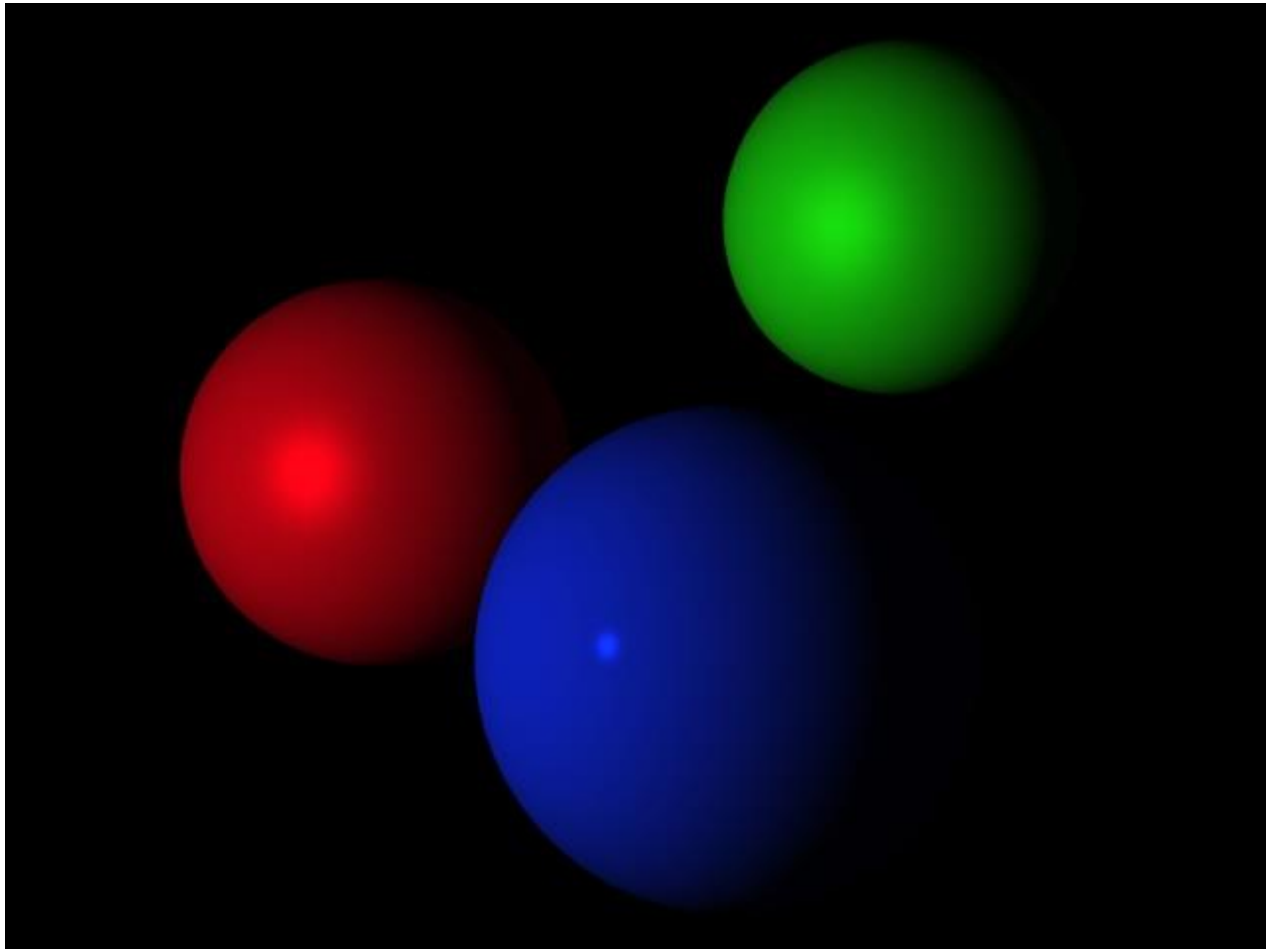
Phong's lighting model

$$
\boxed{
\begin{aligned}
I &= I_{amb} + \sum_{l=1}^{n} \left[I_{l,diff} + I_{l,spec} \right] \\
&= k_a I_a + \sum_{l=1}^{n} I_l \left[k_d (n \cdot l) + k_s (h \cdot n)^{m_s} \right]
\end{aligned}
}
$$

