MODELING LIGHT INTENSITIES
(Section 14-1 in _Computer Graphics_)

- Light Source
- Diffuse Reflection
- Specular Reflection
- Transmitted or Refracted Light
- Texture and Surface Pattern
- Shadows

DISPLAYING LIGHT INTENSITIES
(Section 14-2 in _Computer Graphics_)

- Halftoning
- Dithering

Introduction

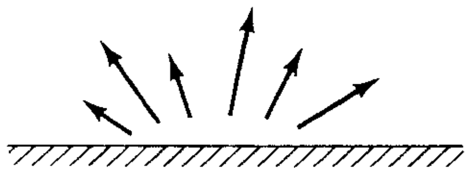
- achieving realistic views
  - generate perspective projections
  - remove hidden surfaces
  - apply light intensities to present shading and color patterns
- calculate light intensities using a shading model based on optical properties of surfaces
  - opaque
  - transparent
  - shiny or matte
  - relative positions of surfaces
  - orientations of surfaces with respect to light sources
  - types of light sources

light sources

- light-emitting sources
  - point sources: the dimensions of the light source are small compared to the dimensions of the object
  - distributed sources: the dimensions of the light source are significant
- light-reflecting sources
  - illuminated surfaces
  - multiple reflections combine to produce ambient light or background light
- light-transmitting sources
  - transparent and translucent objects

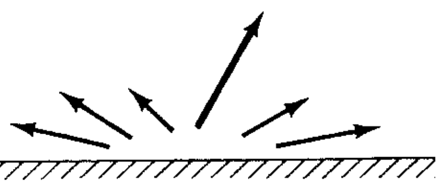
reflections

- diffuse reflection
  - scattered light from point light sources and ambient light sources
  - a matte surface produces primarily diffuse reflection



Diffuse Reflections
From a Surface

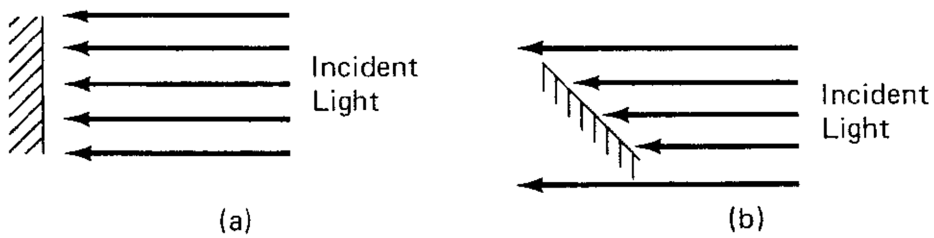
- specular reflection
  - highlights or bright spots
  - more pronounced on shiny surfaces



Specular Reflection
Superimposed on
Diffuse Reflections

diffuse reflection

- effects of ambient light
  - uniform intensity in all directions
  - surfaces range from highly reflective to highly absorbitive
  - $I = k_d I_a$, where
    - I is the intensity at any point on the surface
    - k_d is the coefficient of reflection or reflectivity
    - I_a is the intensity of the ambient light
- effects of point source light
  - the intensity of reflected light depends on the angle of illumination (Lambert's law)
    - perpendicular incident light produces a brighter surface than does oblique incident light

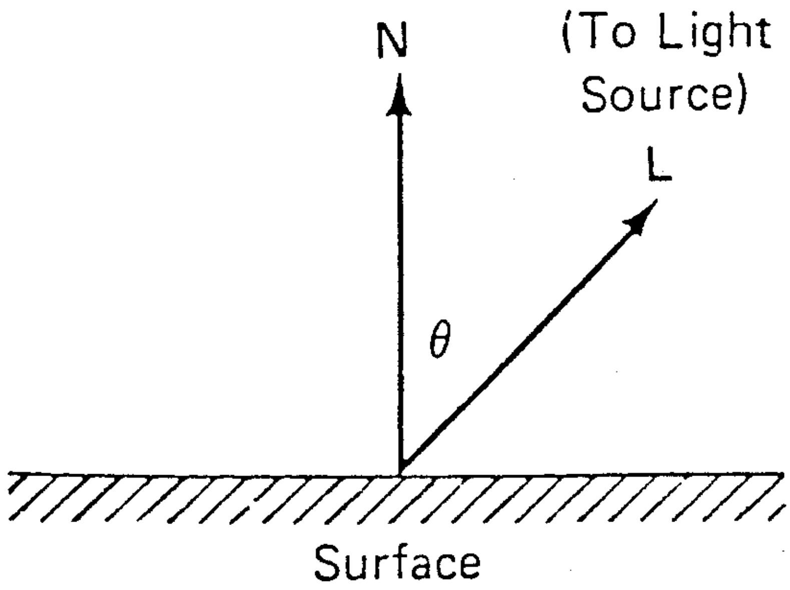


  - for simplification, light sources are treated as being far enough away to produce parallel rays

diffuse reflection, cont.

