COMPUTER VISION

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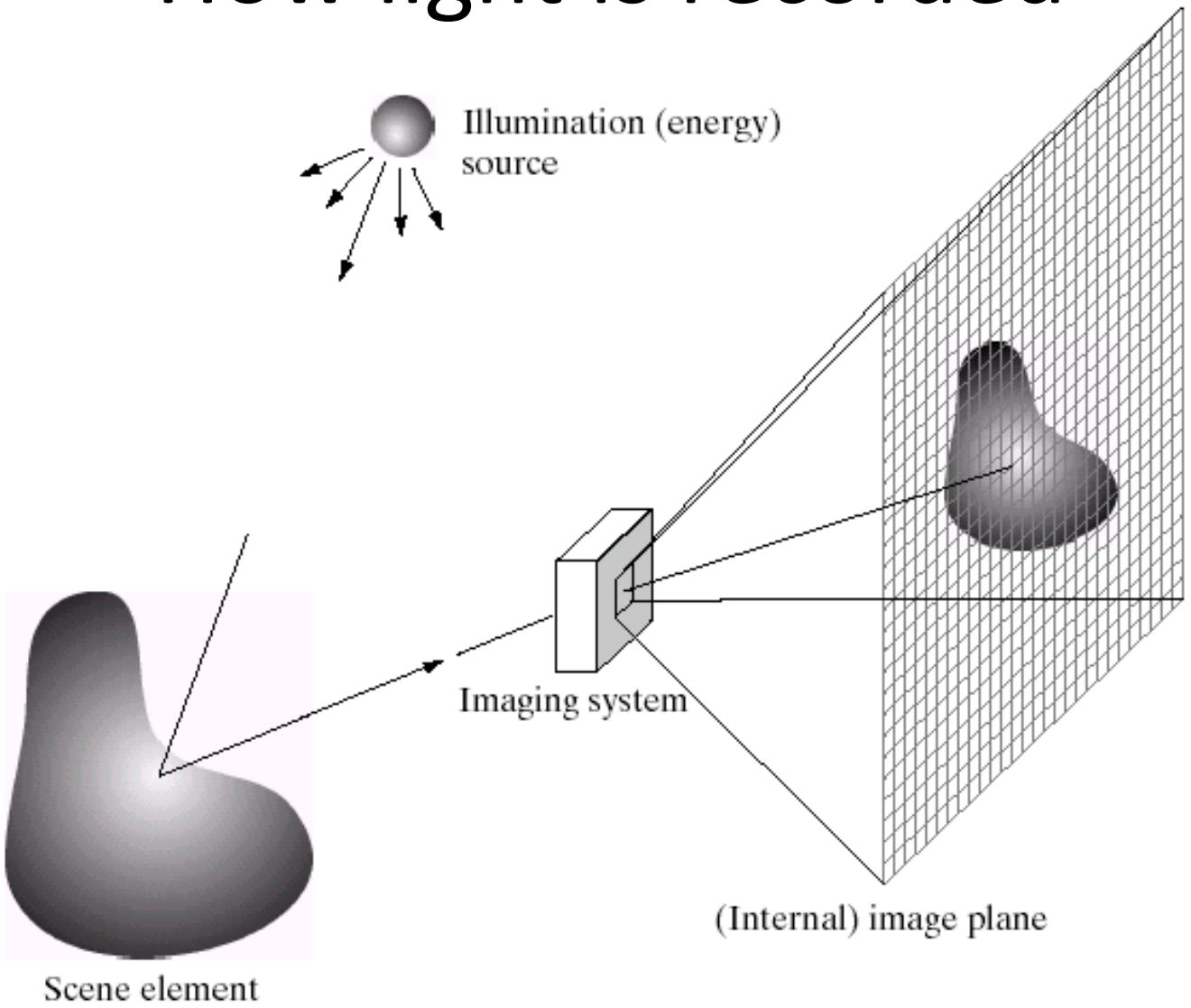
How light is recorded



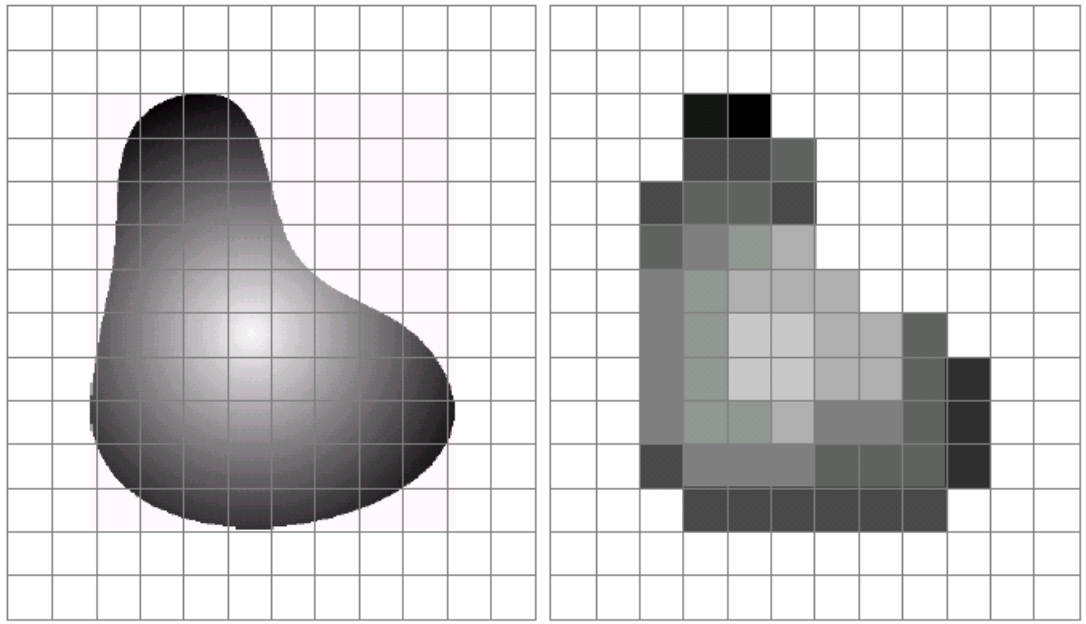
Digital camera

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/cameras-photography/digital/question362.htm

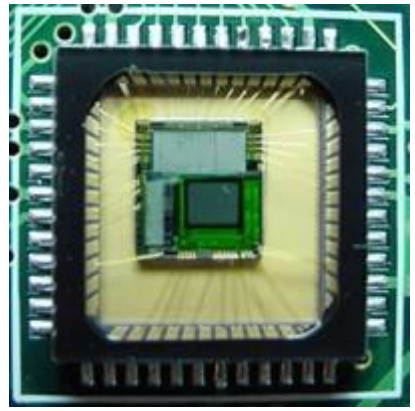
Slide by Steve Seitz

Sensor Array



a b

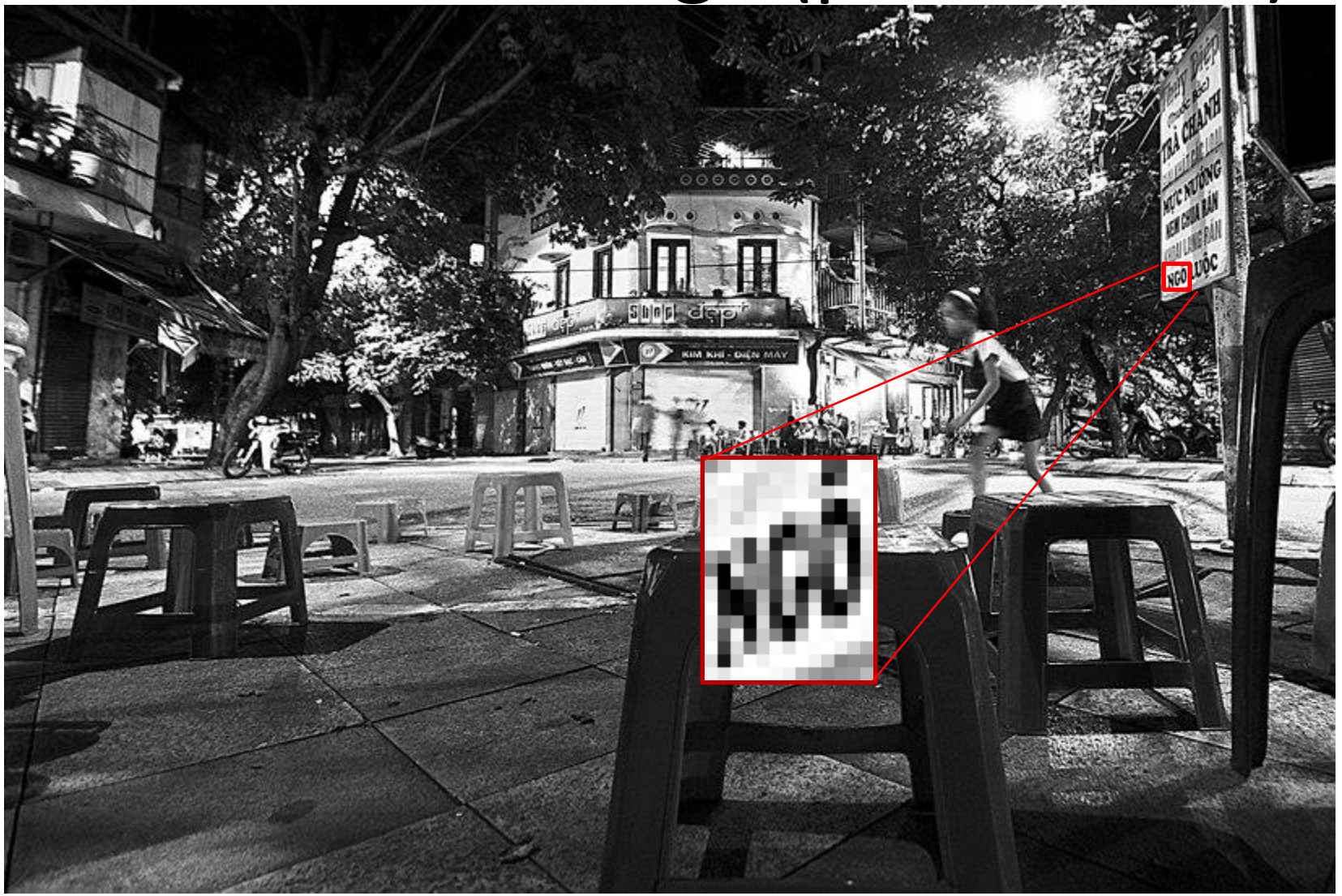
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



