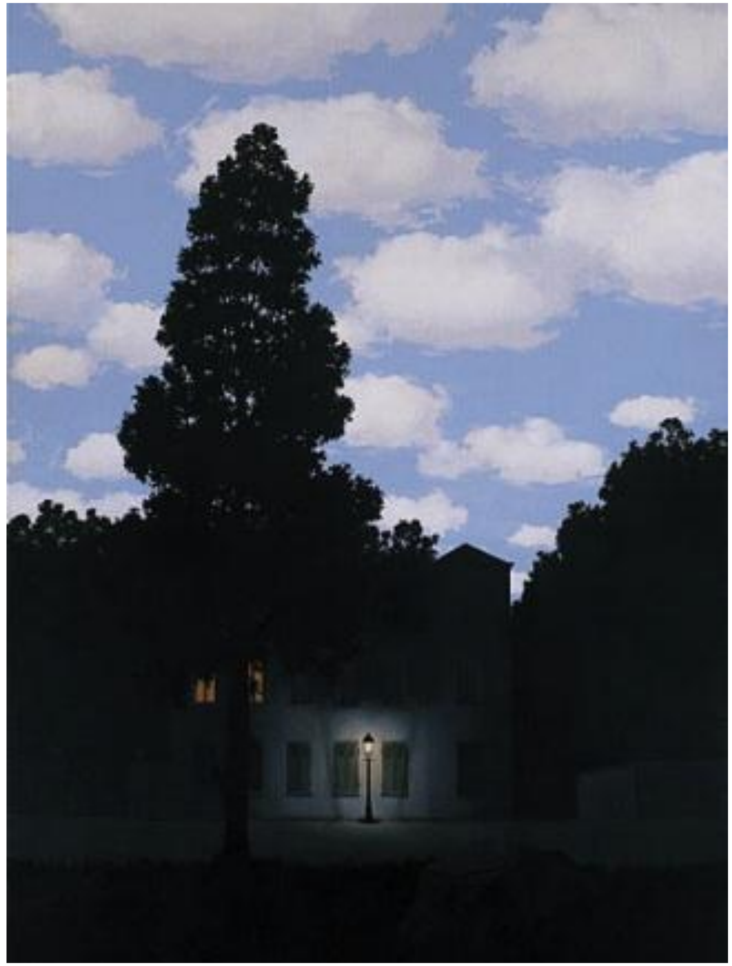
Light and Shading



"Empire of Light", Magritte

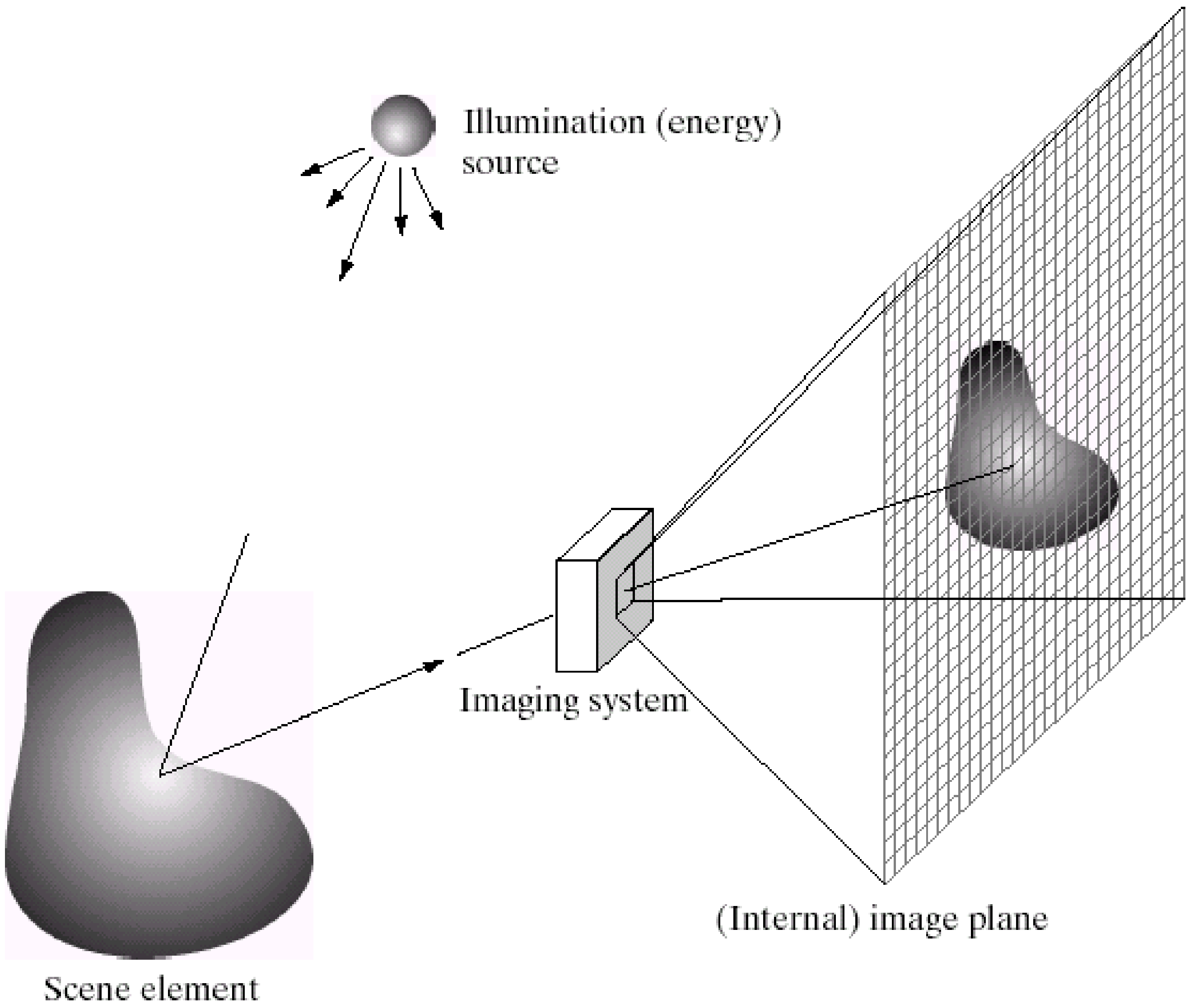
Computer Vision

Derek Hoiem, University of Illinois

Administrative stuff

- Some people waiting to get in
- Tentative office hours
  - Derek: Wed 4pm, 8pm (skype only)
  - Ruiqi: Mon 7pm, Thurs 4pm
- Homework 1 released soon
- Any questions?

How light is recorded



Digital camera

A digital camera replaces film with a sensor array

- Each cell in the array is light-sensitive diode that converts photons to electrons
- Two common types: Charge Coupled Device (CCD) and CMOS
- http://electronics.howstuffworks.com/digital-camera.htm

Slide by Steve Seitz

Sensor Array

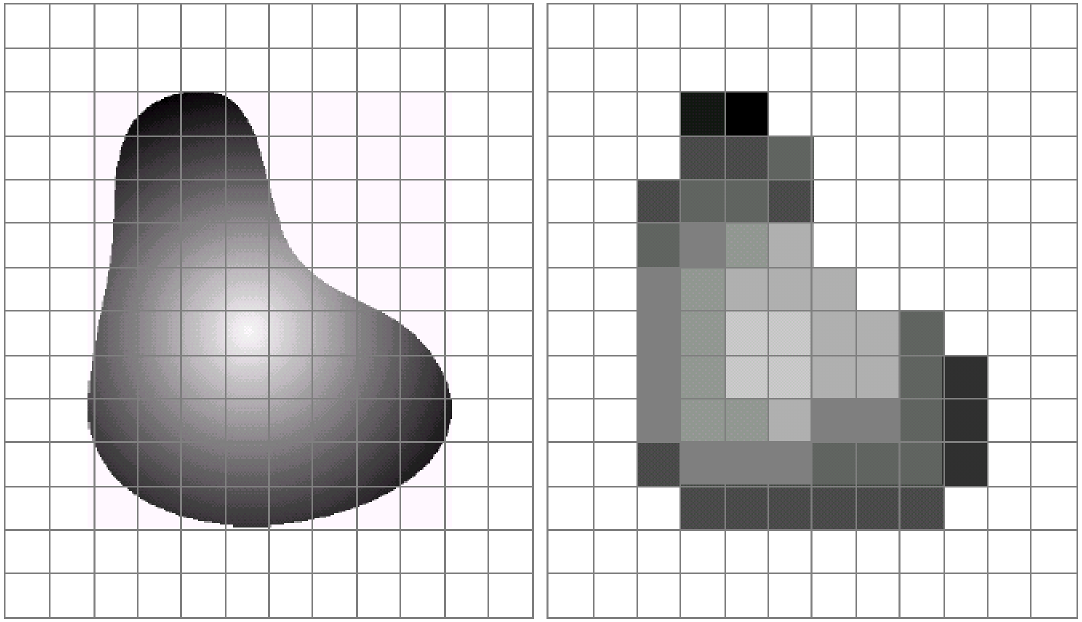
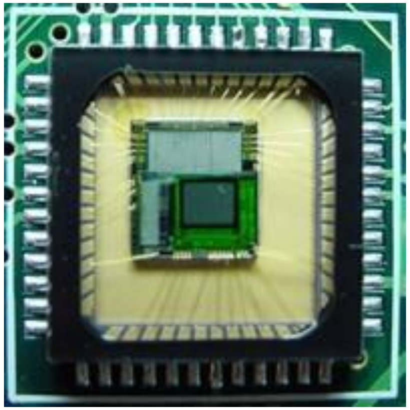


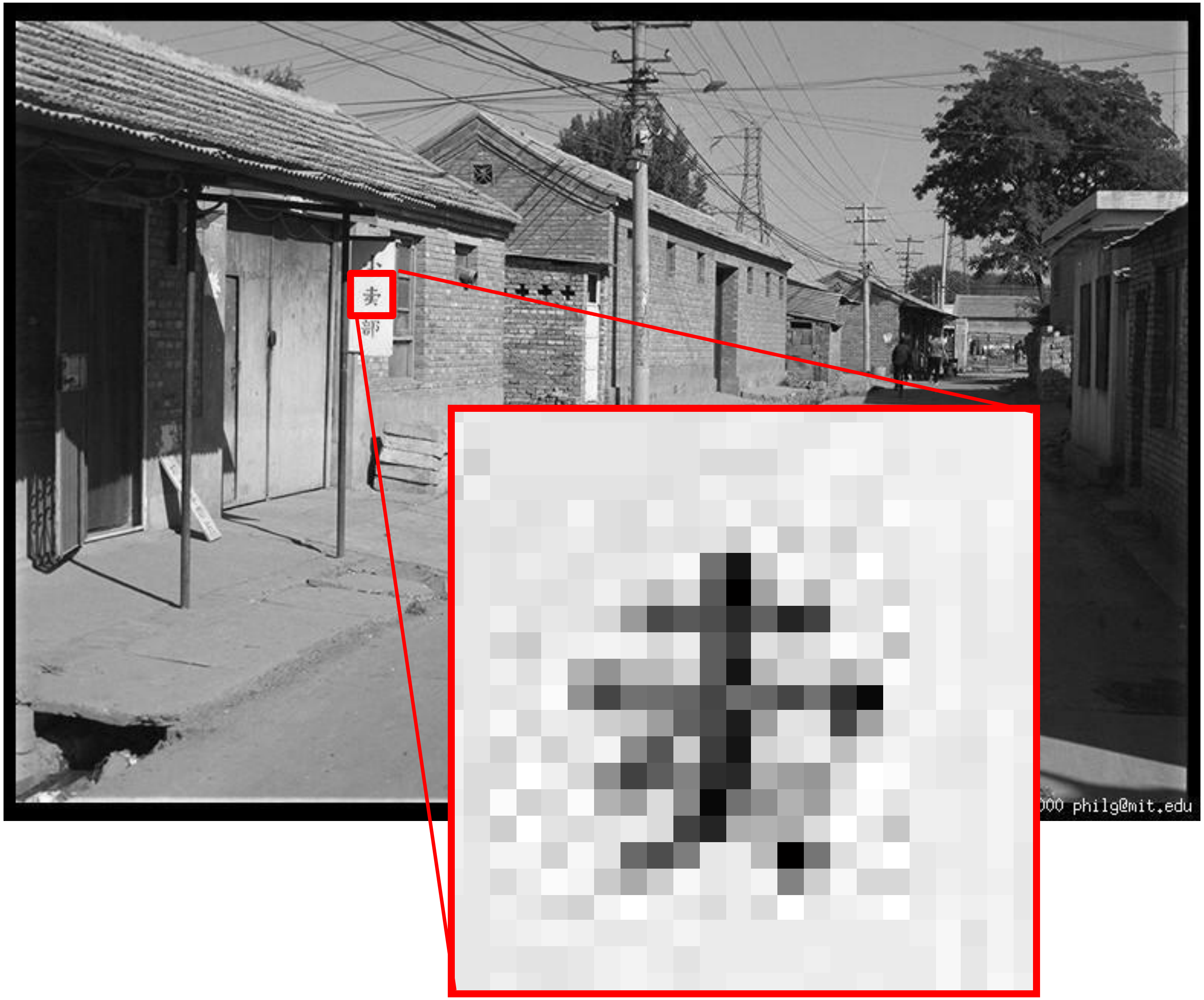
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



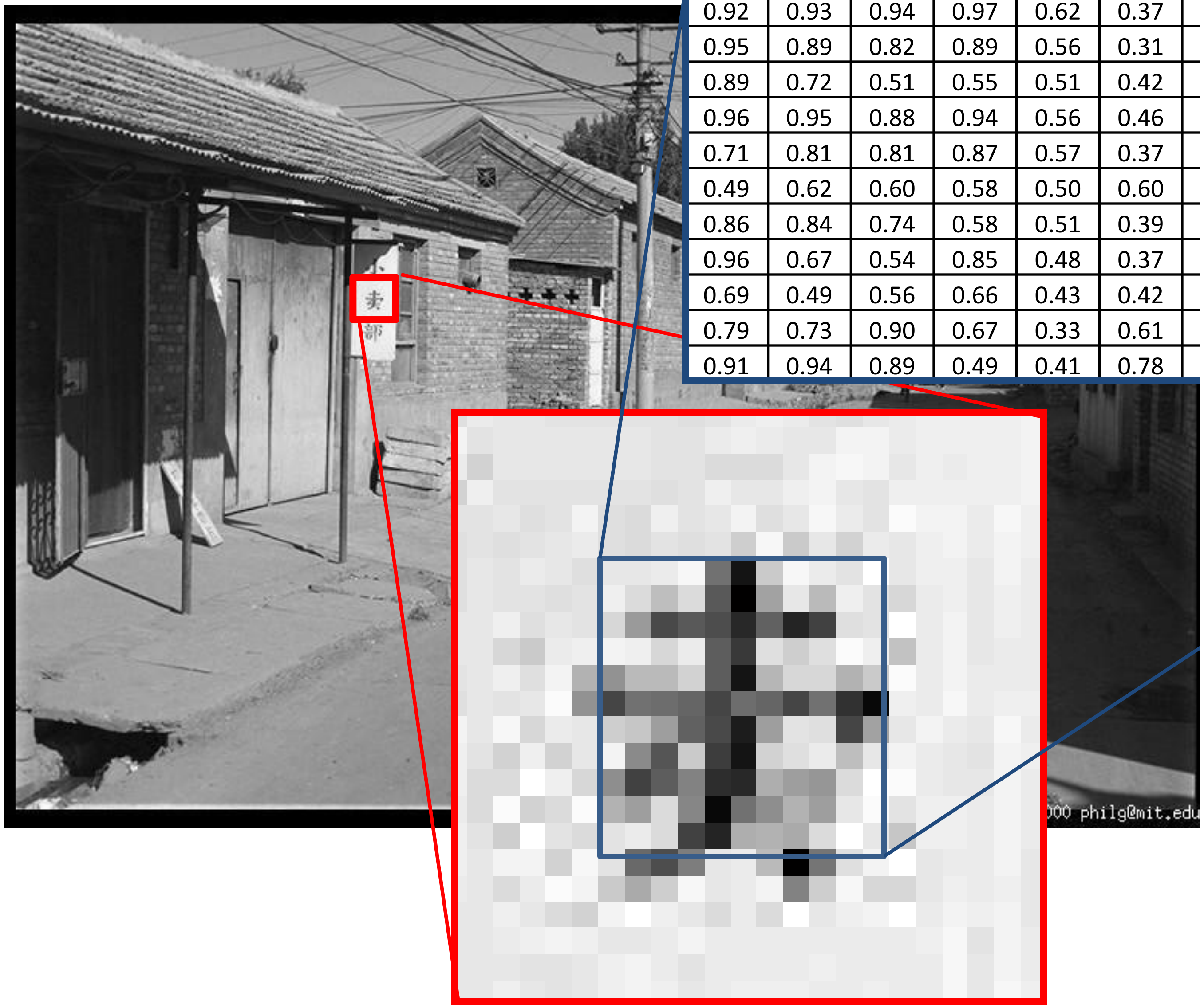
CMOS sensor

Each sensor cell records amount of light coming in at a small range of orientations

The raster image (pixel matrix)



The raster image (pixel matrix)

