COMPUTER VISION

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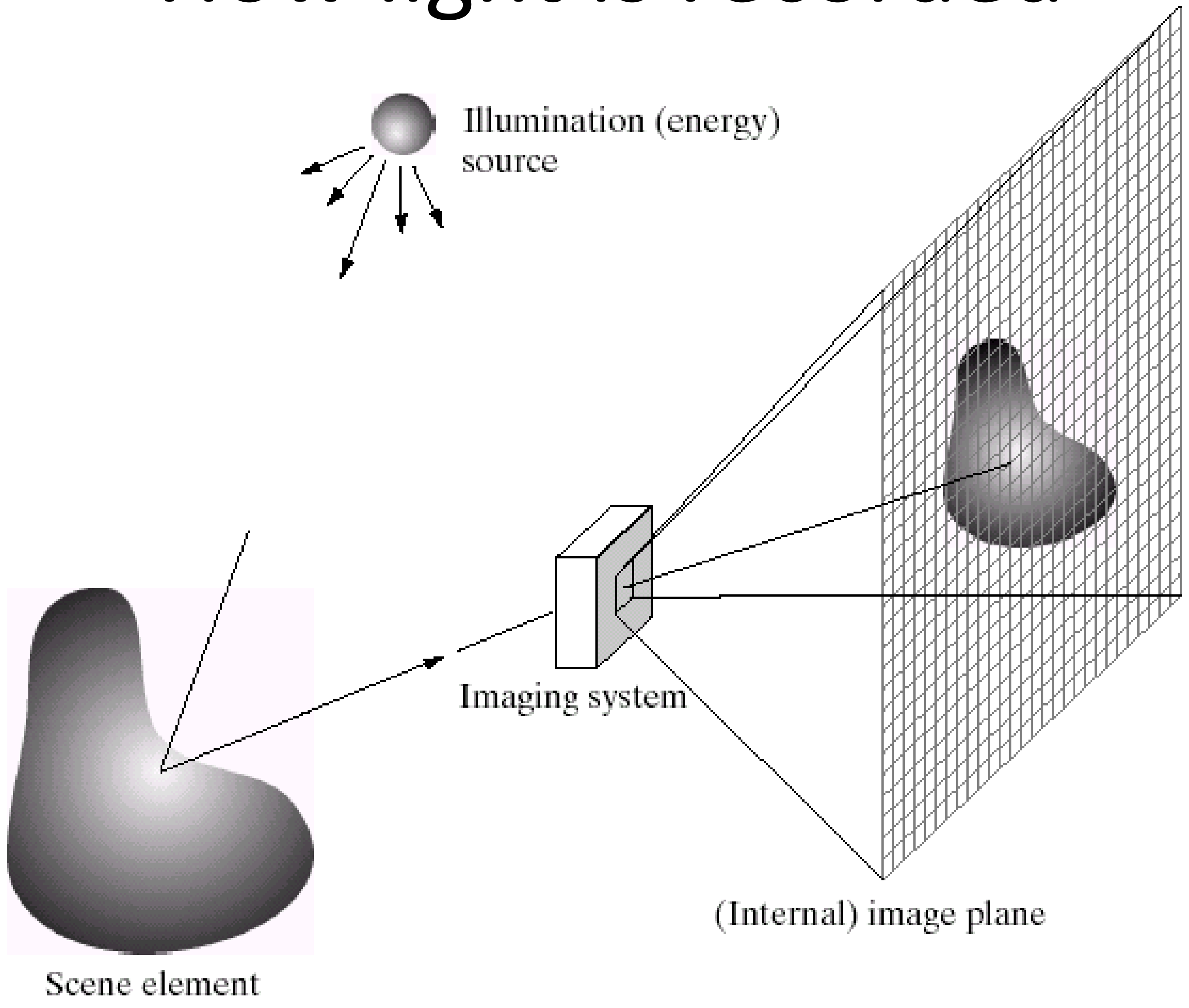
How light is recorded



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

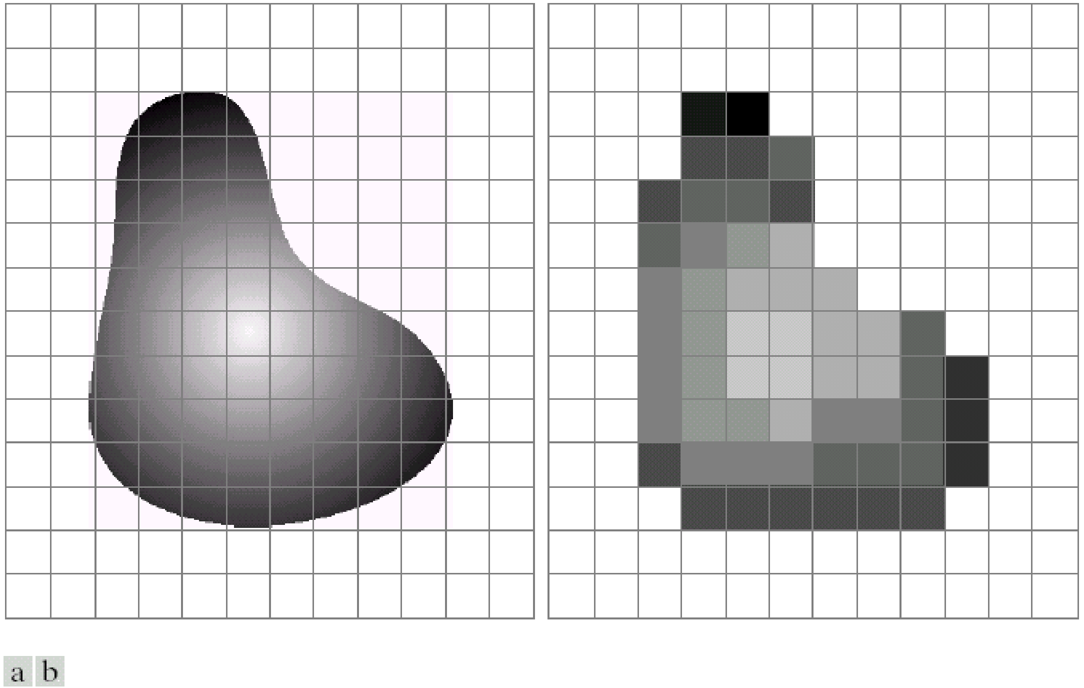
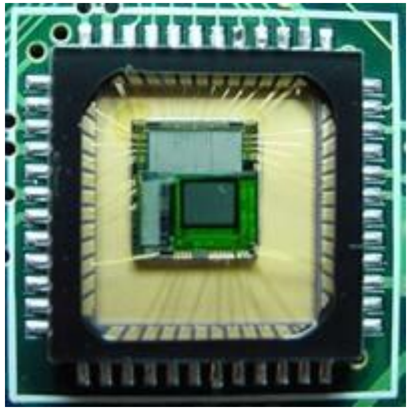


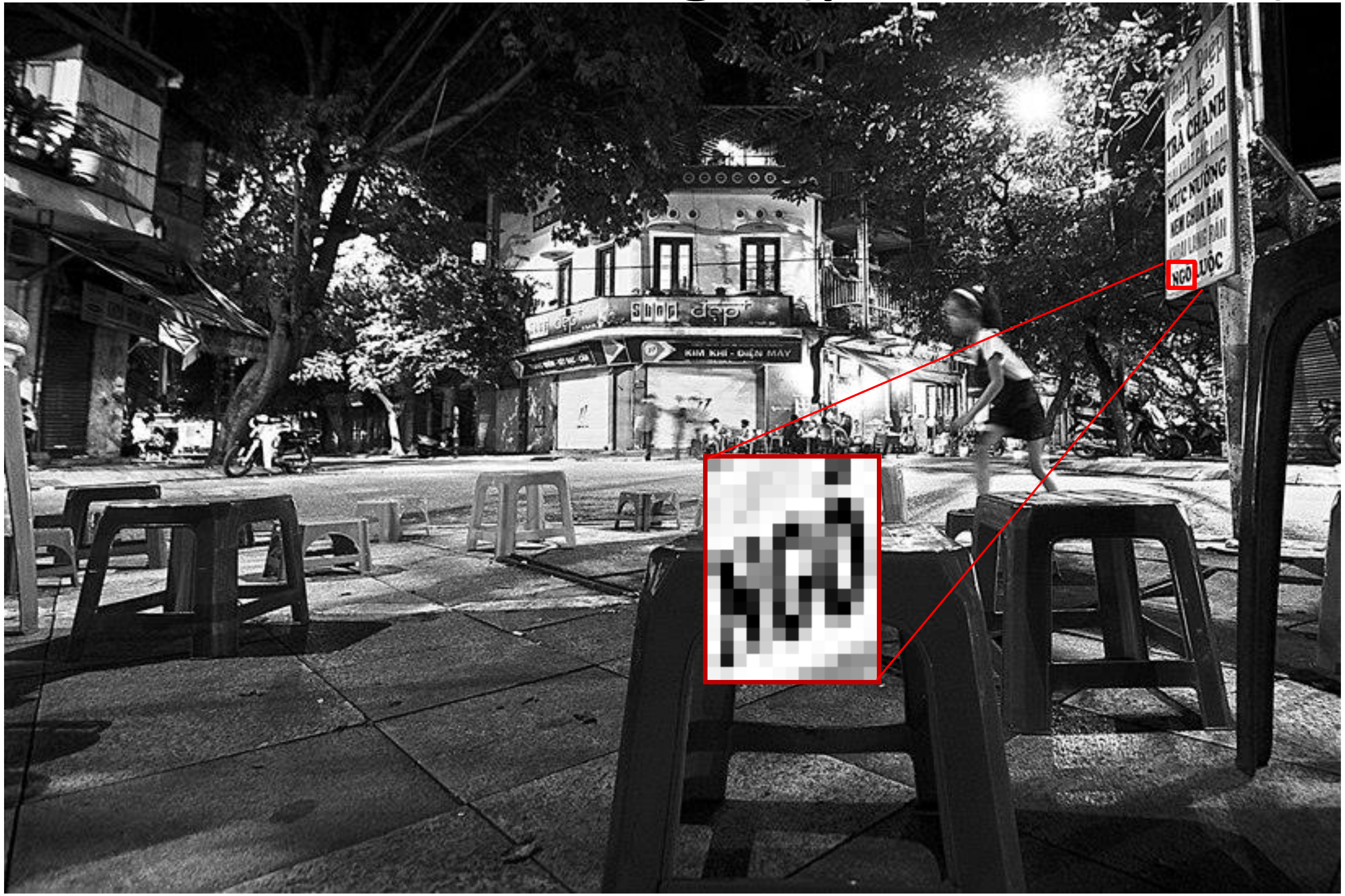
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



