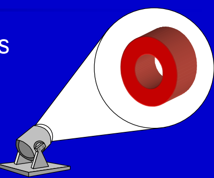
## Illumination

- Natural lighting effects
  - Surface characteristics
  - Shadows
  - Reflections
- Mathematical models
  - Used in computer graphics systems



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## Terminology

- Illumination (lighting) model
  - Calculating light intensity
  - At each point on a surface
- Surface rendering
  - Apply lighting model
  - Obtain pixel intensities of projected surface positions

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## Light Sources

- Light emitters
  - Point sources
  - Distributed sources
- Light reflectors
  - Diffuse reflection
  - Specular reflection

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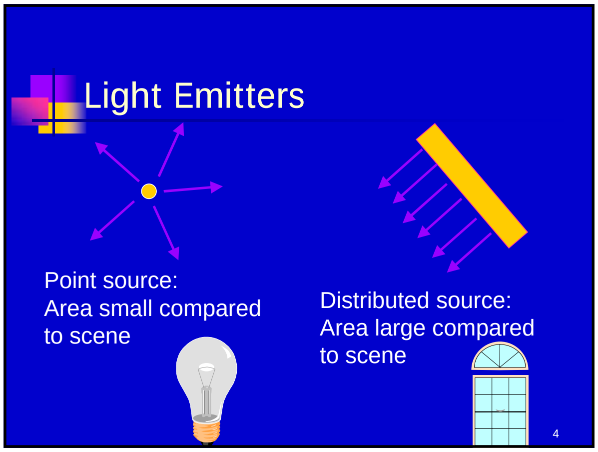


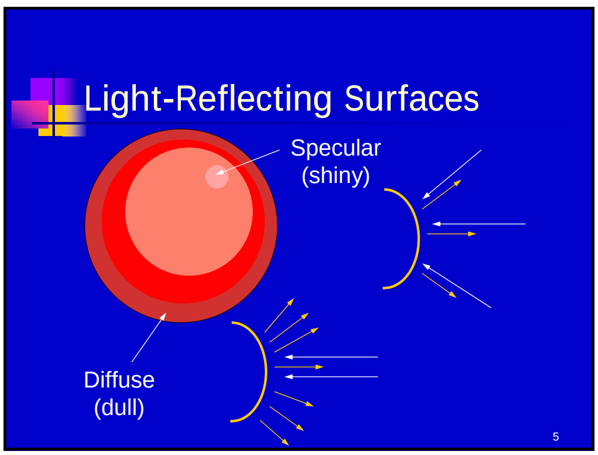


## Ambient Light

$I_a$

- General brightness of scene
  - Light sources, reflections, etc.
- Not spatial or directional
  - Constant for all surfaces
  - Independent of direction
    - Viewing direction, surface orientation
  - Reflected light depends on surface

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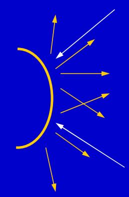
## Ambient Diffuse Reflection

$$I_{ambdiff} = k_d I_a$$

$$0 \le k_d \le 1$$



Incident light from all directions
Reflected light scattered to all directions

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## Directional Source Reflection

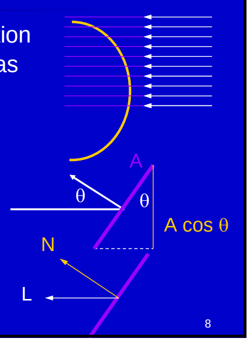
Incident light from one direction
But spread over varying areas

Reflected light scattered equally in all directions
Intensity depends on angle of incidence

$$I_{l,diff} = k_d I_l \cos\theta$$

$$I_{l,diff} = k_d I_l (\mathbf{N} \bullet \mathbf{L})$$

Unit vectors: N (normal) and L (to light source position)

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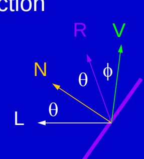
## Specular Reflection

