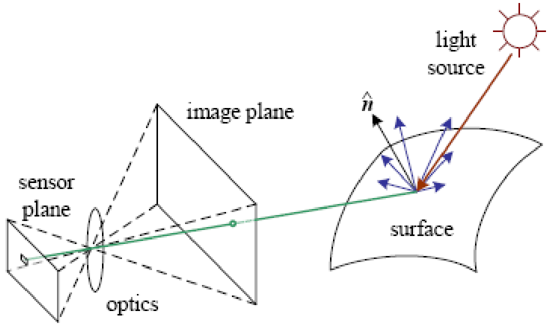
计算机视觉

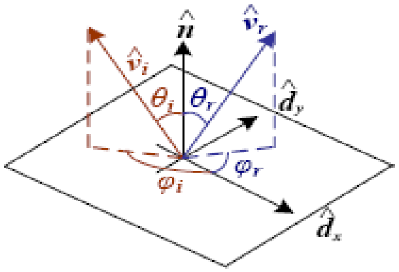
Computer Vision

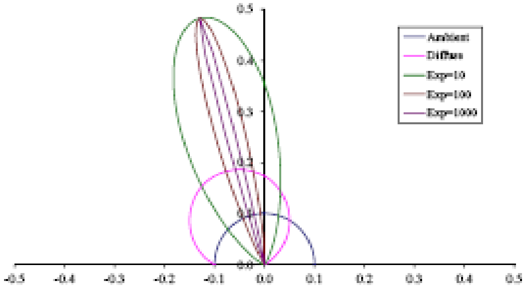
Lecture 3: Light and Shading

张 超

信息科学技术学院 智能科学系







Key issues

- Physical
  - What makes a pixel take its brightness values?
- Inference
  - What can we recover from the world using those brightness values?
- Human
  - What can people do?
    - which suggests problems we might be able to solve

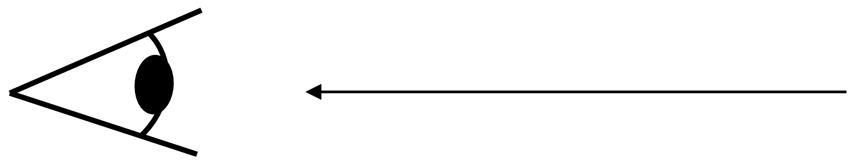
Modeling Pixel Brightness

- Camera response
- Surface reflection
- Illumination

What is light?

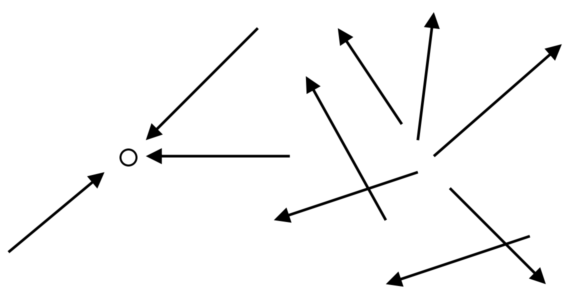
Electromagnetic radiation (EMR) moving along rays in space

- R(l) is EMR, measured in units of power (watts)
  - l is wavelength



Light field

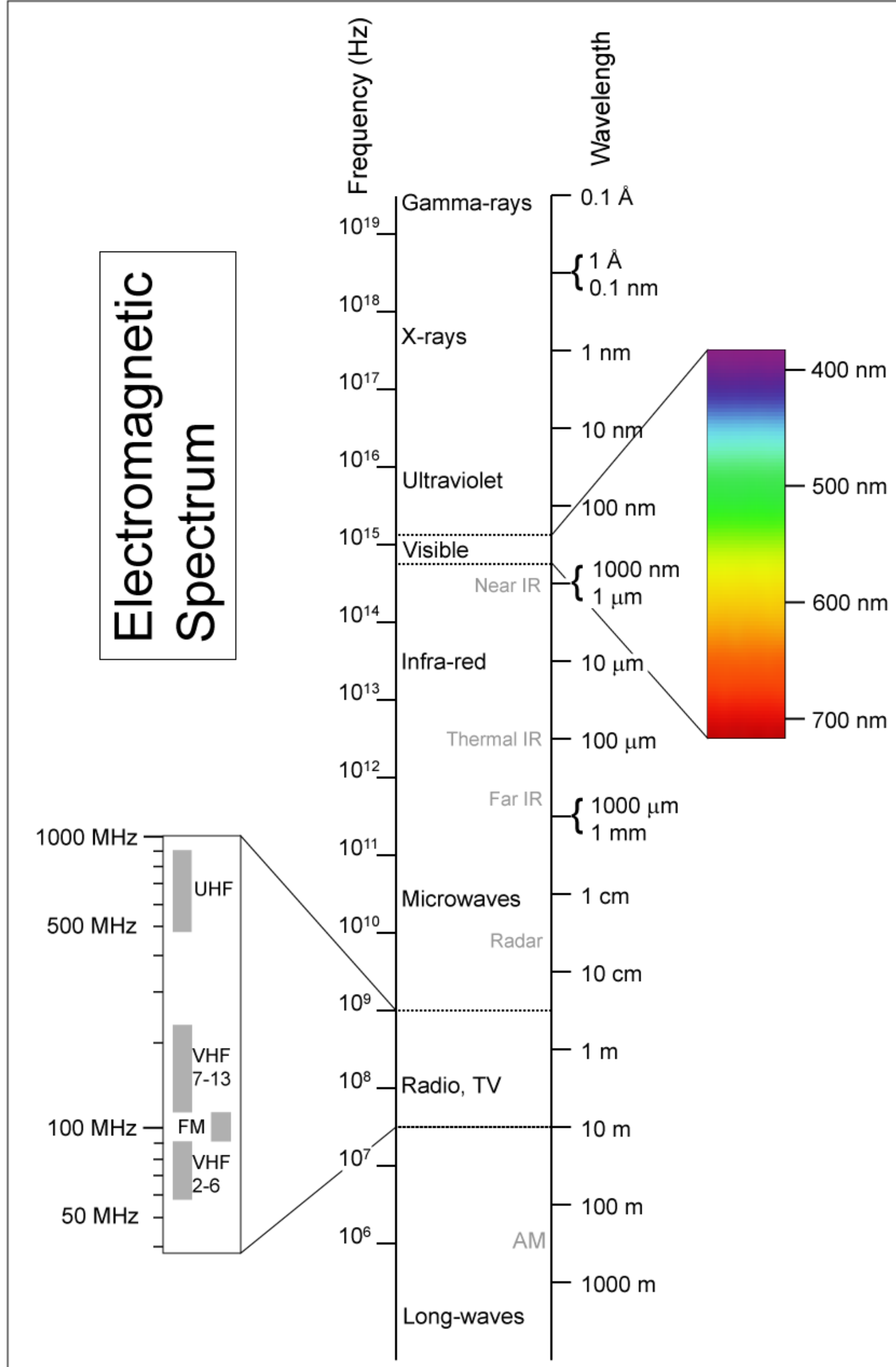
- We can describe all of the light in the scene by specifying the radiation (or **“radiance 辐射”** along all light rays) arriving at every point in space and from every direction