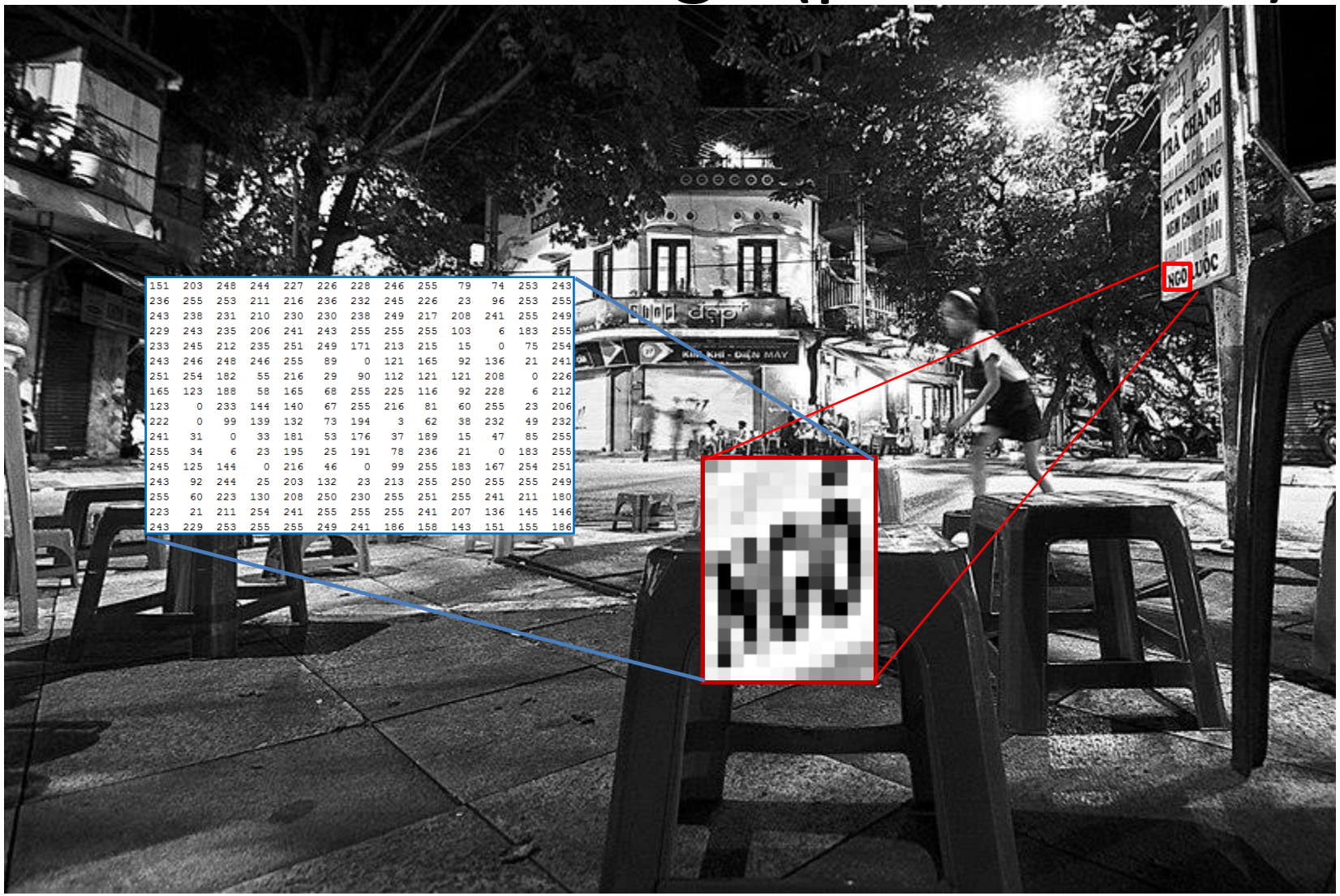
CMOS sensor

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

The raster image (pixel matrix)



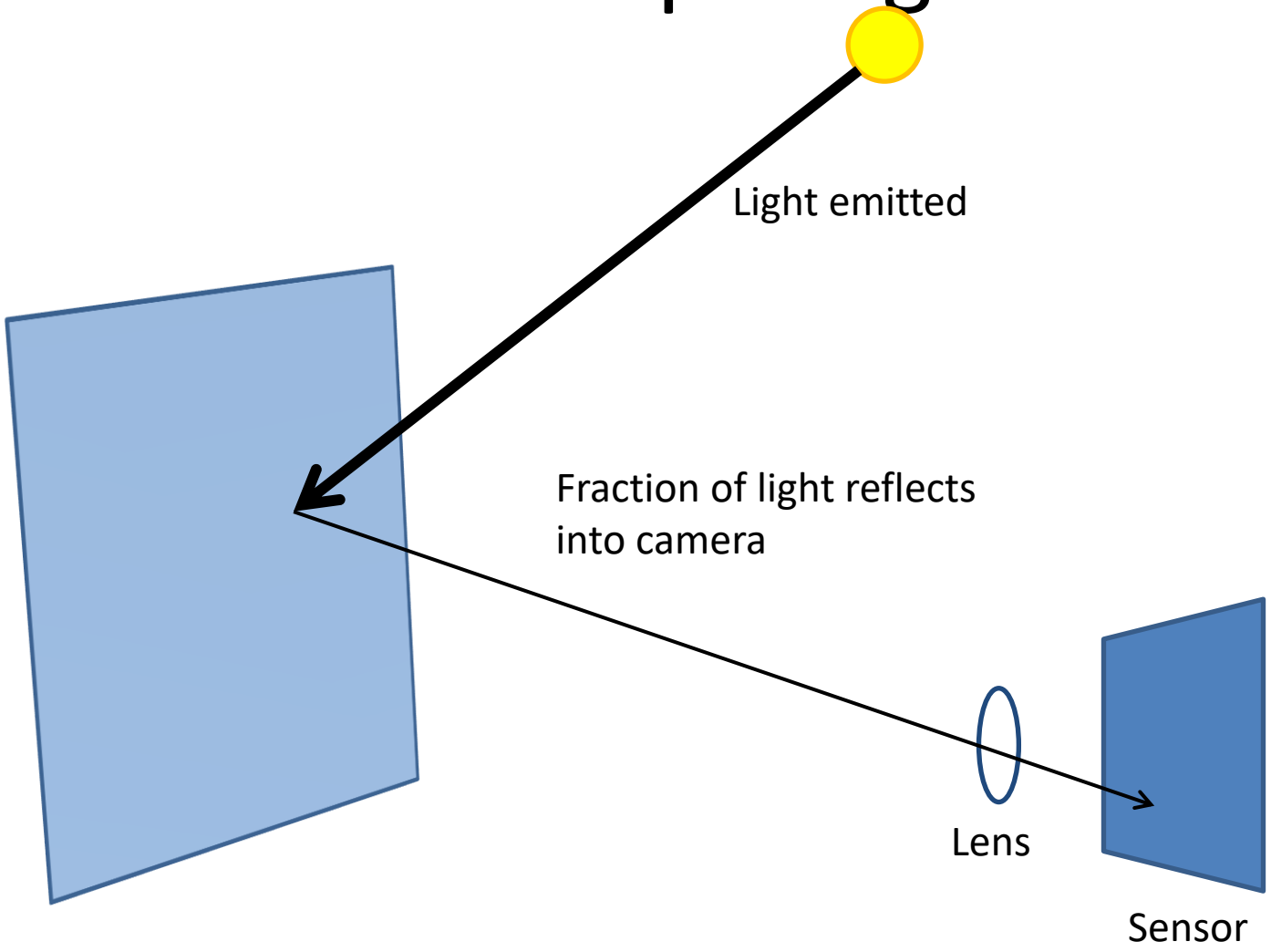
The raster image (pixel matrix)



Today's class: Light and Shading

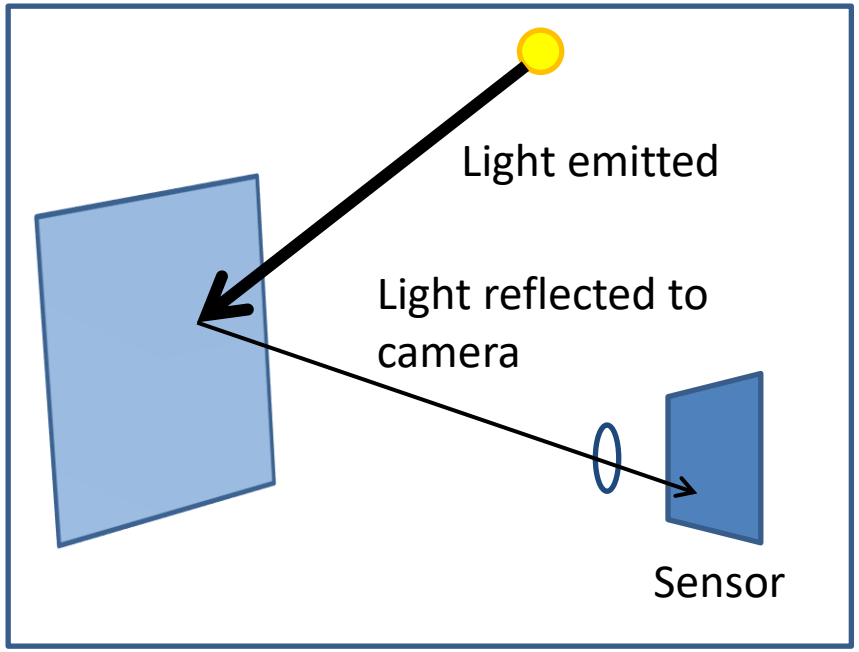
- What determines a pixel's intensity?
- What can we infer about the scene from pixel intensities?

How does a pixel get its value?



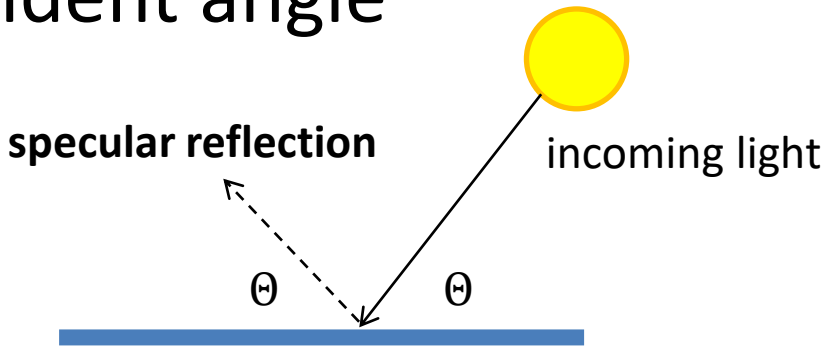
How does a pixel get its value?