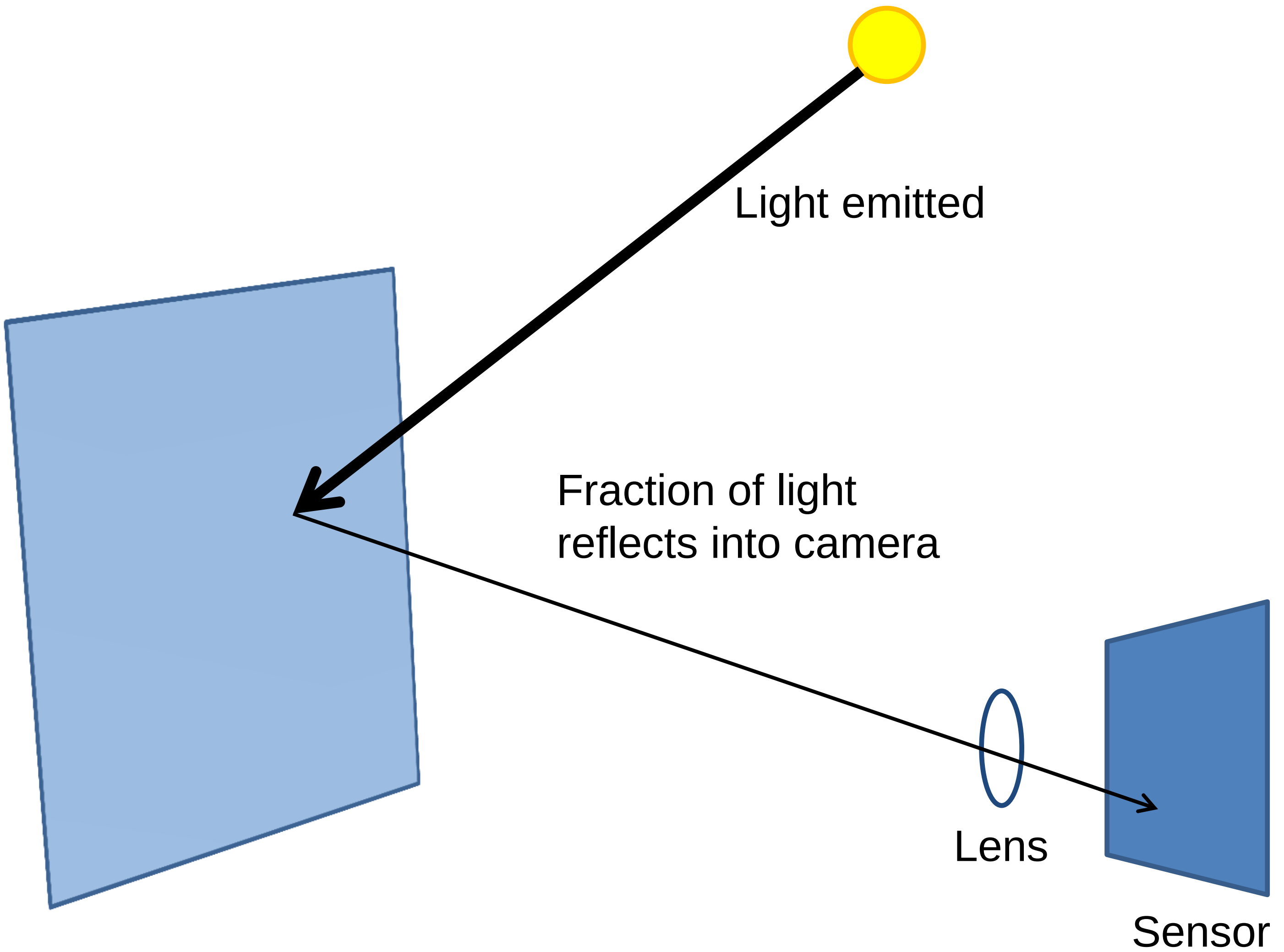


0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

Today's class: Light and Shading

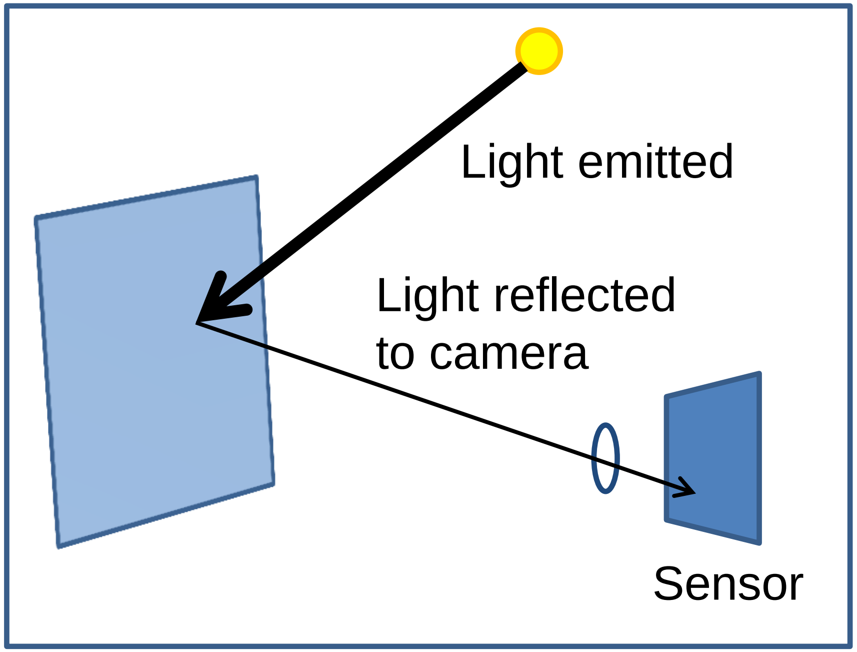
- What determines a pixel's intensity?
- What can we infer about the scene from pixel intensities?

How does a pixel get its value?



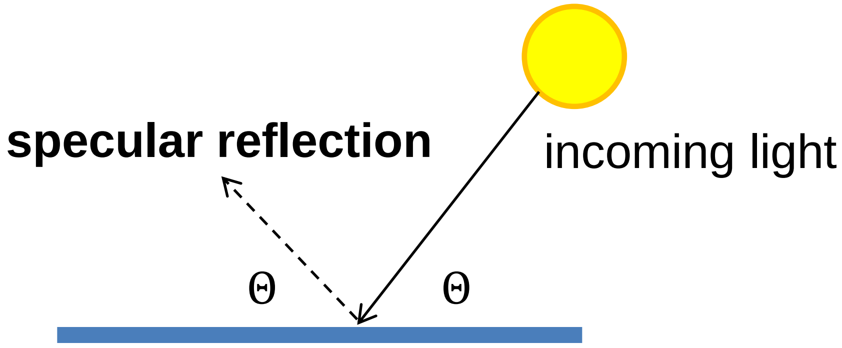
How does a pixel get its value?

- Major factors
  - Illumination strength and direction
  - Surface geometry
  - Surface material
  - Nearby surfaces
  - Camera gain/exposure

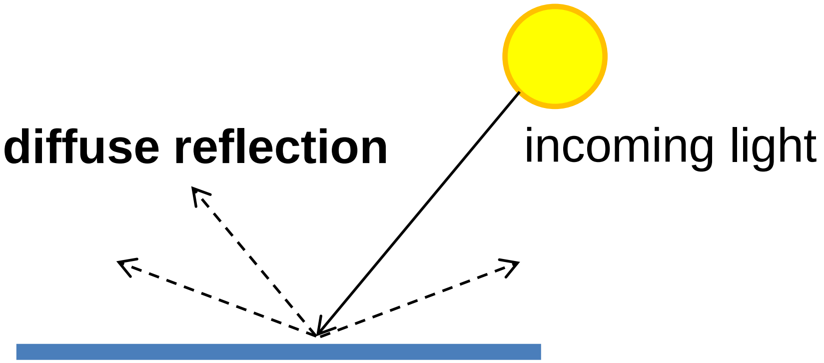


Basic models of reflection

- Specular: light bounces off at the incident angle
  - E.g., mirror

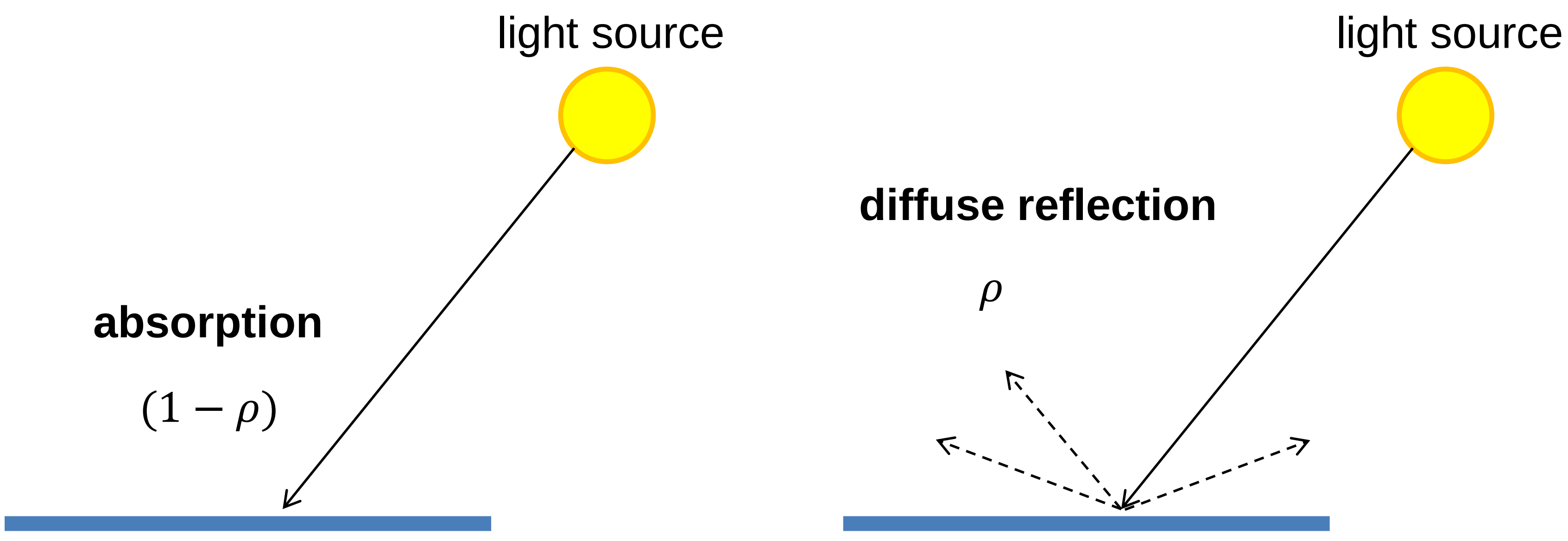


- Diffuse: light scatters in all directions
  - E.g., brick, cloth, rough wood



Lambertian reflectance model

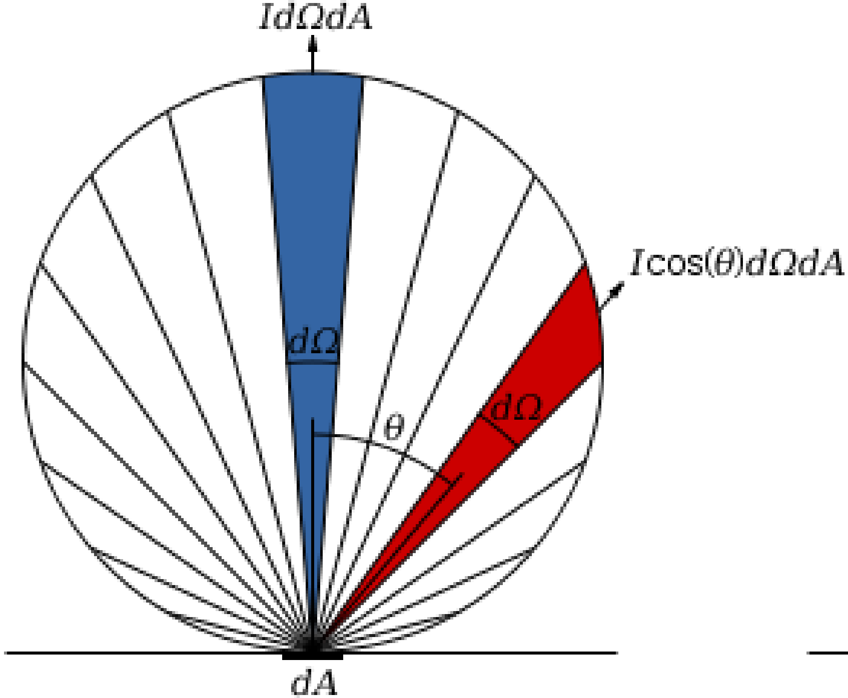
- Some light is absorbed (function of albedo ρ)
- Remaining light is scattered (diffuse reflection)
- Examples: soft cloth, concrete, matte paints

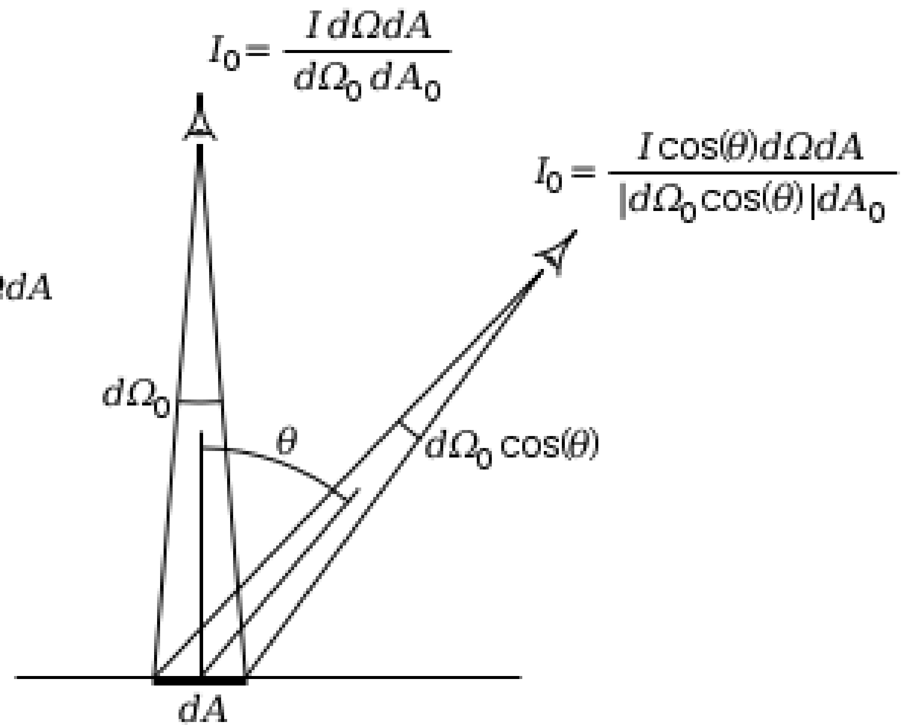


Diffuse reflection: Lambert's cosine law

Intensity does *not* depend on viewer angle.

- Amount of reflected light proportional to $\cos(\theta)$
- Visible solid angle also proportional to $\cos(\theta)$



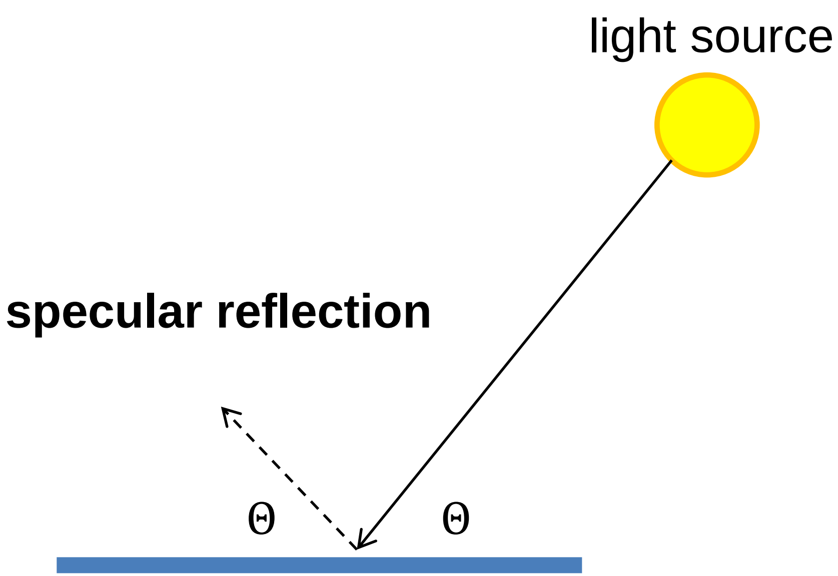


http://en.wikipedia.org/wiki/Lambert%27s_cosine_law

Specular Reflection

- Reflected direction depends on light orientation and surface normal
  - E.g., mirrors are fully specular
  - Most surfaces can be modeled with a mixture of diffuse and specular components

Flickr, by suzysputnik



Flickr, by piratejohnny

Most surfaces have both specular and diffuse components

- Specularity = spot where specular reflection dominates (typically reflects light source)

Photo: northcountryhardwoodfloors.com

Typically, specular component is small

Intensity and Surface Orientation

Intensity depends on illumination angle because less light comes in at oblique angles.

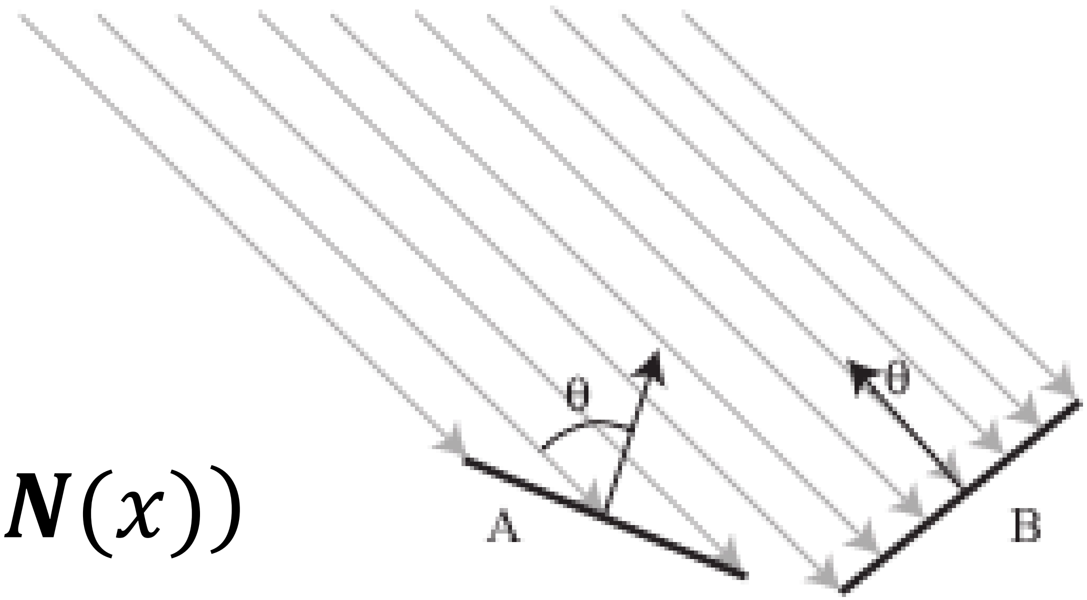
ρ = albedo

$\boldsymbol{S}$ = directional source

$\boldsymbol{N}$ = surface normal

I = reflected intensity

$$I(x) = \rho(x)(\boldsymbol{S} \cdot \boldsymbol{N}(x))$$

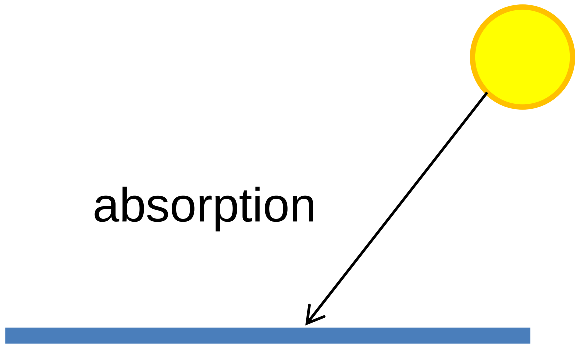


Slide: Forsyth

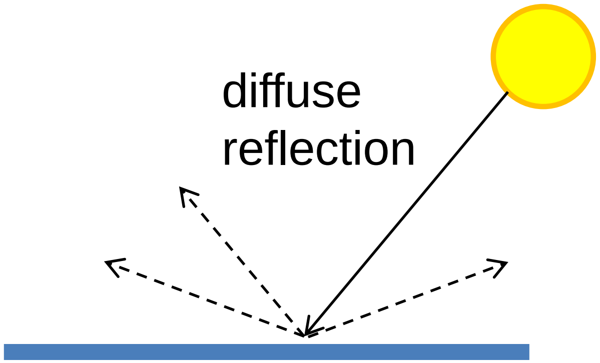

1
2

Recap

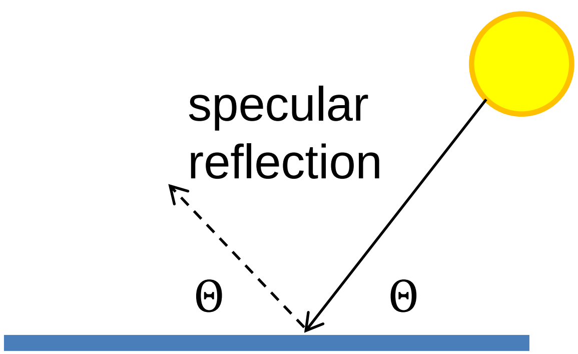
- When light hits a typical surface
  - Some light is absorbed (1-ρ)
    - More absorbed for low albedos