$$R(X, Y, Z, \theta, \phi, \lambda, t)$$

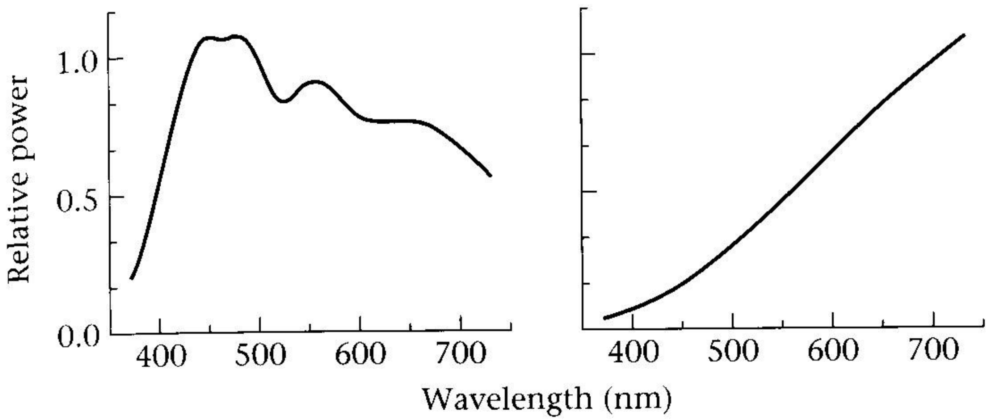
Visible light

- We “see” electromagnetic radiation in a range of wavelengths



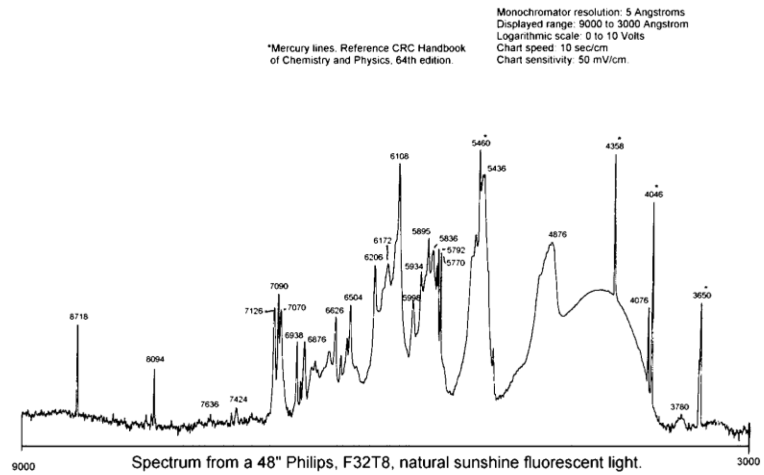
Light spectrum

- The appearance of light depends on its power spectrum
  - How much power (or energy) at each wavelength



daylight

tungsten bulb

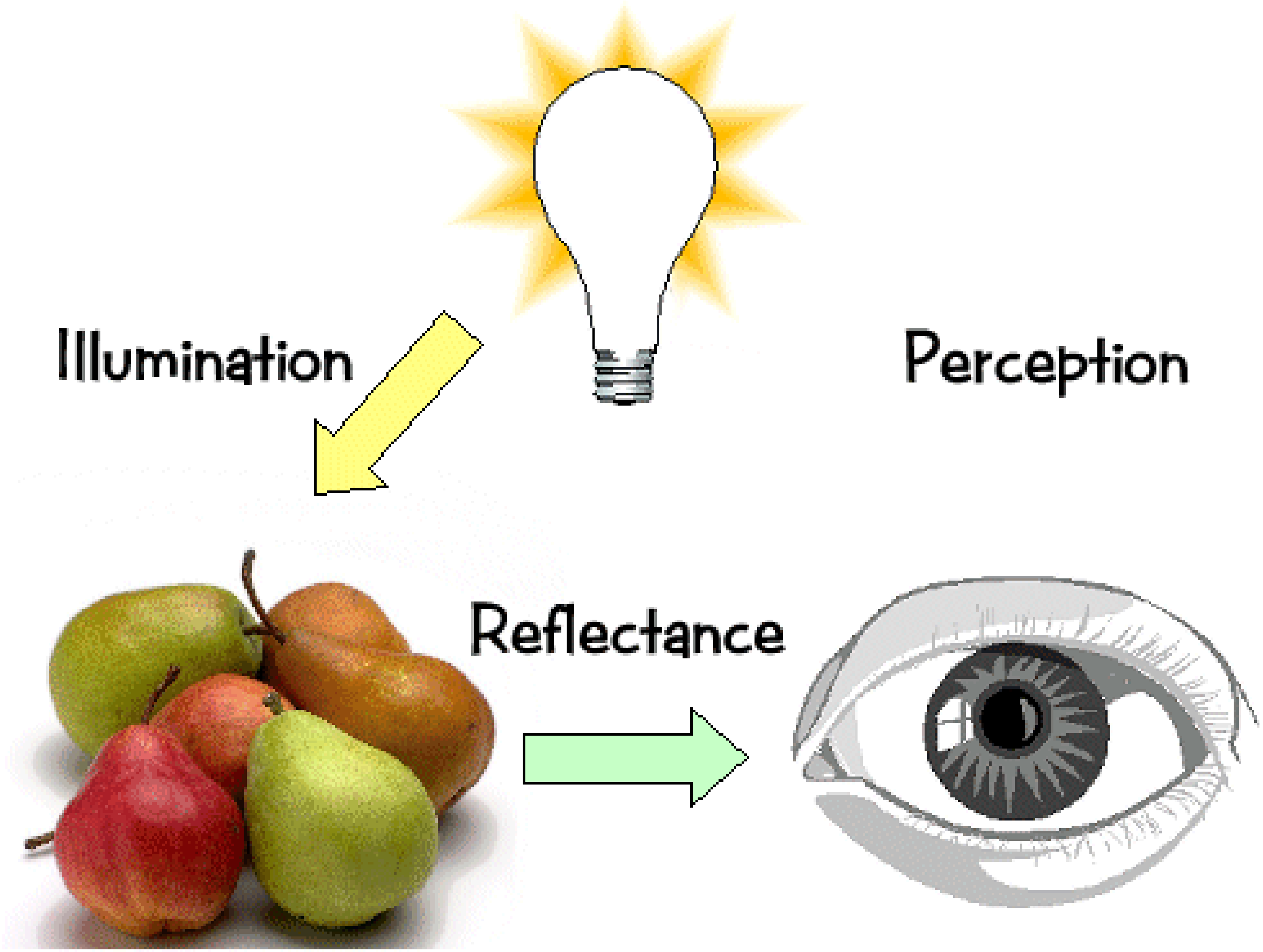


fluorescent light

Our visual system converts a light spectrum into “color”

- This is a rather complex transformation

Light transport



Light sources

- Basic types
  - point source
  - directional source
    - a point source that is infinitely far away
  - area source
    - a union of point sources
- More generally
  - a light field can describe *any* distribution of light sources
- What happens when light hits an object?

