University of British Columbia
CPSC 314 Computer Graphics
Jan-Apr 2008

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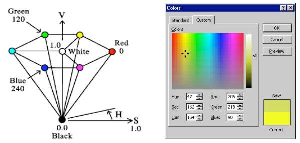
## Lighting/Shading II

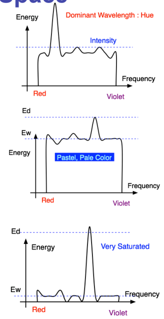
## Week 7, Wed Feb 27

http://www.ugrad.cs.ubc.ca/~cs314/Vjan2008

## Review: HSV Color Space

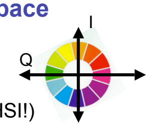
- hue: dominant wavelength, “color”
- saturation: how far from grey
- value/brightness: how far from black/white
- cannot convert to RGB with matrix alone
- true luminance information not available




## Review: YIQ Color Space

- color model used for color TV
  - Y is luminance (same as CIE)
  - I & Q are color (not same I as HSI!)
  - using Y backwards compatible for B/W TVs
  - conversion from RGB is linear




$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.30 & 0.59 & 0.11 \\ 0.60 & -0.28 & -0.32 \\ 0.21 & -0.52 & 0.31 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- green is much lighter than red, and red lighter than blue

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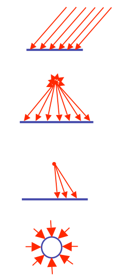
## Review: Light Sources

- directional/parallel lights
  - point at infinity: $(x,y,z,0)^T$
- point lights
  - finite position: $(x,y,z,1)^T$
- spotlights
  - position, direction, angle
- ambient lights



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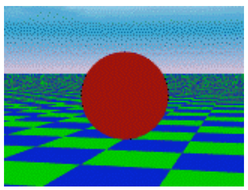
## Ambient Light Sources

- scene lit only with an ambient light source



Light Position Not Important

Viewer Position Not Important

Surface Angle Not Important

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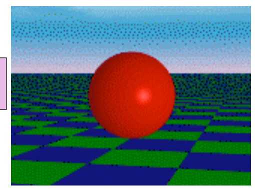
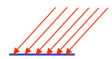
## Directional Light Sources

- scene lit with ambient and directional light

Surface Angle Important





Light Position Not Important

Viewer Position Not Important

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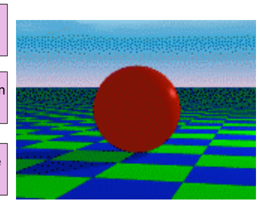
## Point Light Sources

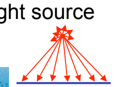
- scene lit with ambient and point light source

Light Position Important

Viewer Position Important

Surface Angle Important





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## Light Sources

- geometry: positions and directions
  - coordinate system used depends on when you specify
  - standard: world coordinate system
    - effect: lights fixed wrt world geometry
    - demo: http://www.xmission.com/~nate/tutors.html
  - alternative: camera coordinate system
    - effect: lights attached to camera (car headlights)
  - points and directions undergo normal model/view transformation
- illumination calculations: camera coords

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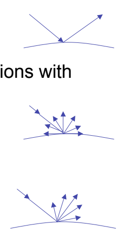
## Types of Reflection

- *specular* (a.k.a. *mirror* or *regular*) reflection causes light to propagate without scattering.
- *diffuse* reflection sends light in all directions with equal energy.
- *glossy/mixed* reflection is a weighted combination of specular and diffuse.



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## Specular Highlights

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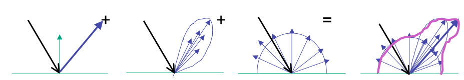
## Reflectance Distribution Model

- most surfaces exhibit complex reflectances
  - vary with incident and reflected directions.
  - model with combination




specular + glossy + diffuse = reflectance distribution

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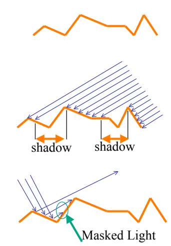
## Surface Roughness

- at a microscopic scale, all real surfaces are rough
- cast shadows on themselves
- “mask” reflected light:

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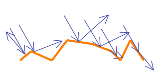
## Surface Roughness



- notice another effect of roughness:
  - each “microfacet” is treated as a perfect mirror.
  - incident light reflected in different directions by different facets.
  - end result is mixed reflectance.
    - smoother surfaces are more specular or glossy.
    - random distribution of facet normals results in diffuse reflectance.