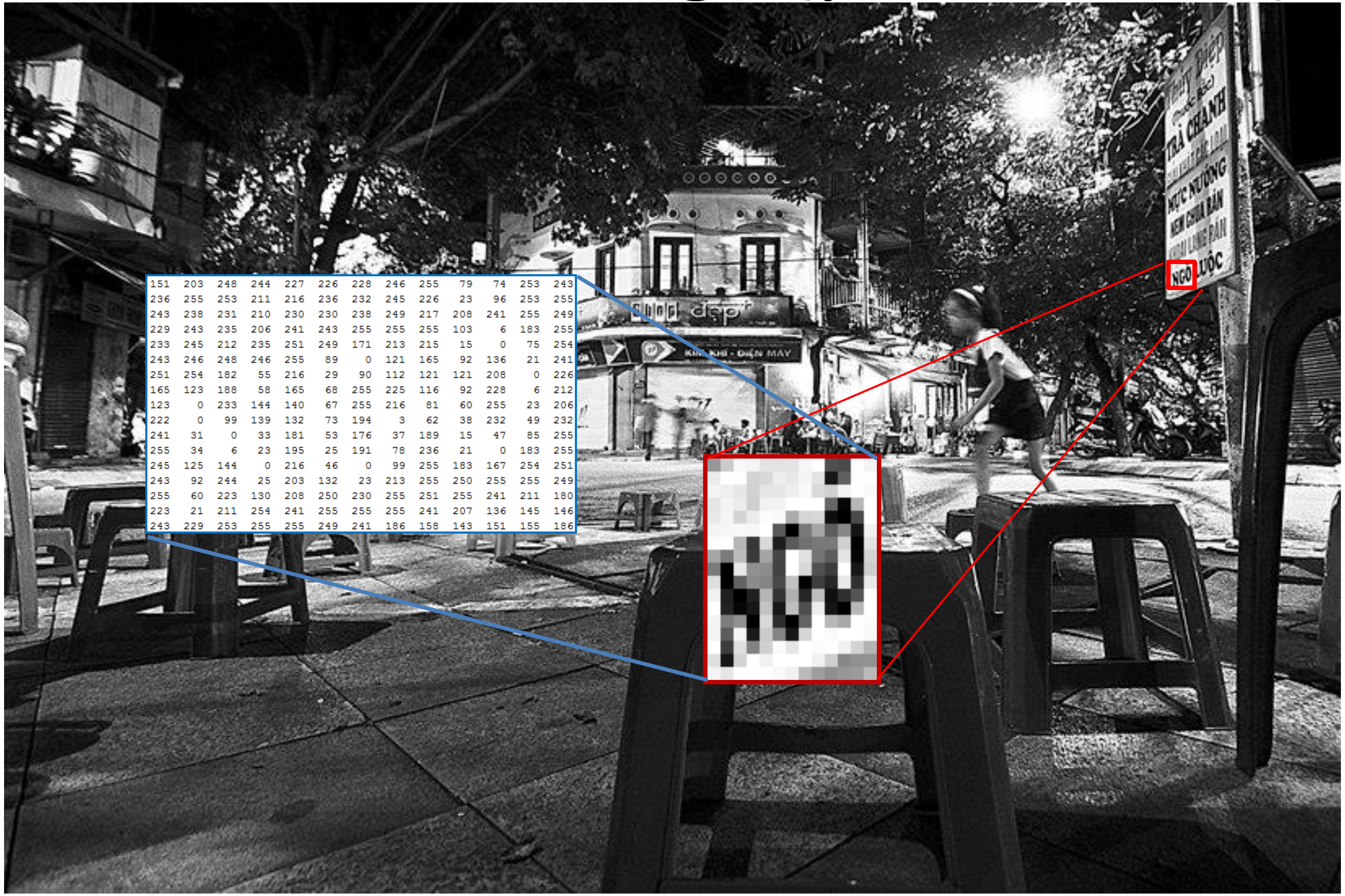
CMOS sensor

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)

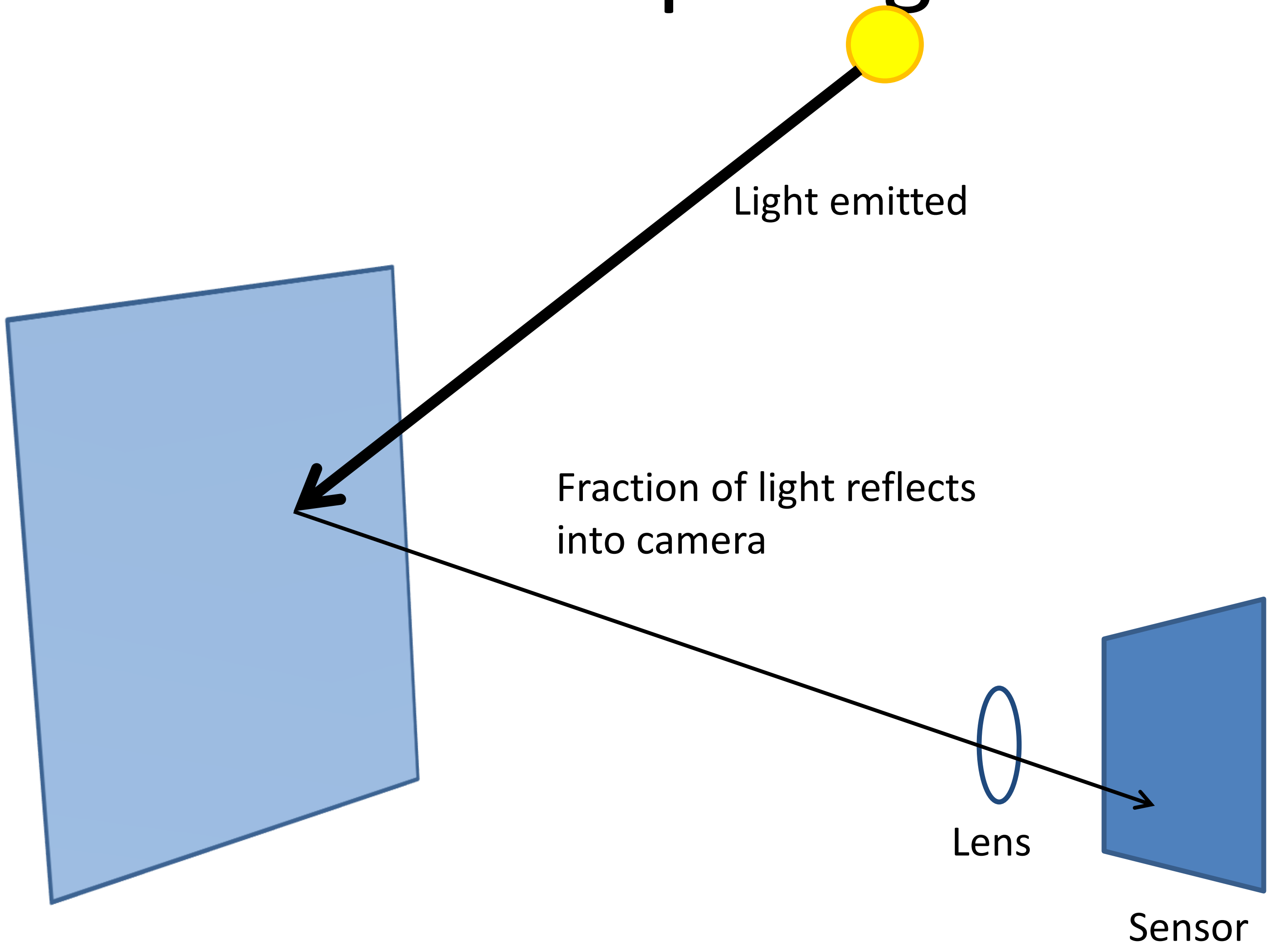


151	203	248	244	227	226	228	246	255	79	74	253	243
236	255	253	211	216	236	232	245	226	23	96	253	255
243	238	231	210	230	230	238	249	217	208	241	255	249
229	243	235	206	241	243	255	255	255	103	6	183	255
233	245	212	235	251	249	171	213	215	15	0	75	254
243	246	248	246	255	89	0	121	165	92	136	21	241
251	254	182	55	216	29	90	112	121	121	208	0	226
165	123	188	58	165	68	255	225	116	92	228	6	212
123	0	233	144	140	67	255	216	81	60	255	23	206
222	0	99	139	132	73	194	3	62	38	232	49	232
241	31	0	33	181	53	176	37	189	15	47	85	255
255	34	6	23	195	25	191	78	236	21	0	183	255
245	125	144	0	216	46	0	99	255	183	167	254	251
243	92	244	25	203	132	23	213	255	250	255	255	249
255	60	223	130	208	250	230	255	251	255	241	211	180
223	21	211	254	241	255	255	255	241	207	136	145	146
243	229	253	255	255	249	241	186	158	143	151	155	186

Today’s class: Light and Shading

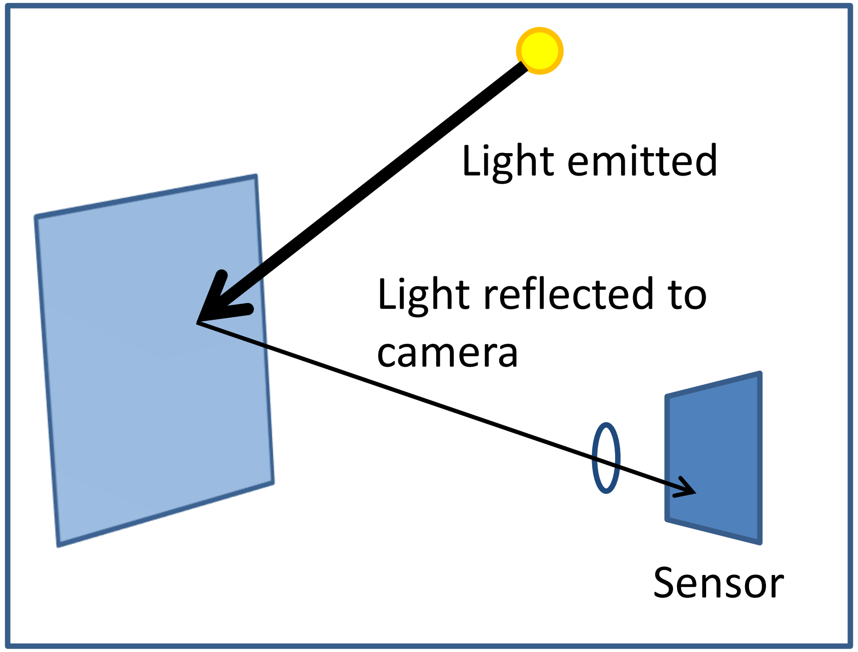
- What determines a pixel’s intensity?
- What can we infer about the scene from pixel intensities?

How does a pixel get its value?



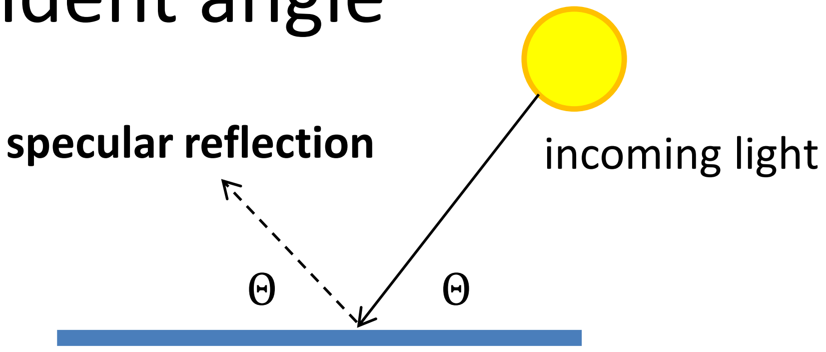
How does a pixel get its value?