- $$I = \frac{k_d I_p}{d + d_0}(N \cdot L)$$

  - I is the intensity of any point on the surface
  - k_d is the coefficient of reflection or reflectivity
  - I_p is the intensity of the point source
  - d is the distance from the point source to a point on the surface
  - d_o is a constant which prevents the denominator from approaching zero
  - N is the surface normal
  - L is the unit vector to the point source



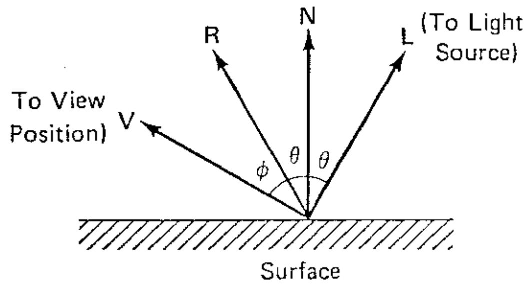
ambient light and diffuse reflection

- $$I = k_d I_a + \frac{k_d I_p}{d + d_0}(N \cdot L)$$

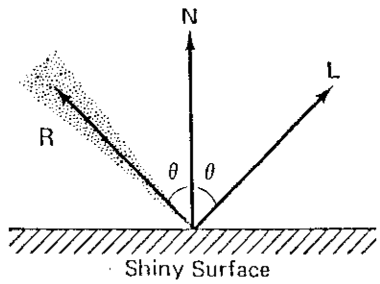
- when color is modeled, there is one component of this form for each color

specular reflection

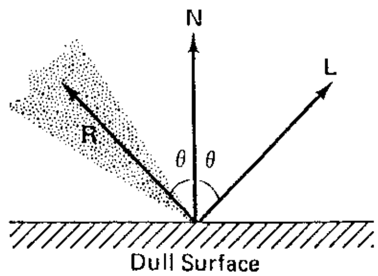
- at certain angles, shiny surfaces reflect all incident light
- a specular reflection is a spot of reflected light that is the same color as the incident light
- for an ideal reflector, the angle of incidence is equal to the angle of specular reflection



  - shiny surfaces have a narrow reflection range



  - dull surfaces have a wider reflection range



- diffuse reflection and specular reflection are modeled with simplifications to increase efficiency

specular reflection, continued

$$I = \frac{I_p}{d + d_0}(w(\theta)\cos^n\phi)$$

- W(Θ) depends on the surface material and is determined empirically
- Φ is the angle between the R (the angle of specular reflection) and V (the unit vector to the viewer)
- n is high for shiny surfaces

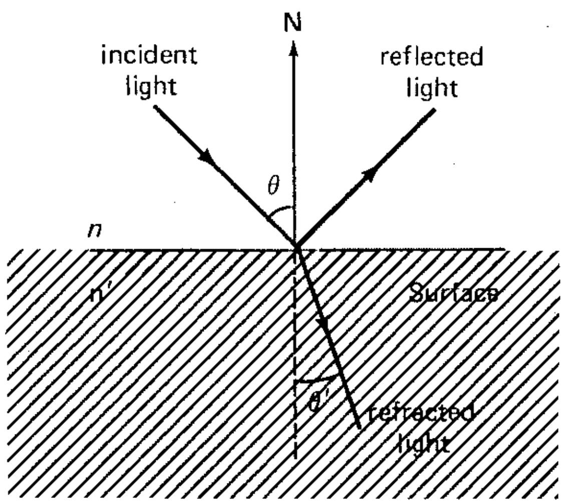
complete reflection model

$$I = \underbrace{k_d\, I_a}_{\text{ambient component}} + \overbrace{\frac{I_p}{d + d_0}\Big[k_d\,(N \cdot L)}^{\text{diffuse component due to point source light}} + w(\theta)\cos^n\phi\Big]$$

specular component

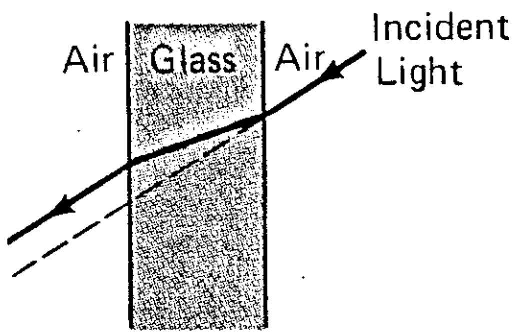
transmitted or refracted light

- usually from light-reflecting surfaces
  - see figure 14-10 on page 281
- diffuse refraction from translucent, light-scattering surfaces
  - implemented by diminishing the intensity (spreading it over a finite area)
  - costly to implement
- specular refraction
  - light incident on a transparent surface has a reflected component and a refracted component



transmitted or refracted light, continued

- commonly modeled by shifting the path of the incident light or by ignoring path shifts altogether