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

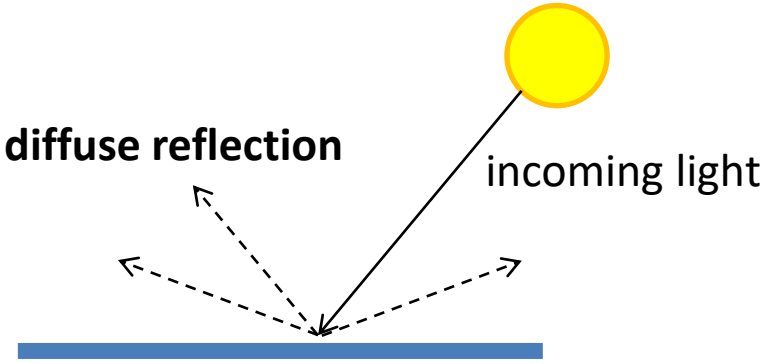


Basic models of reflection

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

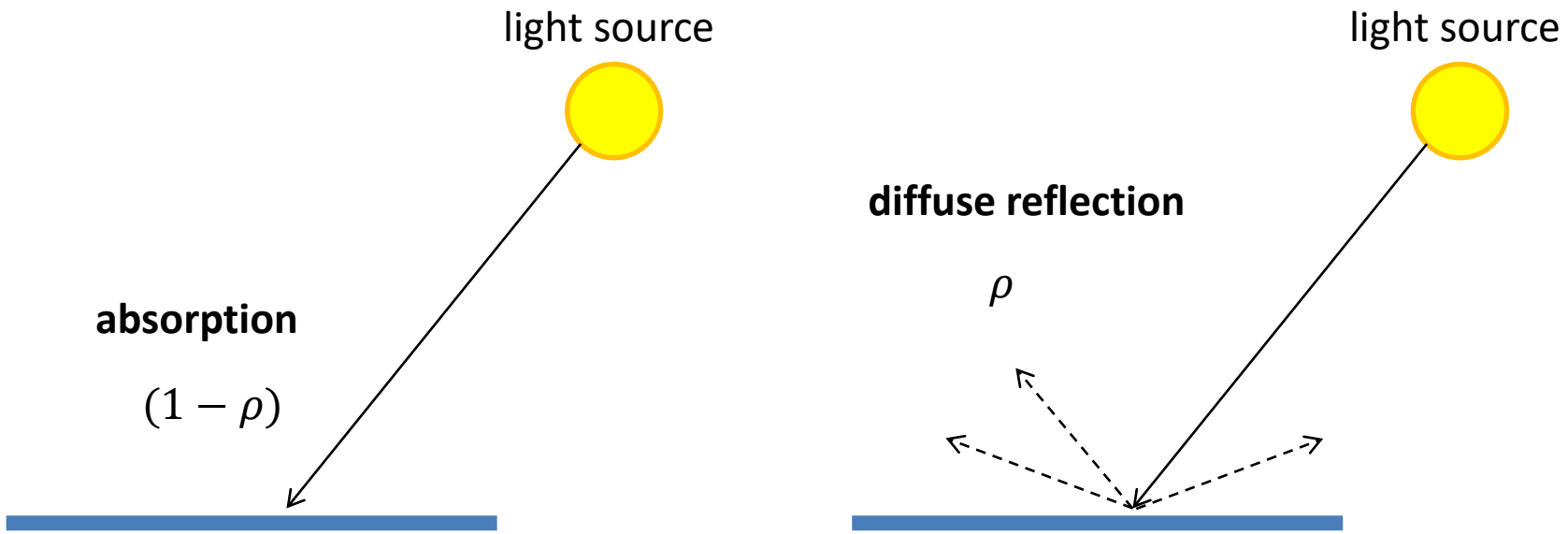


- Diffuse: light scatters in all directions
  - E.g., brick, cloth, rough wood



Lambertian reflectance model

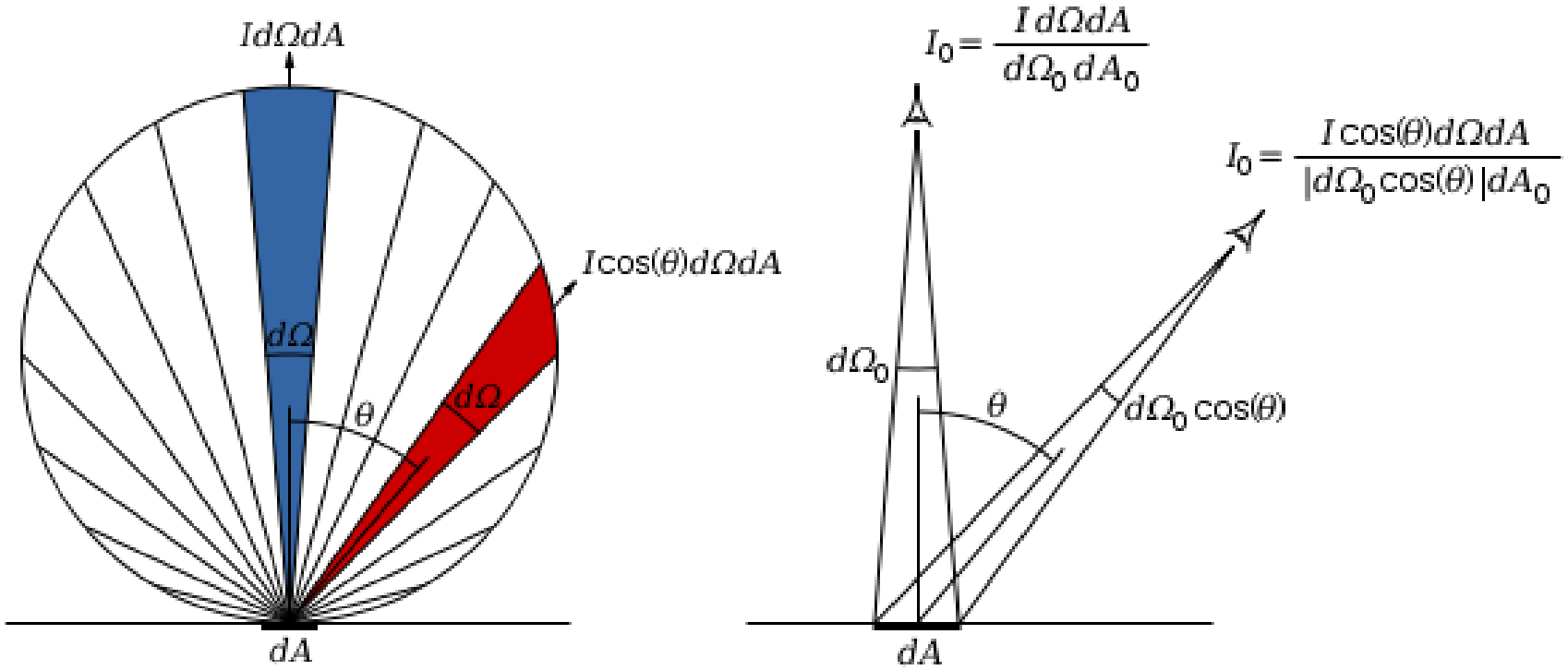
- Some light is absorbed (function of albedo ρ)
- Remaining light is scattered (diffuse reflection)
- Examples: soft cloth, concrete, matte paints



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 $\cos(\theta)$



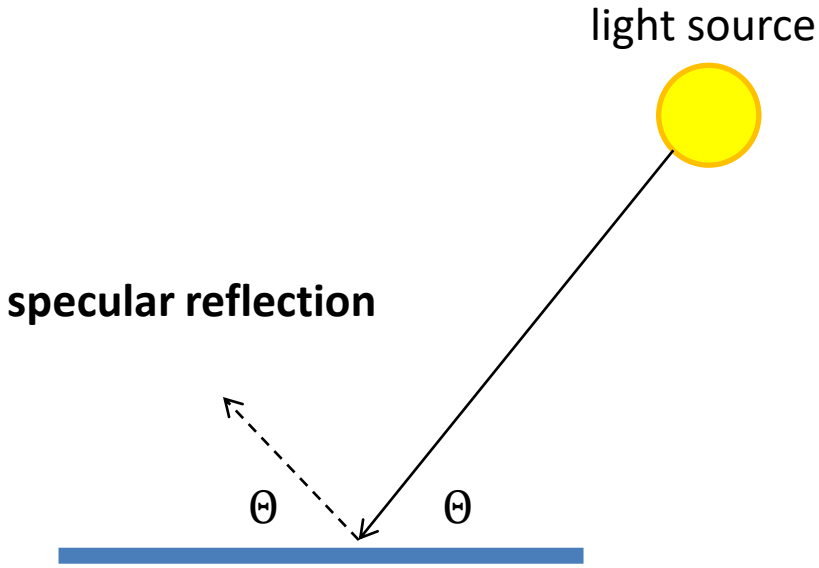
http://en.wikipedia.org/wiki/Lambert%27s_cosine_law

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

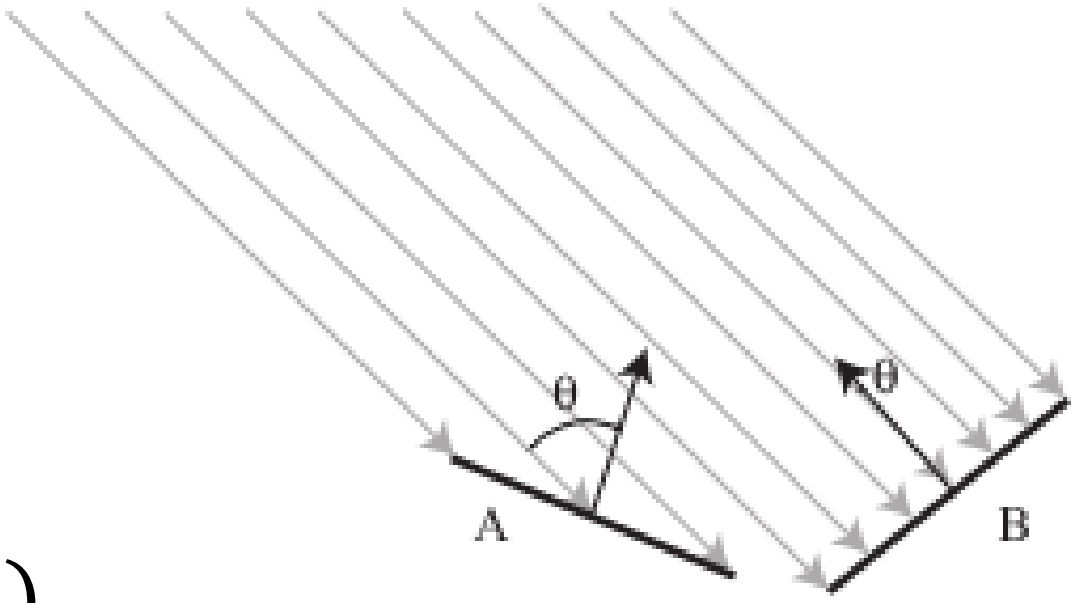
Intensity depends on illumination angle because less light comes in at oblique angles.

ρ = albedo

$\boldsymbol{S}$ = directional source

$\boldsymbol{N}$ = surface normal

I = reflected intensity



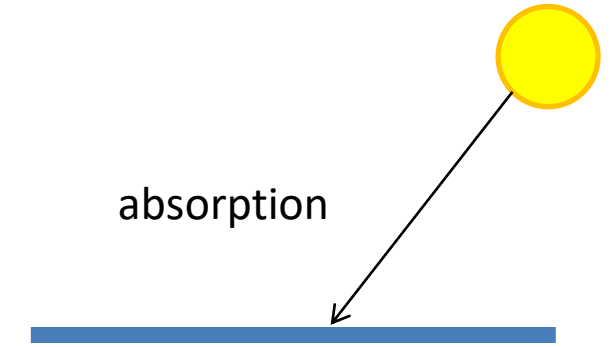
$$I(x) = \rho(x)(\boldsymbol{S} \cdot \boldsymbol{N}(x))$$

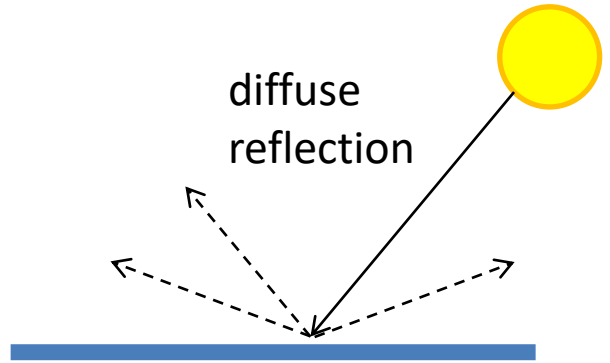
Slide: Forsyth

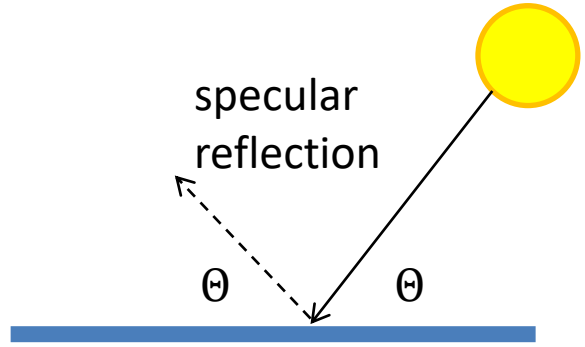

2
1
CHỦ TỊCH
HỒ - CHÍ - MINH

Recap

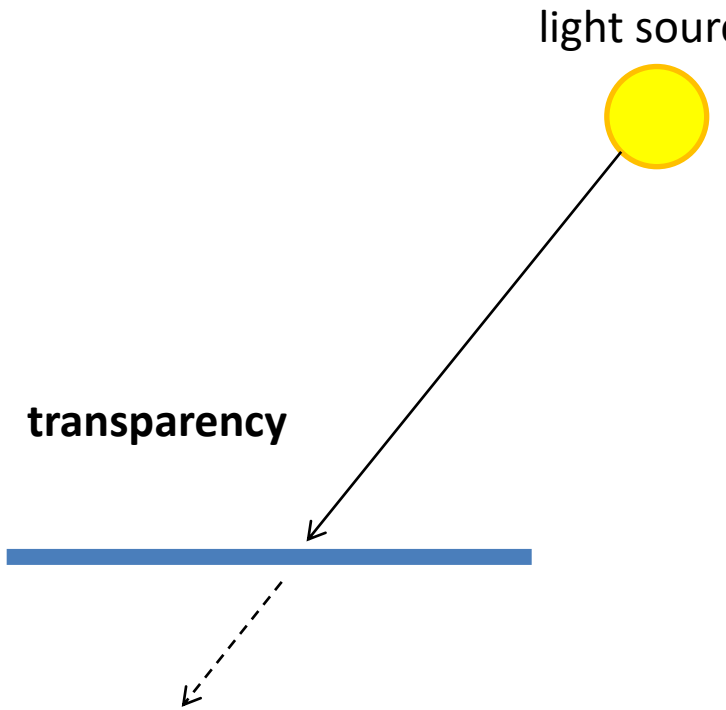
- When light hits a typical surface
  - Some light is absorbed (1-ρ)
    - More absorbed for low albedos
  - Some light is reflected diffusely
    - Independent of viewing direction
  - Some light is reflected specularly
    - Light bounces off (like a mirror), depends on viewing direction