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

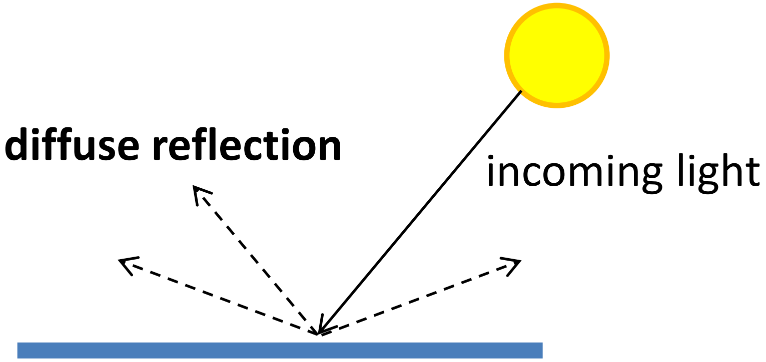


Basic models of reflection

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

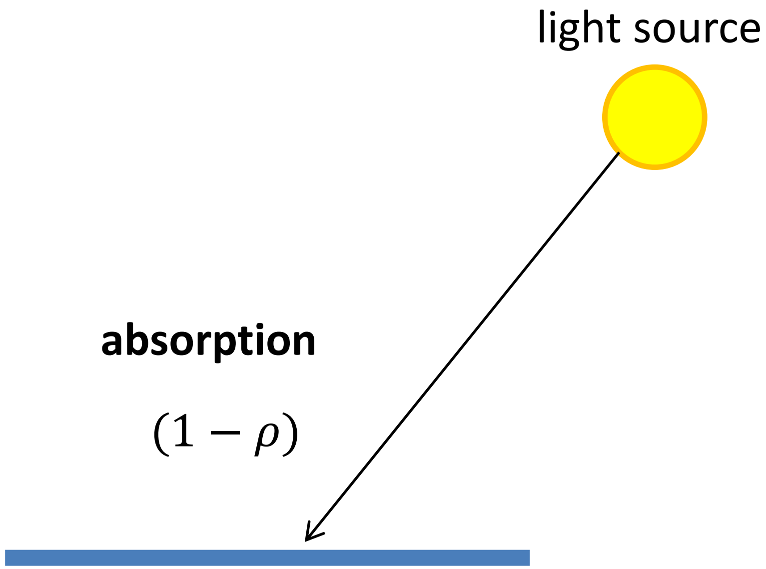


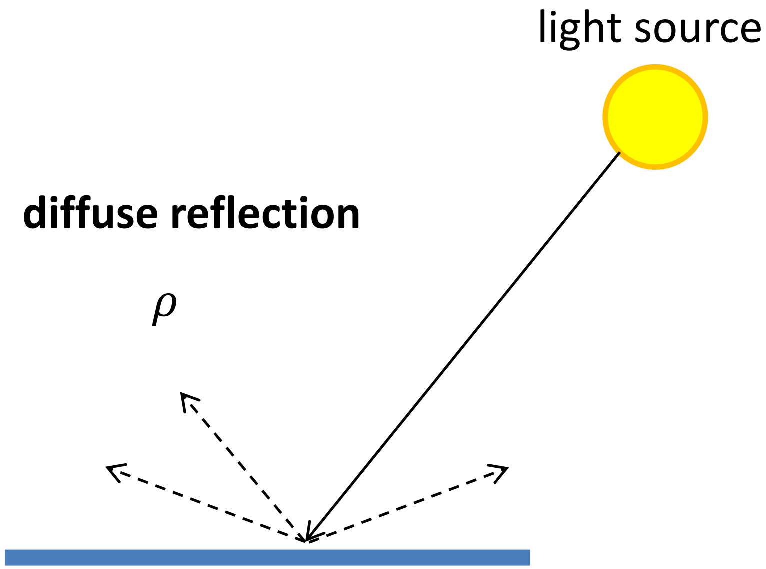
- Diffuse: light scatters in all directions
  - E.g., brick, cloth, rough wood



Lambertian reflectance model

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

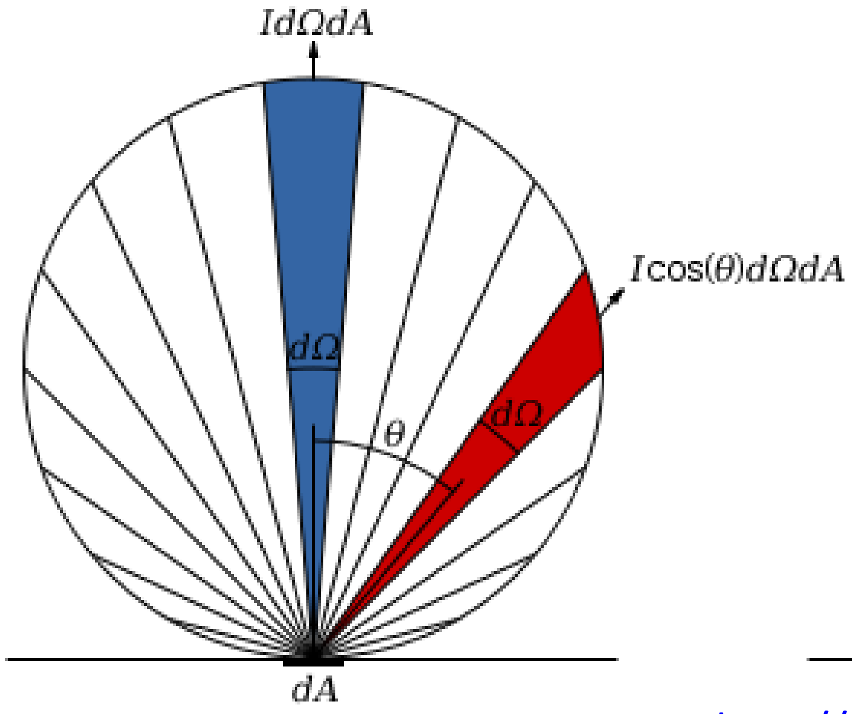


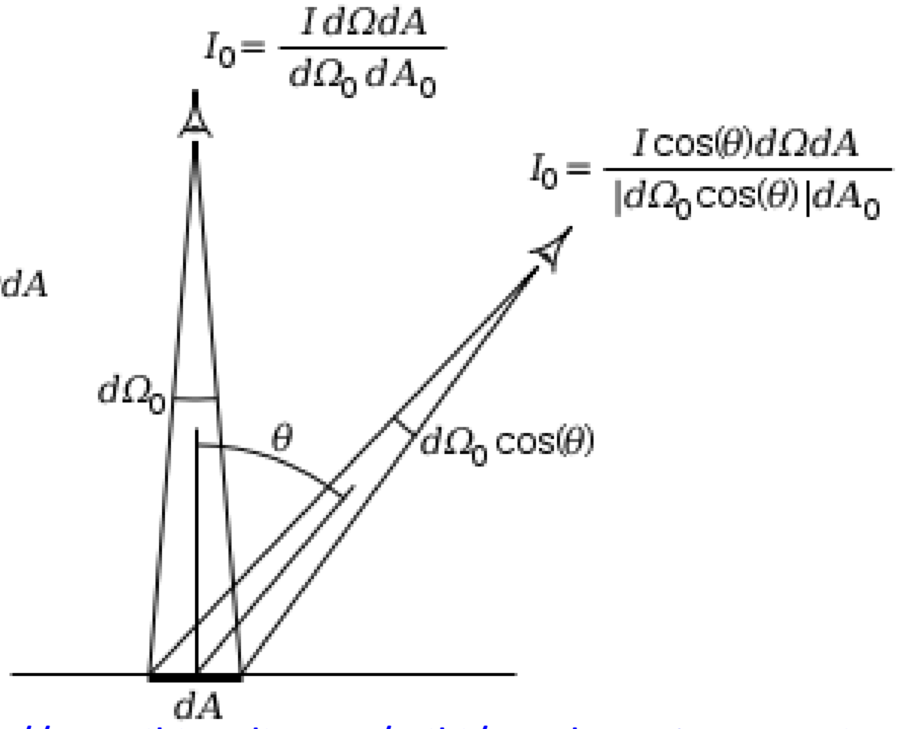


Diffuse reflection: Lambert's cosine law

Intensity does *not* depend on viewer angle.

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

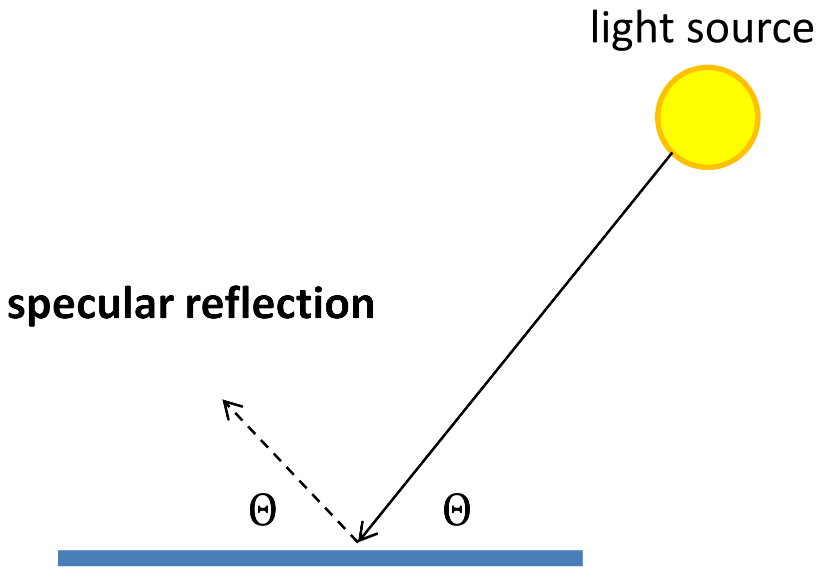




http://en.wikipedia.org/wiki/Lambert%27s_cosine_law

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)

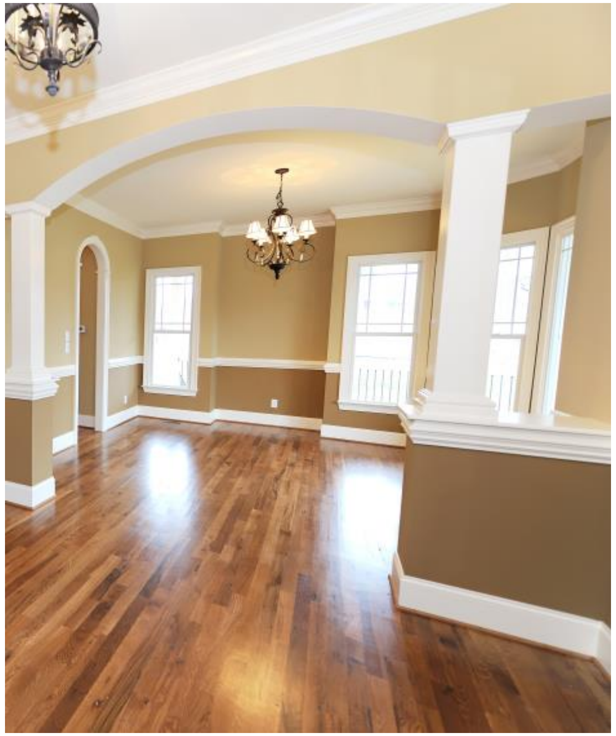
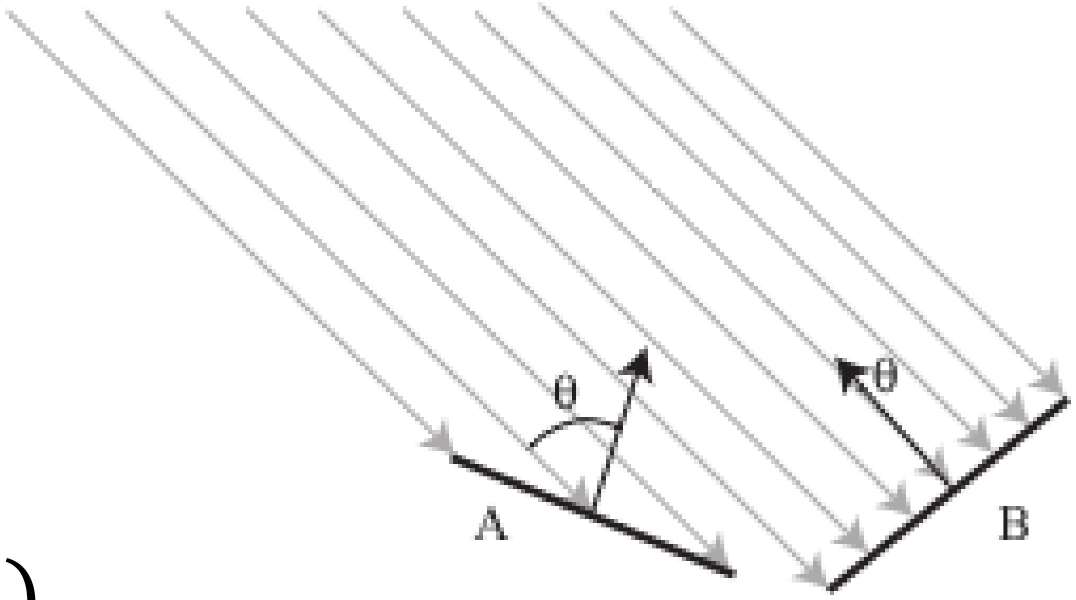