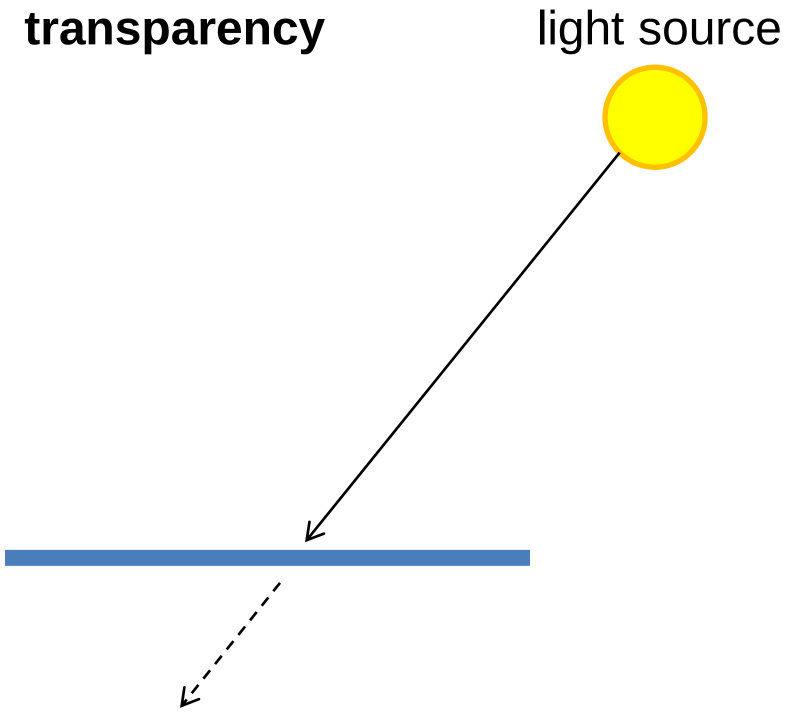
  - Some light is reflected diffusely
    - Independent of viewing direction

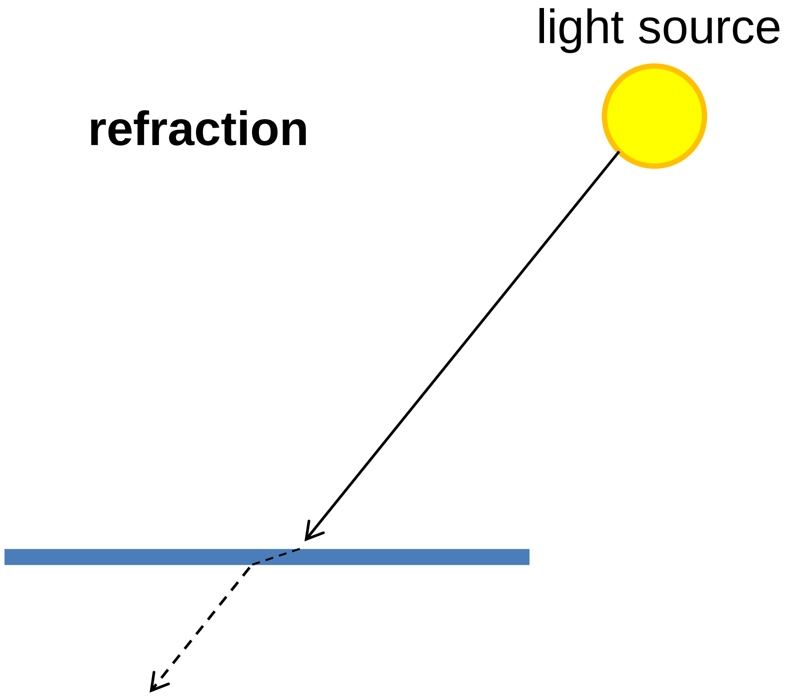


  - Some light is reflected specularly
    - Light bounces off (like a mirror), depends on viewing direction

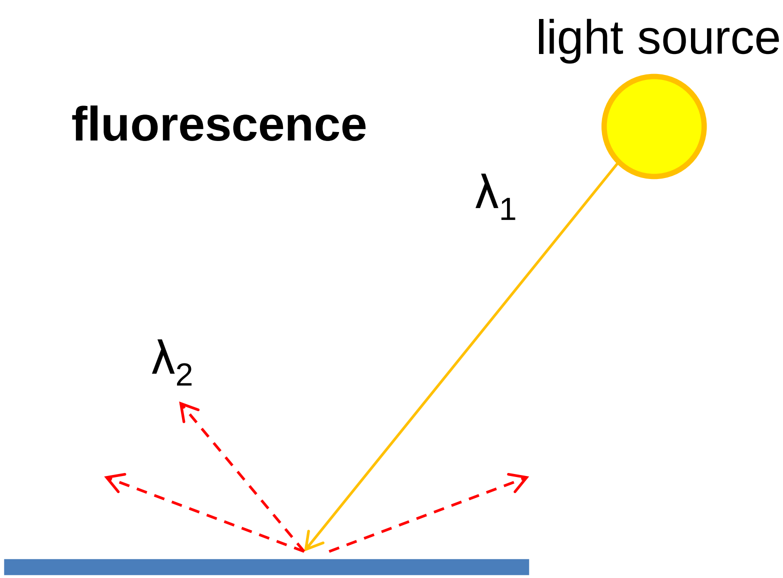


Other possible effects

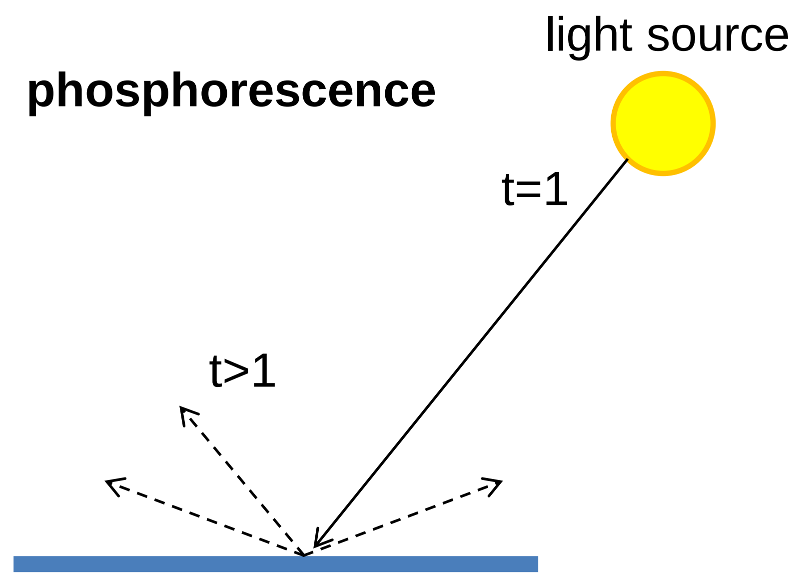




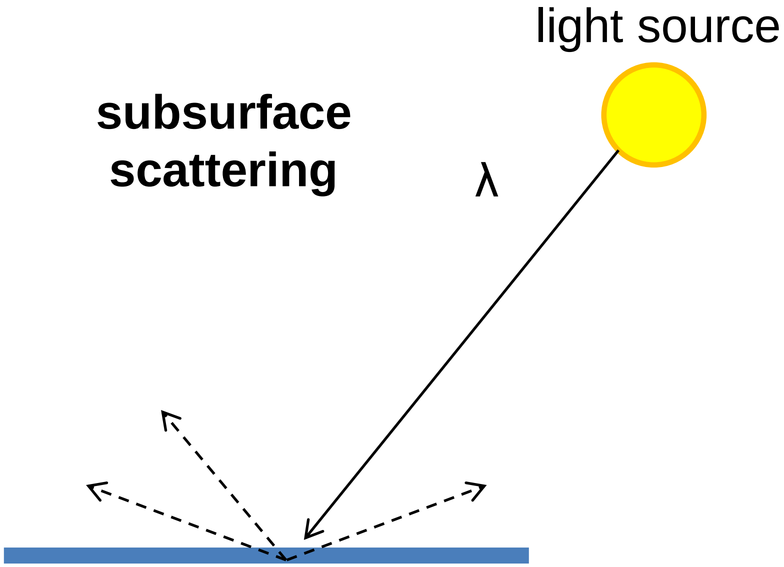
fluorescence



phosphorescence

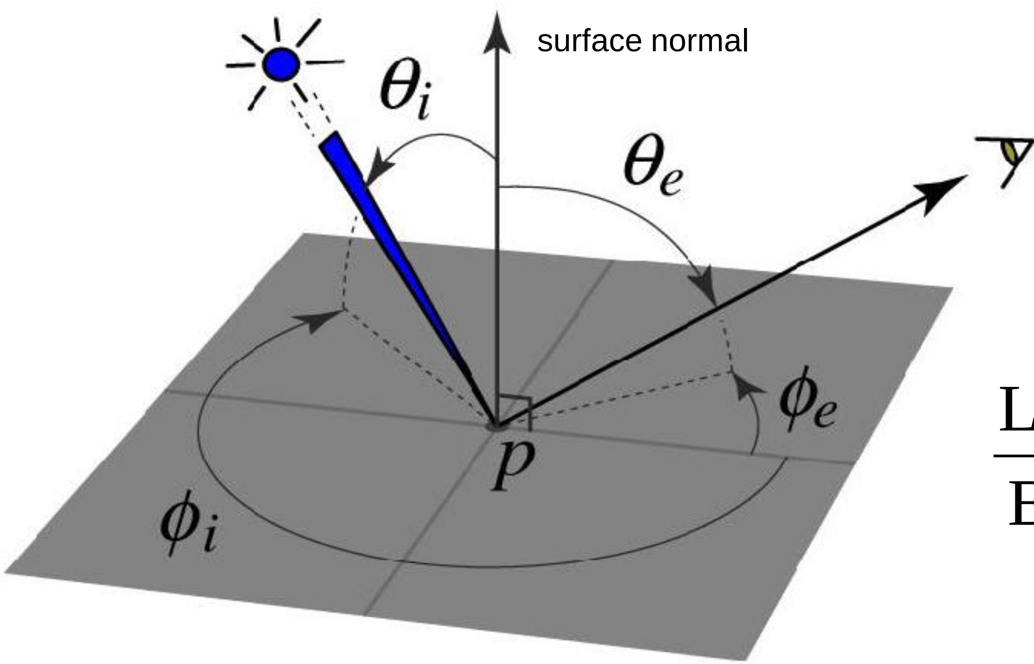


subsurface scattering



BRDF: Bidirectional Reflectance Distribution Function

- Model of local reflection that tells how bright a surface appears when viewed from one direction when light falls on it from another



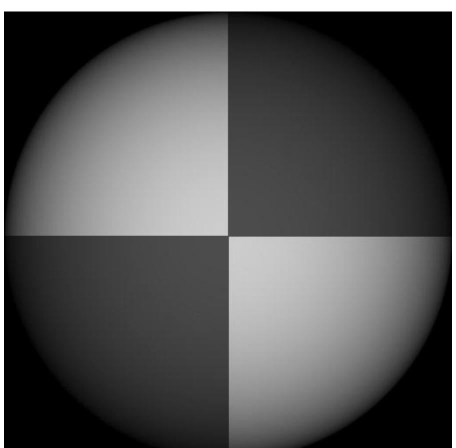
$$\rho(\theta_i, \phi_i, \theta_e, \phi_e; \lambda) =$$

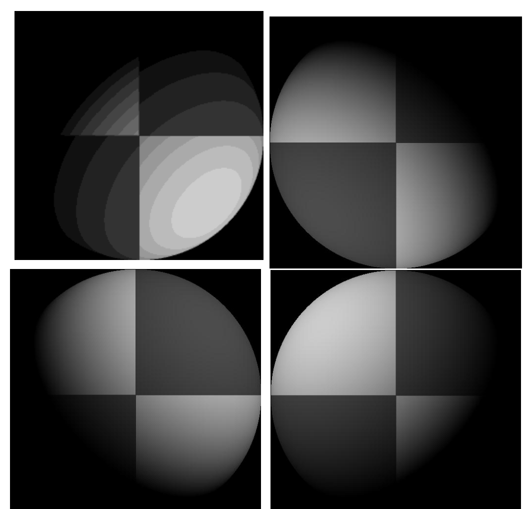
$$\frac{L_e(\theta_e, \phi_e)}{E_i(\theta_i, \phi_i)} = \frac{L_e(\theta_e, \phi_e)}{L_i(\theta_i, \phi_i) \cos\theta_i d\omega}$$

Slide credit: S. Savarese

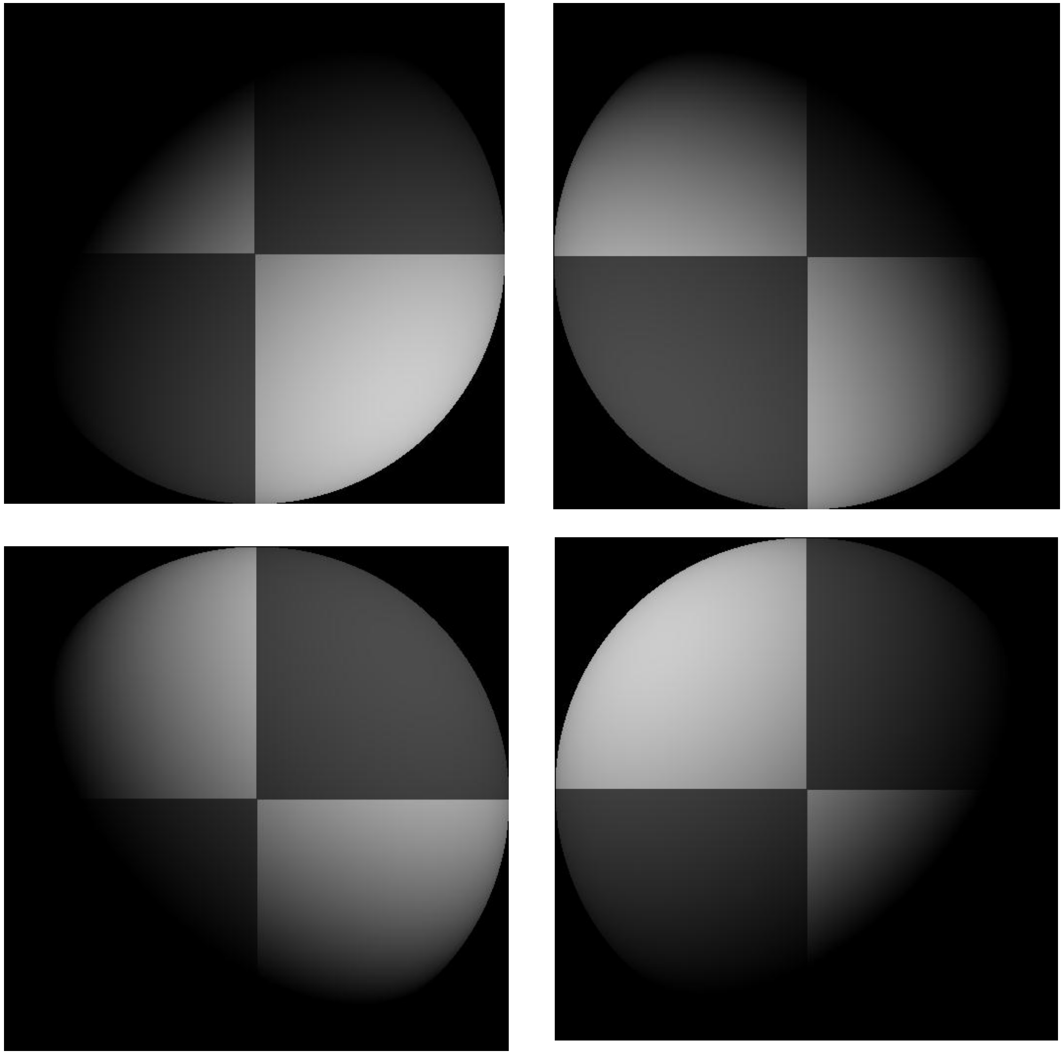
Application: photometric stereo

- Assume:
  - a set of point sources that are infinitely distant
  - a set of pictures of an object, obtained in exactly the same camera/object configuration but using different sources
  - A Lambertian object (or the specular component has been identified and removed)