Modeling Pixel Brightness

- Light arrives at a surface
  - from a light source
  - from another surface
- It is reflected into the camera
  - many possible effects
- It arrives at a sensor at the back of the camera
  - and a record is made
  - this could be a linear or a non-linear function of the amount of light

Effects in camera

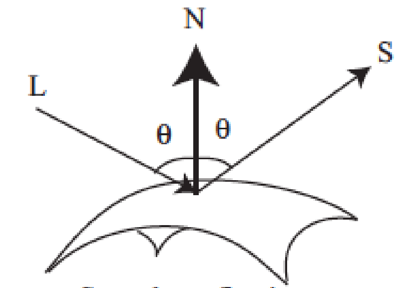
- Film
  - Record is made by chemical processes in the film
  - These are non-linear
    - Typically,
      - dark patches are lighter than they should be
      - light patches are darker than they should be
      - so that more detail is visible
- CCD
  - Linear devices
    - with non-linearities produced by electronics to mimic film
- Calibration
  - Can be hard to find curves of camera response vs light input
  - Instead, use calibration algorithms

Reflection at a surface

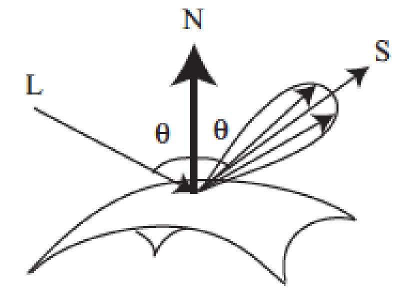
- Many effects when light strikes a surface -- could be:
  - absorbed; transmitted; reflected; scattered
    - eg some people can see arteries, veins under their skin because
      - light is transmitted through skin, reflected at blood vessel, transmitted out
  - Simplify
    - Assume that
      - surfaces don't fluoresce
      - surfaces don't emit light (i.e. are cool)
      - all the light leaving a point is due to that arriving at that point

The important reflection modes

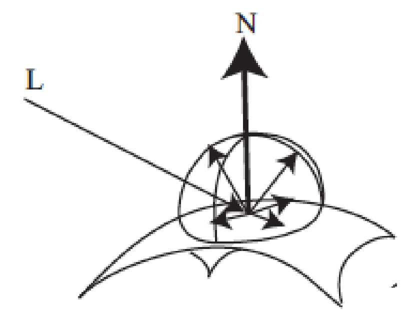
- Specular reflection (mirror like)
  - Pure mirror:
    - incoming, outgoing directions and normal are coplanar
    - incoming, outgoing angles to normal are equal
  - Most specular surfaces:
    - some light leaves the surface along directions near to the specular direction as well
- Diffuse reflection
  - Light leaves in equal amounts in each direction
    - so surface looks equally bright from each viewing direction