Photo: northcountryhardwoodfloors.com

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

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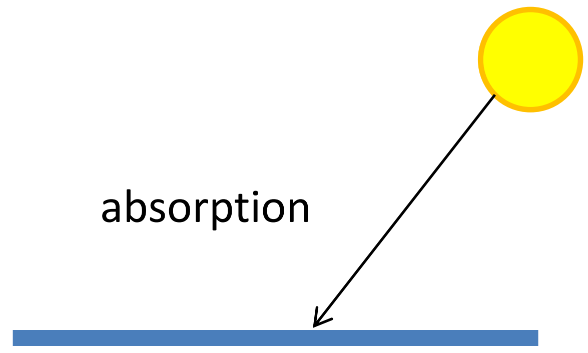
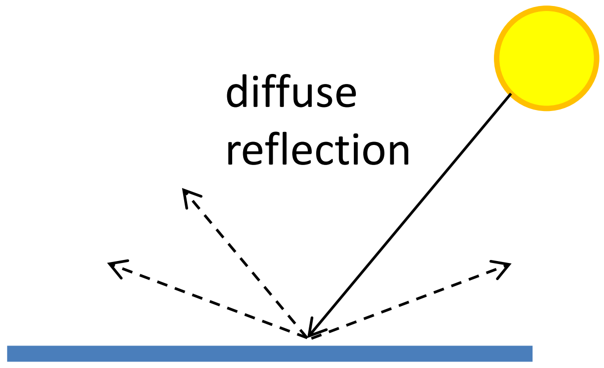
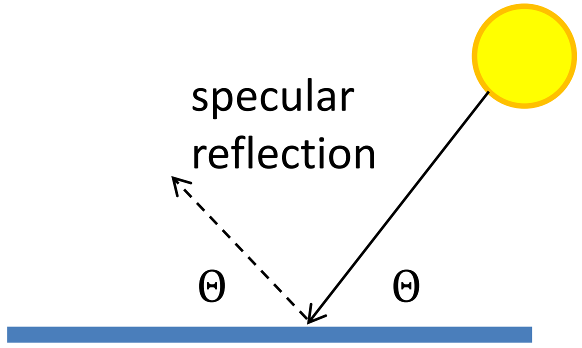
Recap

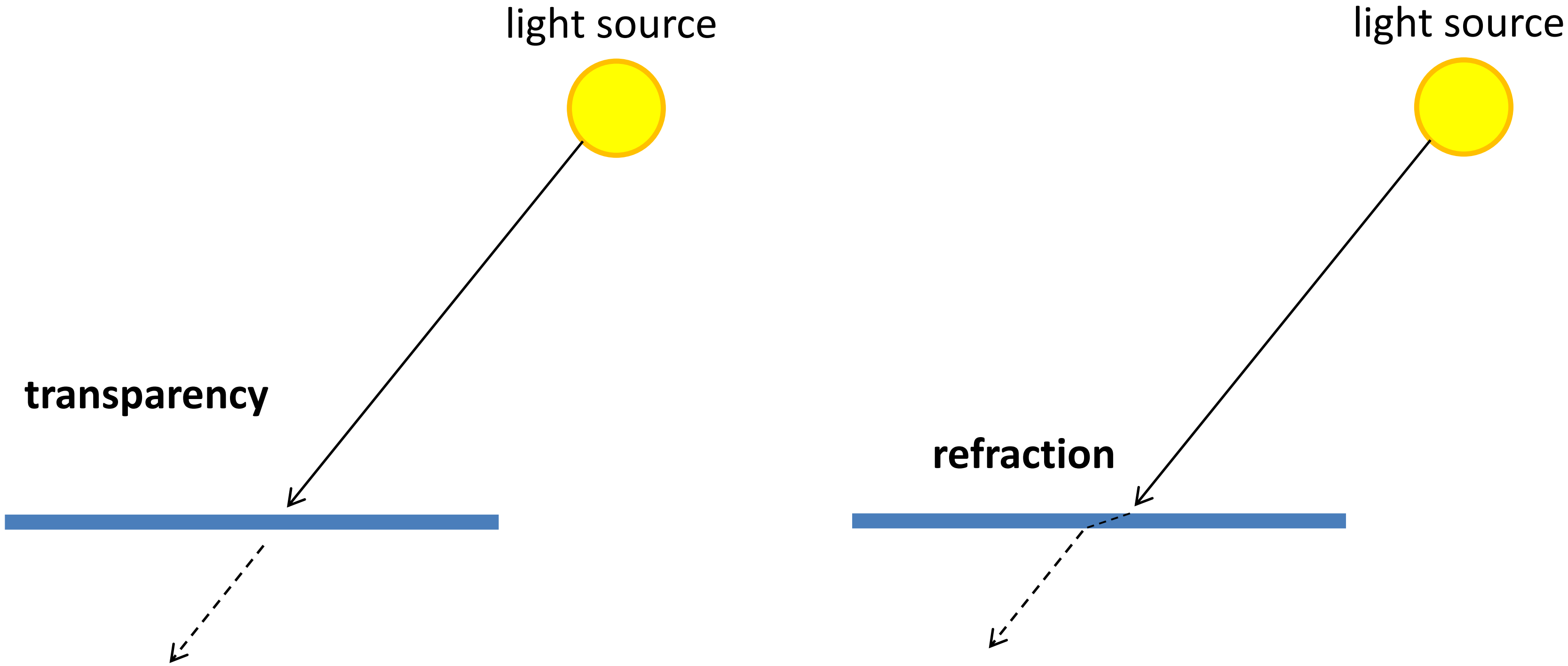
- When light hits a typical surface
  - Some light is absorbed (1-ρ)
    - More absorbed for low albedos
  - Some light is reflected diffusely
    - Independent of viewing direction
  - Some light is reflected specularly
    - Light bounces off (like a mirror), depends on viewing direction