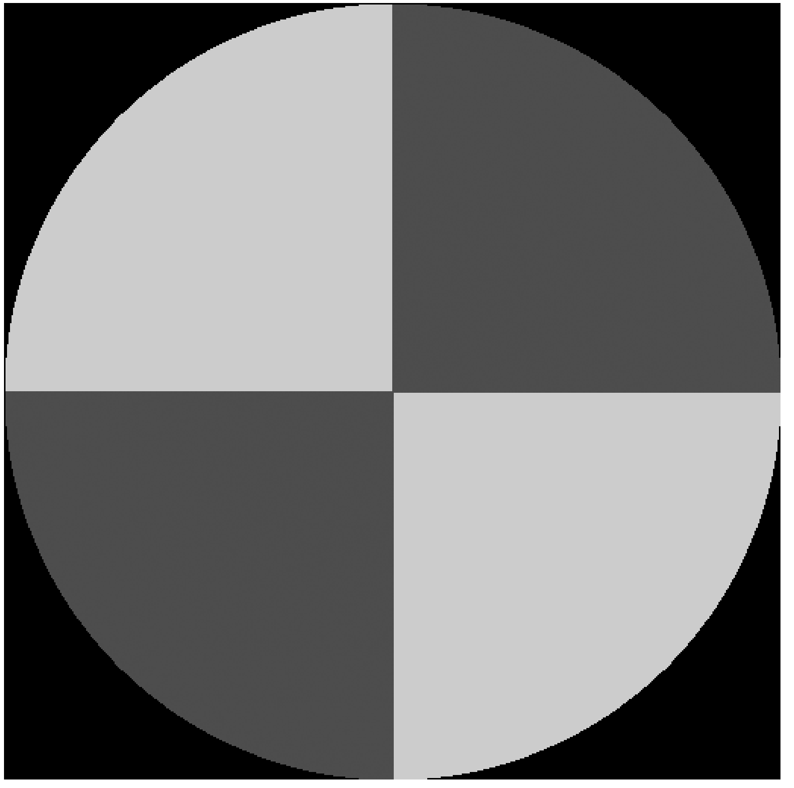
Photometric stereo slides by Forsyth



Each image is: $I_i(x) = \boldsymbol{S}_i \cdot (p(x)\boldsymbol{N}(x))$

So if we have enough images with known sources, we can solve for $\boldsymbol{B}(x) = p(x)\boldsymbol{N}(x)$

albedo times
3D normal

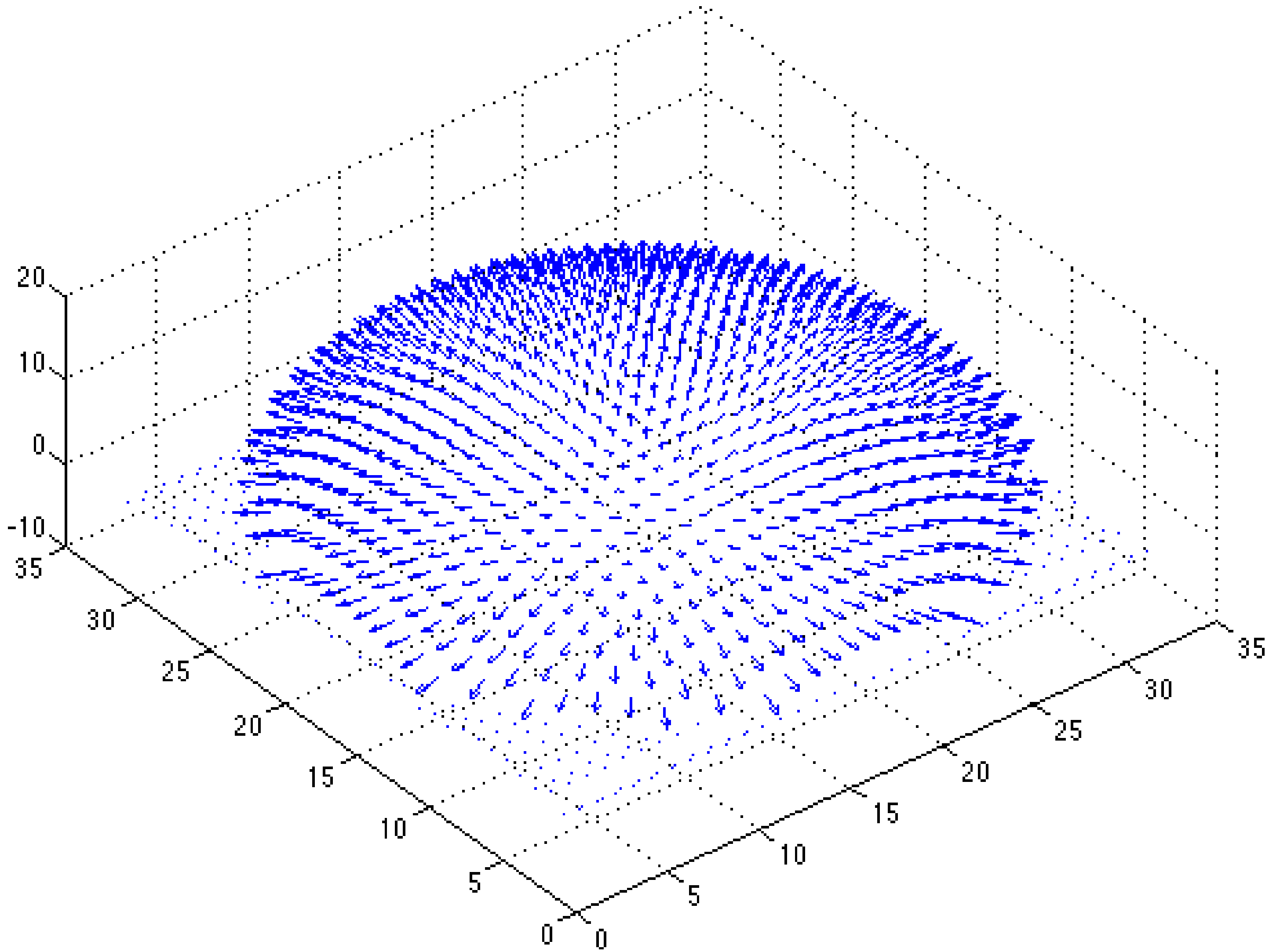


$$\boldsymbol{B}(x) = p(x)\boldsymbol{N}(x)$$

And the albedo (shown here) is given by:

$$p(x) = \sqrt{\boldsymbol{B}(x) \cdot \boldsymbol{B}(x)}$$

(the normal is a unit vector)


20
10
0
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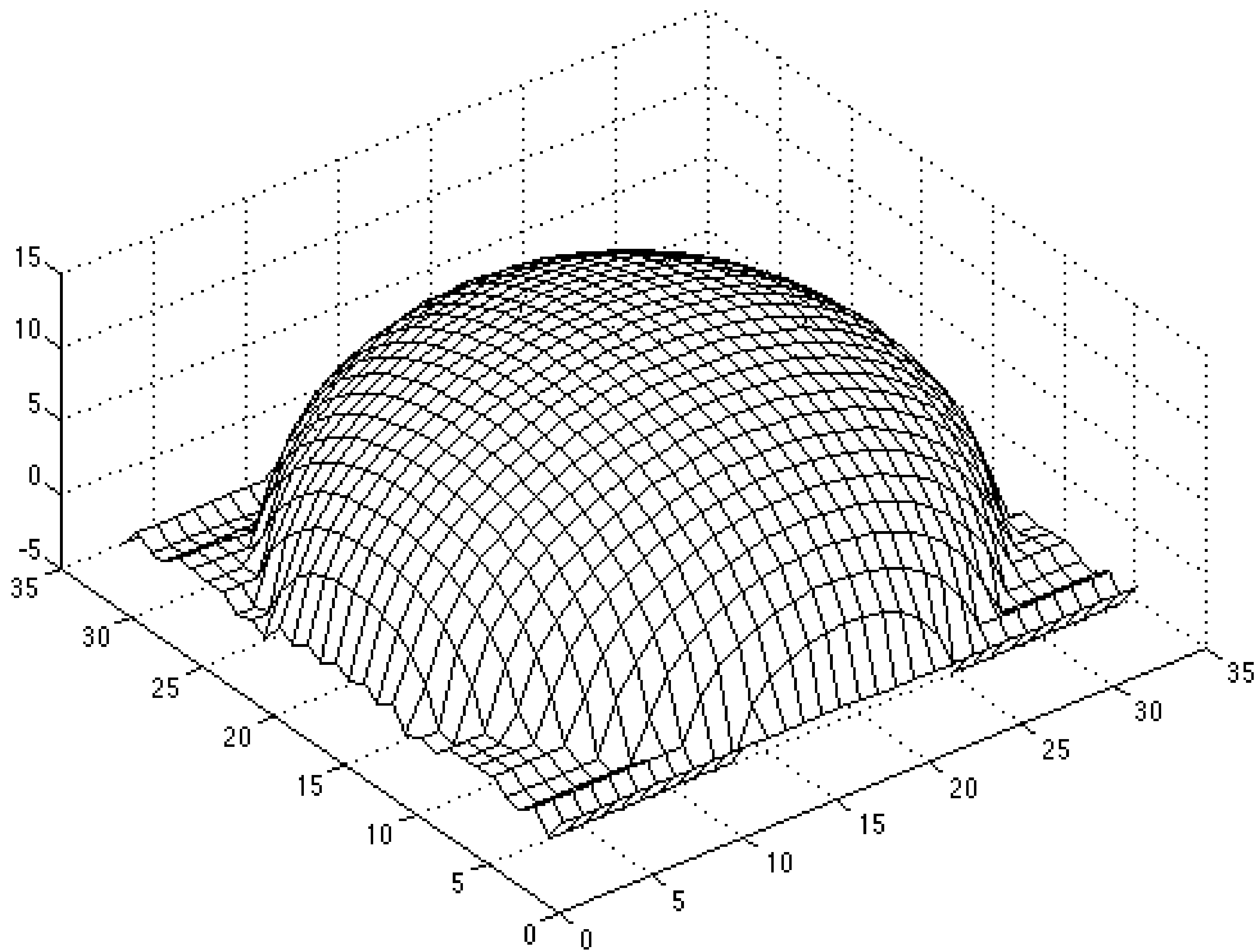
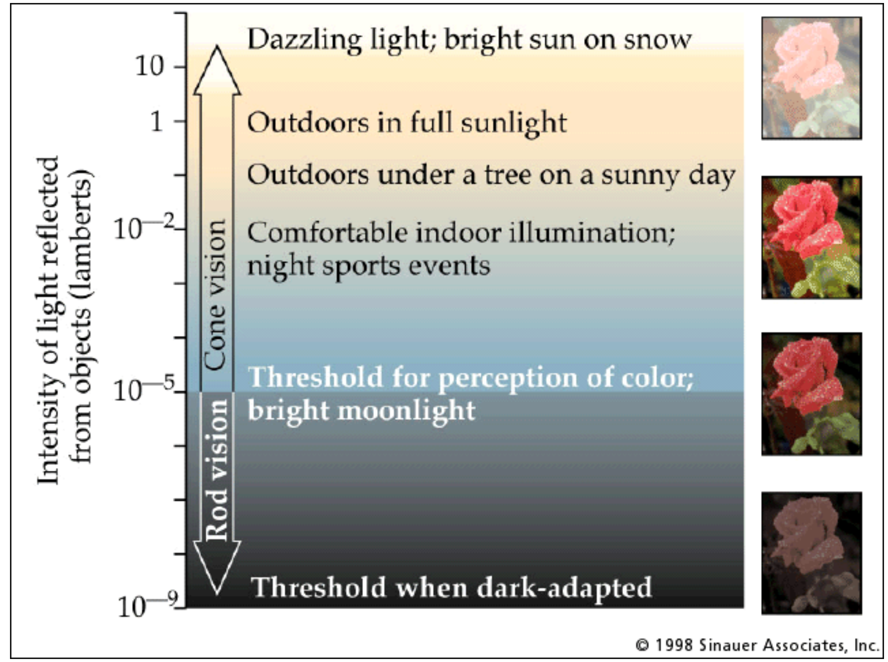
35

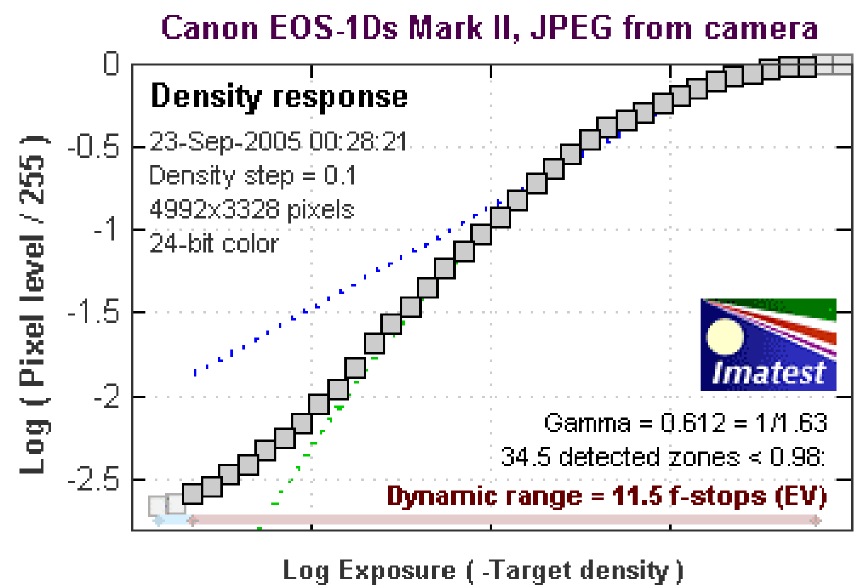


15
10
5
0
-5
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35

Dynamic range and camera response

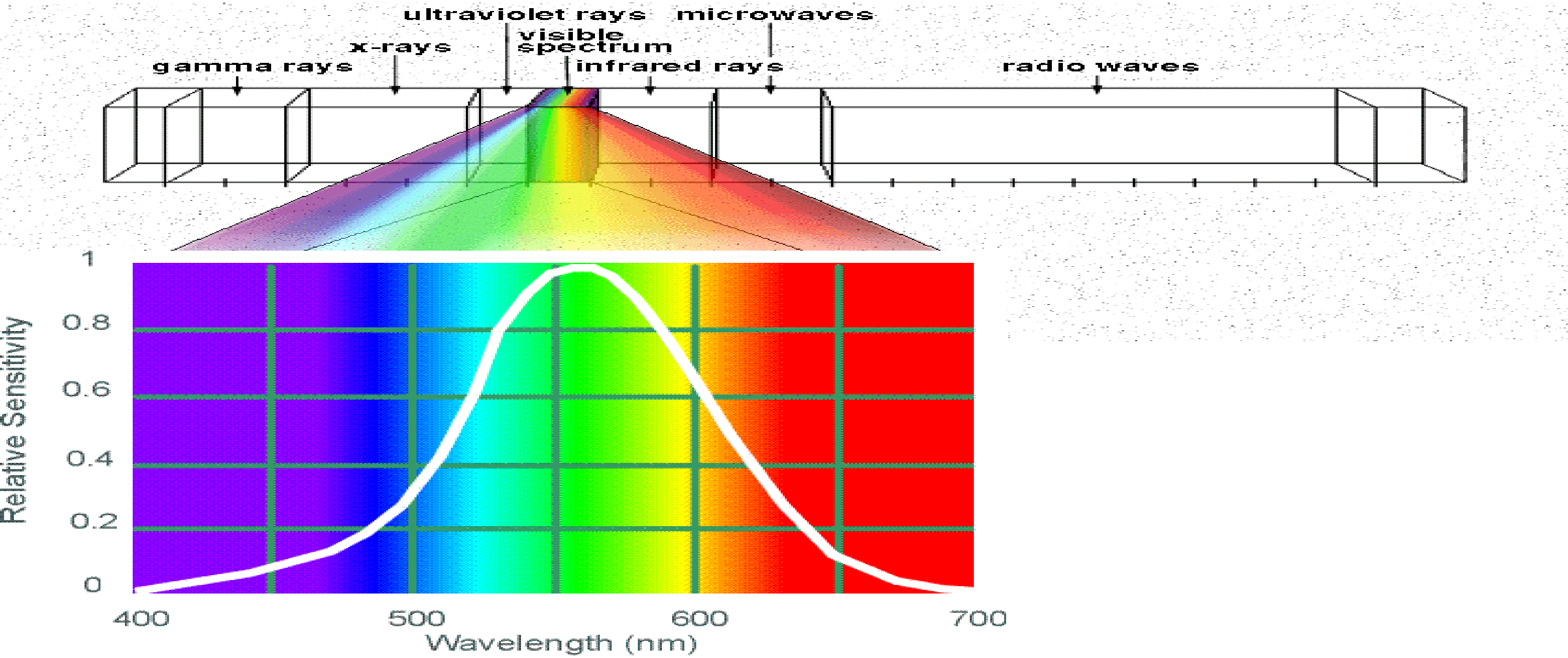
- Typical scenes have a huge dynamic range
- Camera response is roughly linear in the mid range (15 to 240) but non-linear at the extremes
  - called saturation or undersaturation