Reflected light not diffused
Angle of incidence = angle of reflection

For perfect reflector, no reflection visible at any other angle

For imperfect reflectors, some reflection visible at angle $\phi$ from **R**

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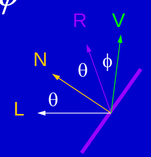
## Phong Model (1)

Empirical model of specular reflection

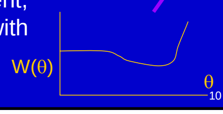
$$I_{spec} = W(\theta) I_l \cos^{n_s} \phi$$




Specular reflection parameter, $n_s$, is large for shiny surfaces, small for dull ones

Specular reflection coefficient, W(θ), generally increases with angle of incidence

Model by constant ($k_s$)?

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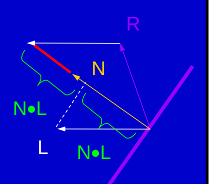
## Phong Model (2)

$$I_{spec} = k_s I_l (\mathbf{V} \bullet \mathbf{R})^{n_s}$$

Need to calculate **R** to get $I_{spec}$




$$\mathbf{R} + \mathbf{L} = 2(\mathbf{N} \bullet \mathbf{L})\mathbf{N}$$

$$\mathbf{R} = 2(\mathbf{N} \bullet \mathbf{L})\mathbf{N} - \mathbf{L}$$

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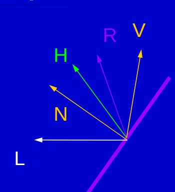
## Halfway Vector Simplification

$$I_{spec} = k_s I_l (\mathbf{V} \bullet \mathbf{R})^{n_s}$$

⇓

$$I_{spec} = k_s I_l (\mathbf{N} \bullet \mathbf{H})^{n_s}$$

$$\mathbf{H} = \frac{\mathbf{L} + \mathbf{V}}{|\mathbf{L} + \mathbf{V}|}$$




H is the surface normal that would produce maximum specular reflection.

If both light and viewer at a distance, H is constant for all surfaces.

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## Multiple Light Sources

$$I = I_{diff} + I_{spec}$$

$$= k_a I_a + \sum_{i=1}^{n} I_l \left[ k_d \left( \mathbf{N} \bullet \mathbf{L}_i \right) + k_s \left( \mathbf{N} \bullet \mathbf{H} \right)^{n_s} \right]$$

- We assume linear superposition of effects of all light sources.
- It may be necessary to scale to avoid intensity saturation.

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## Other Lighting Issues

- Not all sources are points
  - Control intensity by direction (Warn)
- Intensity falls off at distance
  - Attenuation functions
    - Empirical rather than exact models
- Color
  - Adjust reflection coefficients

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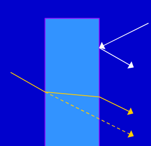
## Transparent Surfaces



- Reflection
  - Diffuse, specular
- Transmission
  - Refraction
    - Ignore or approximate path shift?
  - Diffuse effects (e.g., frosted glass)

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## Gamma Correction

- Display transfer function
  - Voltage in versus intensity out
  - Non-linear (exponential)
- Compensate drive signal
  - Logarithmic precompensation

$I = aV^{\gamma}$ $V = \left(\frac{I}{a}\right)^{1/\gamma}$ $\gamma \approx 2.2$

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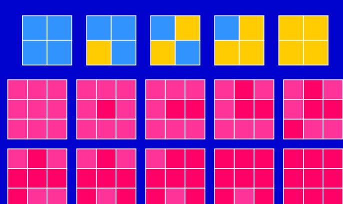
## Halftones and Dithering

What if intensity/color choices limited?

Approximate intensity, at expense of resolution; introduce randomness?



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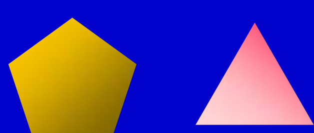
## Gouraud Shading

- Polygon surface rendering
- Determine vertex intensities
- Linearly interpolate across surface



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