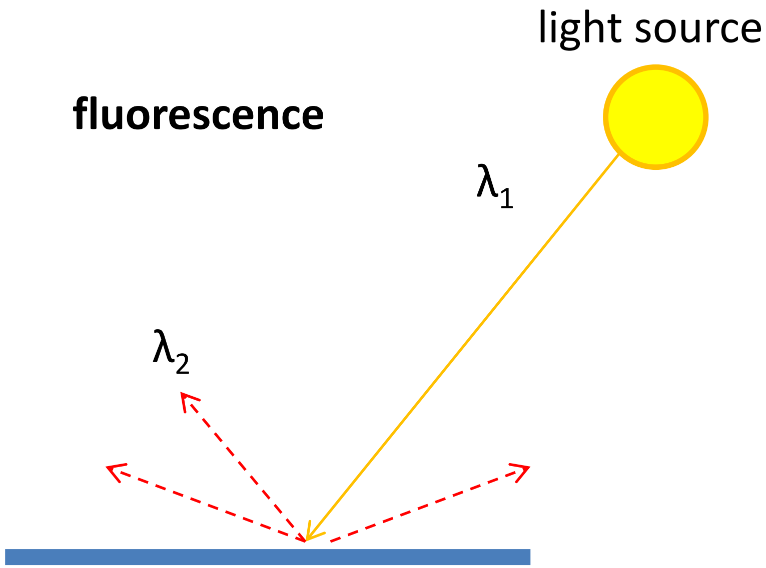


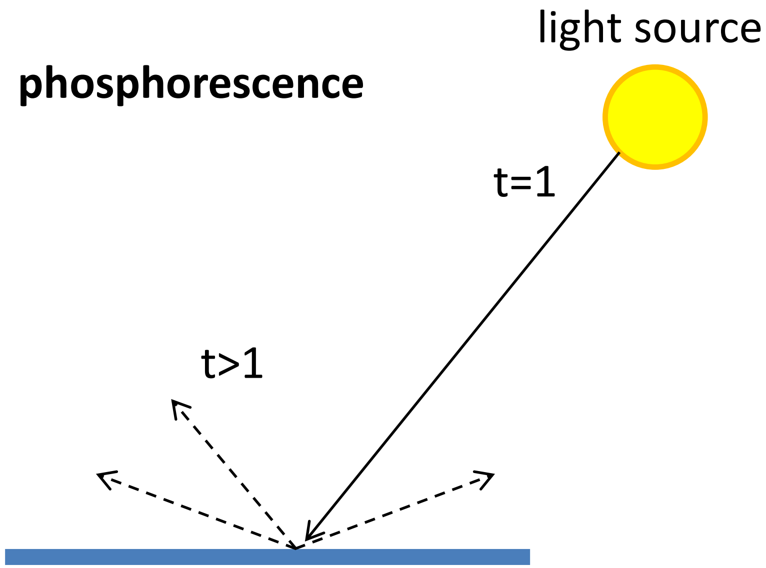


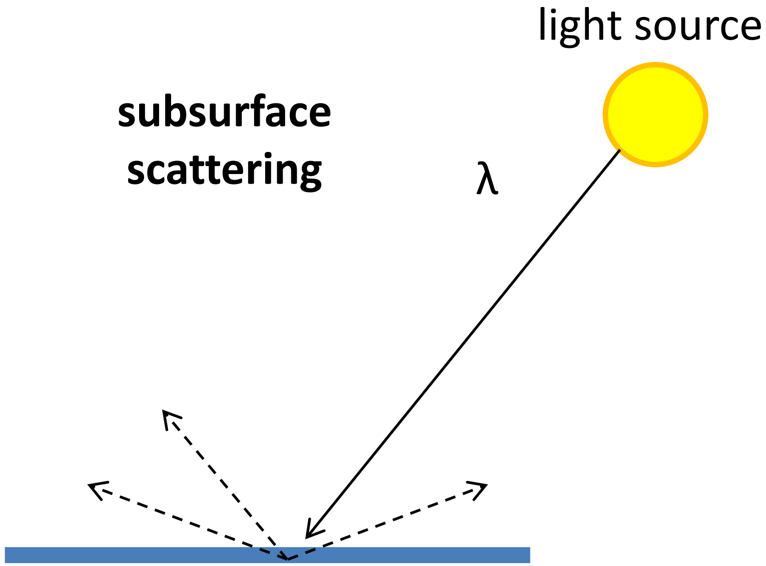


Other possible effects



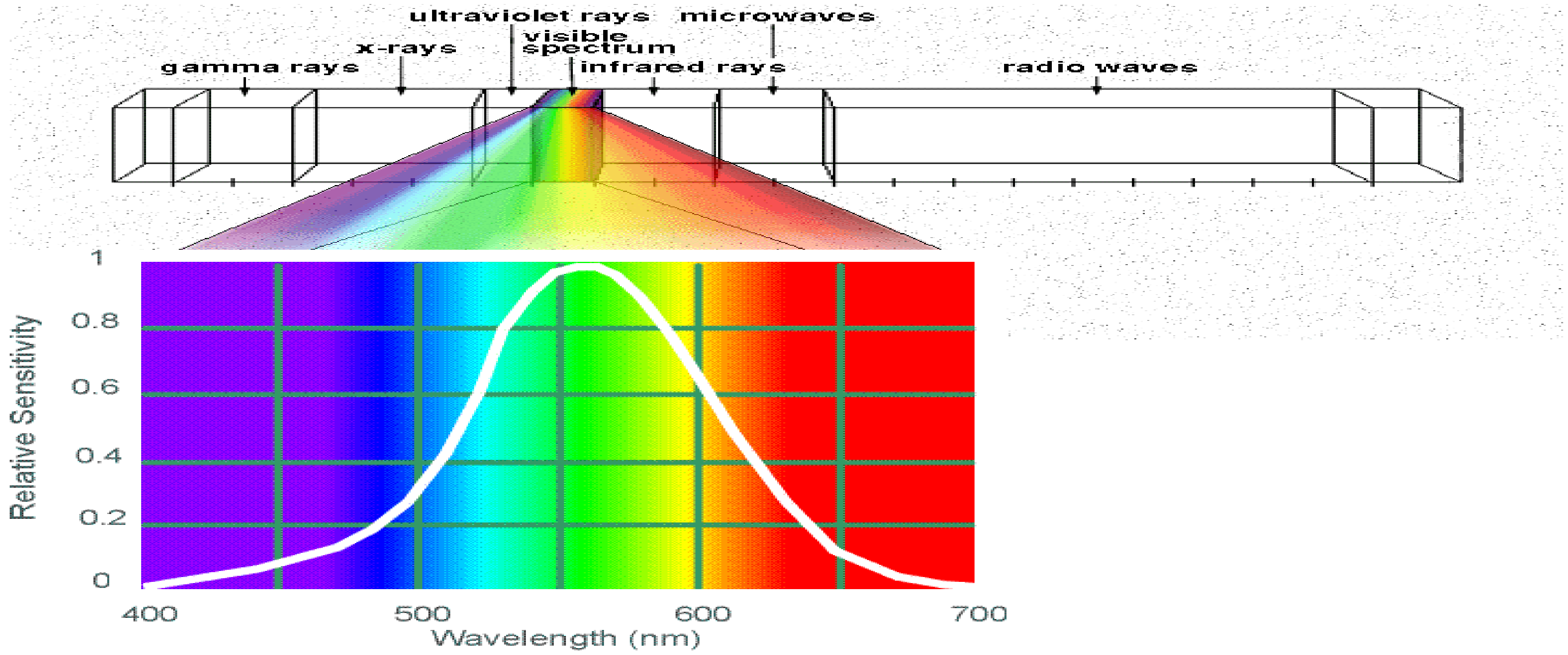

light source
fluorescence
λ_1
λ_2


light source
phosphorescence
t=1
t>1


light source
subsurface
scattering
λ

Color

Light is composed of a spectrum of wavelengths

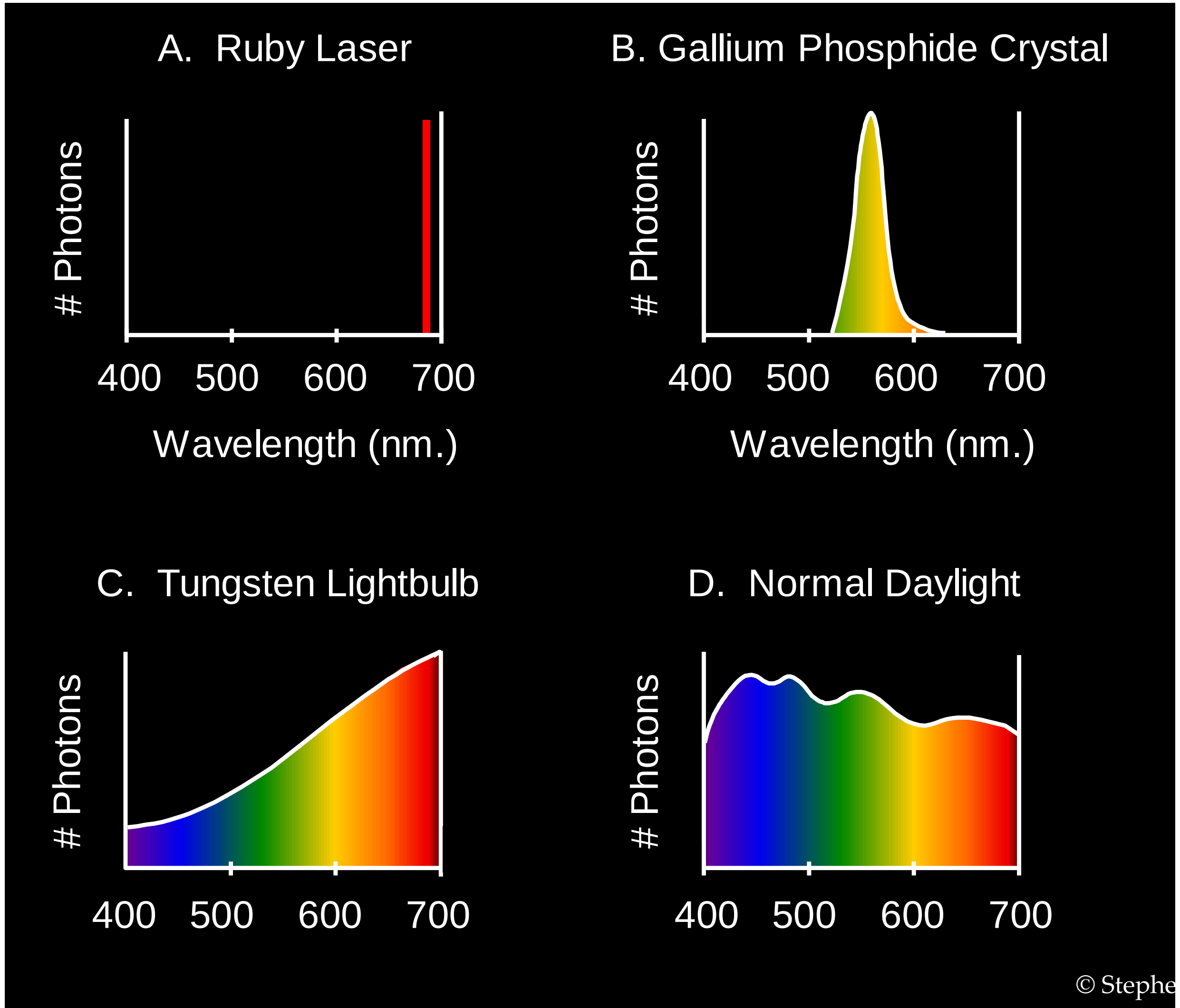


Human Luminance Sensitivity Function

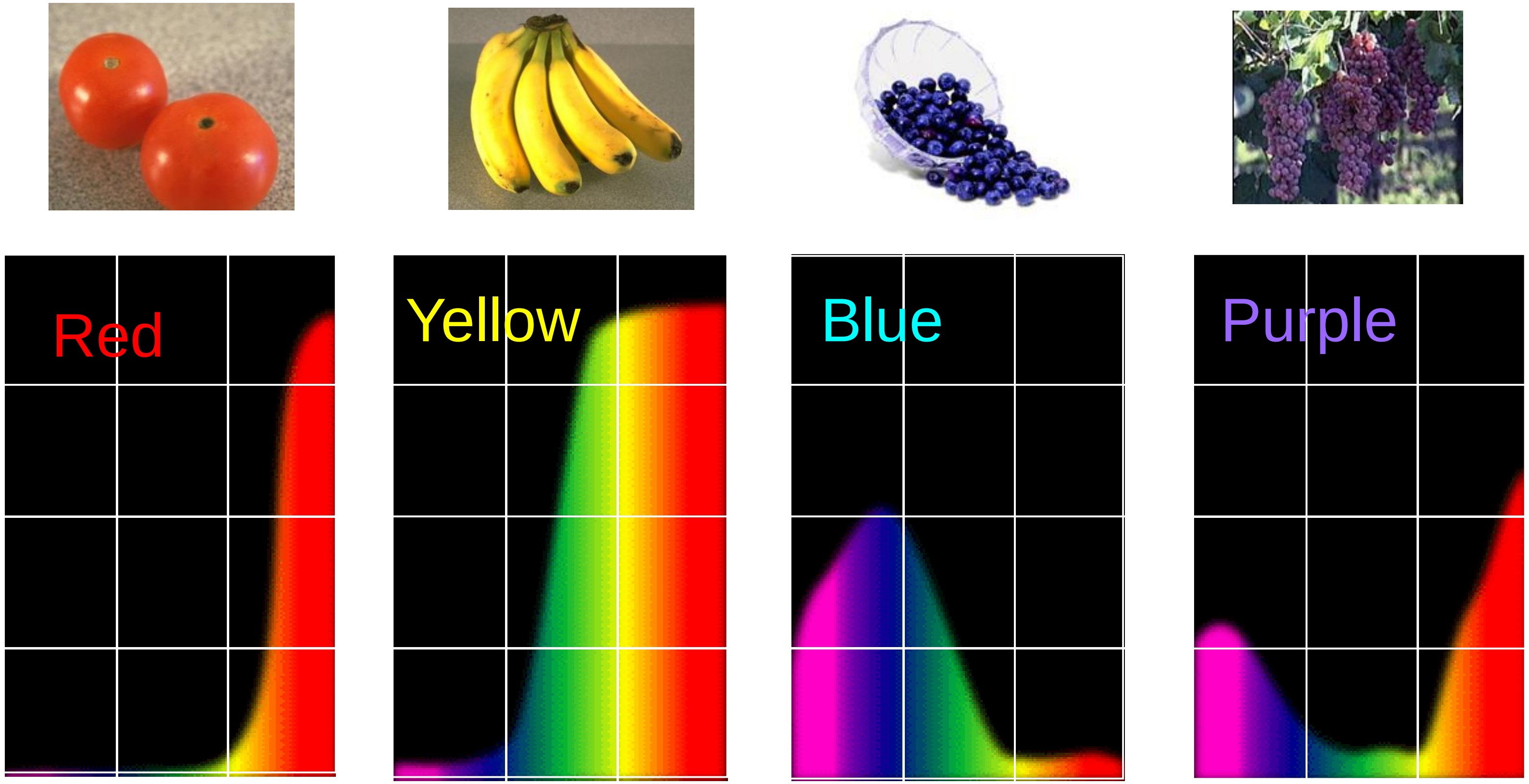
Slide Credit: Efros

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

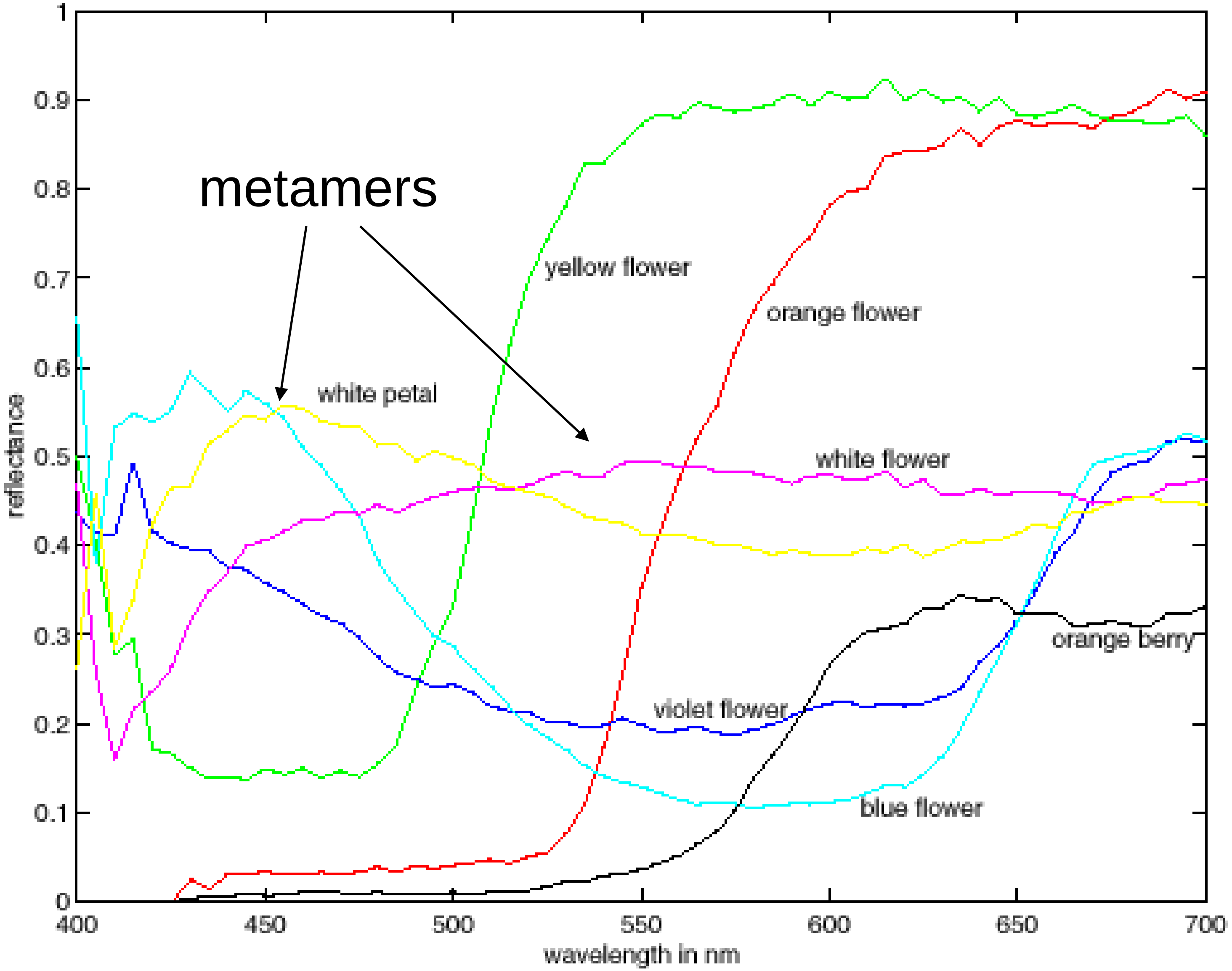
Some examples of the spectra of light sources