Color

Light is composed of a spectrum of wavelengths

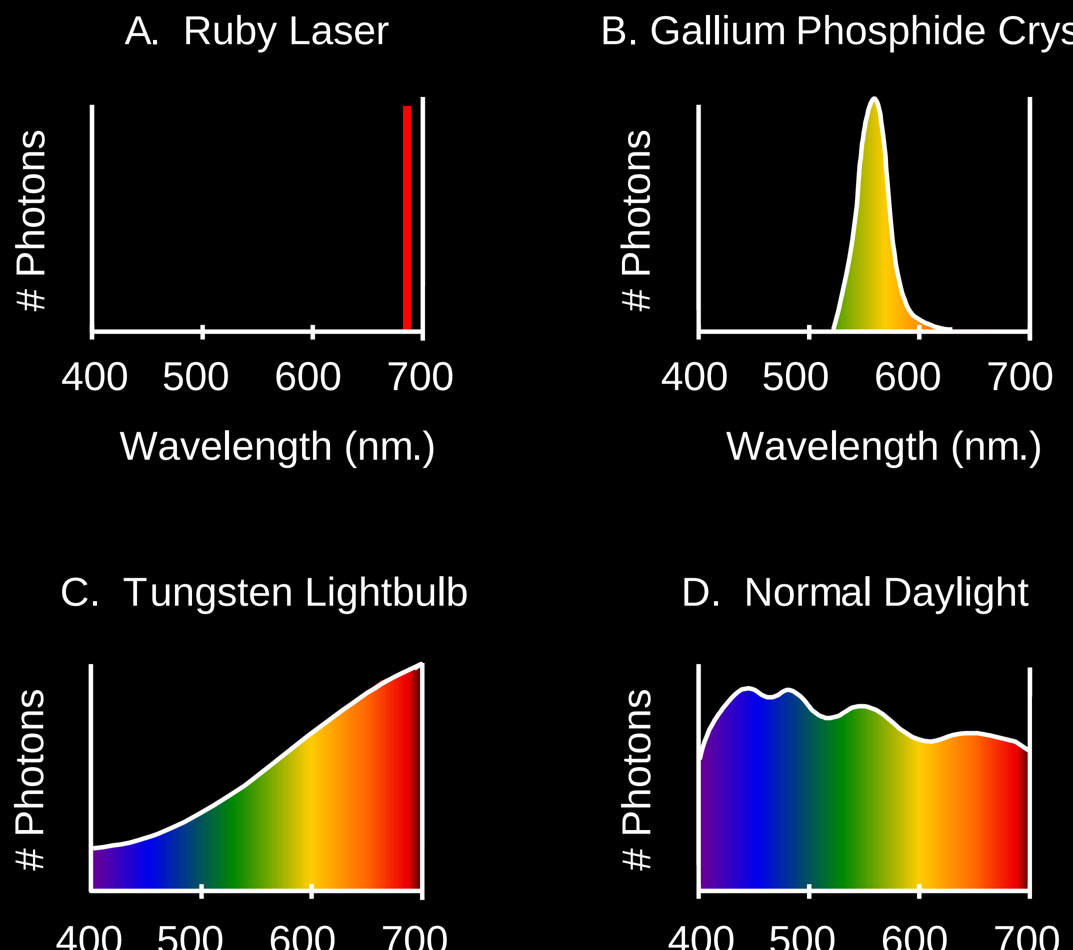


Human Luminance Sensitivity Function

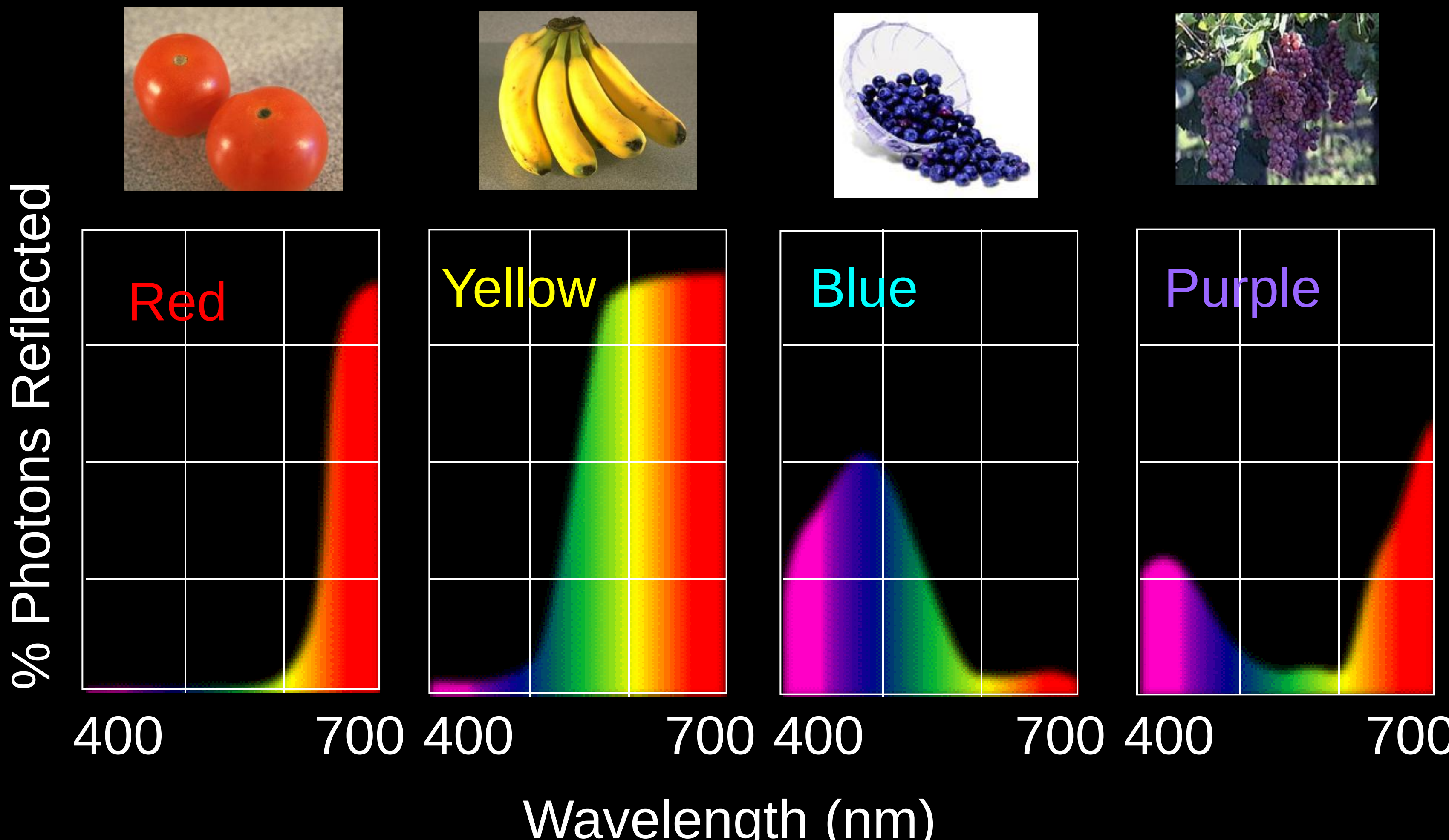
Slide Credit: Efros

http://www.yorku.ca/eye/photopik.htm

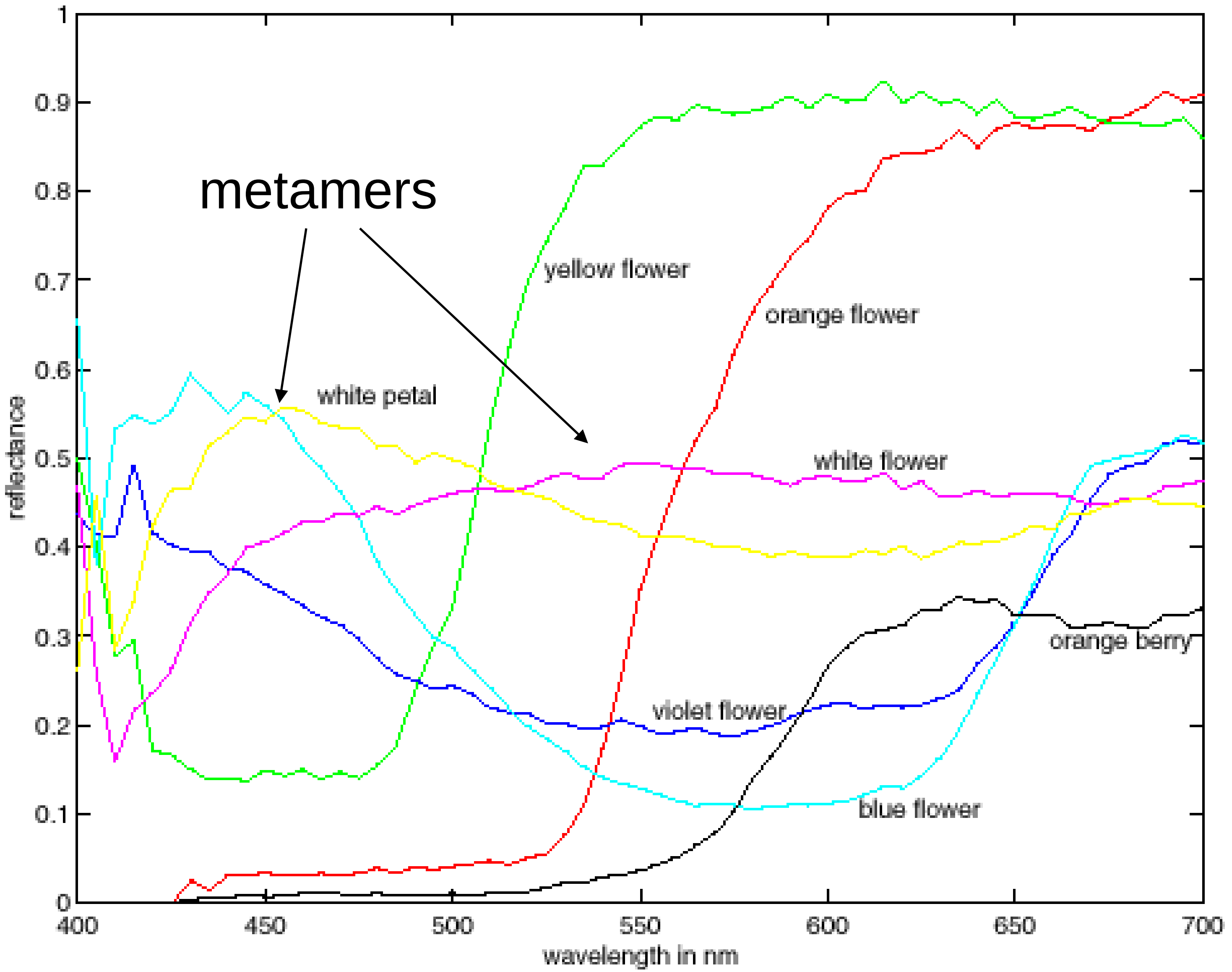
Some examples of the spectra of light sources



Some examples of the reflectance spectra of surfaces

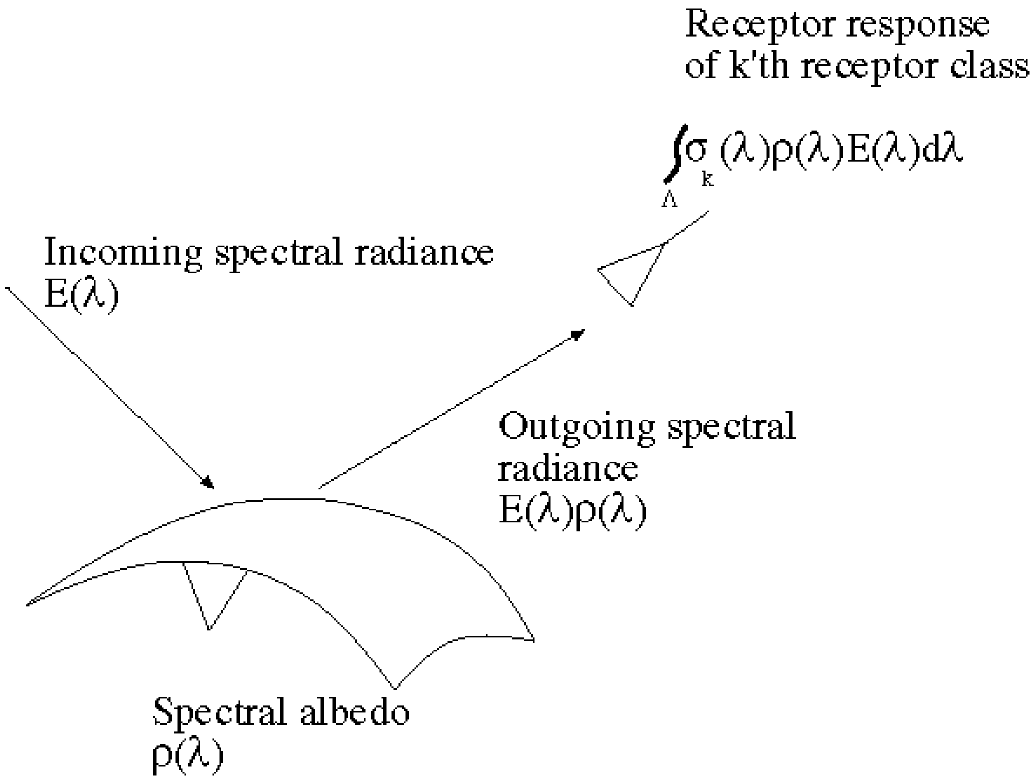


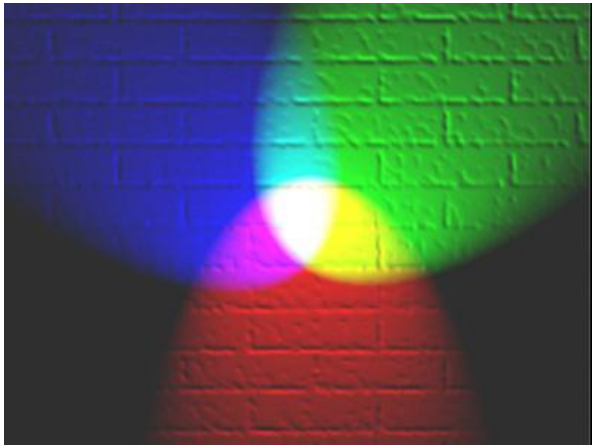
More spectra



The color of objects

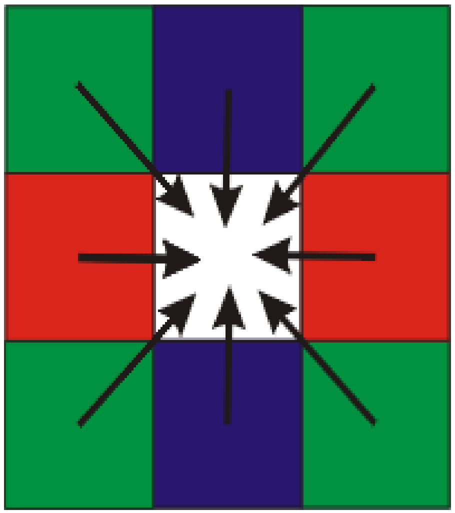
- Colored light arriving at the camera involves two effects
  - The color of the light source (illumination + inter-reflections)
  - The color of the surface

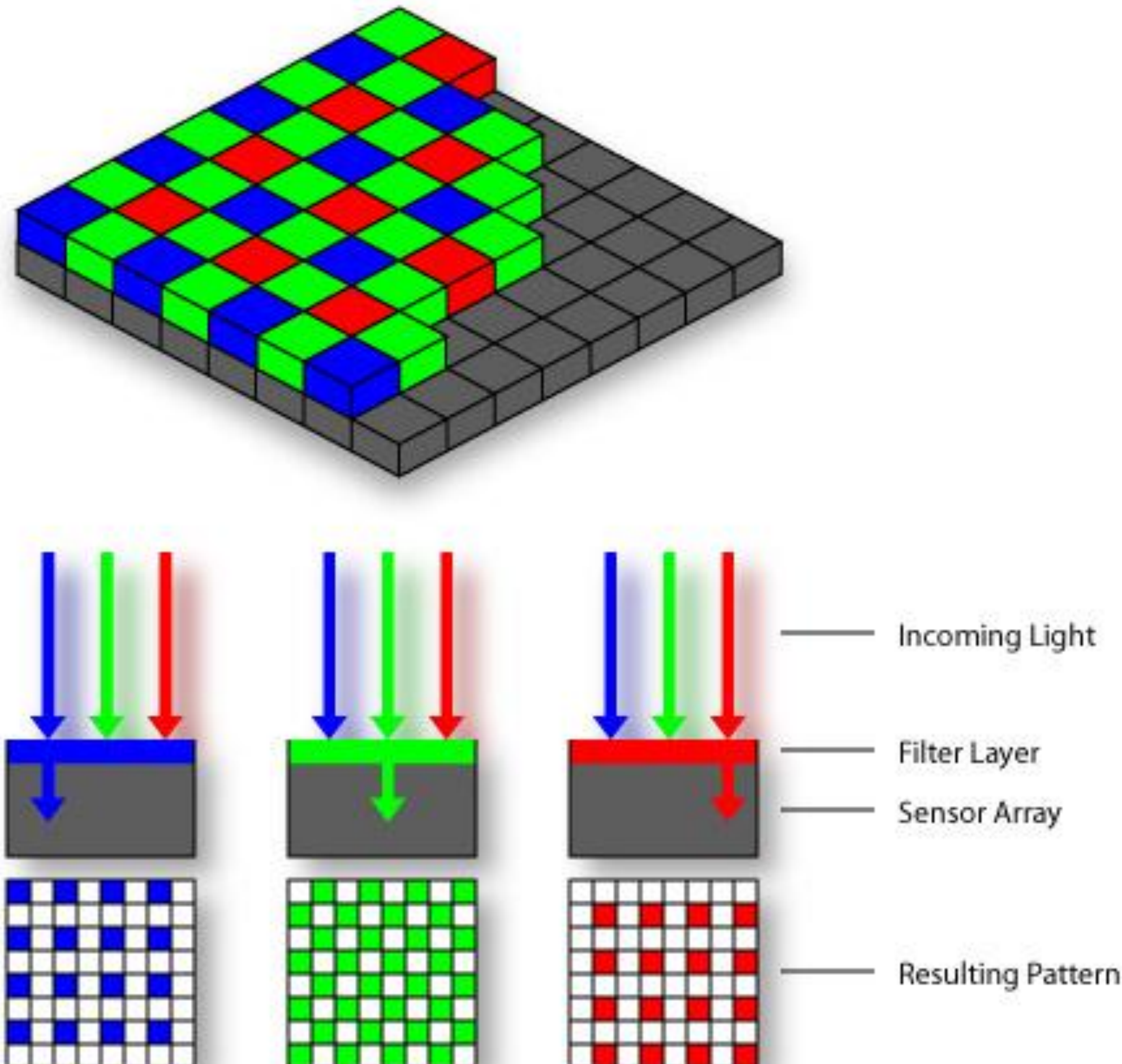




Slide: Forsyth

Color Sensing: Bayer Grid





- Estimate RGB at each cell from neighboring values

http://en.wikipedia.org/wiki/Bayer_filter

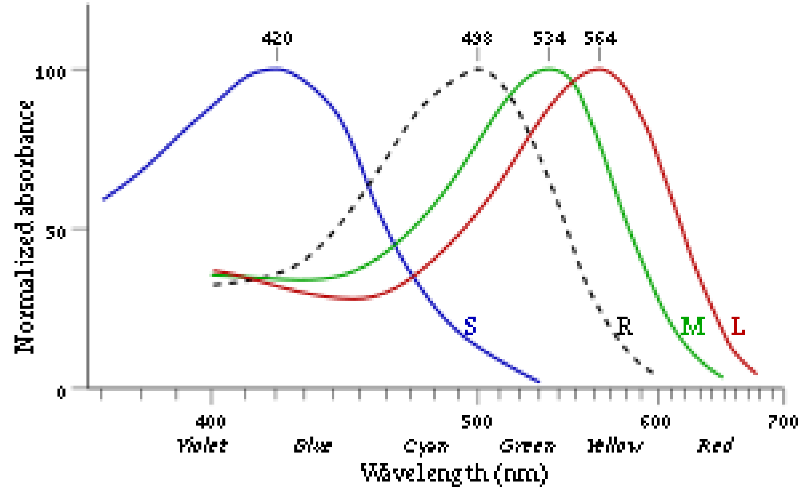
Slide by Steve Seitz

Color Image

Why RGB?

If light is a spectrum, why are images RGB?