Common Exam Question

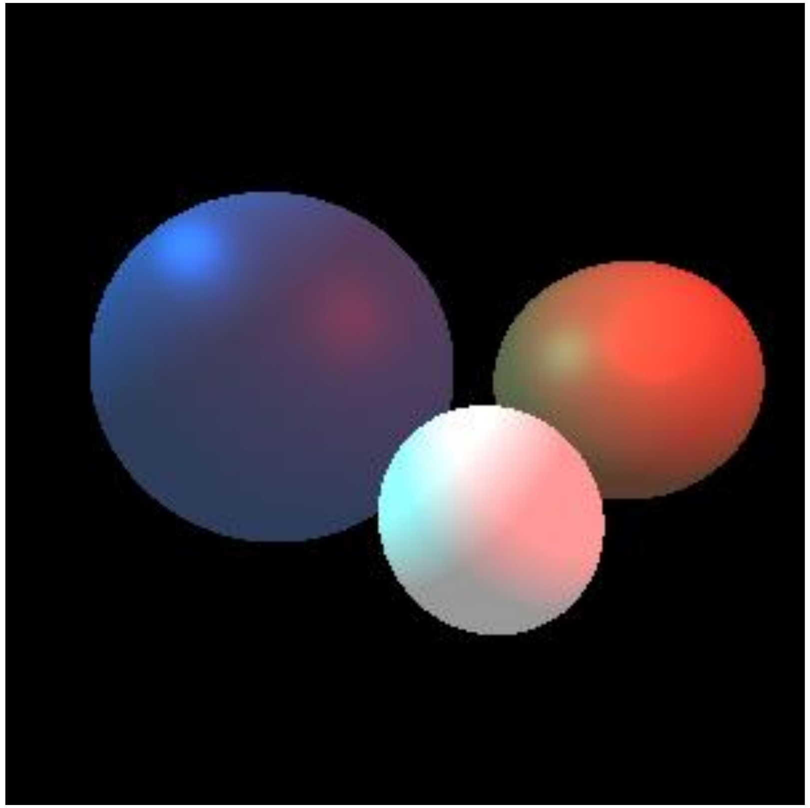
(ambient) (diffuse) (Specular)

The image – diffuse and specular



$$I_r = I(k_d(n.l) + k_s(h.n)^m)$$

+ ambient lighting and red source



$$I_r = k_a I_a + \sum_{j=1}^{p} I_j \left(k_d (n.\, l_i) + k_s (h_j.\, n)^m \right)$$

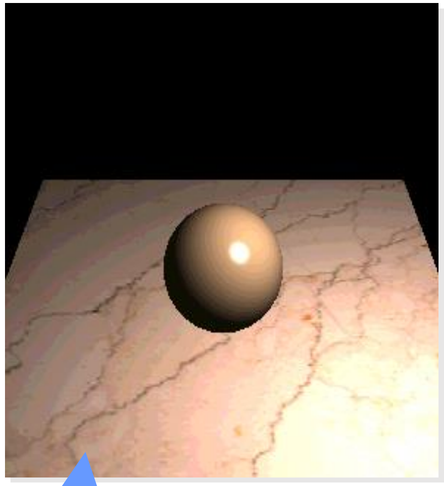
Προσθήκη εξασθένισης

- Μπορούμε να προσαρμόσουμε το μοντέλο φωτισμού μας για να συμπεριλάβει και την εξασθένιση (όπως είδαμε πιο πάνω)
- Οπότε έχουμε:

$$I = I_{ambdiff} + \sum_{l=1}^{n} \left[f_{l,radatten} f_{l,angatten} \left(I_{l,diff} + I_{l,spec} \right) \right]$$