Some examples of the reflectance spectra of surfaces

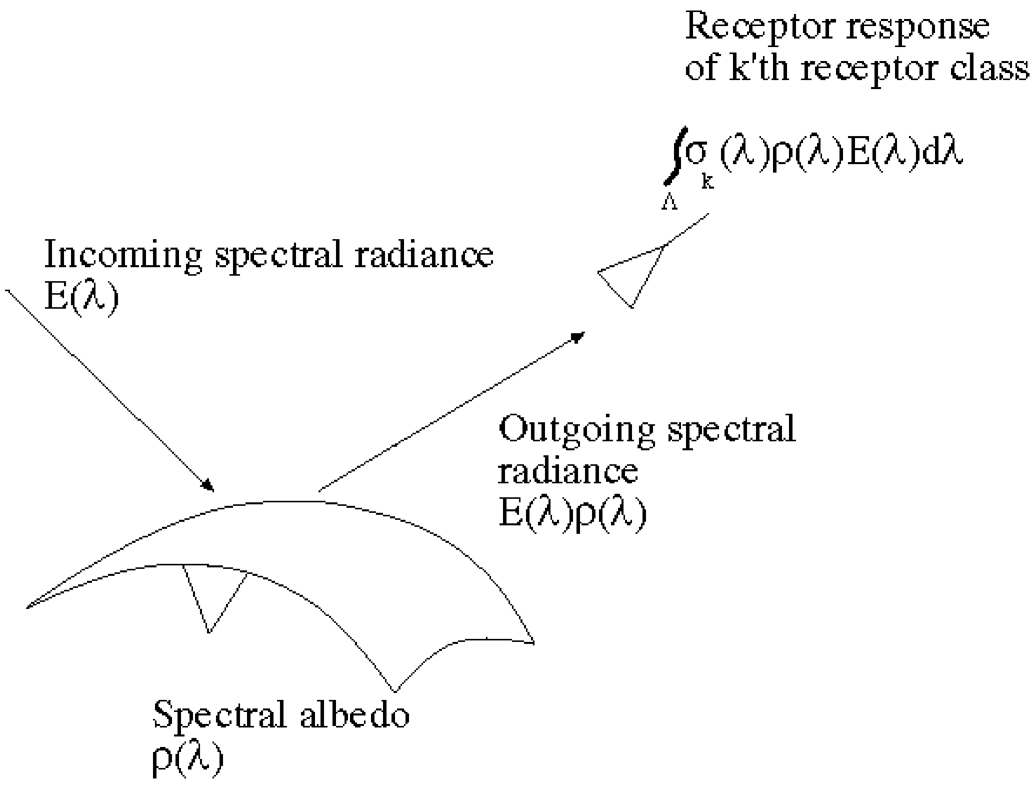


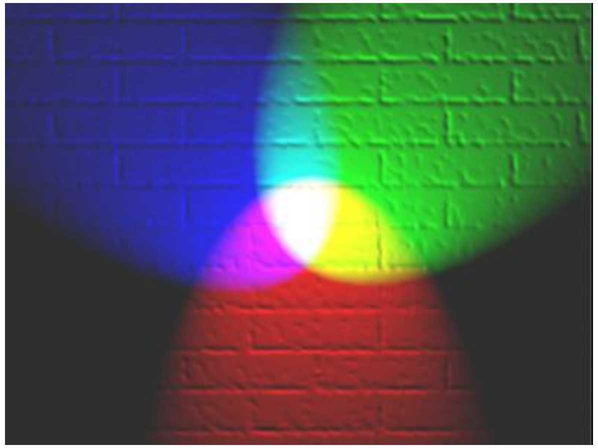
More spectra



The color of objects

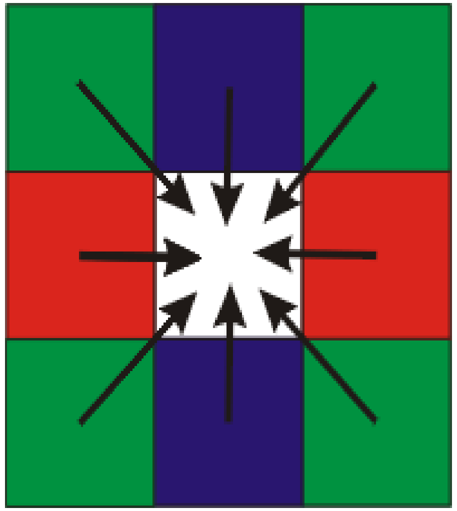
- Colored light arriving at the camera involves two effects
  - The color of the light source (illumination + inter-reflections)
  - The color of the surface

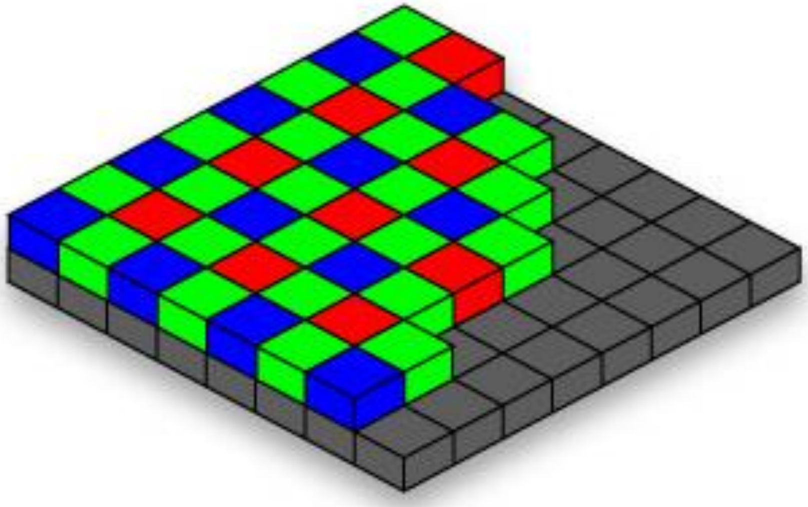


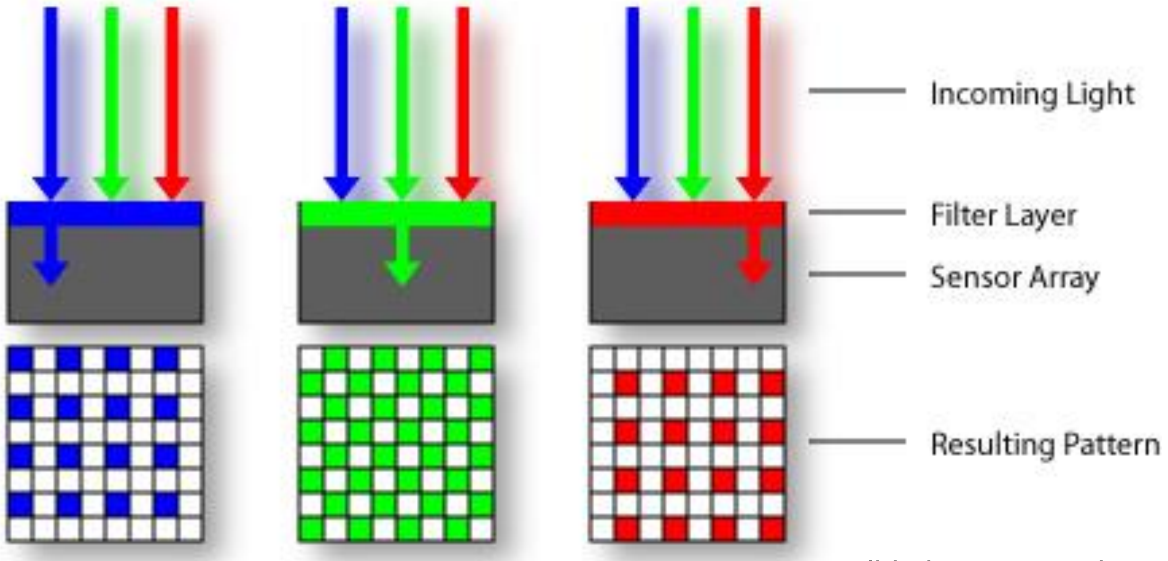


Slide: Forsyth

Color Sensing: Bayer Grid







- Estimate RGB at each cell from neighboring values

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

Slide by Steve Seitz

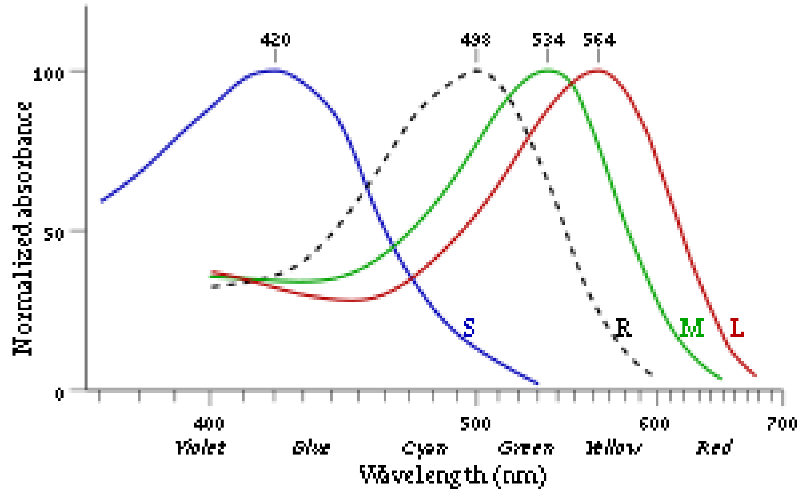
Which image plane is R, G, or B?

Why RGB?

If light is a spectrum, why are images RGB?

Human color receptors

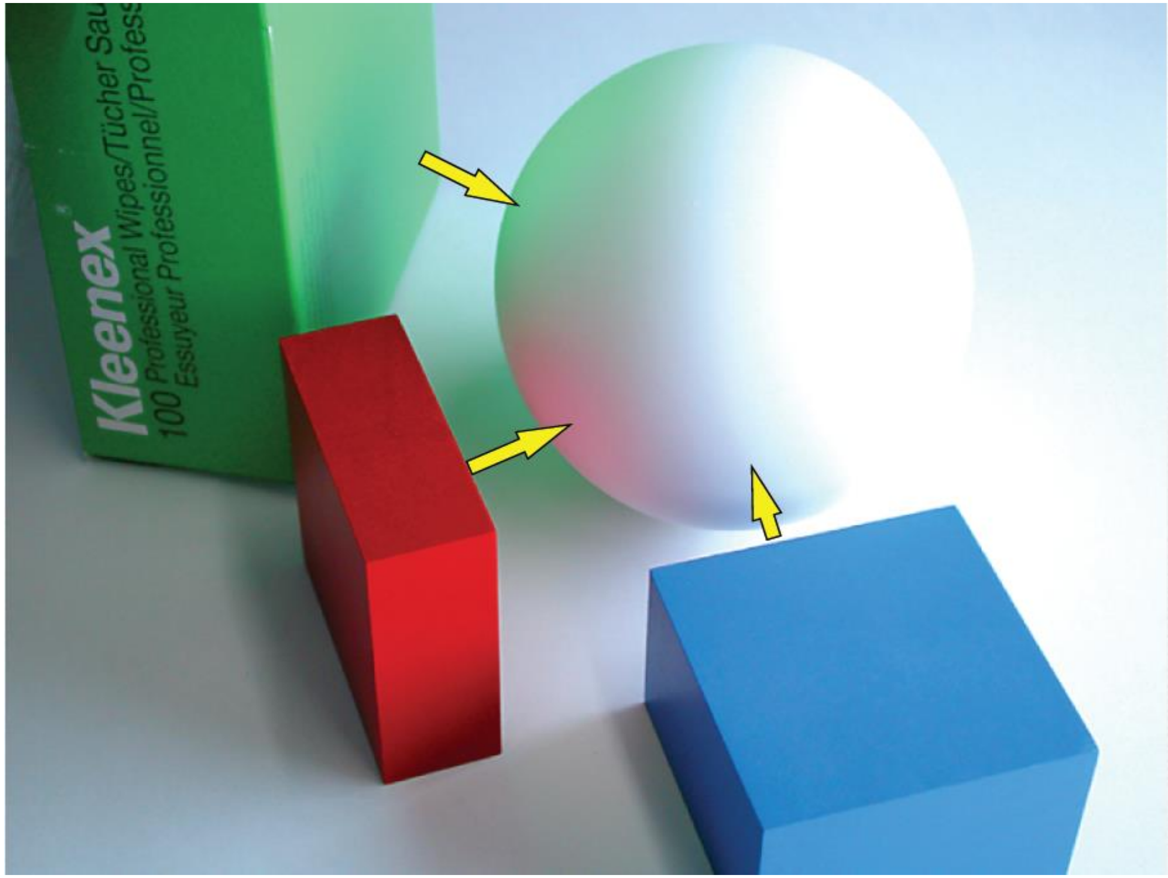
- Long (red), Medium (green), and Short (blue) cones, plus intensity rods
- Fun facts
  - “M” and “L” on the X-chromosome
    - That’s why men are more likely to be color blind (see what it’s like: http://www.vischeck.com/vischeck/vischeckURL.php)
  - “L” has high variation, so some women are tetrachromatic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