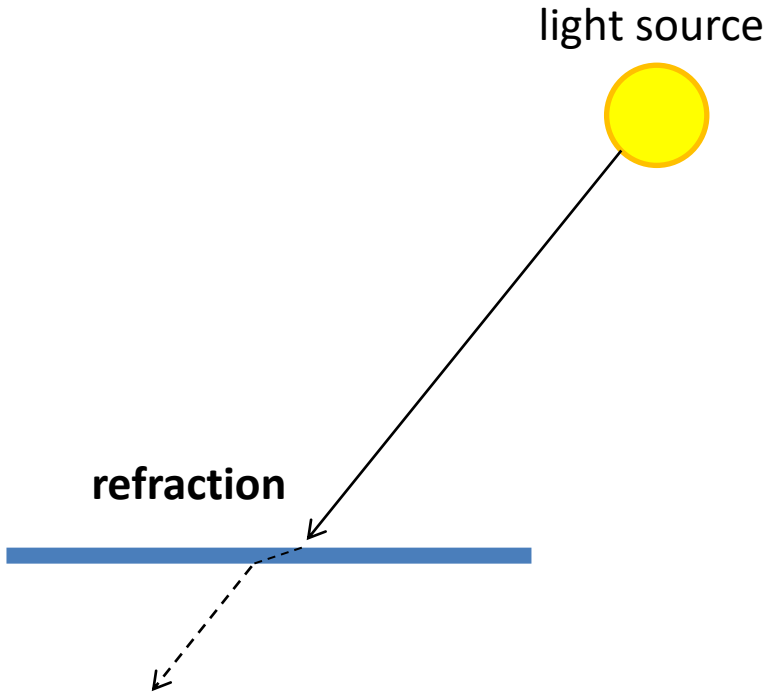


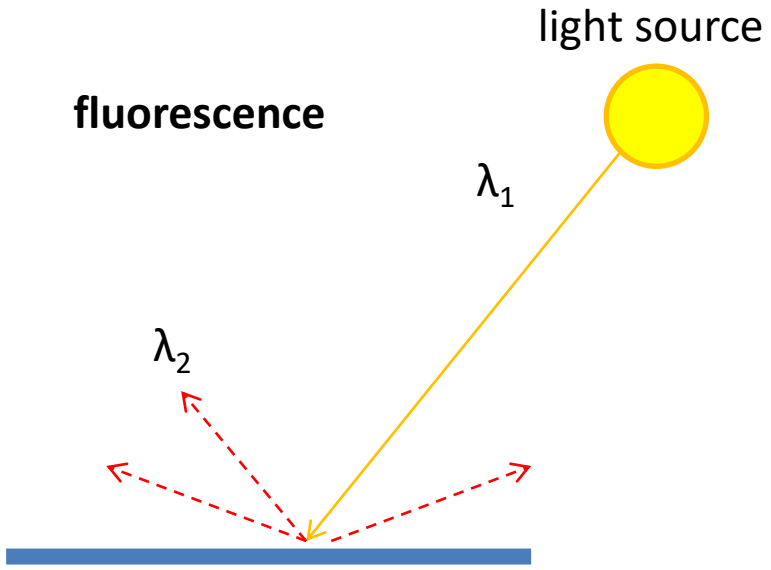


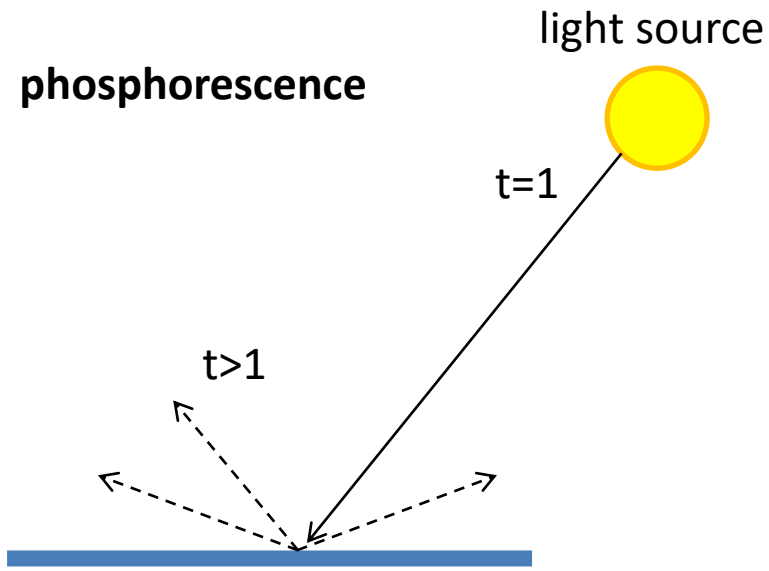


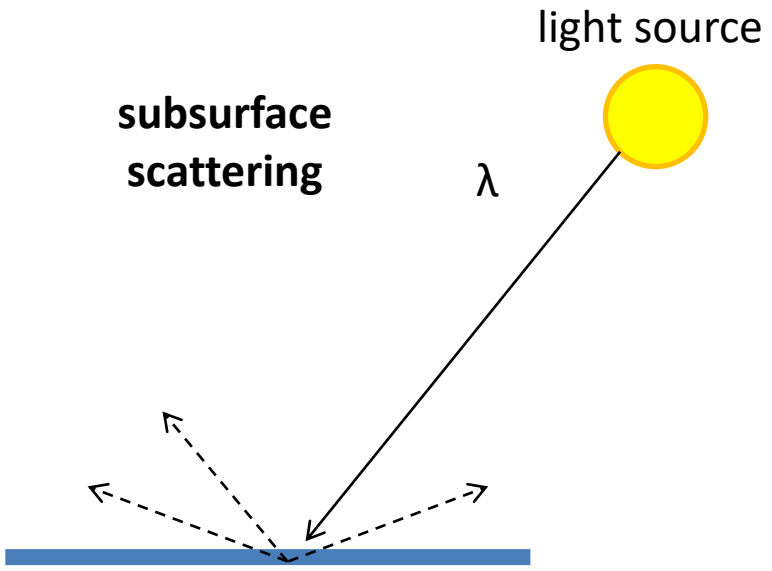
Other possible effects





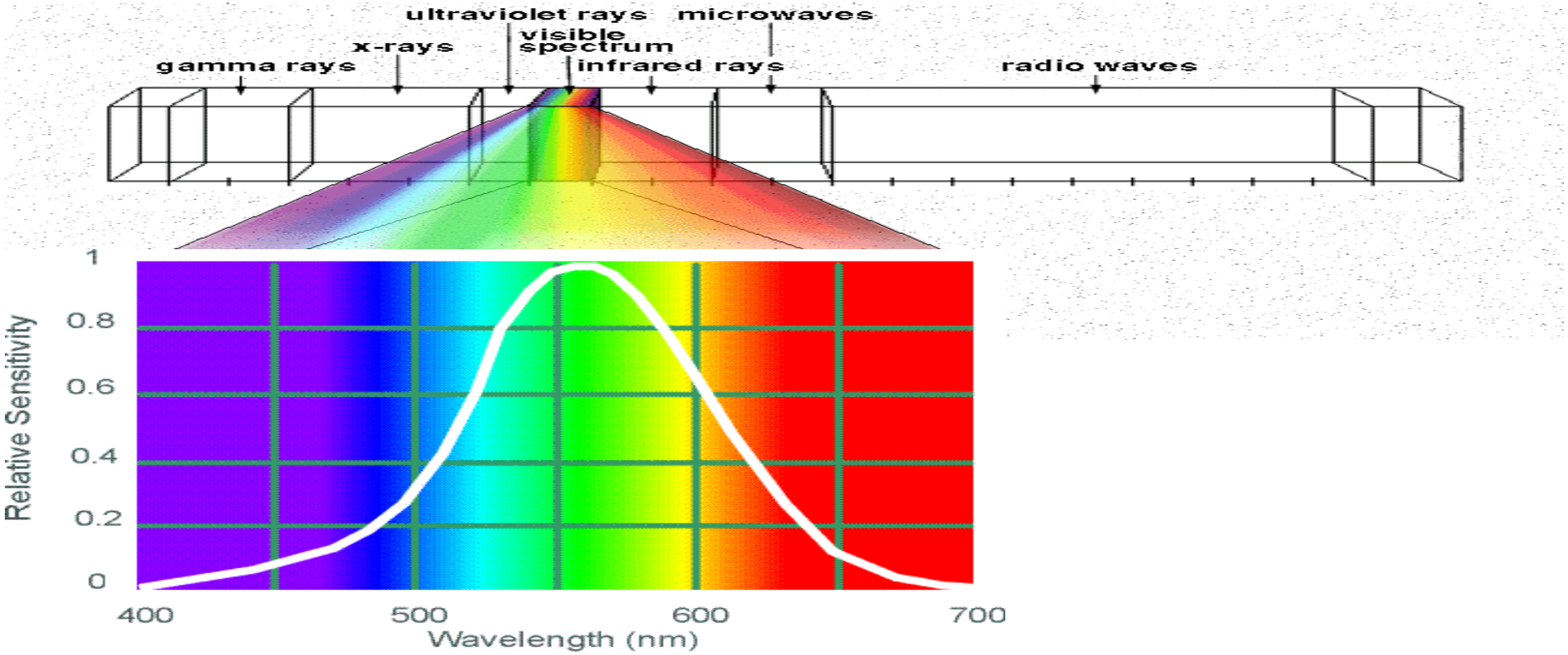

light source
fluorescence
λ_1
λ_2


light source
phosphorescence
t=1
t>1


light source
subsurface
scattering
λ

Color

Light is composed of a spectrum of wavelengths

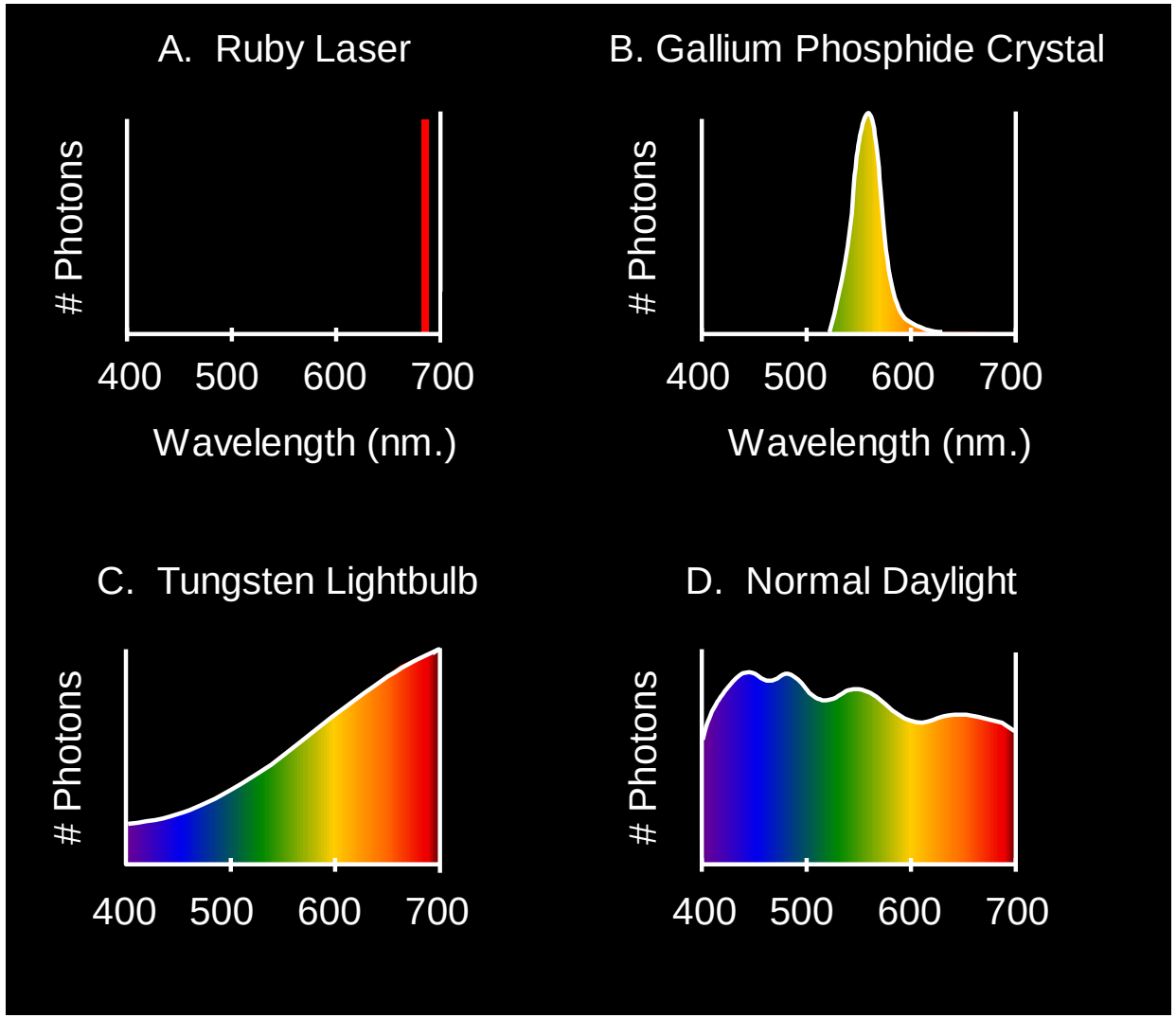


Human Luminance Sensitivity Function

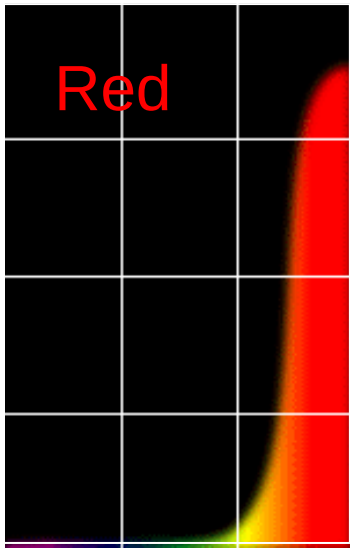
Slide Credit: Efros

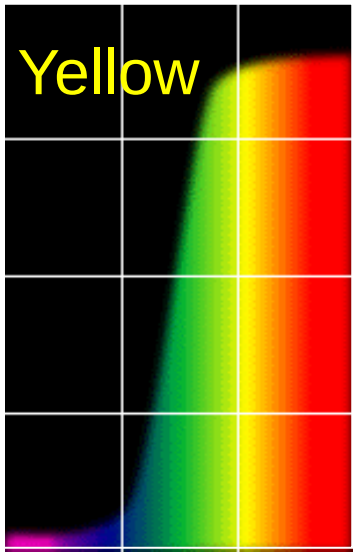
http://www.yorku.ca/eye/photopik.htm

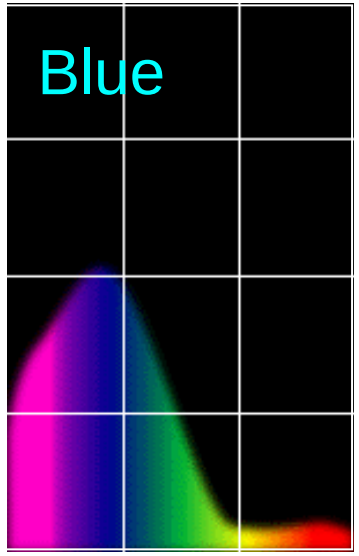
Some examples of the spectra of light sources