Specular reflection



Specularity



Diffuse reflection

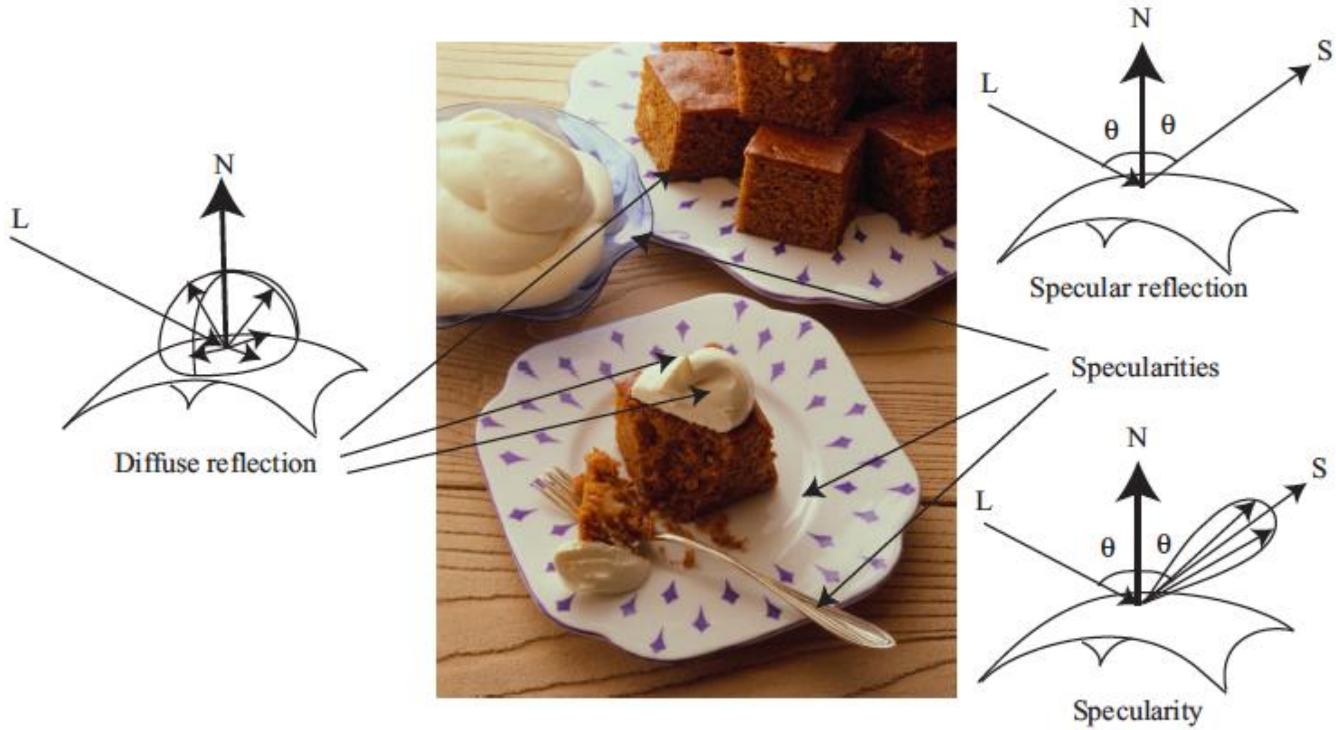


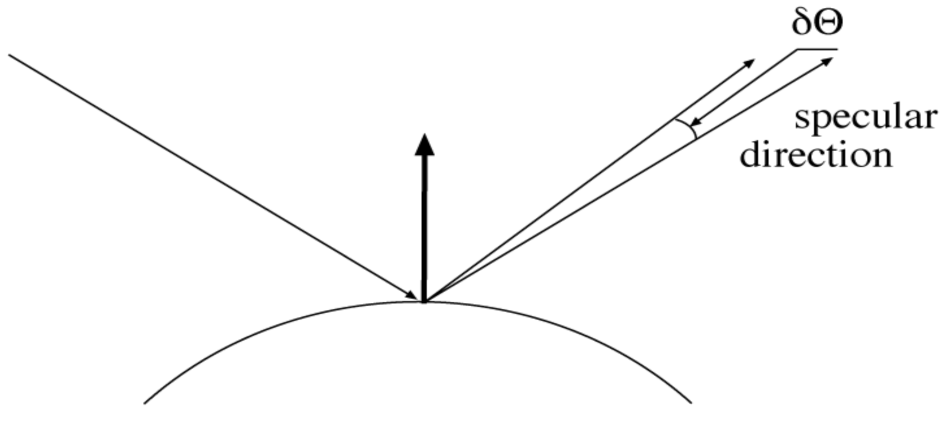
FIGURE 2.1: The two most important reflection modes for computer vision are diffuse reflection (**left**), where incident light is spread evenly over the whole hemisphere of outgoing directions, and specular reflection (**right**), where reflected light is concentrated in a single direction. The specular direction $\boldsymbol{S}$ is coplanar with the normal and the source direction ($\boldsymbol{L}$), and has the same angle to the normal that the source direction does. Most surfaces display both diffuse and specular reflection components. In most cases, the specular component is not precisely mirror like, but is concentrated around a range of directions close to the specular direction (**lower right**). This causes specularities, where one sees a mirror like reflection of the light source. Specularities, when they occur, tend to be small and bright. In the photograph, they appear on the metal spoon and on the plate. Large specularities can appear on flat metal surfaces (arrows). Most curved surfaces (such as the plate) show smaller specularities. Most of the reflection here is diffuse; some cases are indicated by arrows. *Martin Brigdale © Dorling Kindersley, used with permission.*

Specularities

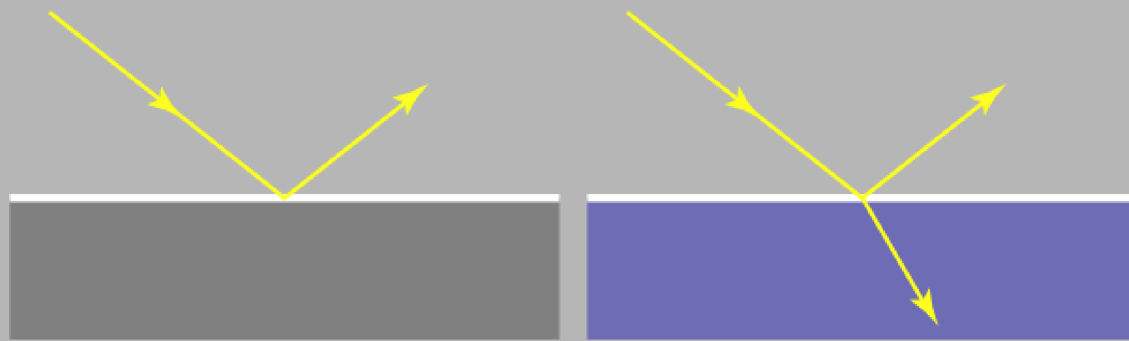
- Mirrors are bright
  - Reflect most incoming light
- Most specular surfaces aren't pure mirrors
  - eg plastics; rough or brushed metal surfaces; lacquers; varnishes
  - The only significant specular reflection is the light source
  - Result: small, bright patches on specular surfaces
    - Specularities
    - Move when the light source moves
    - Move when the viewing direction moves
    - Shape, motion depend on local geometry of the surface
- Specular albedo (反射率)
  - percentage of incoming light that is specularly reflected

Phong's model

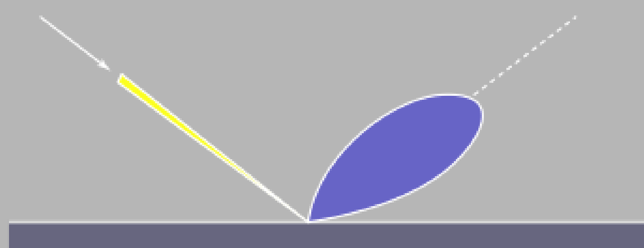
- Exact shape of the specular lobe seldom matters.
- Typical cases:
  - very, very small --- mirror
  - small -- blurry mirror
  - bigger -- see only light sources as "specularities"
  - very big -- faint specularities
- Phong's model
  - reflected energy falls off with $\cos^n(\delta\vartheta)$



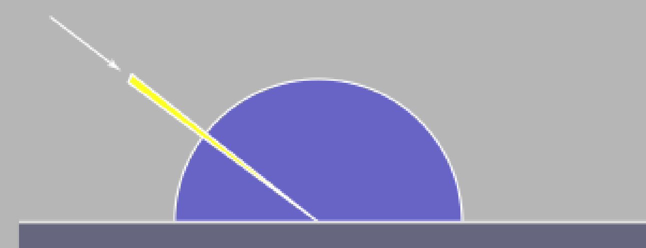
Classic reflection behavior



ideal specular (Fresnel)