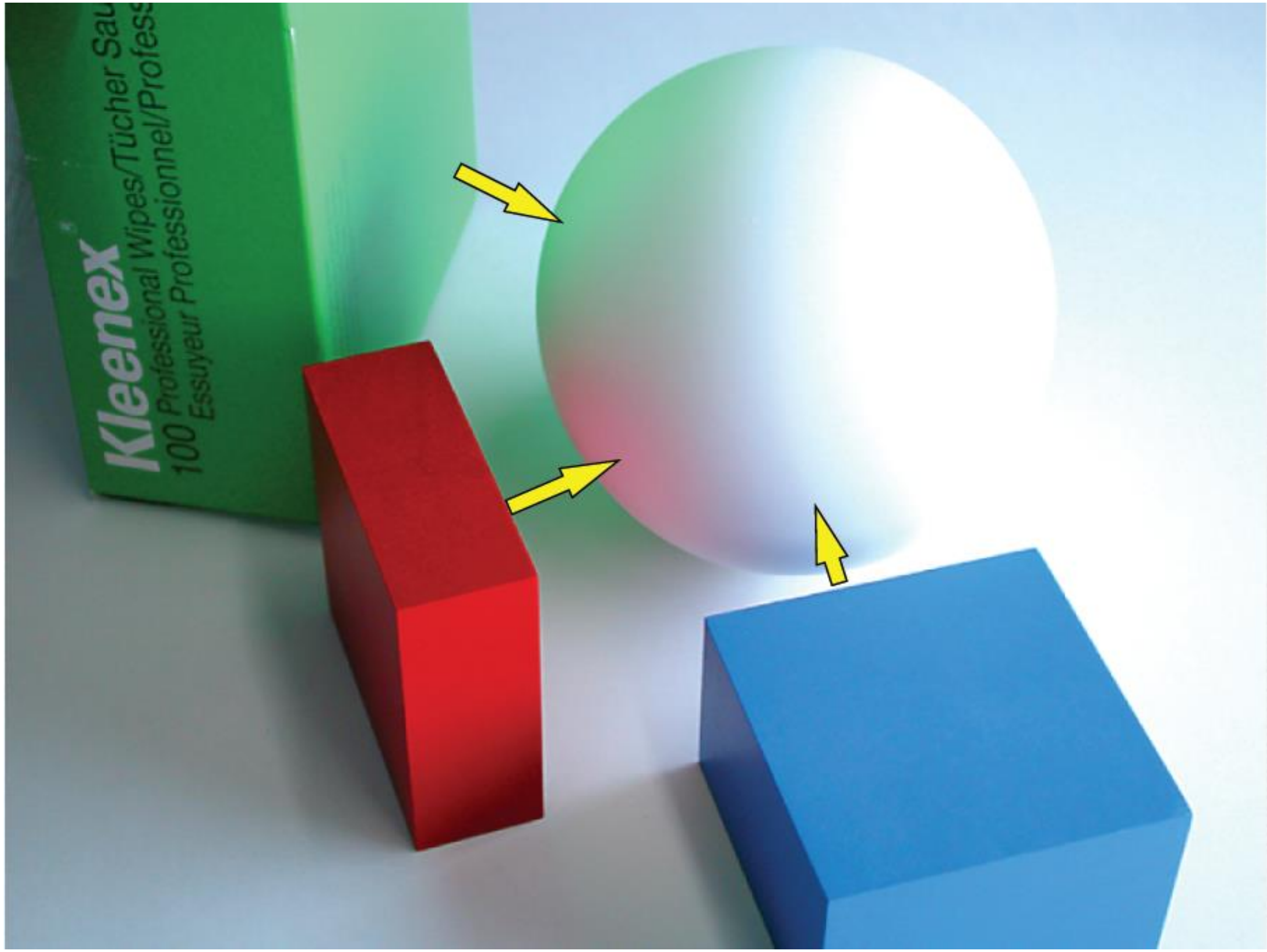
So far: light→surface→camera

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



From Koenderink slides on image texture and the flow of light

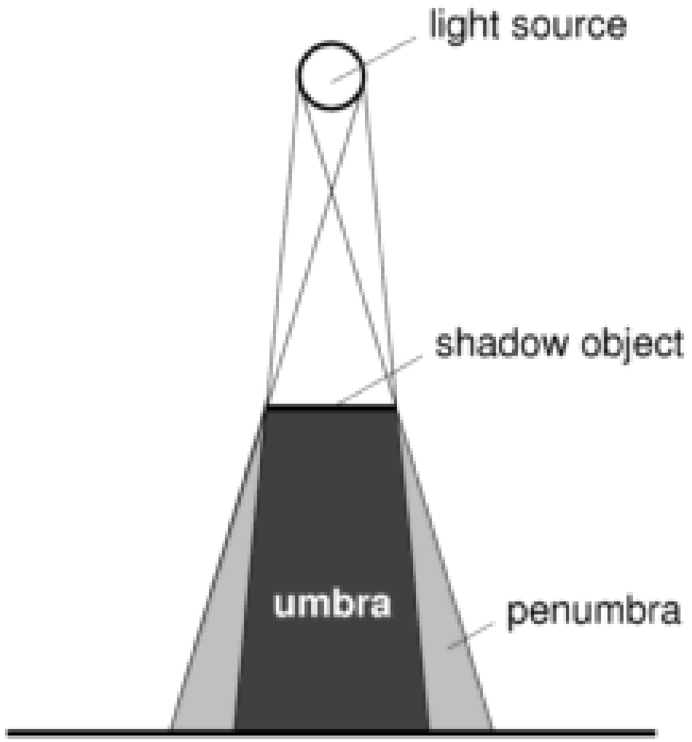
Inter-reflection affects the apparent color of objects



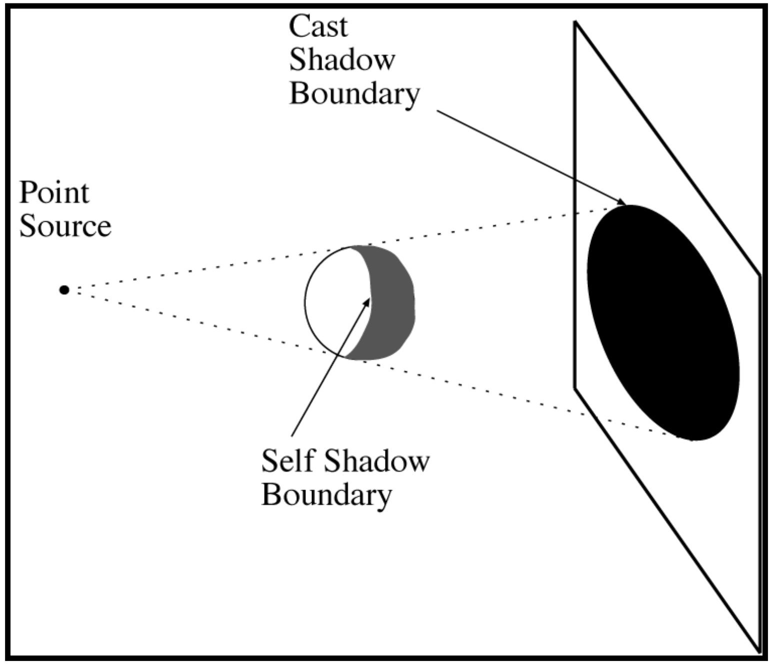
From Koenderink slides on image texture and the flow of light