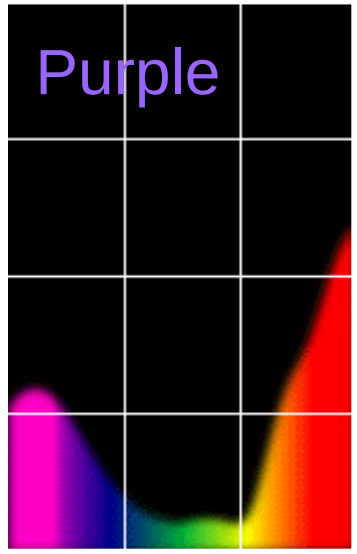


Some examples of the reflectance spectra of surfaces

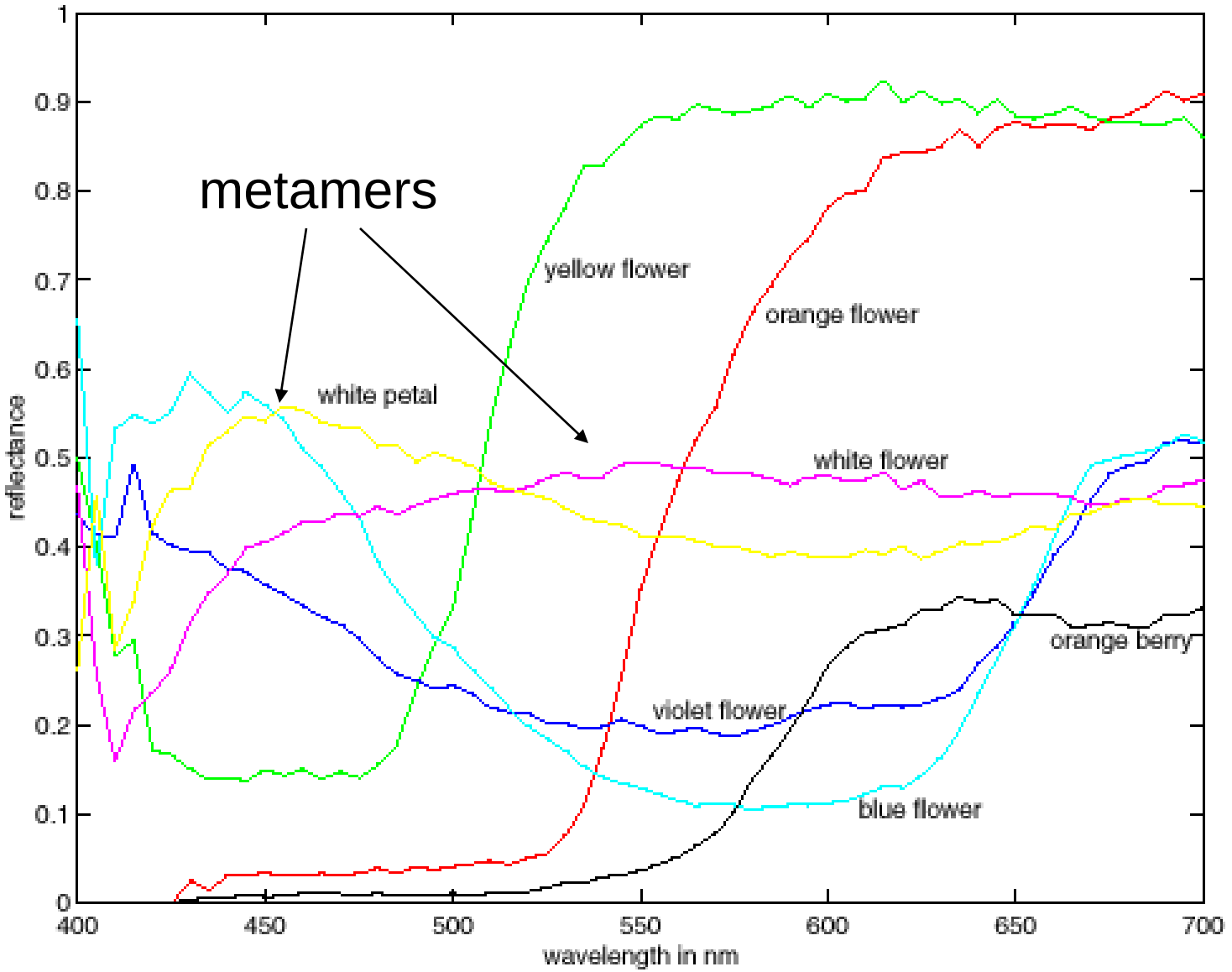






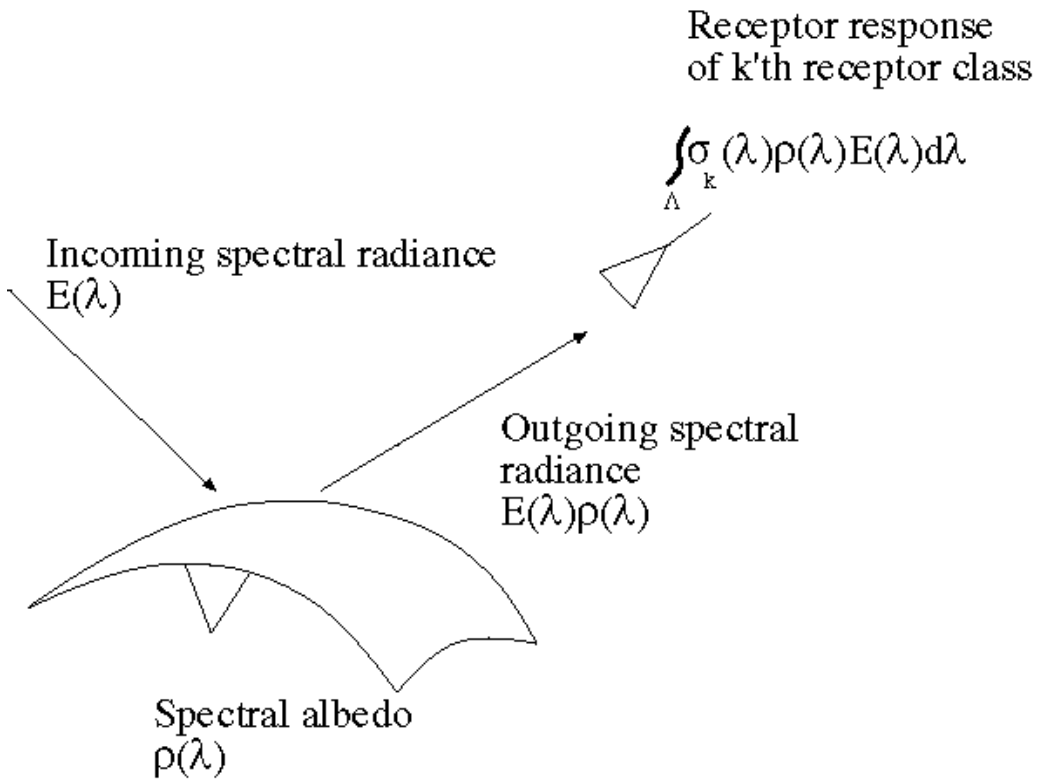


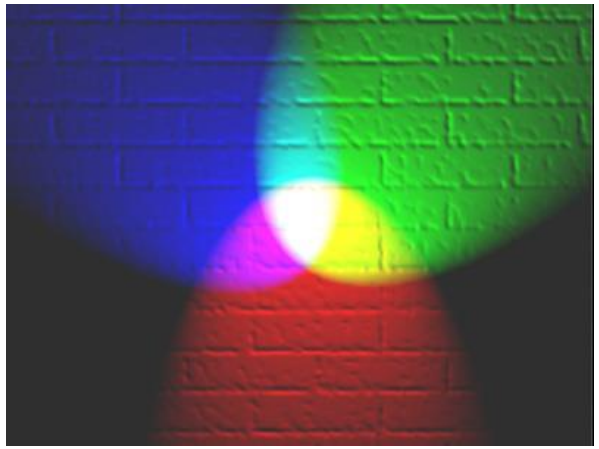
More spectra



The color of objects

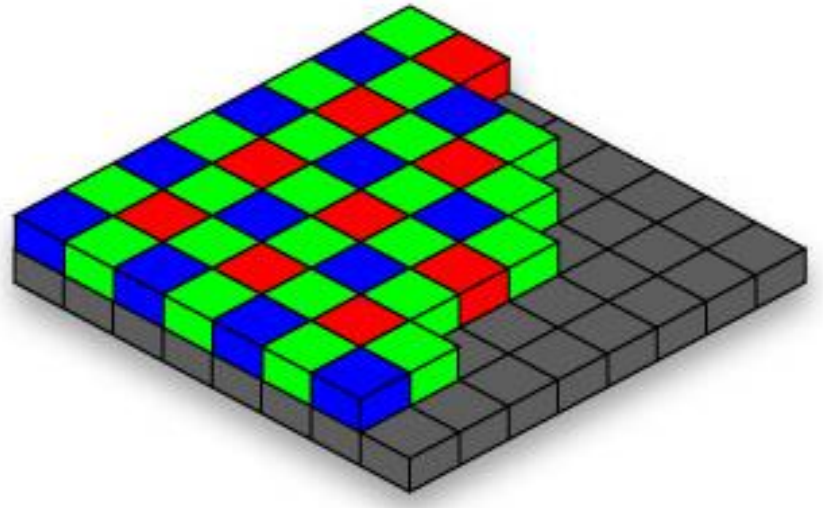
- Colored light arriving at the camera involves two effects
  - The color of the light source (illumination + inter-reflections)
  - The color of the surface



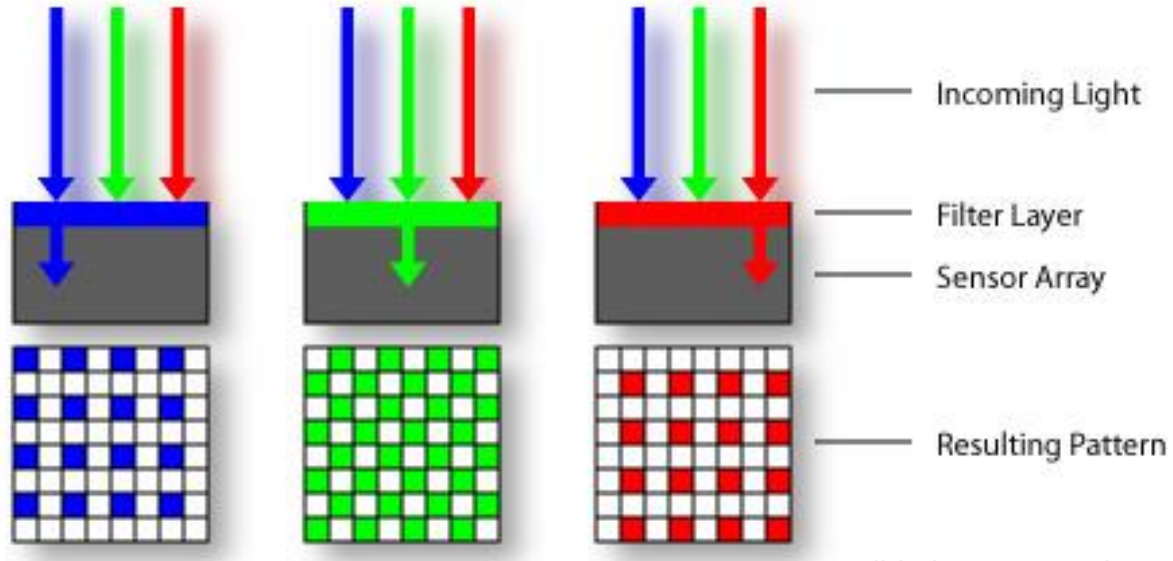


Slide: Forsyth

Color Sensing: Bayer Grid



- Estimate RGB at each cell from neighboring values



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

