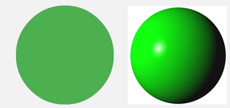
Lighting and Shading

Lights and Materials

We see what we see because light bounces off things in the world and into our eyes.

The interaction of light and surfaces is essential for –

- the perception of 3D in a 2D image



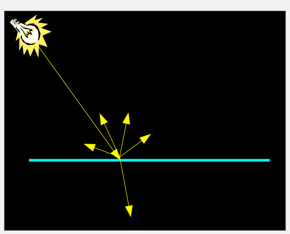
- realism

https://pixabay.com/illustrations/sphere-ball-plastic-round-3d-953964/
https://commons.wikimedia.org/wiki/File:Blender3D_MarbleExample1.jpg
https://www.maxpixel.net/Wood-Toy-Earth-Blue-Ball-Plastic-Green-587688
https://www.publicdomainpictures.net/en/view-image.php?image=80376&picture=plastic-easter-eggs
https://en.wikipedia.org/wiki/File:Glass_Float_Small.JPG

A Bit About Light

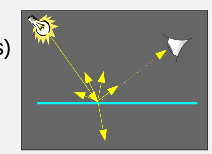
when light strikes a surface…

- some energy is absorbed (and is converted to heat)
- some is transmitted (if not opaque)
- the rest is reflected



A Bit About Light

light energy reaching viewer depends on…



(geometry)

- position and orientation of the light source(s)
- position and orientation of the eye
- position and orientation of the surface

(surface material)

- color of the surface
- reflectivity and transparency of the surface
- roughness of the surface

(light source)

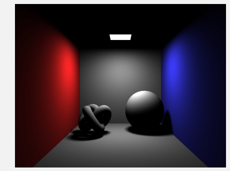
- color of light produced by the light source(s)
- polarization

Types of Lighting Models

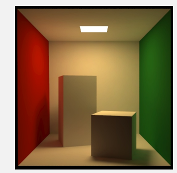
- a *lighting model* specifies how to determine the color (illumination) of a point in the scene

Types of Lighting Models

- non-global illumination models
  - concentrate on direct illumination
    - *direct illumination* comes directly from a light source
  - can't capture effects such as shadows, inter-object reflection, refraction, fog



- global illumination models
  - consider all light in the scene, including indirect illumination
    - *indirect illumination* is light which has first bounced off at least one other object



http://sunflow.sourceforge.net/index.php?pg=gall
https://commons.wikimedia.org/wiki/File:Cornell_box.png

Types of Lighting Models

- physically-based models
  - model the actual physical energy transfer in the scene
  - idea: if you use the same math as reality, it'll look good – right?
  - often very computationally intensive
- non-physically-based models
  - model the appearance rather than the physics

A Simple Lighting Model

- non-global illumination
  - but approximates global illumination
  - does not handle inter-object reflection
- not physically-based
- achromatic light
- two kinds of light sources
  - point light sources
  - ambient light
- model two kinds of reflection (direct illumination)
  - diffuse reflection
  - specular reflection
- no transparency
- no shadows

Lighting

light reaching viewer =

light produced by light source

$\times$

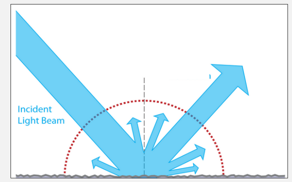
fraction of light reaching the surface

$\times$

fraction of light reflected in the direction of the viewer

Modeling Reflection

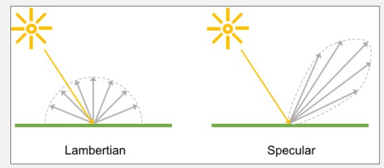
- …fraction of light reflected in the direction of the viewer…



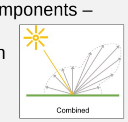
incident light can be reflected in any direction

what fraction is reflected in a particular direction is a property of the surface material

fully described by a *bidirectional reflectance distribution function* (BRDF)



our simple lighting model approximates the BRDF with the combination of two components – *diffuse* (Lambertian) and *specular* reflection



https://commons.wikimedia.org/wiki/File:BSDF05_800.png
https://github.com/tensorflow/graphics/blob/master/tensorflow_graphics/notebooks/reflectance.ipynb

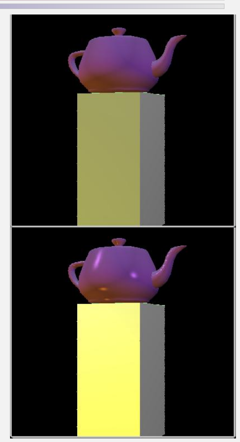
Modeling Reflection

diffuse (Lambertian) reflection

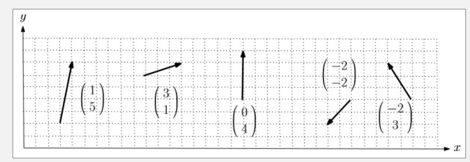
– typical of dull matte surfaces

specular reflection

– models bright highlights on shiny objects



Math – Vectors



$$v = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

the length of v $\quad |v| = \sqrt{x^2 + y^2 + z^2}$

a unit vector has length 1

make a vector length 1 by *normalizing* $\quad \frac{v}{|v|} = \begin{bmatrix} x/|v| \\ y/|v| \\ z/|v| \end{bmatrix}$