rough specular

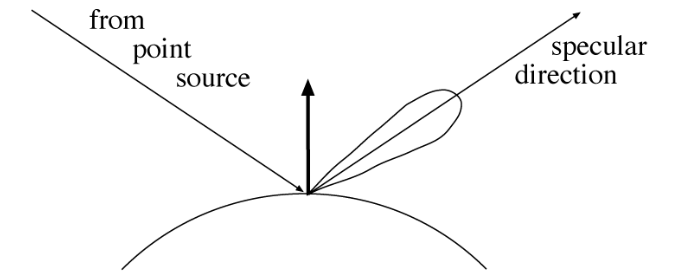


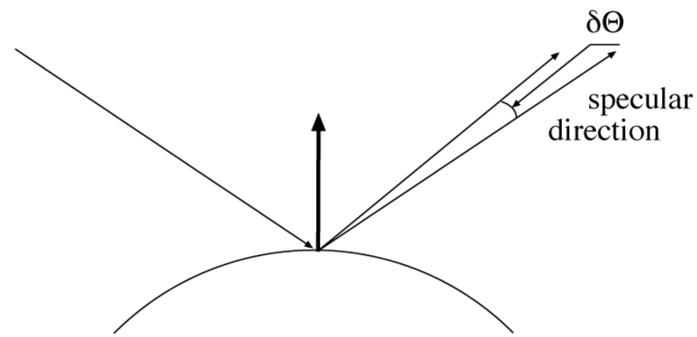
Lambertian

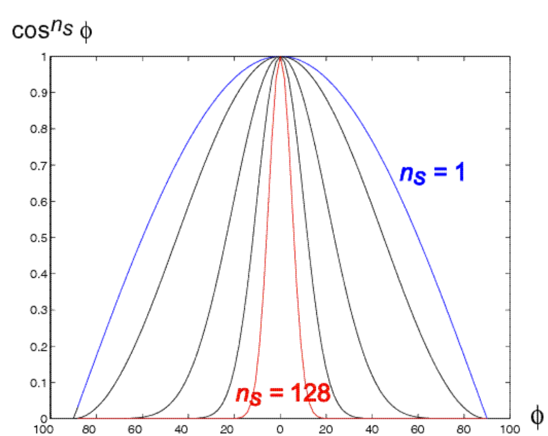
Specular reflection

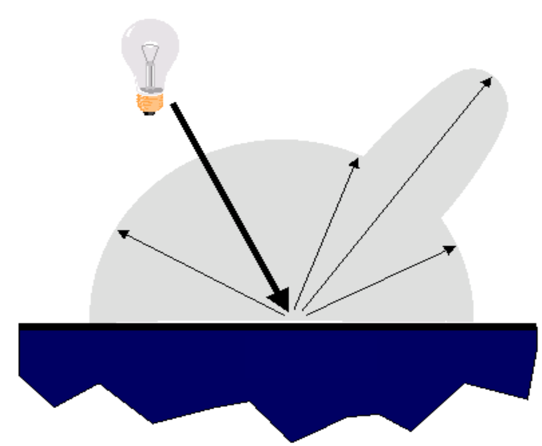
- Radiation arriving along a source direction leaves along the specular direction (source direction reflected about normal)
- Some fraction is absorbed, some reflected
- On real surfaces, energy usually goes into a lobe of directions
- Phong model: reflected energy falls of with

$$\cos^n(\delta\theta)$$

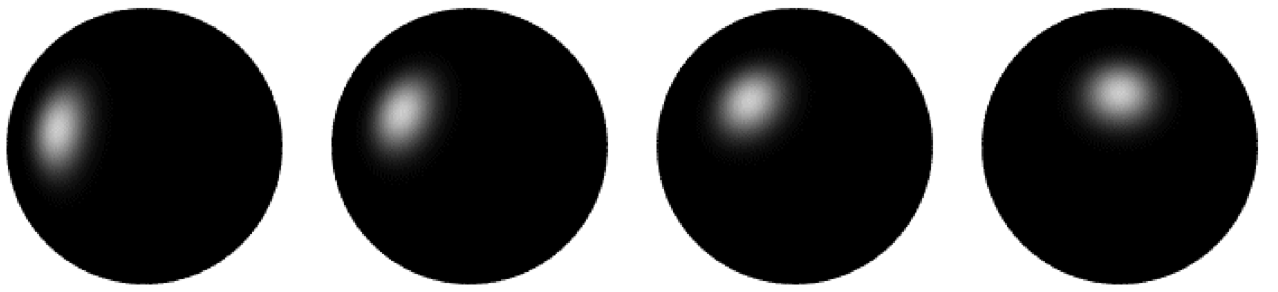




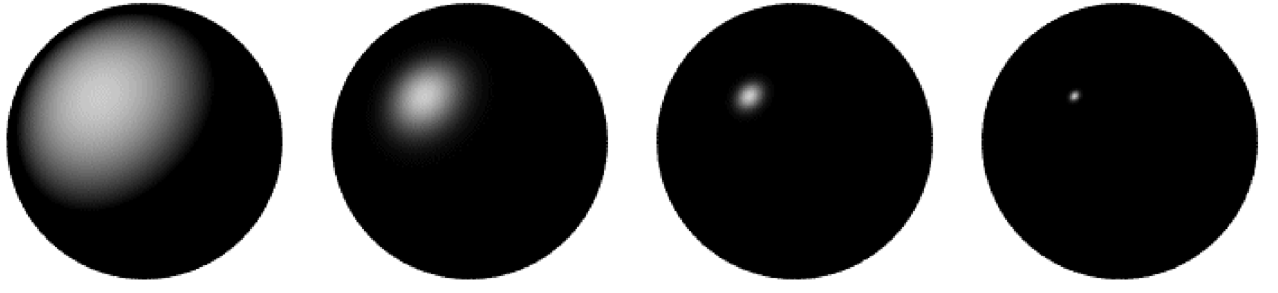




Specular reflection

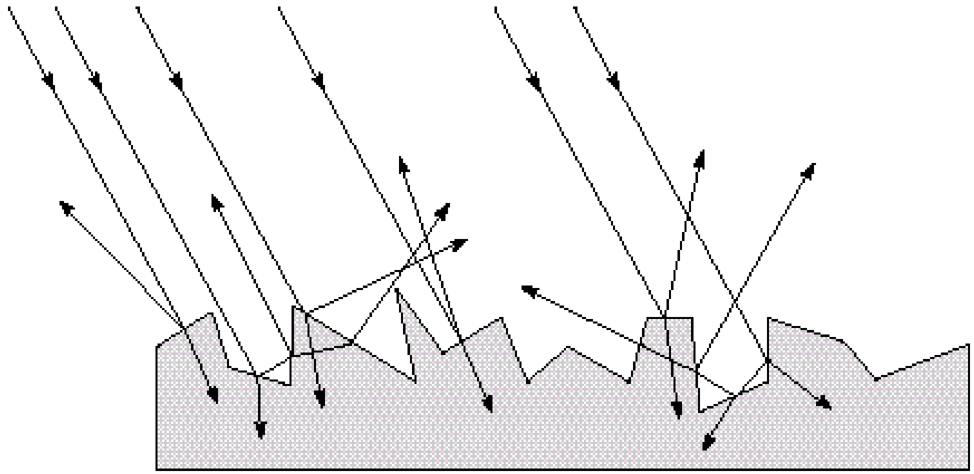


Moving the light source



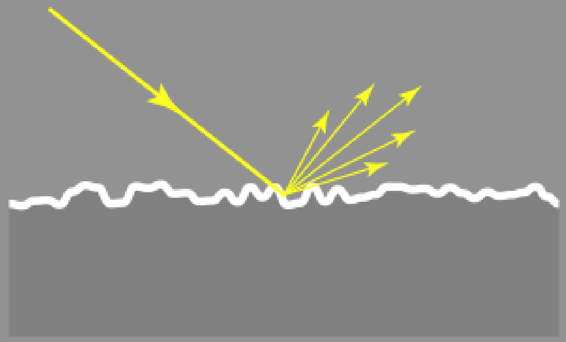
Changing n_s

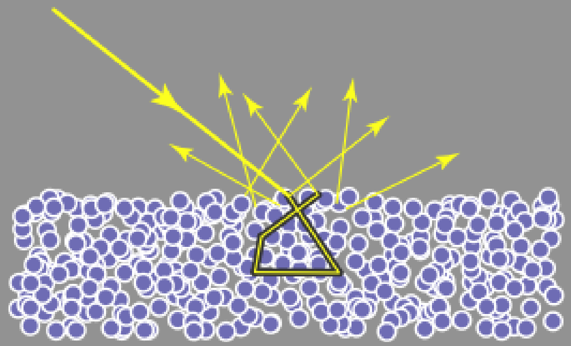
Diffuse reflection



- Diffuse reflection
  - Dull, matte surfaces like chalk or latex paint
  - Microfacets scatter incoming light randomly
  - Effect is that light is reflected equally in all directions