Slide by Steve Seitz

Which image plane is R, G, or B?

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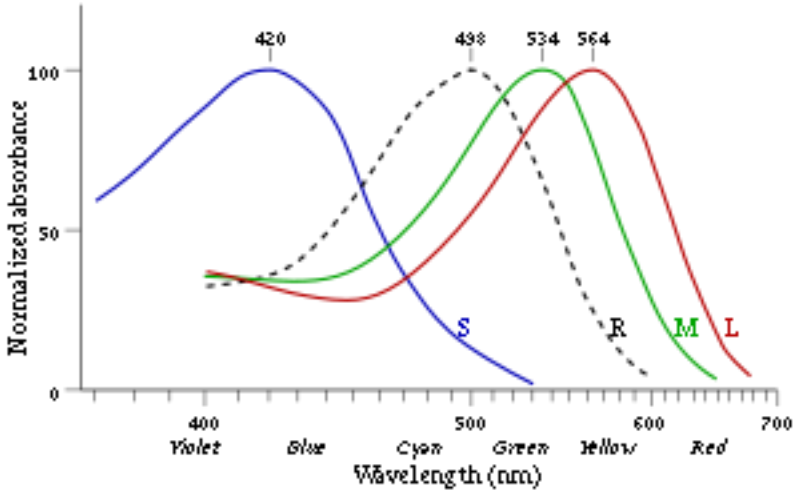
Why RGB?

If light is a spectrum, why are images RGB?

Human color receptors

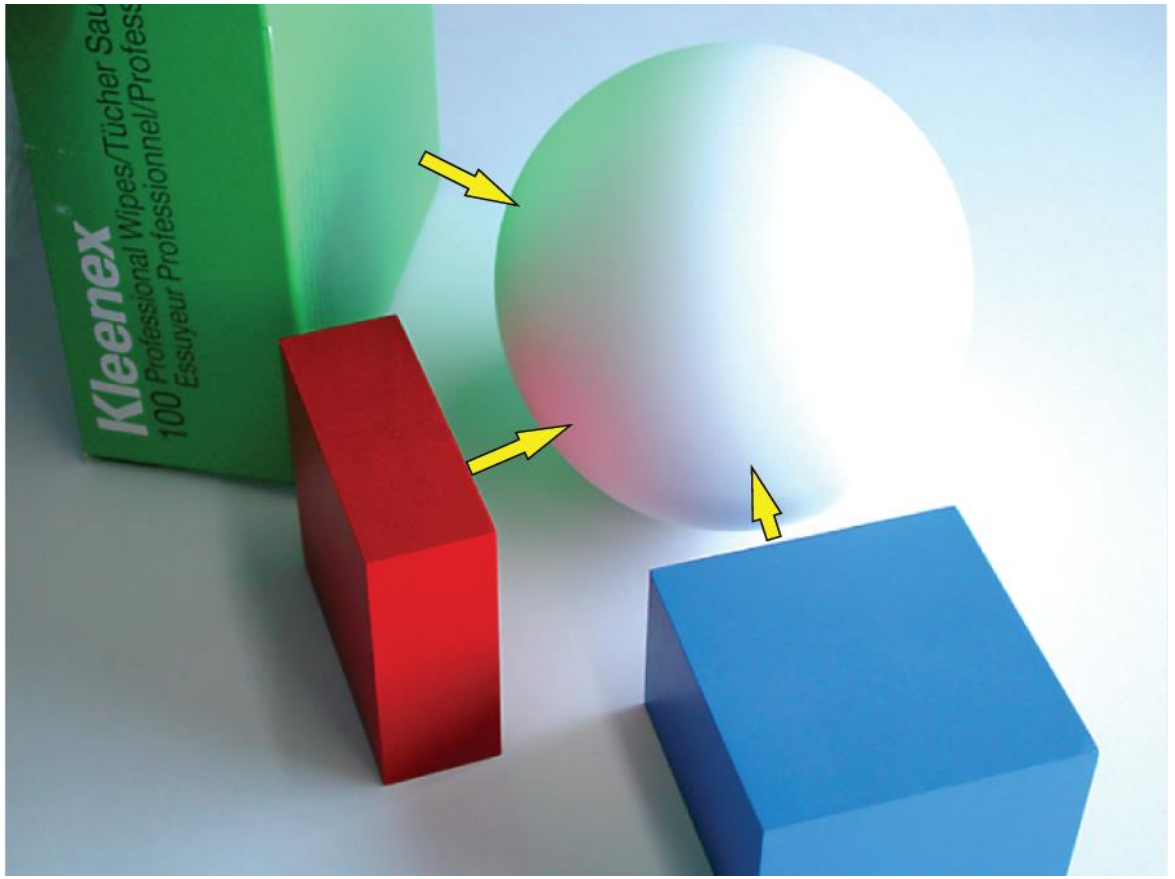
- Long (red), Medium (green), and Short (blue) cones, plus intensity rods
- Fun facts
  - "M" and "L" on the X-chromosome
    - That's why men are more likely to be color blind (see what it's like: http://www.vischeck.com/vischeck/vischeckURL.php)
  - "L" has high variation, so some women are tetrachromatic
  - 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