Math – Dot Products

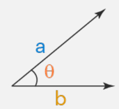
- the dot product of two vectors *a* and *b* is the sum of the products of each component

$$\mathbf{a}\cdot\mathbf{b} = \sum_{i=1}^{n} a_i b_i = a_1 b_1 + a_2 b_2 + \cdots + a_n b_n$$

- the value of the dot product is related to the angle between the vectors

$$\mathbf{a}\cdot\mathbf{b} = \|\mathbf{a}\|\,\|\mathbf{b}\|\cos\theta,$$

  - if *a* and *b* are unit vectors, a · b = cos θ



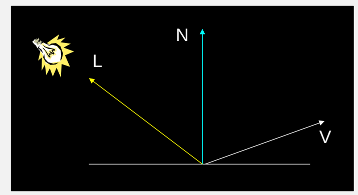
a . b = |a||b| cos θ

Mathematics of Reflection – Geometric Ingredients

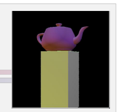
N – outward pointing surface normal
V – vector from point to viewer's eye
L – vector from point to the light source

surface normal is a vector perpendicular to the surface

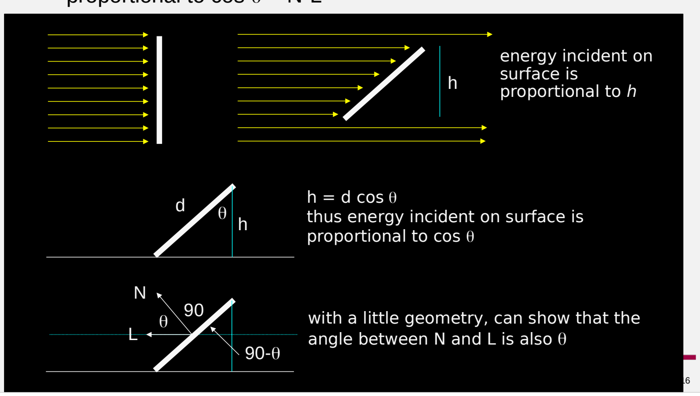
all are *unit vectors* (length 1)



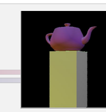
Mathematics of Diffuse Reflection



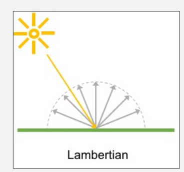
- energy incident on surface depends on the orientation of the surface with respect to the light
  - proportional to cos θ = N·L

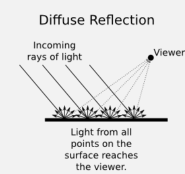


Mathematics of Diffuse Reflection

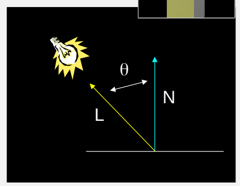


- light is reflected equally in all directions
  - viewer position doesn't matter



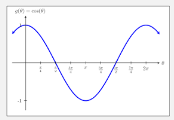


Mathematics of Diffuse Reflection



- energy incident on surface is proportional to cos θ = N·L
- same energy reflected in all directions

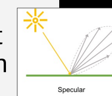
$$I_{diffuse} = f\, I_s\, md\, (L \cdot N)$$

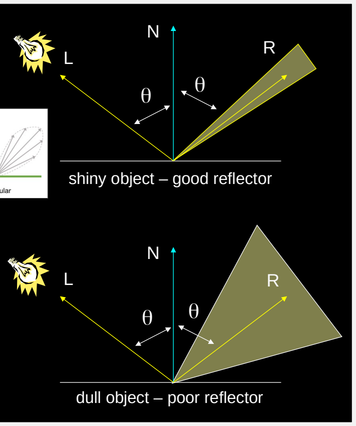


- f = 0 if V·N < 0 or L·N < 0, 1 otherwise
- I_s = intensity of light source
- md = diffuse reflection coefficient (0 ≤ md ≤ 1)
- N = outward surface normal
- L = vector towards light source

Mathematics of Phong Specular Reflection

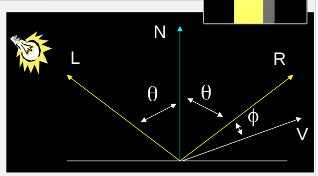
- perfect specular reflector reflects light (only) at same angle θ as incident light
- other surfaces reflect light in small region around perfect reflection direction R
- viewer only sees reflected light if V is within cone of reflection
- performs well for plastic, less well for metal