Human color receptors

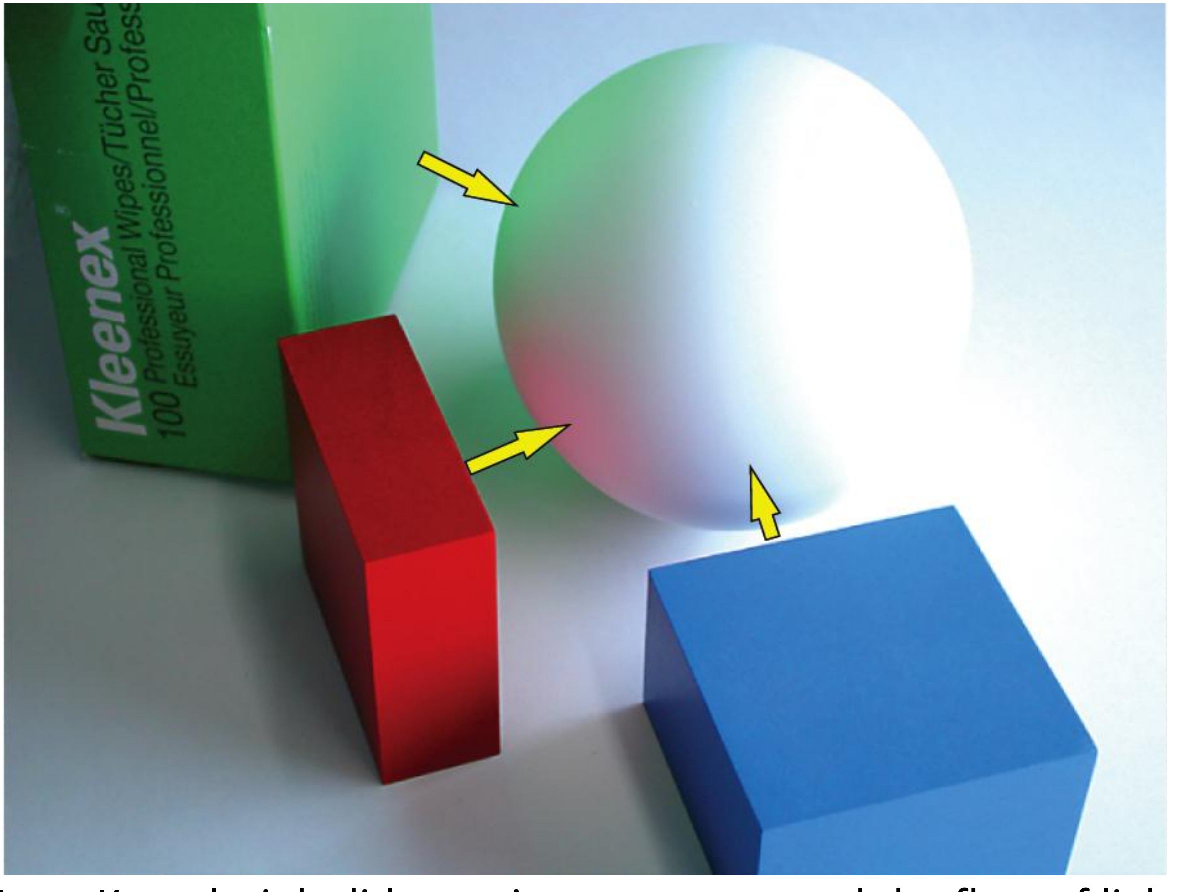


- Long (red), Medium (green), and Short (blue) cones, plus intensity rods
- Fun facts
  - “M” and “L” on the X-chromosome
    - That’s why men are more likely to be color blind (see what it’s like: http://www.vischeck.com/vischeck/vischeckURL.php)
  - “L” has high variation, so some women are tetrachromatic
  - Some animals have 1 (night animals), 2 (e.g., dogs), 4 (fish, birds), 5 (pigeons, some reptiles/amphibians), or even 12 (mantis shrimp) types of cones

http://en.wikipedia.org/wiki/Color_vision

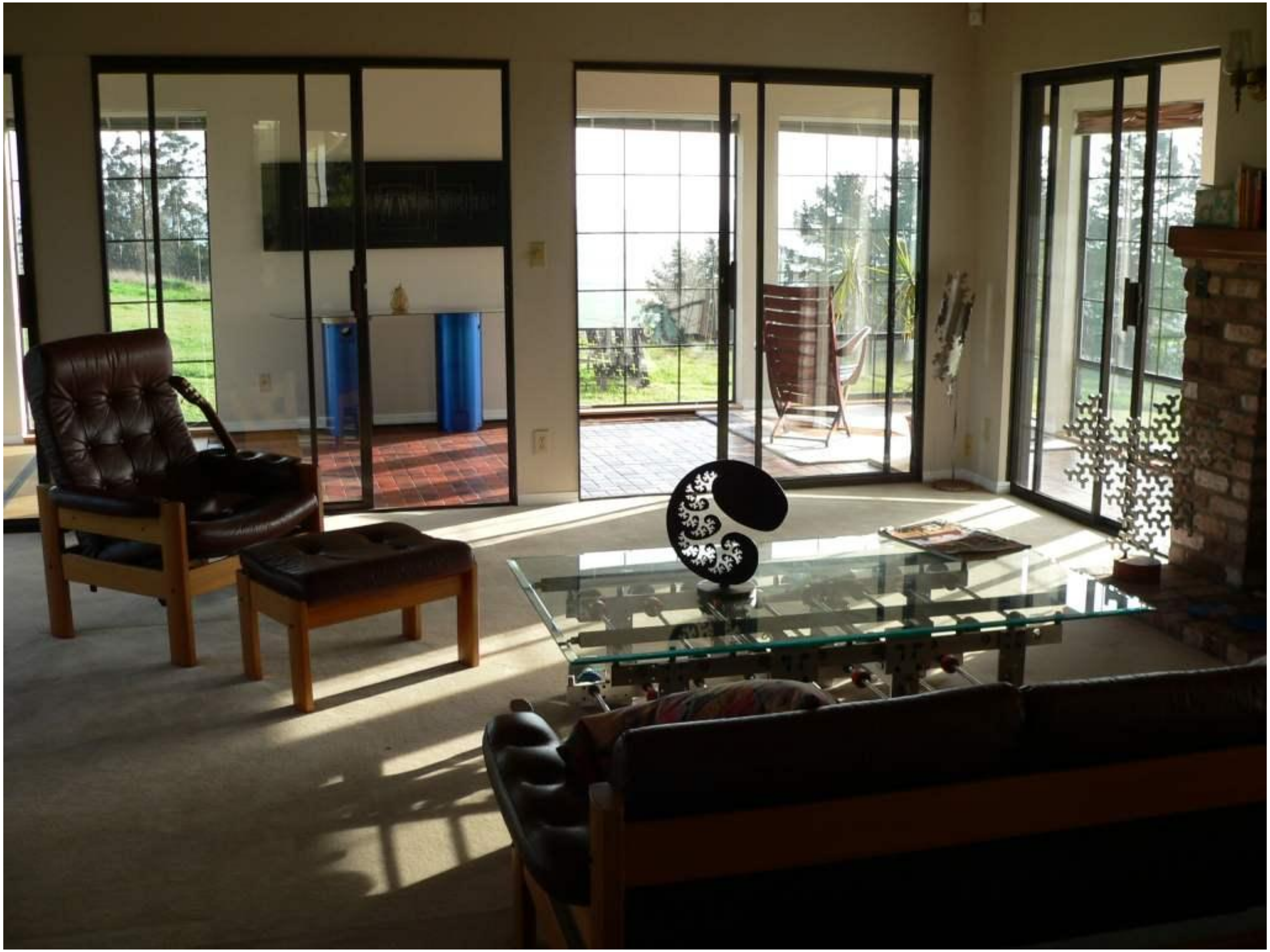
So far: light→surface→camera

- Called a local illumination model
- But much light comes from surrounding surfaces

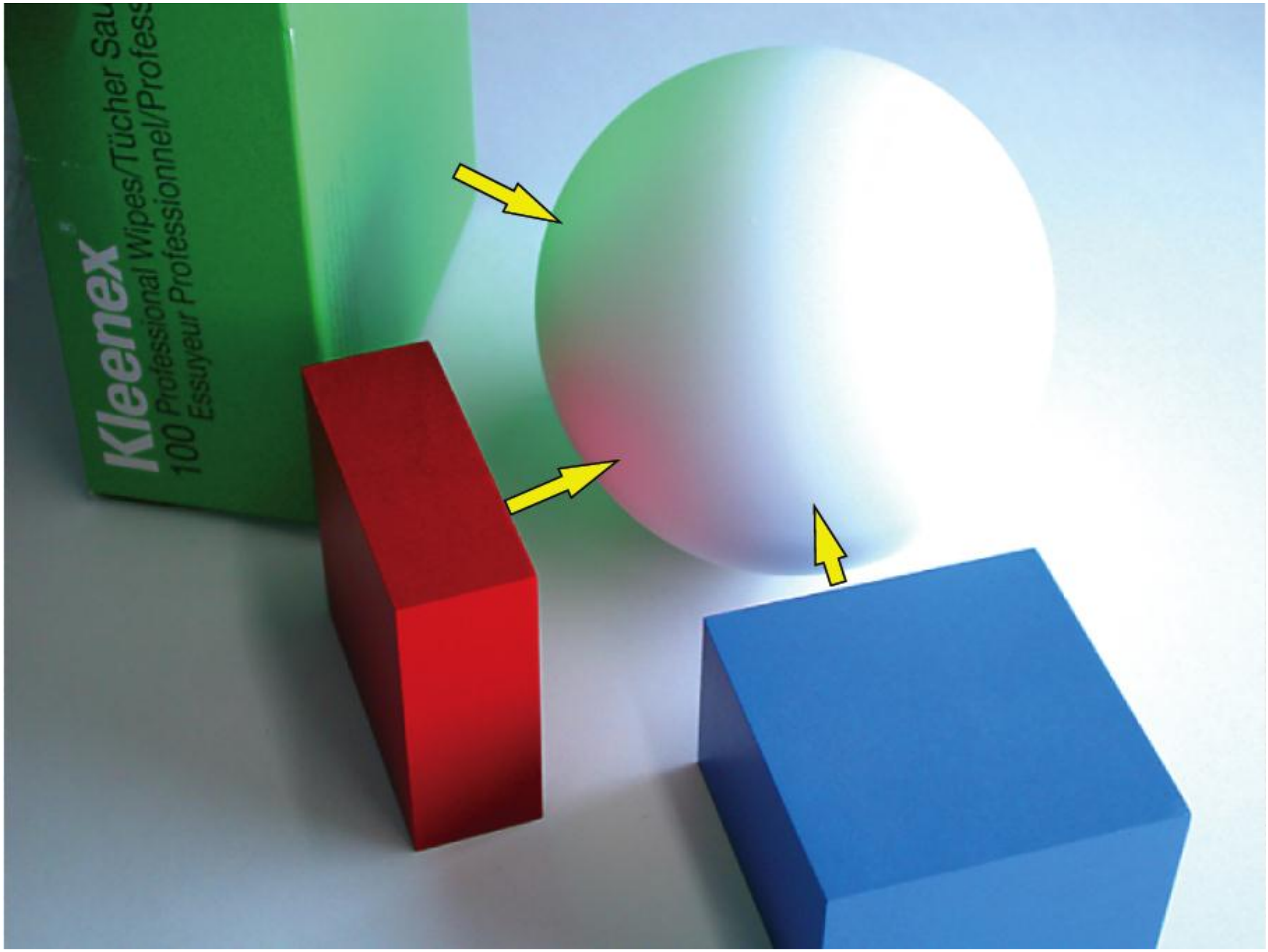


From Koenderink slides on image texture and the flow of light

Inter-reflection is a major source of light



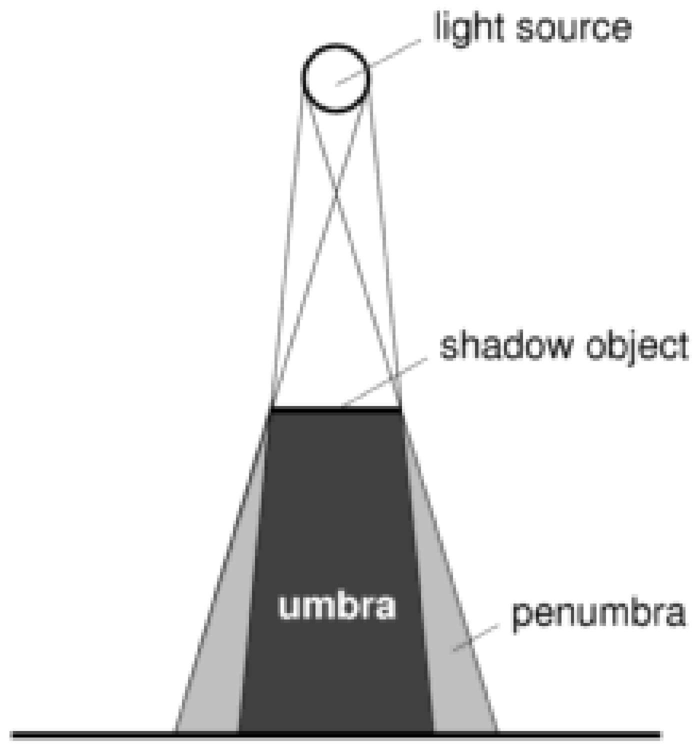
Inter-reflection affects the apparent color of objects



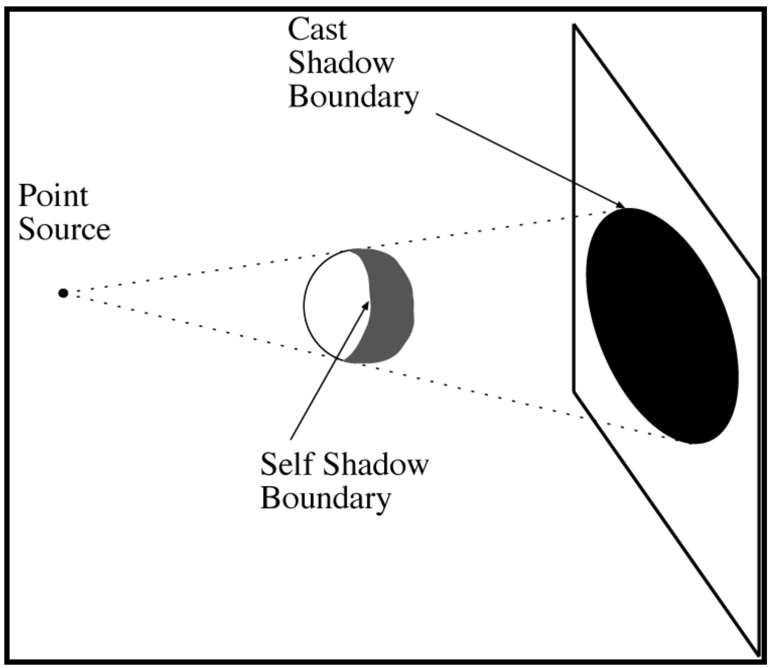
From Koenderink slides on image texture and the flow of light

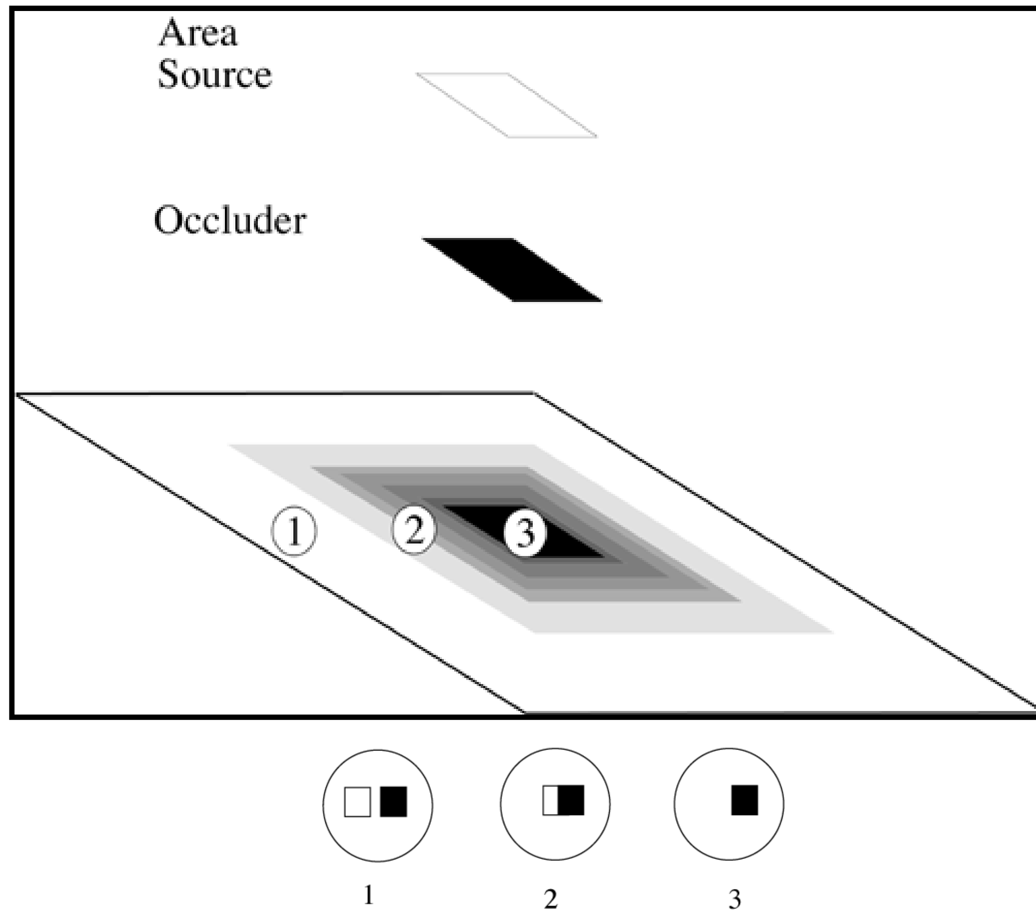
Scene surfaces also cause shadows

- Shadow: reduction in intensity due to a blocked source



Shadows

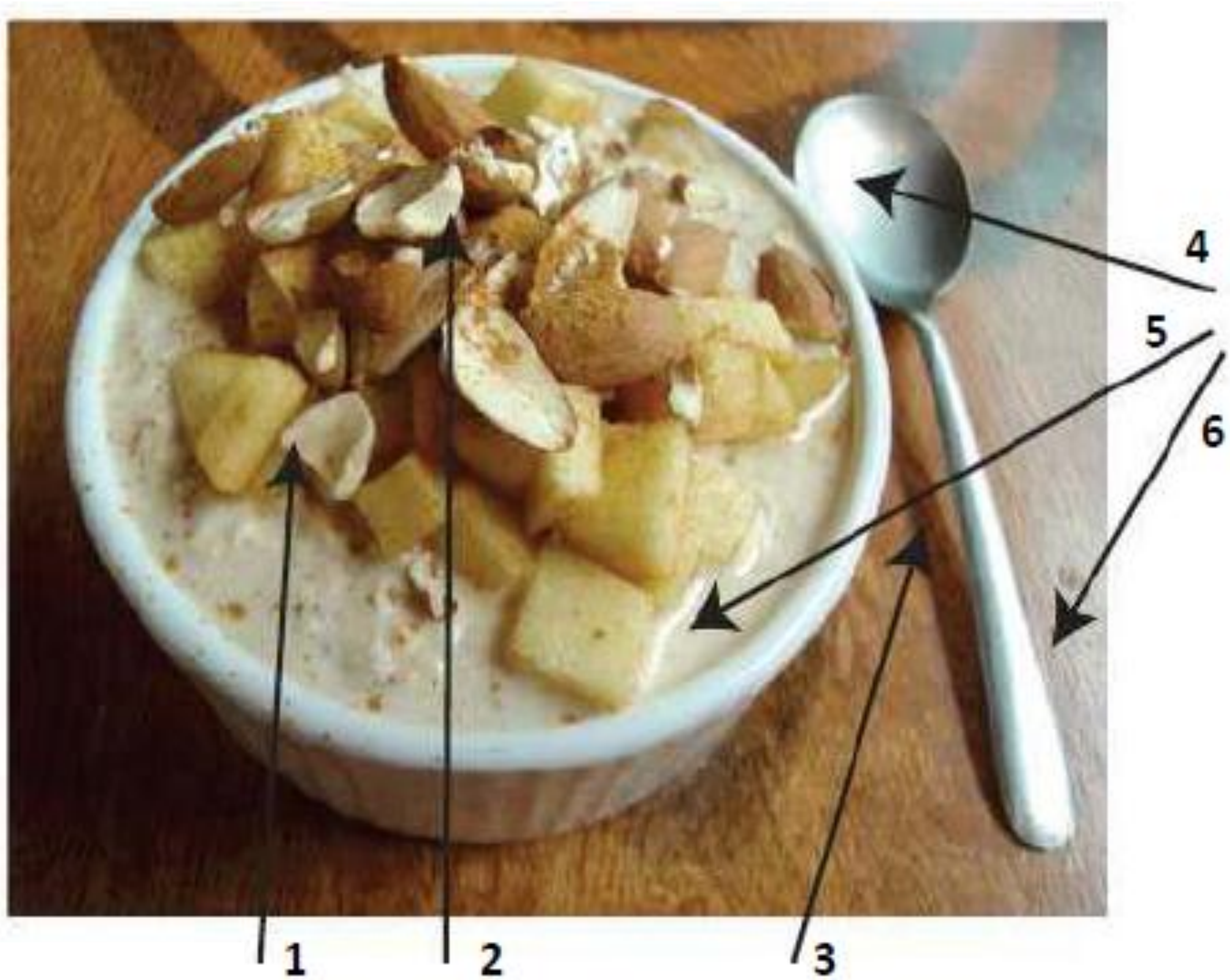

Cast
Shadow
Boundary
Point
Source
Self Shadow
Boundary


Area
Source
Occluder
1
2
3
1
2
3

Models of light sources

- Distant point source
  - One illumination direction
  - E.g., sun
- Area source
  - E.g., white walls, diffuser lamps, sky
- Ambient light
  - Substitute for dealing with interreflections
- Global illumination model
  - Account for interreflections in modeled scene