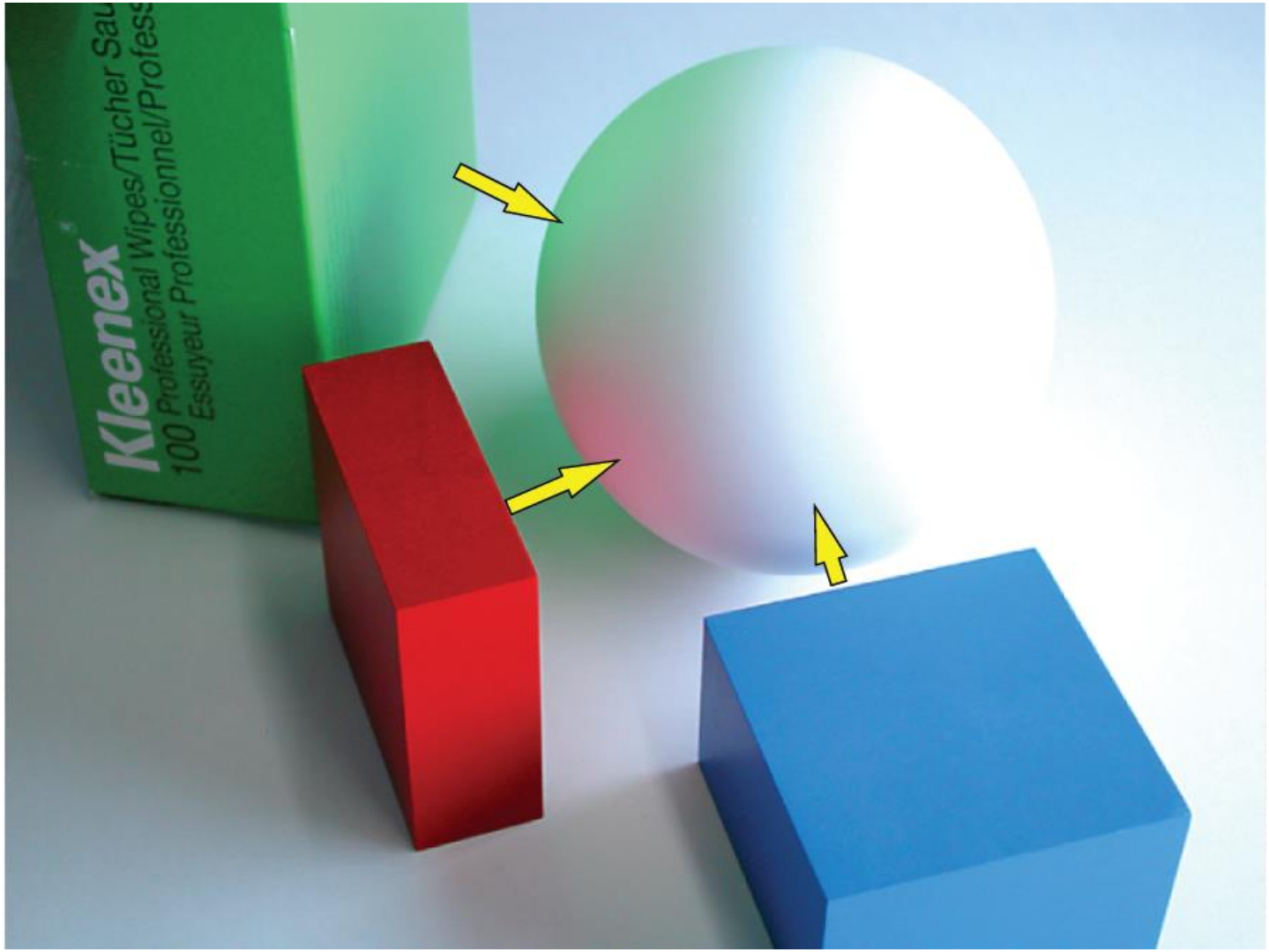
So far: light→surface→camera

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



From Koenderink slides on image texture and the flow of light

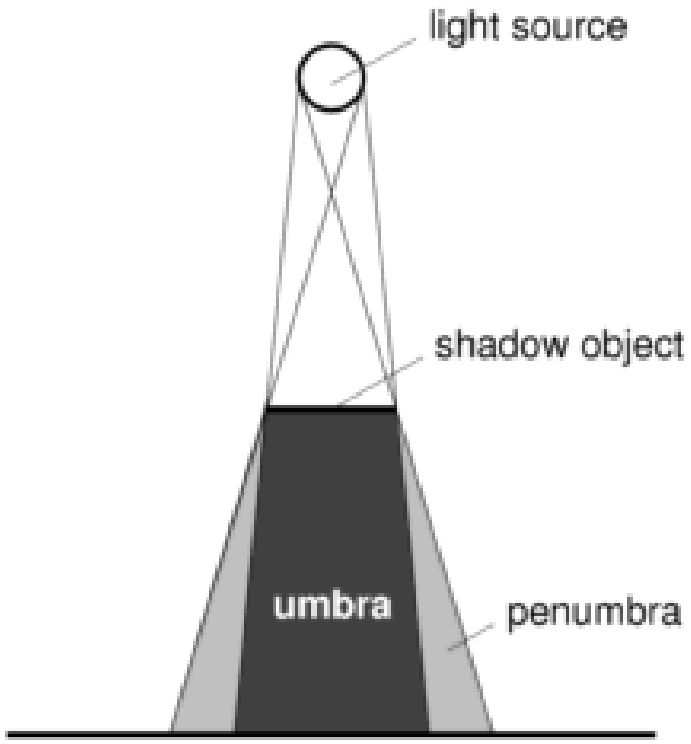
Inter-reflection affects the apparent color of objects



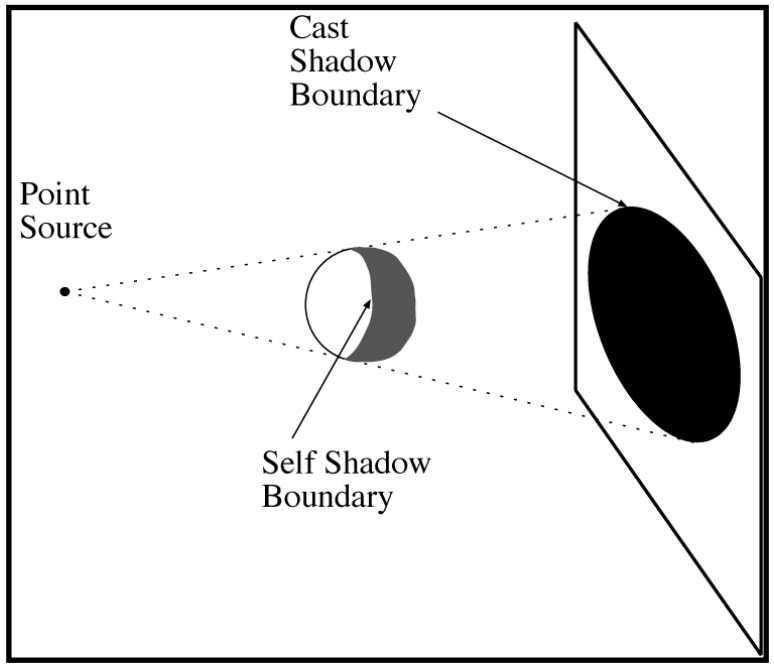
From Koenderink slides on image texture and the flow of light

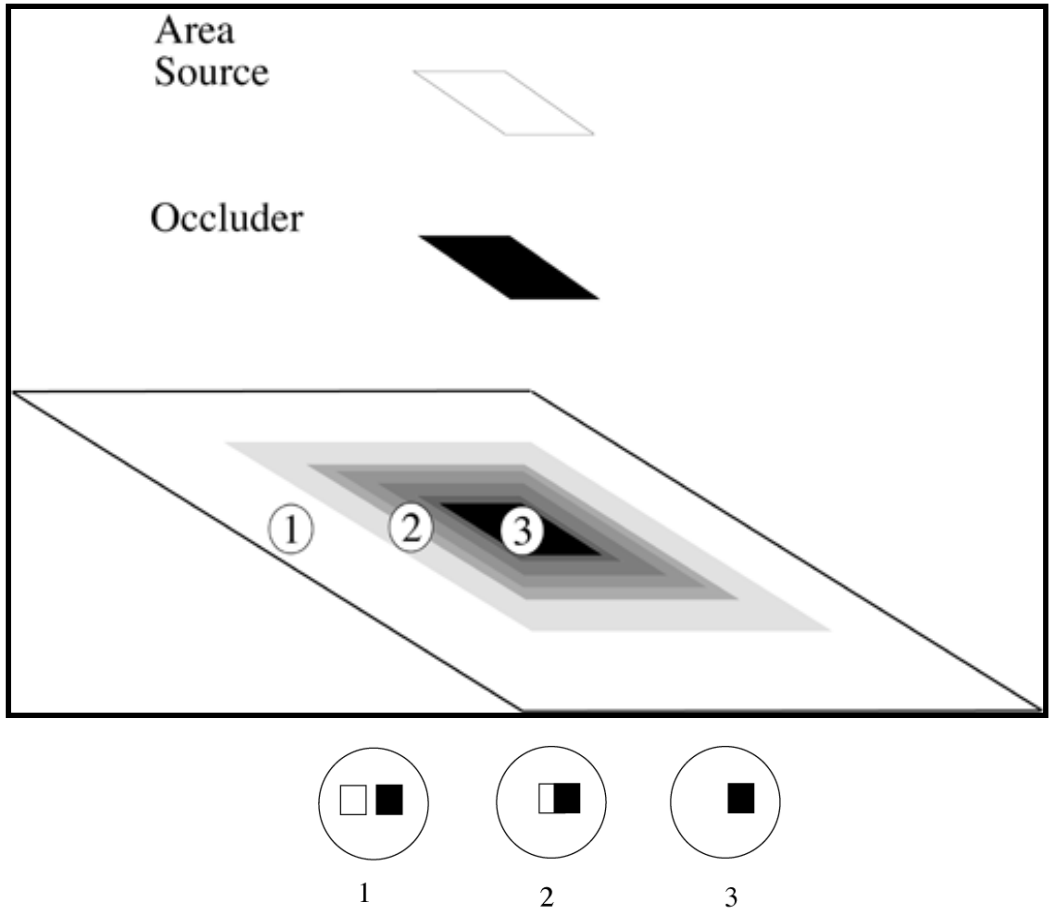
Scene surfaces also cause shadows

- 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

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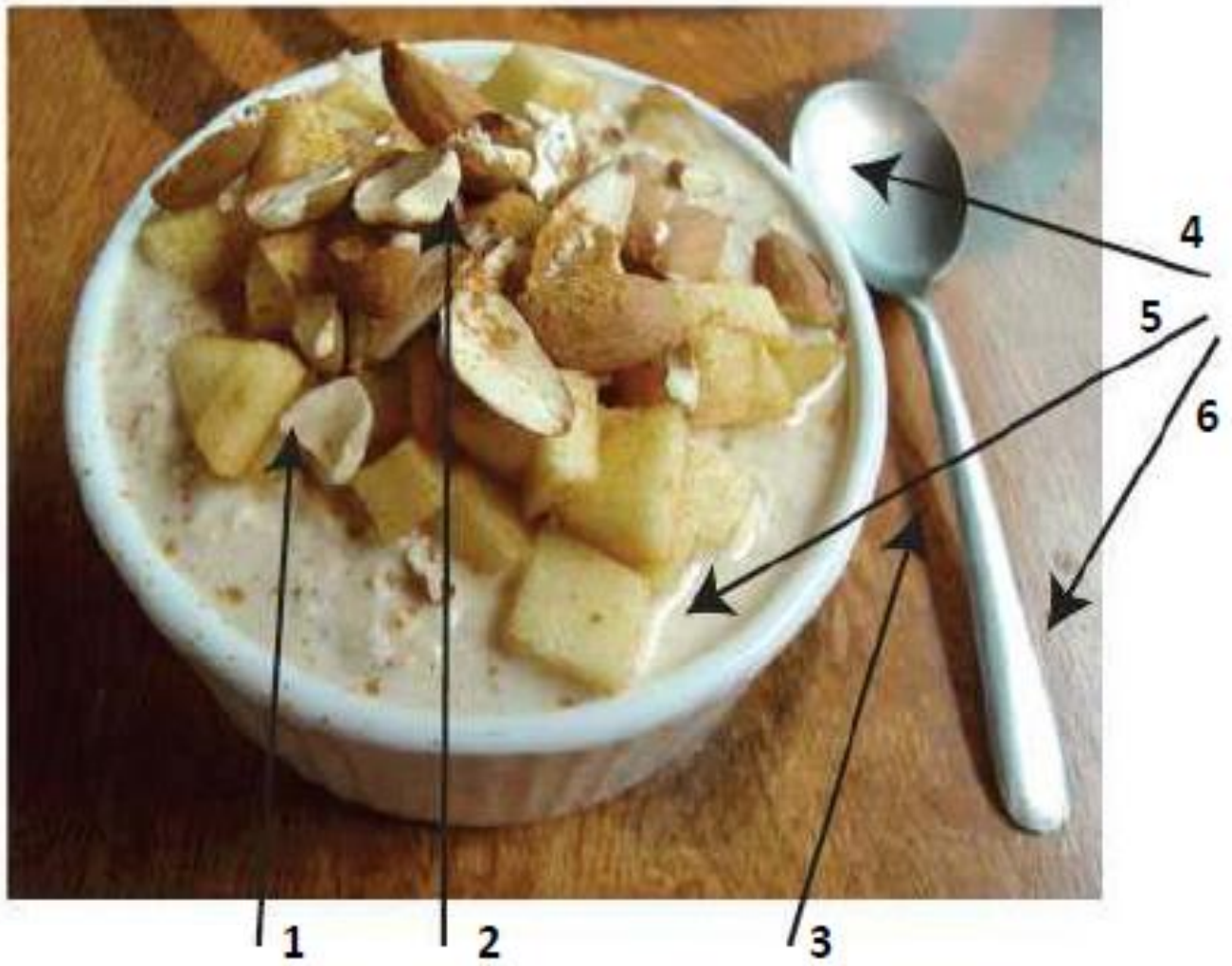
Models of light sources