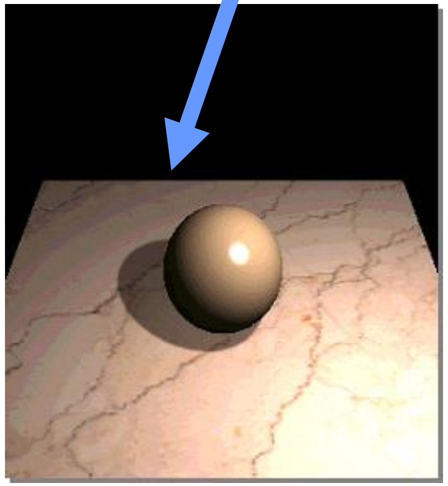
- Όπου $f_{radatten}$ και $f_{angatten}$ είναι η εξασθένιση απόστασης και γωνίας αντίστοιχα

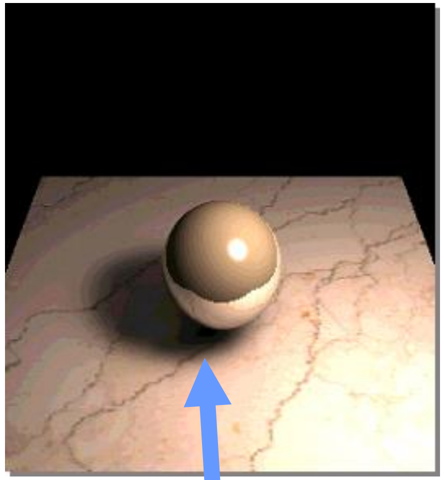
Further different types of rendering.



A bit of texturing enhances the scene considerably making it look more *"real-world-like"*

Fake shadow: gives a better idea of what the image represents (i.e. position of sphere is more apparent)