Non-smooth-surfaced materials





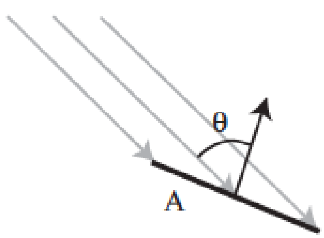
from Steve Marschner

Diffuse reflection

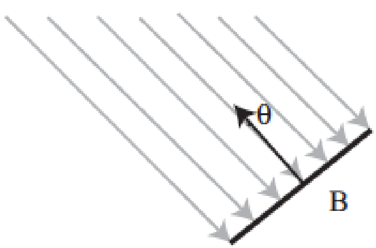
- Light leaves the surface evenly in all directions
  - eg, cotton cloth, carpets, matte paper, matte paints, most “rough” surfaces
- Described by one parameter: Albedo (反射率)
  - percentage of light arriving that leaves
  - range 0-1
    - practical range is smaller
- Light leaving is (Albedo)x(Light arriving)
  - Ambiguity: A surface could be dark because
    - It reflects a small percentage of the light arriving
    - There isn’t very much light arriving

How much light arrives?

- Assume source is far away
  - So light travels in parallel rays
  - (Light arriving) proportional to (number of rays striking surface)
  - Surface A below receives less light than surface B
- Drawing yields
  - (number of rays striking surface) proportional to cos theta
    - where theta is angle between normal and direction of travel
- Shadows
  - If point can’t see the light source, it is in shadow



Diffuse reflection, dark



Diffuse reflection, bright

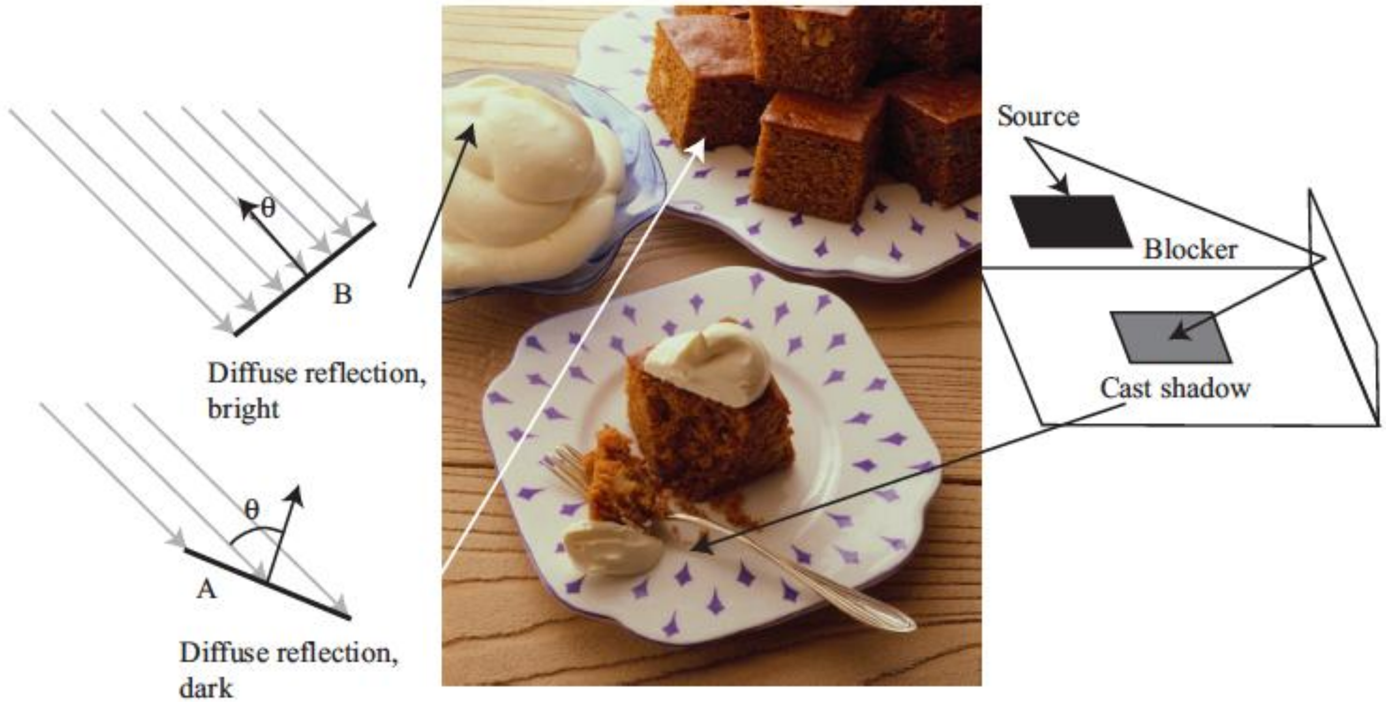
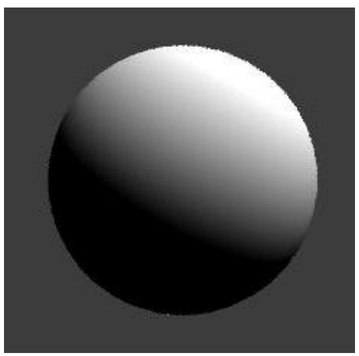
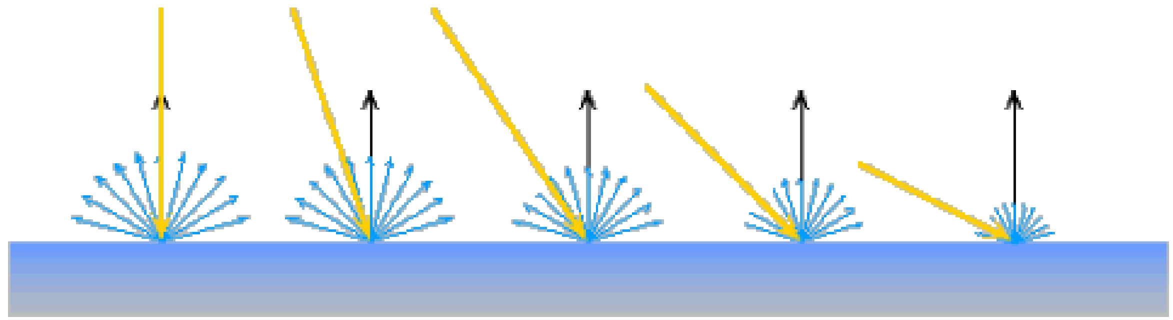