Recap



Possible factors: albedo, shadows, texture, specularities, curvature, lighting direction

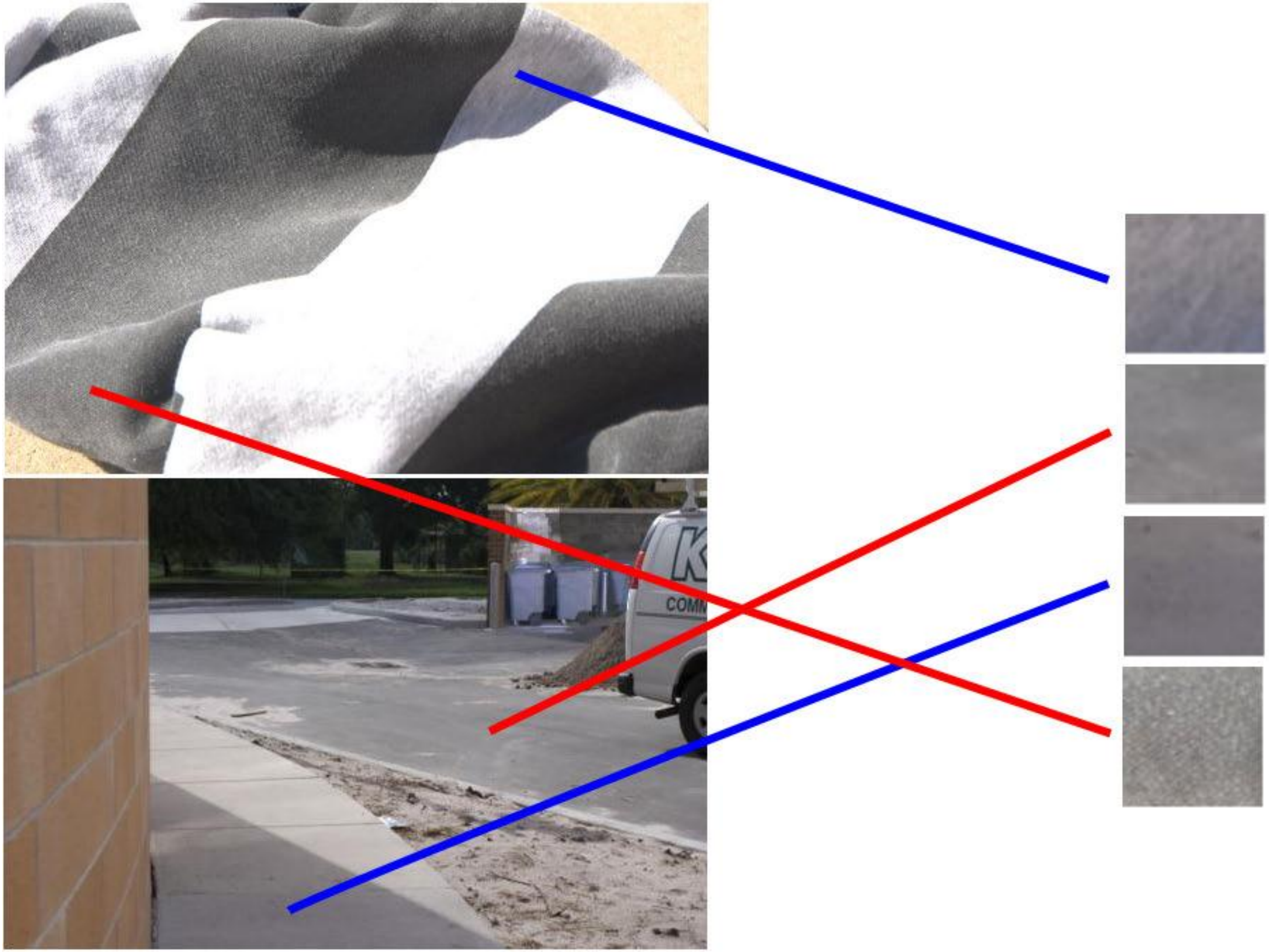
What does the intensity of a pixel tell us?

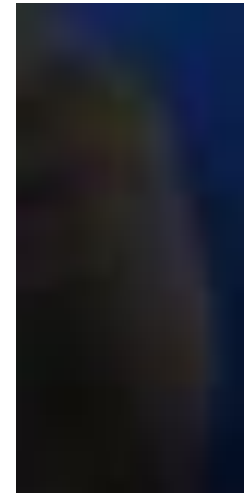
im(234, 452) = 0.58

0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

The plight of the poor pixel

- A pixel's brightness is determined by
  - Light source (strength, direction, color)
  - Surface orientation
  - Surface material and albedo
  - Reflected light and shadows from surrounding surfaces
  - Gain on the sensor
- A pixel's brightness tells us nothing by itself





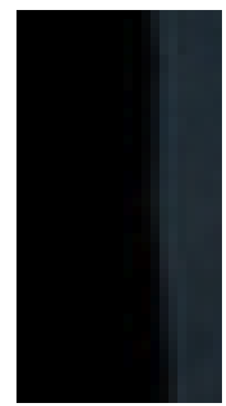


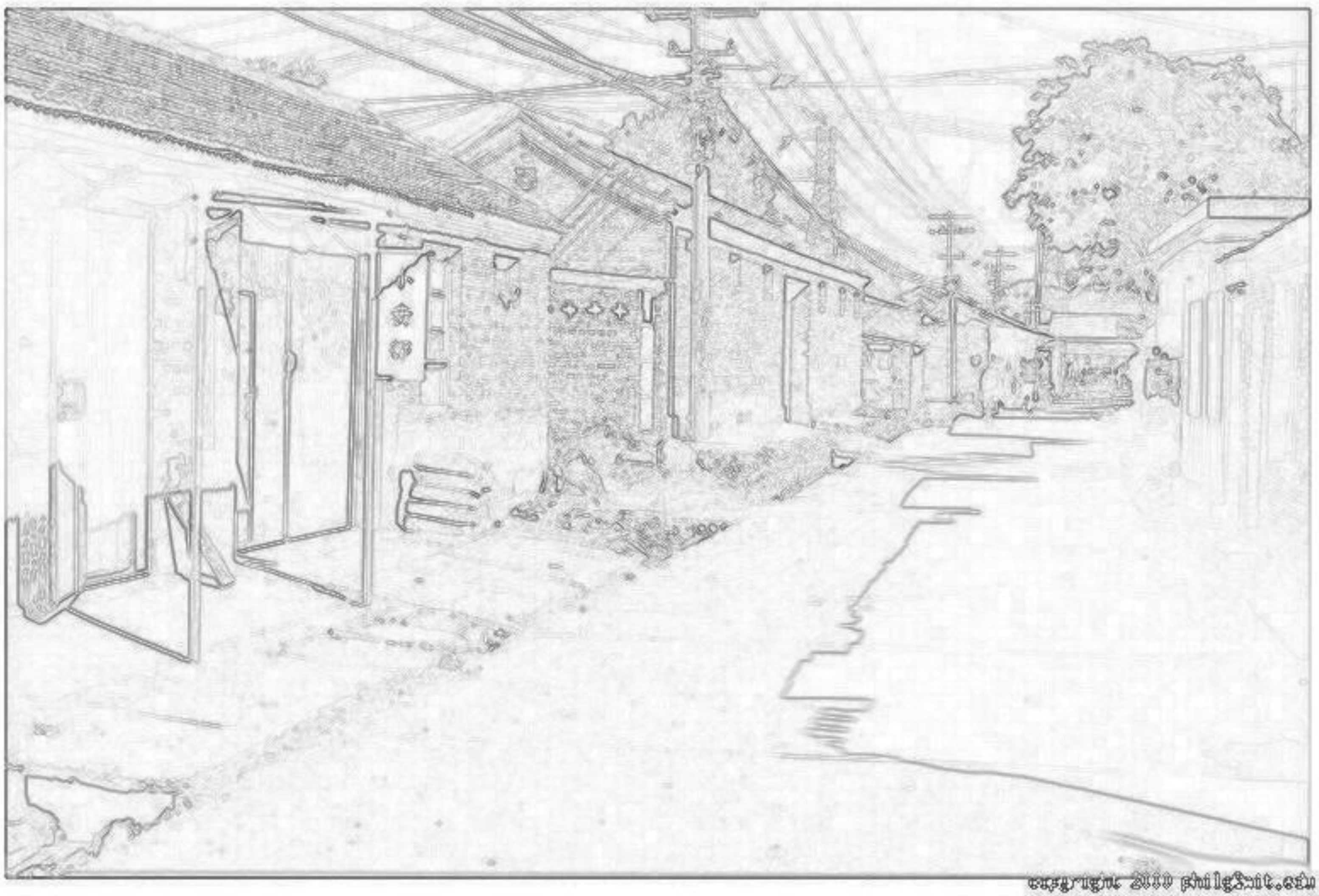
Photo by nickwheeleroz, Flickr

Slide: Forsyth

And yet we can interpret images…

- Key idea: for nearby scene points, most factors do not change much
- The information is mainly contained in *local differences* of brightness

Darkness = Large Difference in Neighboring Pixels



What is this?

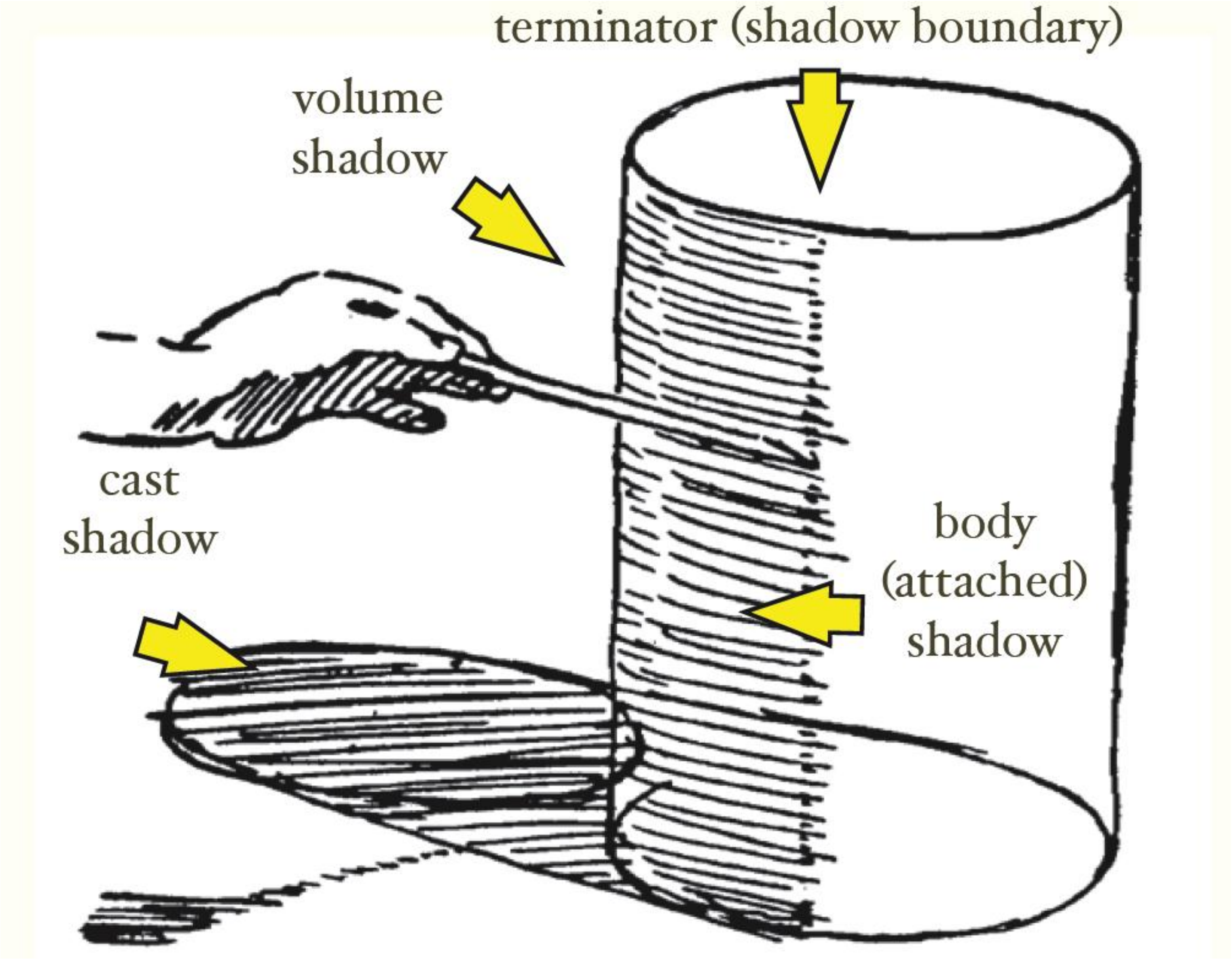

HONDA

What differences in intensity tell us about shape

- Changes in surface normal
- Texture
- Proximity
- Indents and bumps
- Grooves and creases