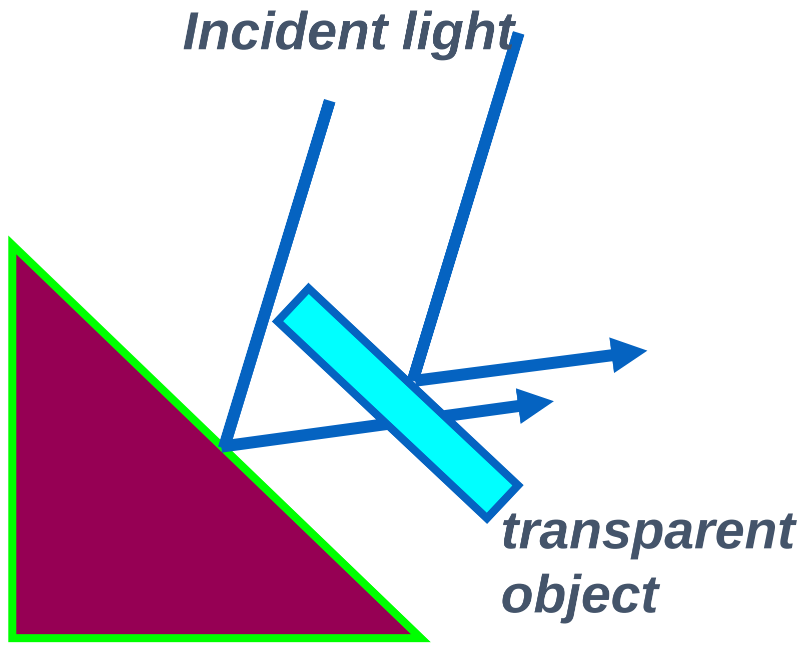




Global Illumination: *"proper"* shadows, specular reflections on objects

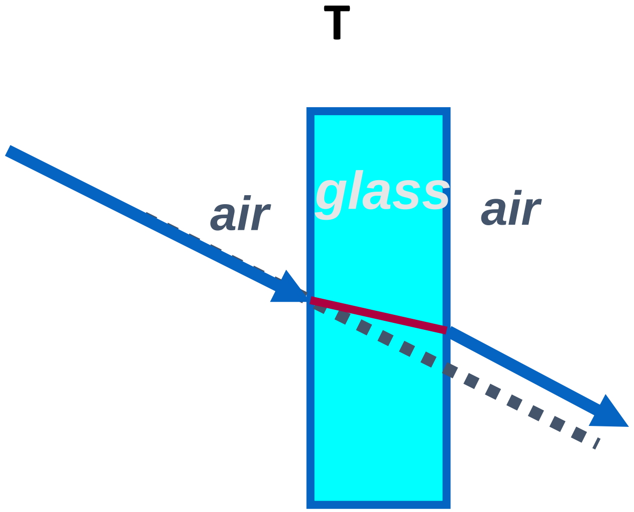
Transparency

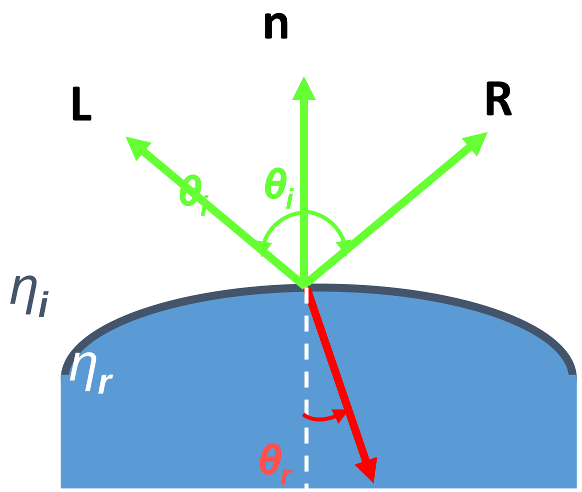
- A transparent surface reflects and refracts light.
- The contribution of the light emitted depends on the degree of transparency of the surface and whether there are light sources behind the transparent surface.



Transparency

- The realistic transparency effect is formed with it the laws of refractive.
- The overall effect of refractive is the displacement of the light-bearing in a parallel course.





Transparency

Snell's Law:

$$\sin\theta_r = \frac{\eta_i}{\eta_r}\sin\theta_i$$

$$\mathbf{T} = \left(\frac{\eta_i}{\eta_r}\cos\theta_i - \cos\theta_r\right)\mathbf{N} - \frac{\eta_i}{\eta_r}\mathbf{L}$$

- The T transmission vector can be used to detect the intersections of the refractive path of light behind the transparent surface

Transparency

- We can calculate the intensity of a refracted surface using an opacity coefficient (k_t). The total intensity is equal to the addition of the reflected and refracted intensity.