- 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

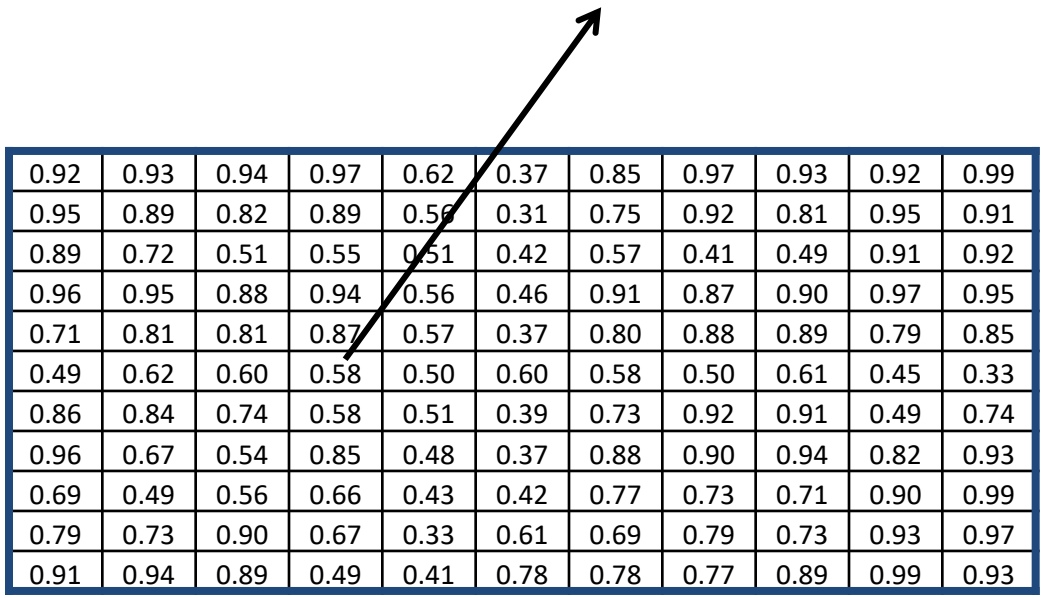
Recap



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

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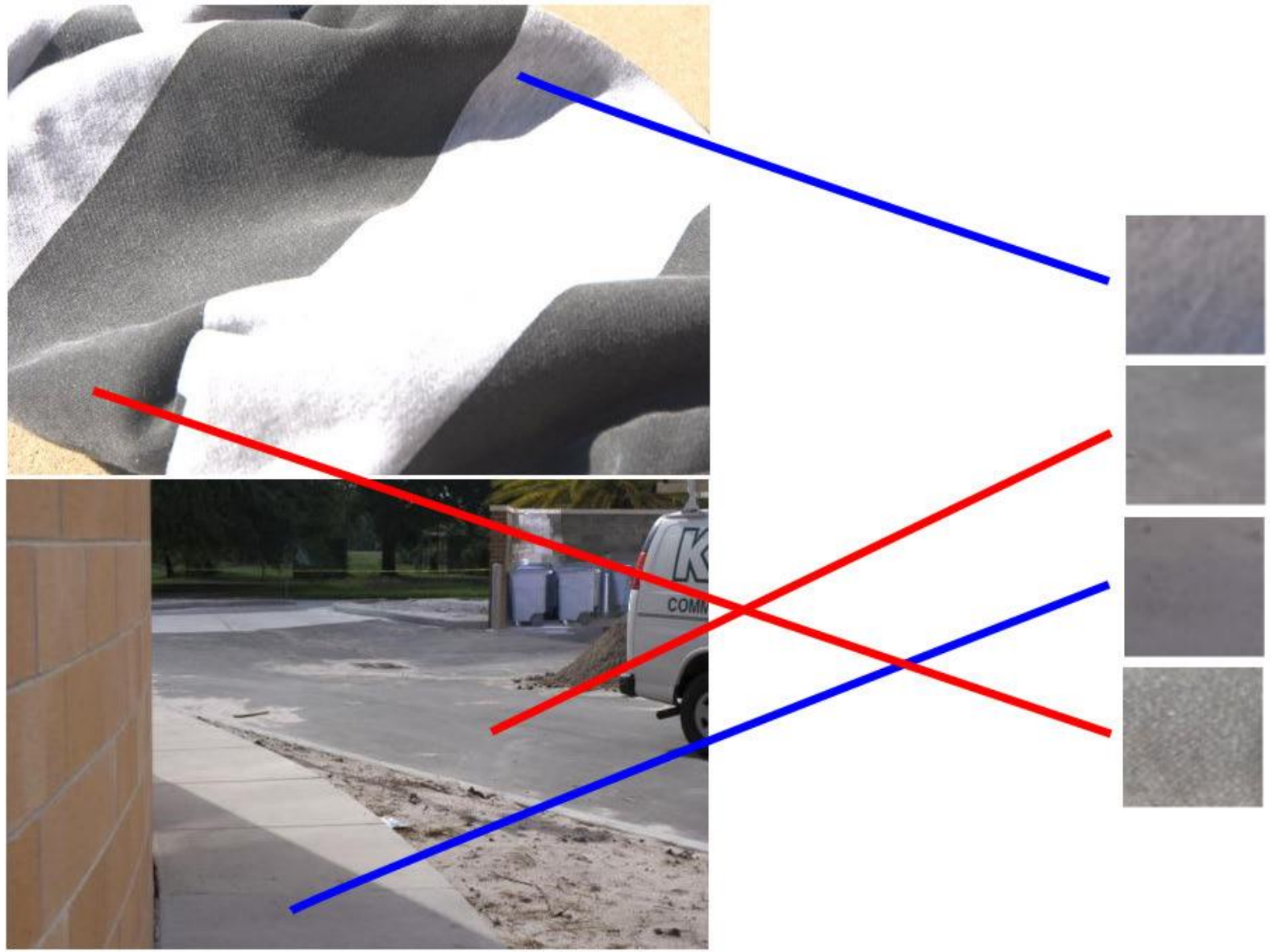
The plight of the poor pixel

- 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



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

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Darkness = Large Difference in Neighboring Pixels

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What is this?

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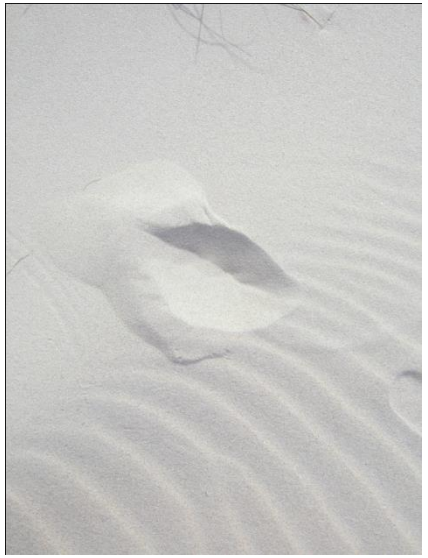
What differences in intensity tell us about shape

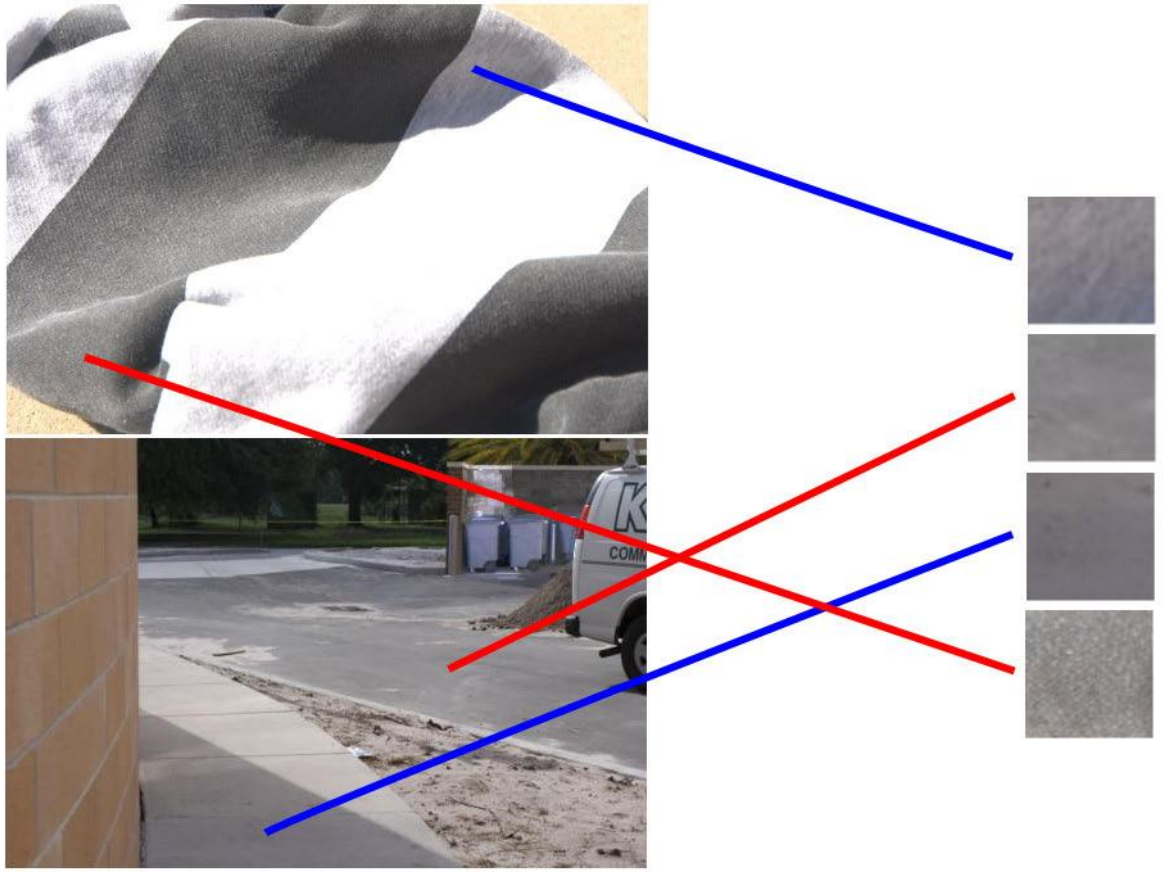
- Changes in surface normal
- Texture
- Proximity
- Indents and bumps
- Grooves and creases



Photos Koenderink slides on image texture and the flow of light

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



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

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