- implemented by modifying the intensity
  - (I_t) of the transparent object according to the intensity (I_b) of the background object and the refraction coefficient (r)
    $I = rI_t + (1 - r)I_b$
- easily accommodated by the depth-sort hidden-surface method
- see figure 14-14 on page 283

texture and surface patterns

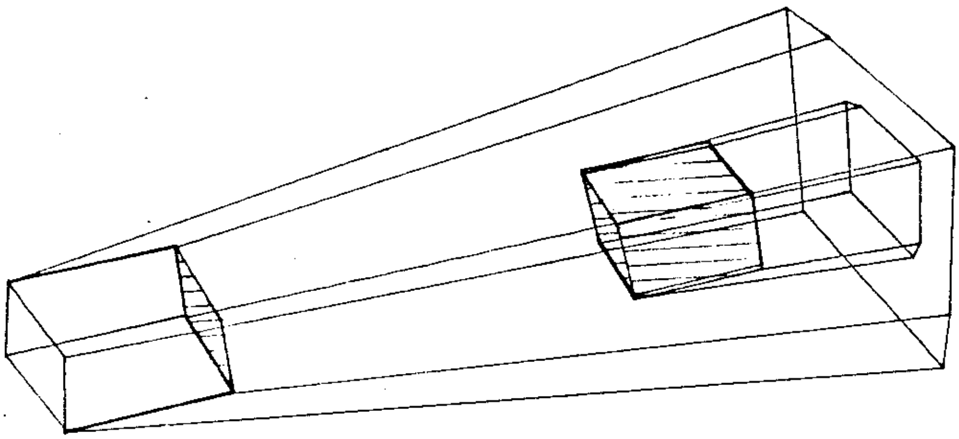
- texture distinguishes
  - orange peel from orange plastic of the same color
  - glazed brick from china of the same color
- surface patterns permit
  - china with designs
  - Persian carpets
  - highways and runways with dividing lines and skid marks

texture and surface patterns, continued

- achieving texture
  - alter the surface normal (as a function of position over the surface)
  - alter the reflection coefficient
  - alter both
  - use texture mapping methods (similar to pattern fill)
- achieving surface patterns
  - the surface pattern is defined as an array
  - the array is mapped onto the object at a designated position
  - patterns can be wrapped around three-dimensional objects

shadows

- use hidden surface methods with the light source at the view position
  - use shadow polyhedra to identify surface sections which cannot be "seen" by the light source
  - compute the shade of each shadow area without a contribution from the light source that produced the shadow



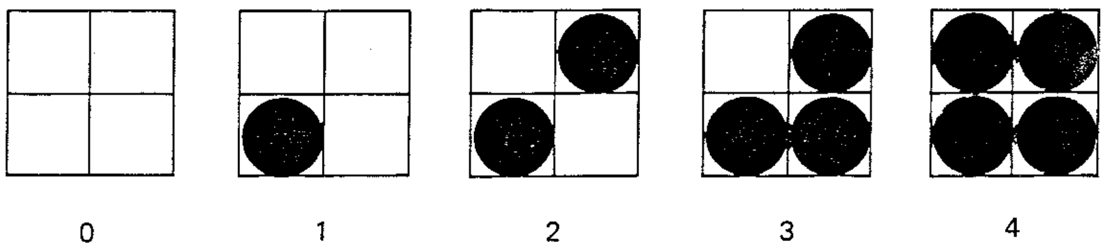
  - alternatively, apply surface patterns to shadow areas
  - see figure 14-17 on page 285
- shadow patterns are valid for any viewing position, as long as the light sources remain stationary

Displaying Light Intensities

- some graphics systems can display several intensity levels
  - a four-level system provides minimal shading capability
  - high quality shading patterns require 32 to 256 levels of intensity
  - intensity information may be stored as
    - an intensity level (I_k)
    - a level number (k)
    - a value proportional to the control grid voltage

halftoning

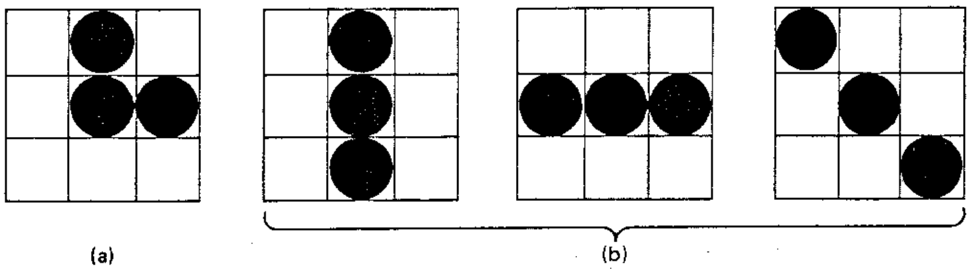
- other graphics systems can display only "on" and "off"
- pixels are treated as being 2-by-2 or 3-by-3 or larger
- 2-by-2 pixels have 5 different intensity levels