FIGURE 2.2: The orientation of a surface patch with respect to the light affects how much light the patch gathers. We model surface patches as illuminated by a distant point source, whose rays are shown as light arrowheads. Patch A is tilted away from the source (θ is close to 90^0) and collects less energy, because it cuts fewer light rays per unit surface area. Patch B, facing the source (θ is close to 0^0), collects more energy, and so is brighter. Shadows occur when a patch cannot see a source. The shadows are not dead black, because the surface can see interreflected light from other surfaces. These effects are shown in the photograph. The darker surfaces are turned away from the illumination direction. *Martin Brigdale © Dorling Kindersley, used with permission.*

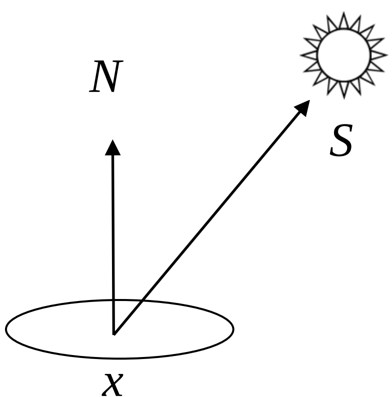
Diffuse reflection: Lambert's law

- Viewed brightness does not depend on viewing direction, but it *does* depend on direction of illumination





$$B(x) = \rho_d(x)\big(N(x) \cdot S_d(x)\big)$$



B: radiosity
ρ: albedo
N: unit normal
S: source vector (magnitude proportional to intensity of the source)

Diffuse+Specular model

- Most surfaces can be modeled as diffuse+specular
  - surface parameters:
    - diffuse albedo,
    - specular albedo,
    - phong parameter

Seldom known, hard to measure,
usually not important

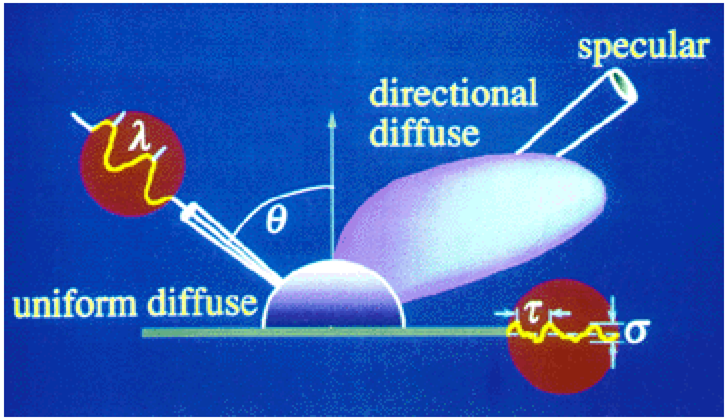
- This justifies the following strategy for many analyses
  - Find and remove specularities
    - which are small, and bright
  - Ignore the missing points, and treat the rest of the image as diffuse

Phong illumination model

$$I_e = k_a I_a + I_i \left[k_d (\mathbf{N} \cdot \mathbf{L})_+ + k_s (\mathbf{V} \cdot \mathbf{R})_+^{n_s} \right]$$

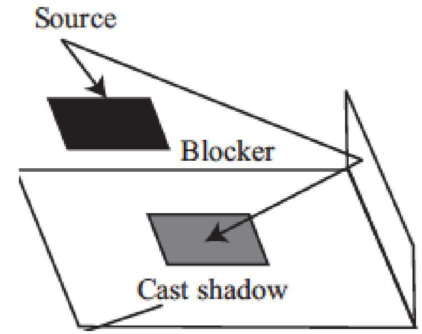
- Phong approximation of surface reflectance
  - Assume reflectance is modeled by three components
    - Diffuse term
    - Specular term
    - Ambient term (to compensate for inter-reflected light)

L, **N**, **V** unit vectors
I_e = outgoing radiance
I_i = incoming radiance
I_a = ambient light
k_a = ambient light reflectance factor
$(x)_+ = \max(x, 0)$



Shadows

- Most shadows aren’t dark
  - because shadow points get light from other surfaces, not just light source



- Area sources
  - Large, bright areas
  - eg diffuser boxes, the sky
  - Yield smooth, blurry shadows
    - Points that can see the whole source are brighter
    - Points that can see only part of the source are darker (penumbra)
    - Points that can see no part of the source are darkest (umbra)

- Other surfaces behave like area sources
  - Smooth, blurry shadows are common (and sometimes too faint to see)