Mathematics of Phong Specular Reflection

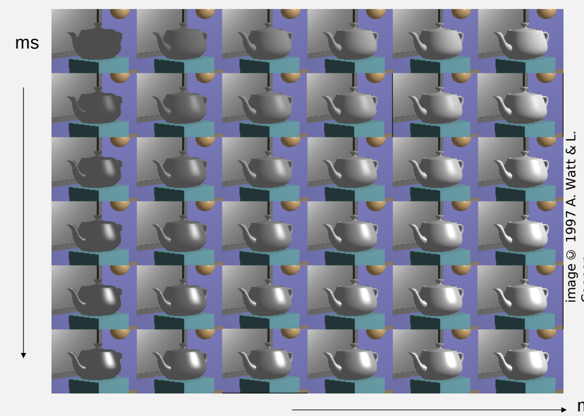
- reflected energy drops off quickly as angle increases from R
  - proportional to $\cos^{mh} \phi = (V \cdot R)^{mh}$
    - mh = specular reflection exponent (*shininess*)



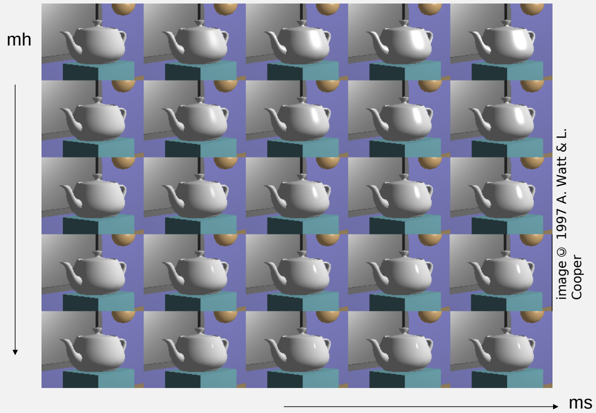
$$I_{specular} = f\, I_s\, ms\, (R \cdot V)^{mh}$$

- f = 0 if R·V < 0 or V·N < 0 or L·N < 0, 1 otherwise
- ms = specular reflection coefficient (0 ≤ ms ≤ 1)
- I_s = intensity of light source
- mh = specular reflection exponent (shininess) (mh ≥ 1)
  - near 1 for rough surfaces, 100+ for very shiny surfaces
- V = vector in direction of viewer
- R = vector in direction of perfect reflection

Specular vs. Diffuse Reflection



Specular Reflection Exp & Coeff



Notes

- constant diffuse reflection coefficient md is an approximation
  - actually depends on light color, incident angle, surface properties
- constant specular reflection coefficient ms is an approximation
  - actually depends on light color, incident angle, surface properties
  - for opaque materials, value is nearly constant for all angles
  - for transparent materials, value rises sharply to 1 for angles near 90 degrees

Ambient Light

- “background” light in scene
  - approximates indirect illumination

Mathematics of Ambient Light

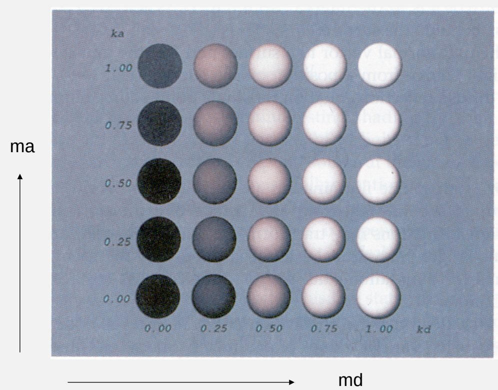
- has no (direct) source – comes from all directions
  - incident light energy is the same for all surfaces in all directions
- reflected uniformly in all directions (diffuse model)
  - independent of viewer position

$$I_{ambient} = ma\ I_a$$

I_a = intensity of ambient light “source”

ma = ambient reflection coefficient $(0 \le ma \le 1)$

Ambient vs. Diffuse Coefficients



Putting It All Together

term	energy leaving light source	fraction of energy received at surface	fraction of energy leaving surface in direction of viewer	total
ambient light	I_a	1	ma	ma I_a
diffuse reflection	I_s	max(0, N·L)	md 0 if V·N < 0	md I_s max(0,N·L) 0 if V·N < 0
specular reflection	I_s	1 0 if L·N < 0	ms max(0, R·V)^{mh} 0 if V·N < 0	ms I_s max(0,R·V)^{mh} 0 if V·N < 0 or L·N < 0

$$I = ma\, I_a + \sum_{all\, lights} \left[md\, I_s max(0, (N \cdot L)) + ms\, I_s max(0, (R \cdot V))^{mh} \right]$$

Putting It All Together

- factors based on geometry of scene
  - N, L, V
  - R
- factors based on the surface material
  - ma, md, ms, mh
- factors based on the light source
  - I_a, I_s

$$I = ma\, I_a + \sum_{all\, lights} \left[md\, I_s max(0, (N \cdot L)) + ms\, I_s max(0, (R \cdot V))^{mh} \right]$$