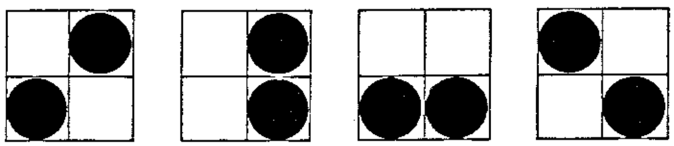
- n-by-n pixels have $n^2 + 1$ different intensity levels
- color variations can be obtained by halftoning (see figure 14-20 on page 287)
- resolution diminishes

halftoning, continued

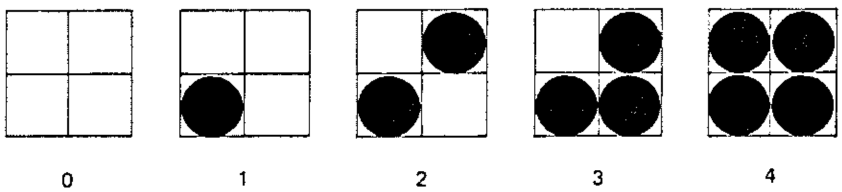
- avoid introducing patterns



- equivalent combinations can be selected randomly



- patterns can be avoided by successively higher grid patterns with the same pixels set



halftoning, continued

- halftoning can be combined with systems that have multiple levels of intensity

$$\underset{0}{\boxed{\begin{array}{c|c} 0 & 0 \\ \hline 0 & 0 \end{array}}} \quad \underset{1}{\boxed{\begin{array}{c|c} 0 & 1 \\ \hline 0 & 0 \end{array}}} \quad \underset{2}{\boxed{\begin{array}{c|c} 0 & 1 \\ \hline 1 & 0 \end{array}}} \quad \underset{3}{\boxed{\begin{array}{c|c} 1 & 1 \\ \hline 1 & 0 \end{array}}} \quad \underset{4}{\boxed{\begin{array}{c|c} 1 & 1 \\ \hline 1 & 1 \end{array}}} \quad \underset{5}{\boxed{\begin{array}{c|c} 1 & 2 \\ \hline 1 & 1 \end{array}}}$$

$$\underset{6}{\boxed{\begin{array}{c|c} 1 & 2 \\ \hline 2 & 1 \end{array}}} \quad \underset{7}{\boxed{\begin{array}{c|c} 2 & 2 \\ \hline 2 & 1 \end{array}}} \quad \underset{8}{\boxed{\begin{array}{c|c} 2 & 2 \\ \hline 2 & 2 \end{array}}} \quad \underset{9}{\boxed{\begin{array}{c|c} 2 & 3 \\ \hline 2 & 2 \end{array}}} \quad \underset{10}{\boxed{\begin{array}{c|c} 2 & 3 \\ \hline 3 & 2 \end{array}}} \quad \underset{11}{\boxed{\begin{array}{c|c} 3 & 3 \\ \hline 3 & 2 \end{array}}} \quad \underset{12}{\boxed{\begin{array}{c|c} 3 & 3 \\ \hline 3 & 3 \end{array}}}$$

- natural when the resolution of the scene is less than the resolution of the output device

dithering techniques

- used with halftoning methods to smooth edges and improve overall appearance
- a dither intensity or dither noise is added to the calculated intensity
- dither noise can be calculated randomly or based on position
- alternatively, intensity is compared to a dither value (thresholding)
  - the pixel is turned on if the intensity exceeds the dither value
  - again, dither values can be generated randomly or based on position
  - example
    - i = x mod 2
    - j = y mod 2
    - if I > D(i, j)
      then turn on pixel at (x, y)
    - where D is a 2-by-2 matrix containing the integers 0 through 3

$$D = \begin{bmatrix} 3 & 1 \\ 0 & 2 \end{bmatrix}$$

MODELING LIGHT INTENSITIES

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- diffuse reflection
- specular reflection
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- texture and surface pattern
- shadows

DISPLAYING LIGHT INTENSITIES

- halftoning
- dithering