Photos Koenderink slides on image texture and the flow of light

Shadows as cues

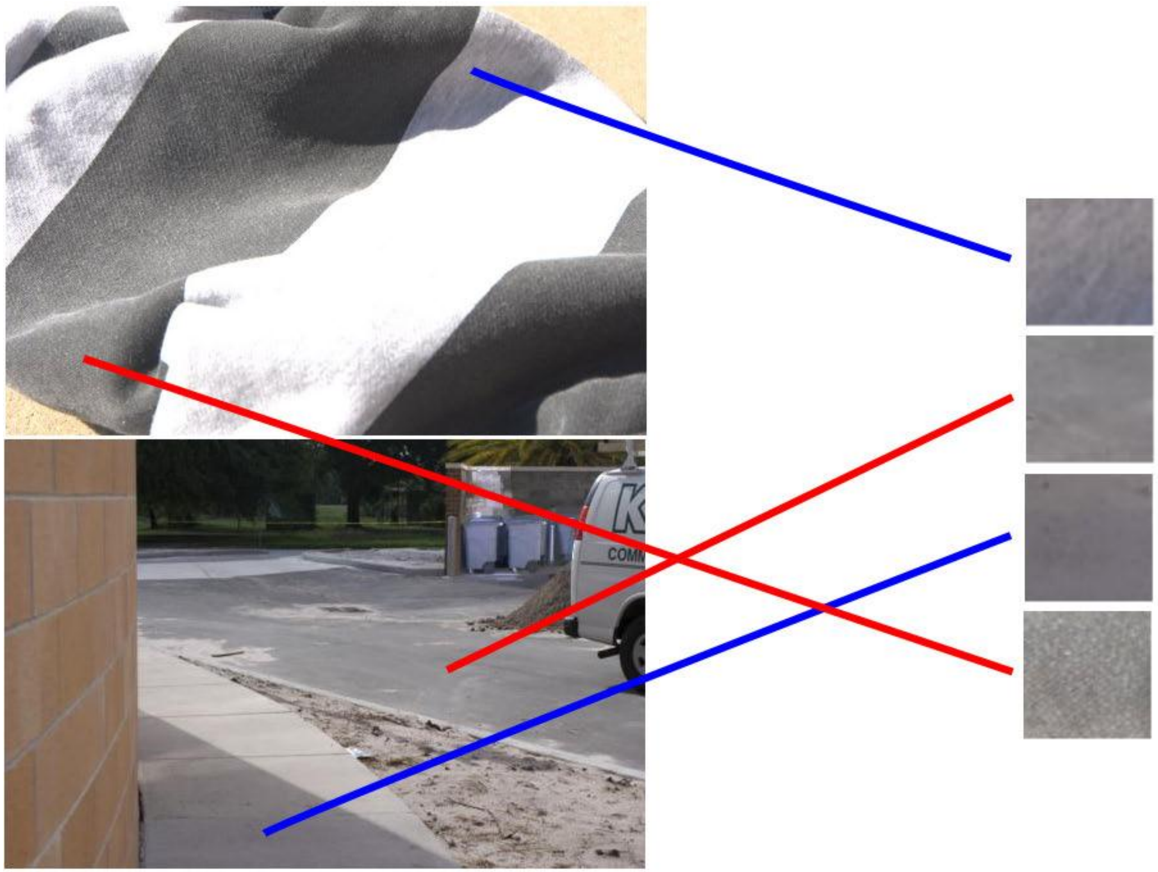


From Koenderink slides on image texture and the flow of light

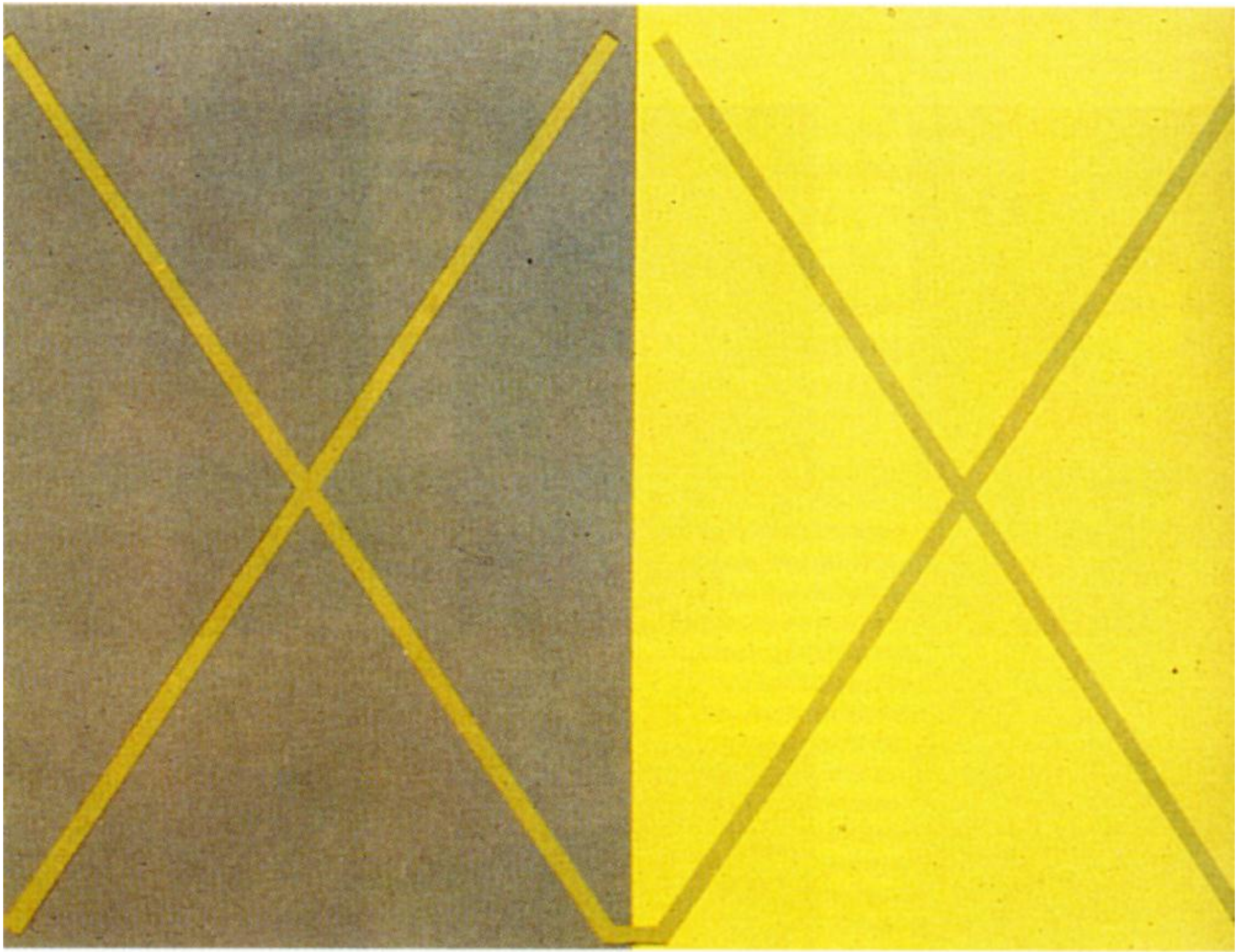
Slide: Forsyth

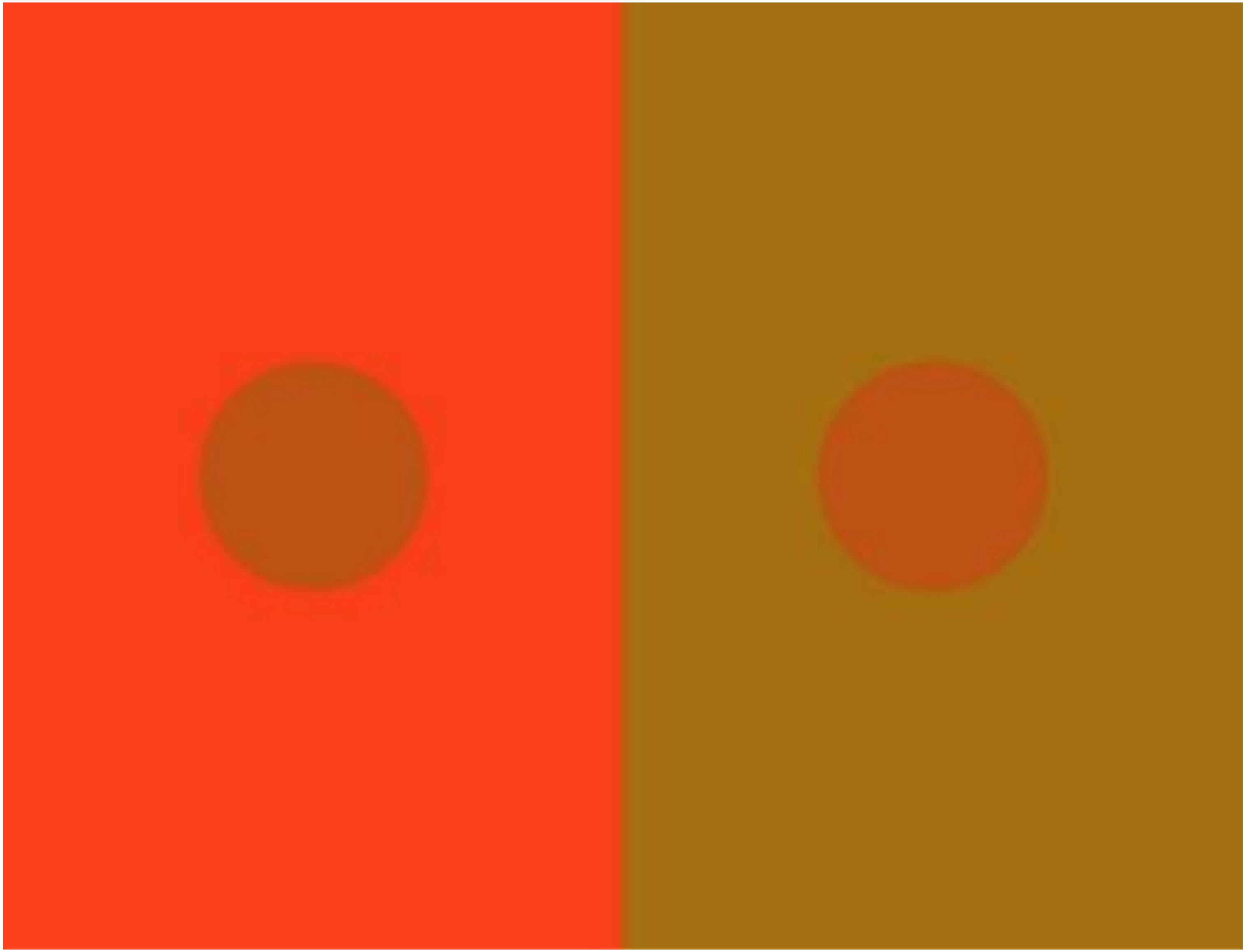
Color constancy

- Interpret surface in terms of albedo or "true color", rather than observed intensity
  - Humans are good at it
  - Computers are not nearly as good



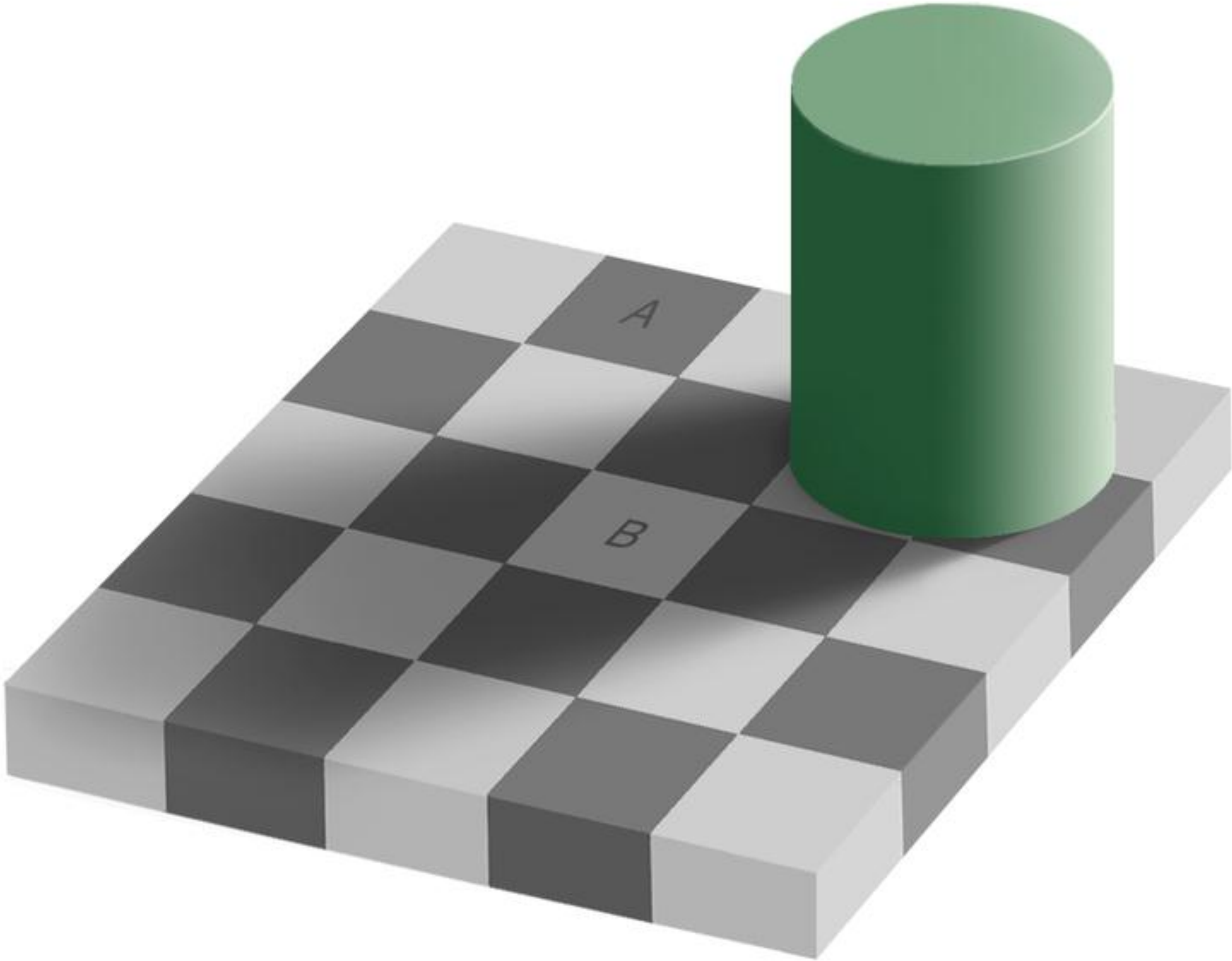
One source of constancy: local comparisons





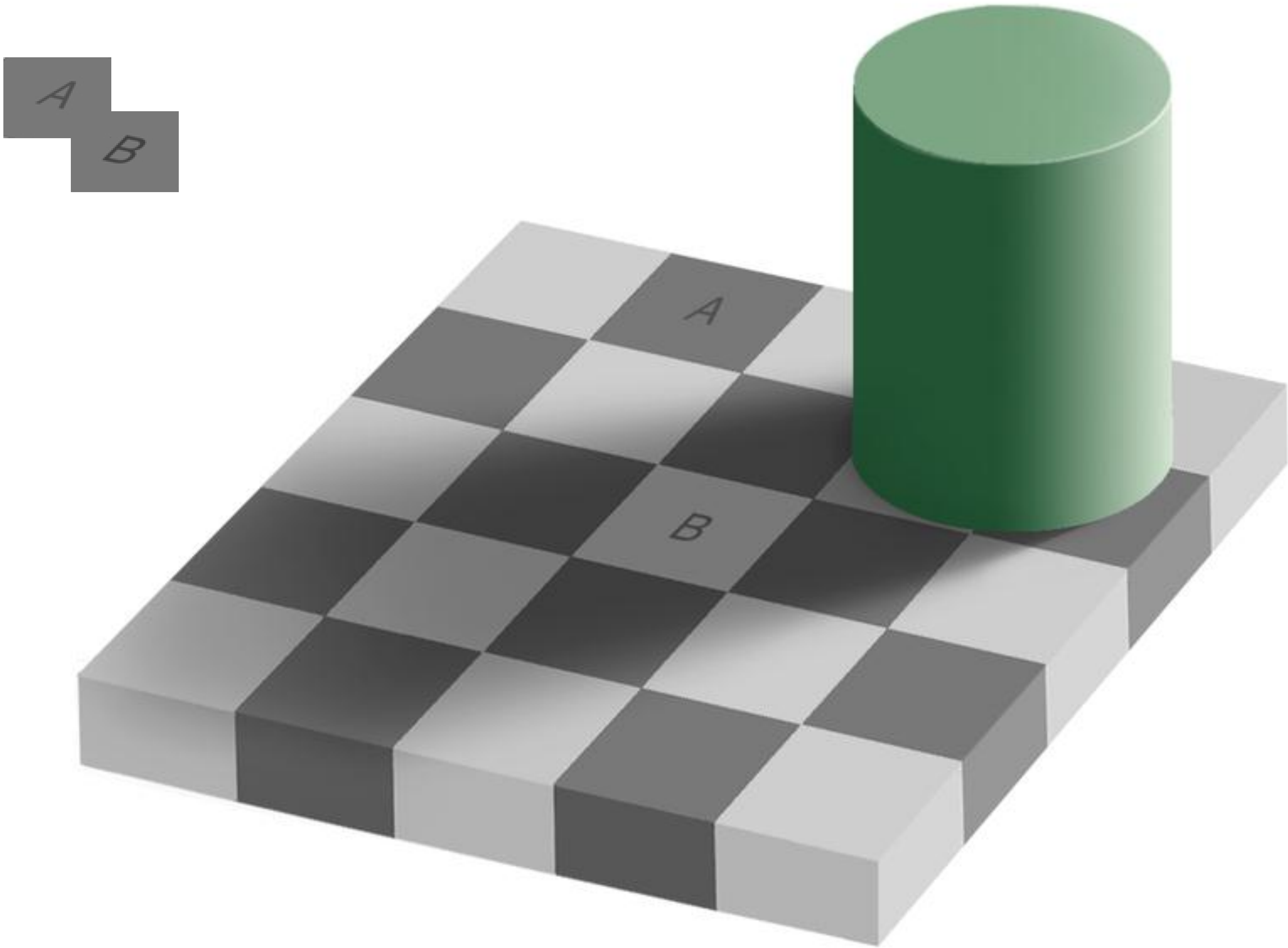
http://www.echalk.co.uk/amusements/OpticalIllusions/colourPerception/colourPerception.html

Perception of Intensity



from Ted Adelson

Perception of Intensity



from Ted Adelson

Color Correction

- Simple idea: multiply R, G, and B values by separate constants

$$\begin{bmatrix} \tilde{r} \\ \tilde{g} \\ \tilde{b} \end{bmatrix} = \begin{bmatrix} \alpha_r & 0 & 0 \\ 0 & \alpha_g & 0 \\ 0 & 0 & \alpha_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

- How to choose the constants?
  - "White world" assumption: brightest pixel is white
    - Divide by largest value
  - "Gray world" assumption: average value should be gray
    - E.g., multiply r channel by avg(r) /avg((r+g+b)/3)
  - White balancing: choose a reference as the white or gray color

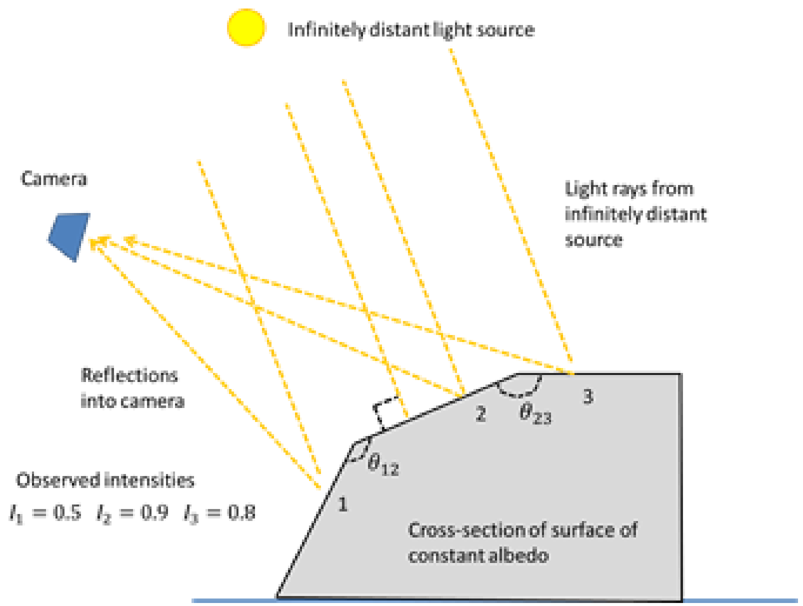
HW 1, Problem 1a

1. Lighting (20%)

A. Answer the following regarding the above image (photo credit: *dolmansaxlil* from Flickr). Consider shadows, specularities, albedo, surface orientation, light sources, etc. Short answers (several words) are sufficient (8%):

1. Why is (2) brighter than (1)? Each points to the asphault.
2. Why is (4) darker than (3)? 4 points to the marking.
3. Why is (5) brighter than (3)? Each points to the side of the wooden block.
4. Why isn't (6) black, given that there is no direct path from it to the sun?

HW 1, Problem 1b



B. Answer the following using the above illustration. Suppose you have observed the intensities of three points on an object (I_1, I_2, I_3), which are lit by an infinitely distant point source (the sun). The surface normal at point 2 is exactly perpendicular to the sun. The surface normals of points 1 and 3 differ in only one angle (θ), as shown in the cross-section.

a. Suppose the surface has a specular component. Will the observed intensities change as the camera moves (if so why/how)? (4%)

b. Suppose the surface material is Lambertian and has uniform (constant) albedo and that the camera response function is linear (and ignore effects due to interreflections in the scene). Show (with equations for arbitrary observed intensities) how to compute the angles θ_{12}, θ_{23} between surfaces containing points 1 and 2 and points 2 and 3. Then, compute the values of θ_{12}, θ_{23} for the observed intensities (0.5, 0.9, 0.8). (8%)

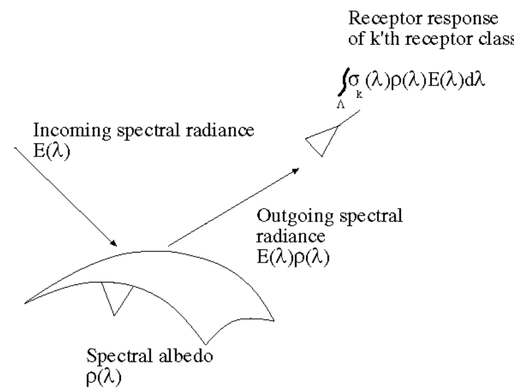
Things to remember

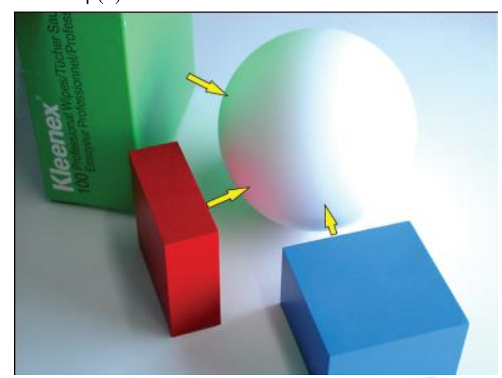
- Important terms: diffuse/specular reflectance, albedo, umbra/penumbra

- Observed intensity depends on light sources, geometry/material of reflecting surface, surrounding objects, camera settings

- Objects cast light and shadows on each other

- Differences in intensity are primary cues for shape





Thank you

- Next class: Image Filters