$$I = (1 - k_t) I_{reflected} + k_t I_{trans.}$$

- Where $1 - k_t$ is the opacity factor

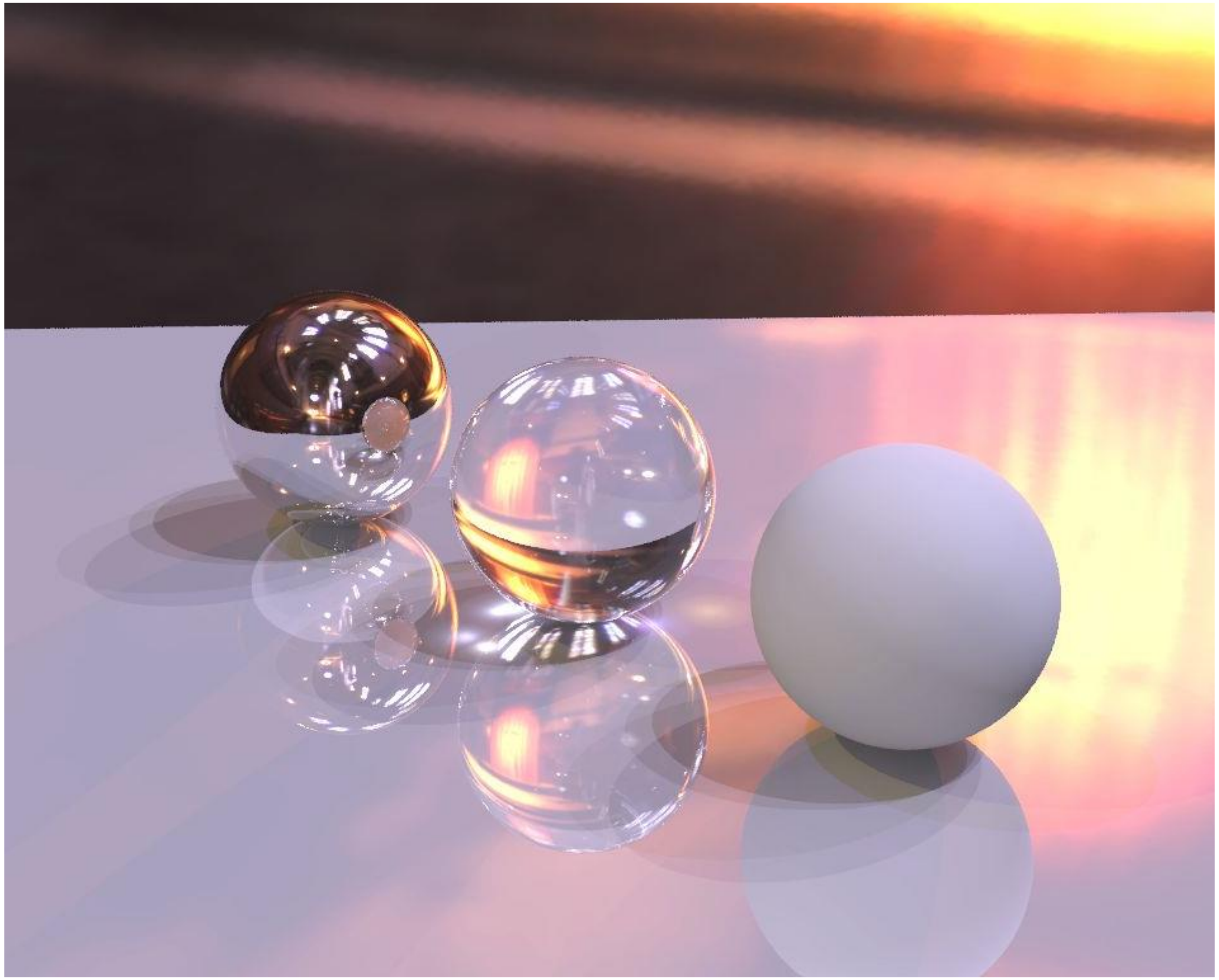
Illumination Models: Non-global vs. Global Models

http://resources.mpi-inf.mpg.de/atrium/gallery.html

Direct (diffuse + specular) lighting + indirect specular reflection

Full global illumination

Computing Illumination: Examples



Advanced Global Illumination Techniques

Real Time Global Illumination

Unreal Engine 4, Quixel Megascans

Rebirth

Volumetric fog and lighting. Models light/fog as a 3d transparent medium with discretized samples in a surrounding volume.

[Technology]
[Demo]
[Interview With 80 Level]

Voxel Global Illumination (VXGI)

Maxwell Renderer

Break scene into voxels using an algorithm similar to an octree. Rather than using original geometry, voxel approximation can be used to efficiently calculate ambient occlusion and interreflections.

[Technology]

[Demo]

Advanced Global Illumination Techniques

Ray Bundling

Hyperion Renderer
Moana

At each step of path tracing, bundle similar rays into groups and treat them as a wave of rays. This reduces the computation of each step, and allows for more iterations, creating better illuminated scenes.

[Technology Explanation]

Advanced Global Illumination Techniques

Ray tracing / Path tracing (cont.)

Nvidia's RTX Platform

Pipeline designed around latest 20-series of graphics cards to target real time ray tracing.

Technology
Demo
Star Wars