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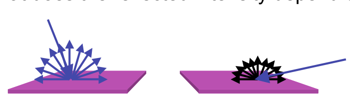
## Physics of Diffuse Reflection

- ideal diffuse reflection
  - very rough surface at the microscopic level
    - real-world example: chalk
  - microscopic variations mean incoming ray of light equally likely to be reflected in any direction over the hemisphere
  - what does the reflected intensity depend on?



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## Lambert’s Cosine Law

- ideal diffuse surface reflection

  the energy reflected by a small portion of a surface from a light source in a given direction is proportional to the cosine of the angle between that direction and the surface normal
- reflected intensity
  - independent of viewing direction
  - depends on surface orientation wrt light
- often called Lambertian surfaces

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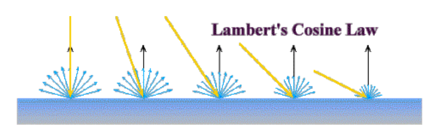
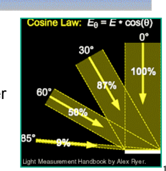
## Lambert’s Law




intuitively: cross-sectional area of the “beam” intersecting an element of surface area is smaller for greater angles with the normal.

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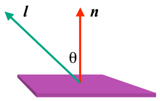
## Computing Diffuse Reflection

- depends on angle of incidence: angle between surface normal and incoming light
  - $I_{diffuse} = k_d I_{light} \cos\theta$
- in practice use vector arithmetic
  - $I_{diffuse} = k_d I_{light} (\mathbf{n} \bullet \mathbf{l})$




- **always normalize vectors used in lighting!!!**
  - **n**, **l** should be unit vectors
- scalar (B/W intensity) or 3-tuple or 4-tuple (color)
  - $k_d$: diffuse coefficient, surface color
  - $I_{light}$: incoming light intensity
  - $I_{diffuse}$: outgoing light intensity (for diffuse reflection)



## Diffuse Lighting Examples

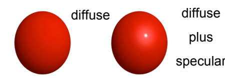
- Lambertian sphere from several lighting angles:

- need only consider angles from 0° to 90°
  - *why?*
  - *demo: Brown exploratory on reflection*
  - http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/reflection2D/reflection_2d_java_browser.html



## Specular Reflection

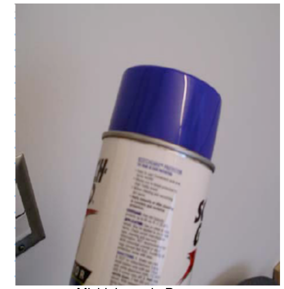
- shiny surfaces exhibit specular reflection
  - polished metal
  - glossy car finish




- specular highlight
  - bright spot from light shining on a specular surface
- view dependent
  - highlight position is function of the viewer's position



## Specular Highlights



Michiel van de Panne



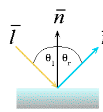
## Physics of Specular Reflection

- at the microscopic level a specular reflecting surface is very smooth
- thus rays of light are likely to bounce off the microgeometry in a mirror-like fashion
- the smoother the surface, the closer it becomes to a perfect mirror



## Optics of Reflection

- reflection follows *Snell's Law:*
  - incoming ray and reflected ray lie in a plane with the surface normal
  - angle the reflected ray forms with surface normal equals angle formed by incoming ray and surface normal

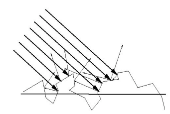



$$\theta_{(l)ight} = \theta_{(r)eflection}$$



## Non-Ideal Specular Reflectance

- Snell's law applies to perfect mirror-like surfaces, but aside from mirrors (and chrome) few surfaces exhibit perfect specularity
- how can we capture the "softer" reflections of surface that are glossy, not mirror-like?
- one option: model the microgeometry of the surface and explicitly bounce rays off of it
- or…





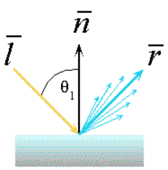
## Empirical Approximation

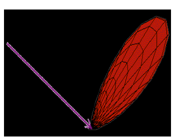
- we expect most reflected light to travel in direction predicted by Snell's Law
- but because of microscopic surface variations, some light may be reflected in a direction slightly off the ideal reflected ray
- as angle from ideal reflected ray increases, we expect less light to be reflected



## Empirical Approximation

- angular falloff



- how might we model this falloff?



## Phong Lighting

- most common lighting model in computer graphics
  - (Phong Bui-Tuong, 1975)

$$\mathbf{I}_{specular} = \mathbf{k}_s \mathbf{I}_{light} (\cos\phi)^{n_{shiny}}$$

- $n_{shiny}$ : purely empirical constant, varies rate of falloff
- $k_s$: specular coefficient, highlight color
- no physical basis, works ok in practice