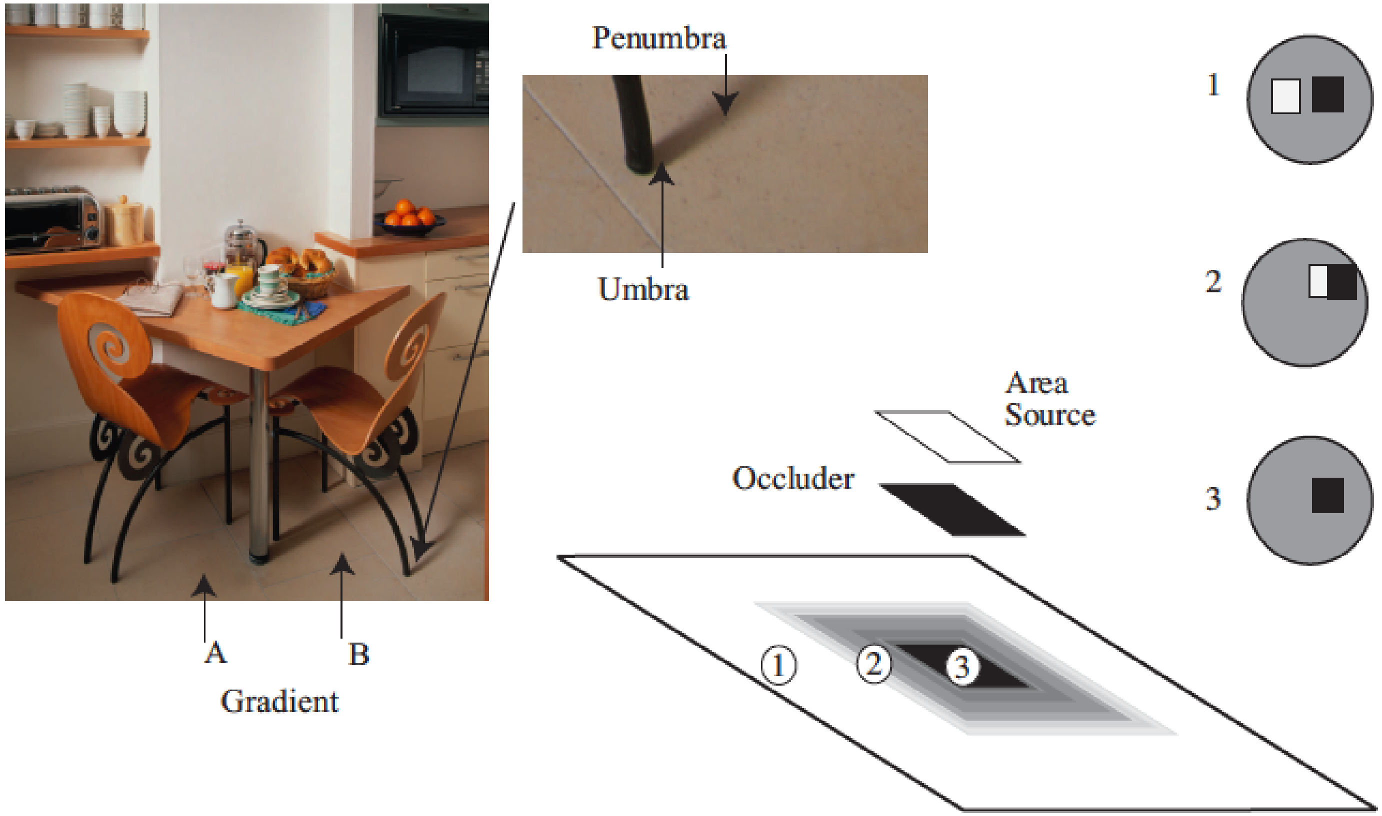


FIGURE 2.3: Area sources generate complex shadows with smooth boundaries, because from the point of view of a surface patch, the source disappears slowly behind the occluder. **Left:** a photograph, showing characteristic area source shadow effects. Notice that A is much darker than B; there must be some shadowing effect here, but there is no clear shadow boundary. Instead, there is a fairly smooth gradient. The chair leg casts a complex shadow, with two distinct regions. There is a core of darkness (the *umbra*—where the source cannot be seen at all) surrounded by a partial shadow (*penumbra*—where the source can be seen partially). A good model of the geometry, illustrated **right**, is to imagine lying with your back to the surface looking at the world above. At point 1, you can see all of the source; at point 2, you can see some of it; and at point 3, you can see none of it. *Peter Anderson © Dorling Kindersley, used with permission.*

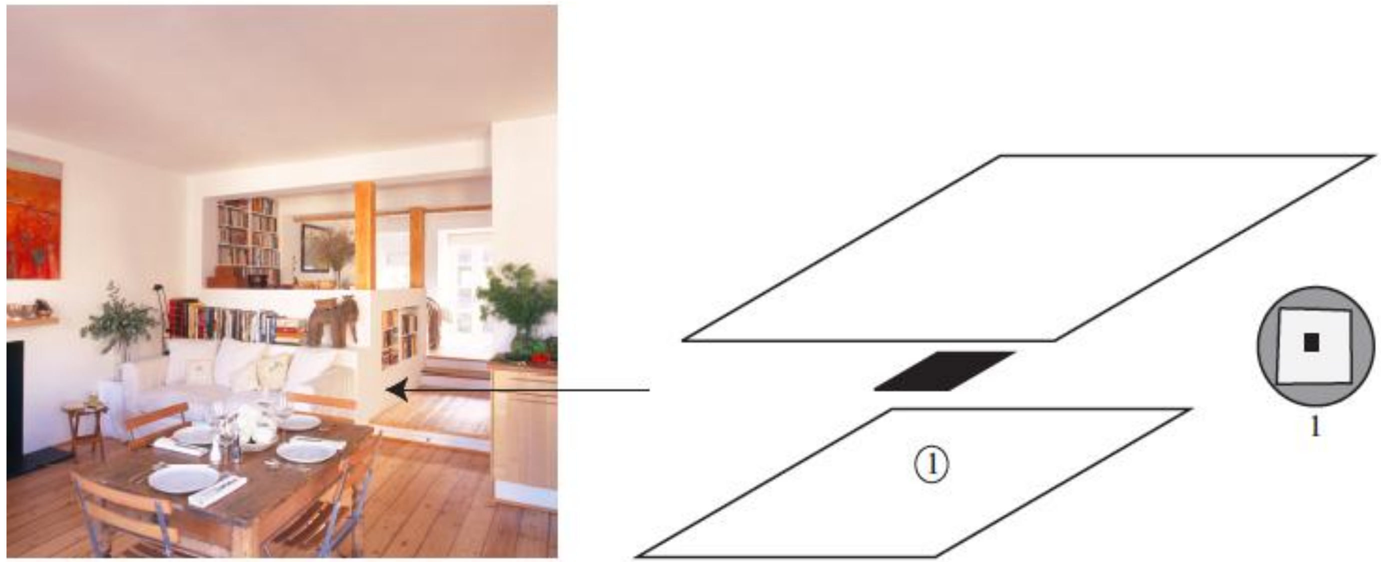


FIGURE 2.4: The photograph on the **left** shows a room interior. Notice the lighting has some directional component (the vertical face indicated by the arrow is dark, because it does not face the main direction of lighting), but there are few visible shadows (for example, the chairs do not cast a shadow on the floor). On the **right**, a drawing to show why; here there is a small occluder and a large area source. The occluder is some way away from the shaded surface. Generally, at points on the shaded surface the incoming hemisphere looks like that at point 1. The occluder blocks out some small percentage of the area source, but the amount of light lost is too small to notice (compare figure 2.3). *Jake Fitzjones © Dorling Kindersley, used with permission.*

Finding the direction of the light

P. Nillius and J.-O. Eklundh, “Automatic estimation of the projected light source direction,” CVPR 2001

Application:
Detecting composite photos

Real photo

Fake photo

M. K. Johnson and H. Farid, Exposing Digital Forgeries by Detecting Inconsistencies in Lighting, ACM Multimedia and Security Workshop, 2005.

Light and shading - Crucial points

- Image brightness is affected by
  - amount of light arriving at surface
  - surface type (diffuse, specular) and amount reflected at surface
  - camera sensitivity
- There are significant ambiguities
  - eg low albedo surface in bright light
    - vs high albedo surface in low light
  - each might reflect about the same amount
- Most surfaces can be modeled as diffuse + specular
  - generally, find and remove specularities
  - treat the rest as diffuse

Readings

- Chapter 2.1, 2.2.2