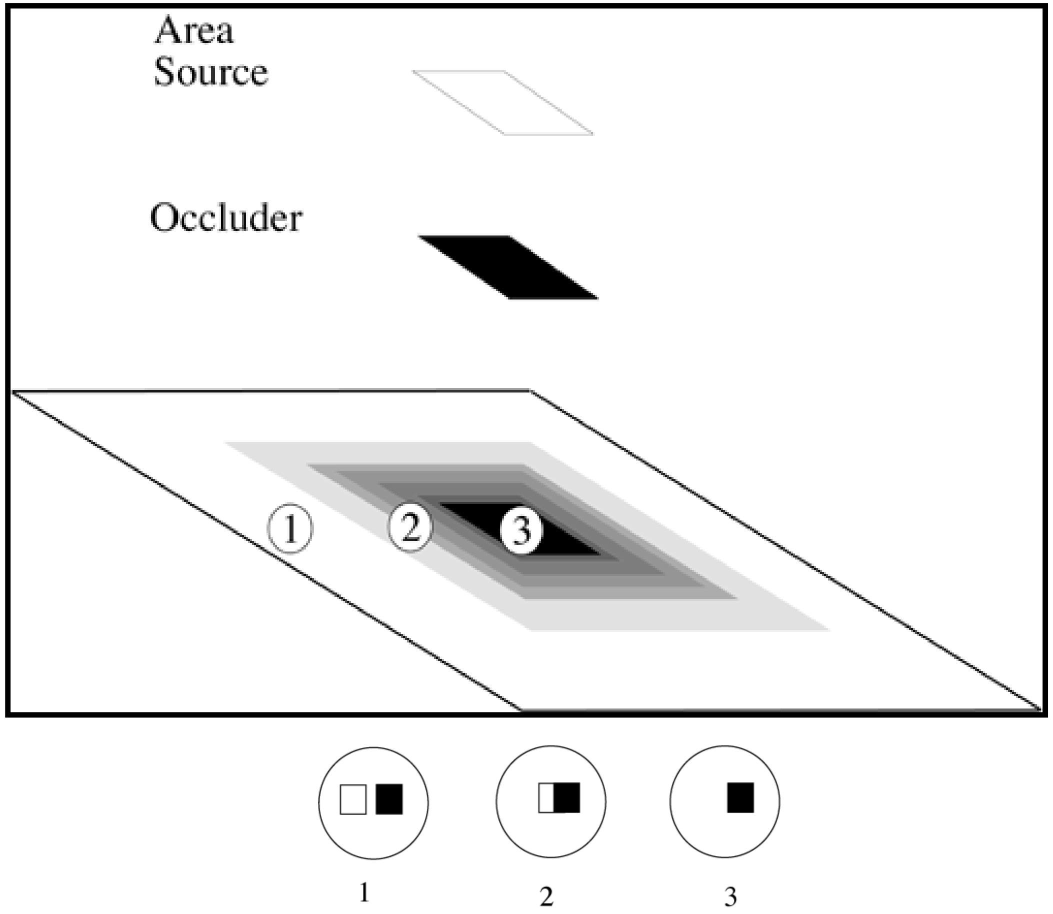
Scene surfaces also cause shadows

- Shadow: reduction in intensity due to a blocked source



Shadows

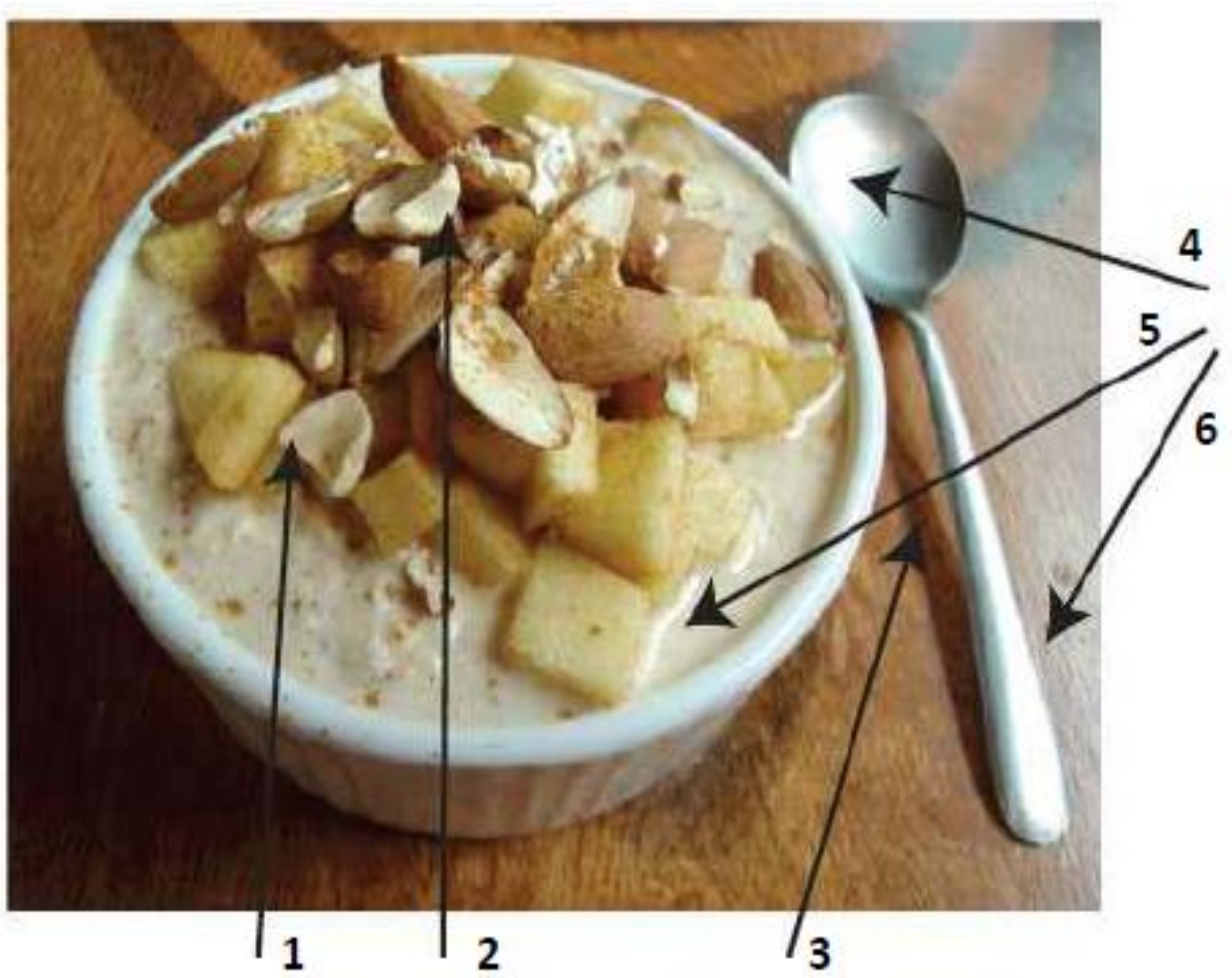

Cast
Shadow
Boundary
Point
Source
Self Shadow
Boundary


Area
Source
Occluder
1
2
3
1
2
3

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?

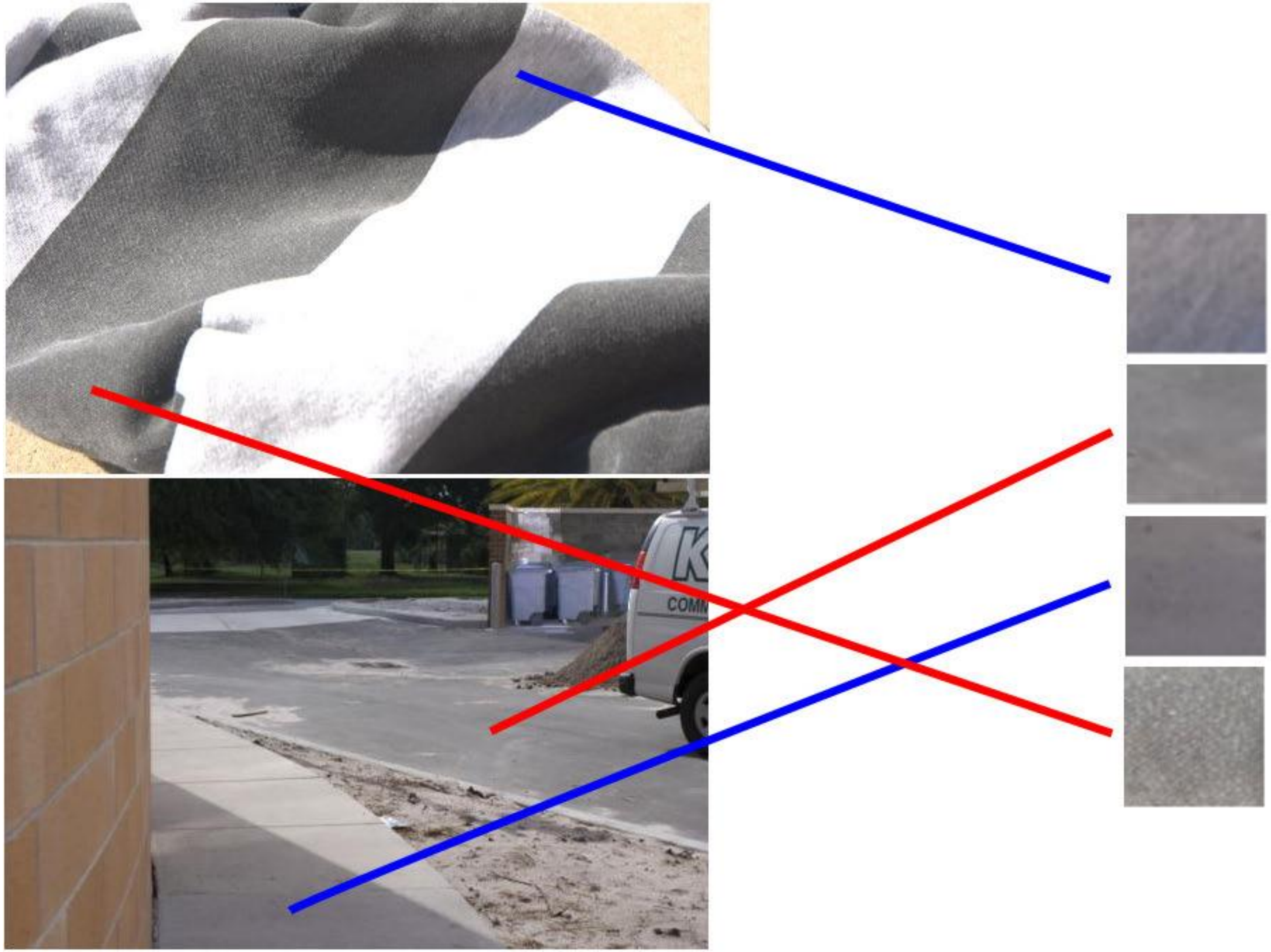
im(234, 452) = 0.58

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



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?

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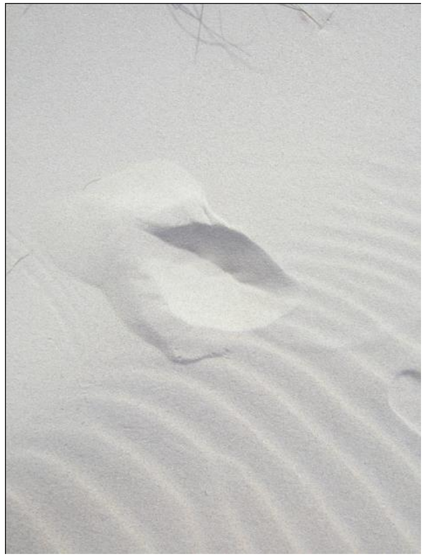
What differences in intensity tell us about shape

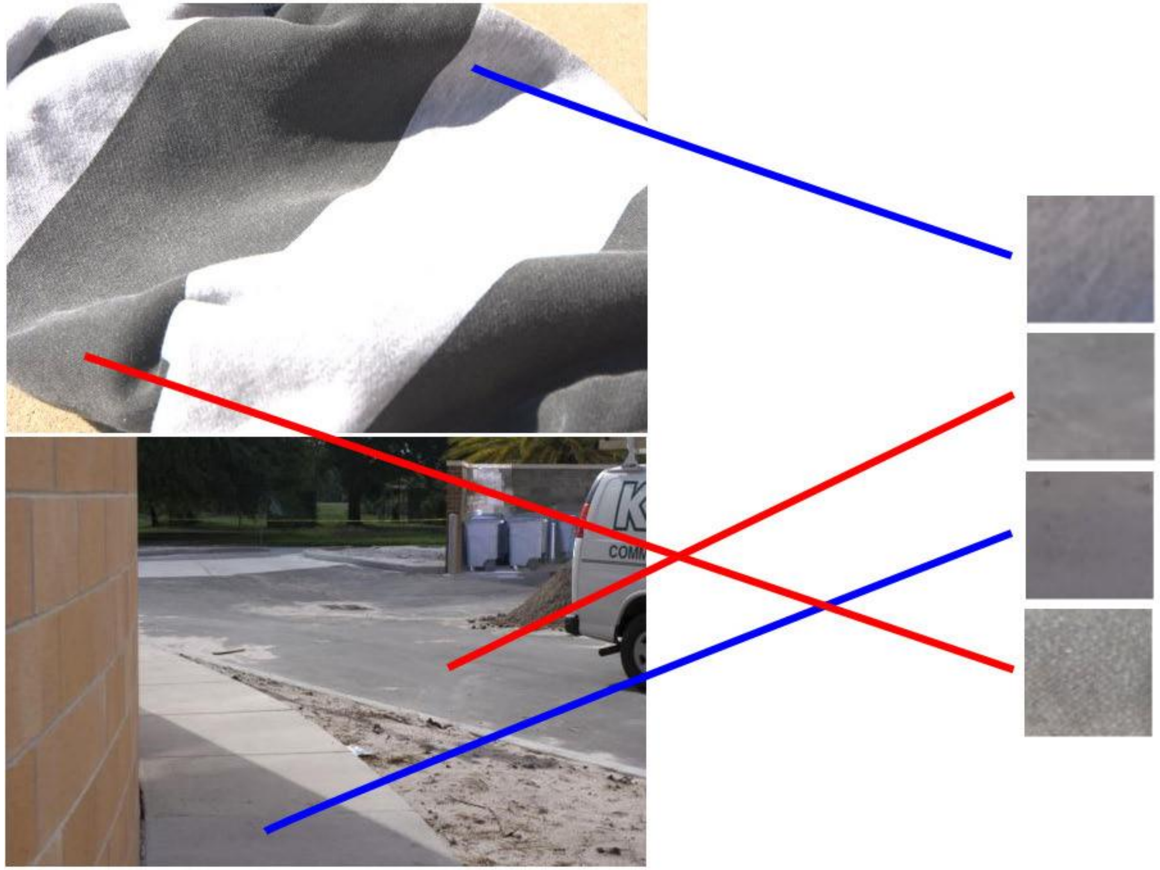
- Changes in surface normal
- Texture
- Proximity
- Indents and bumps
- Grooves and creases



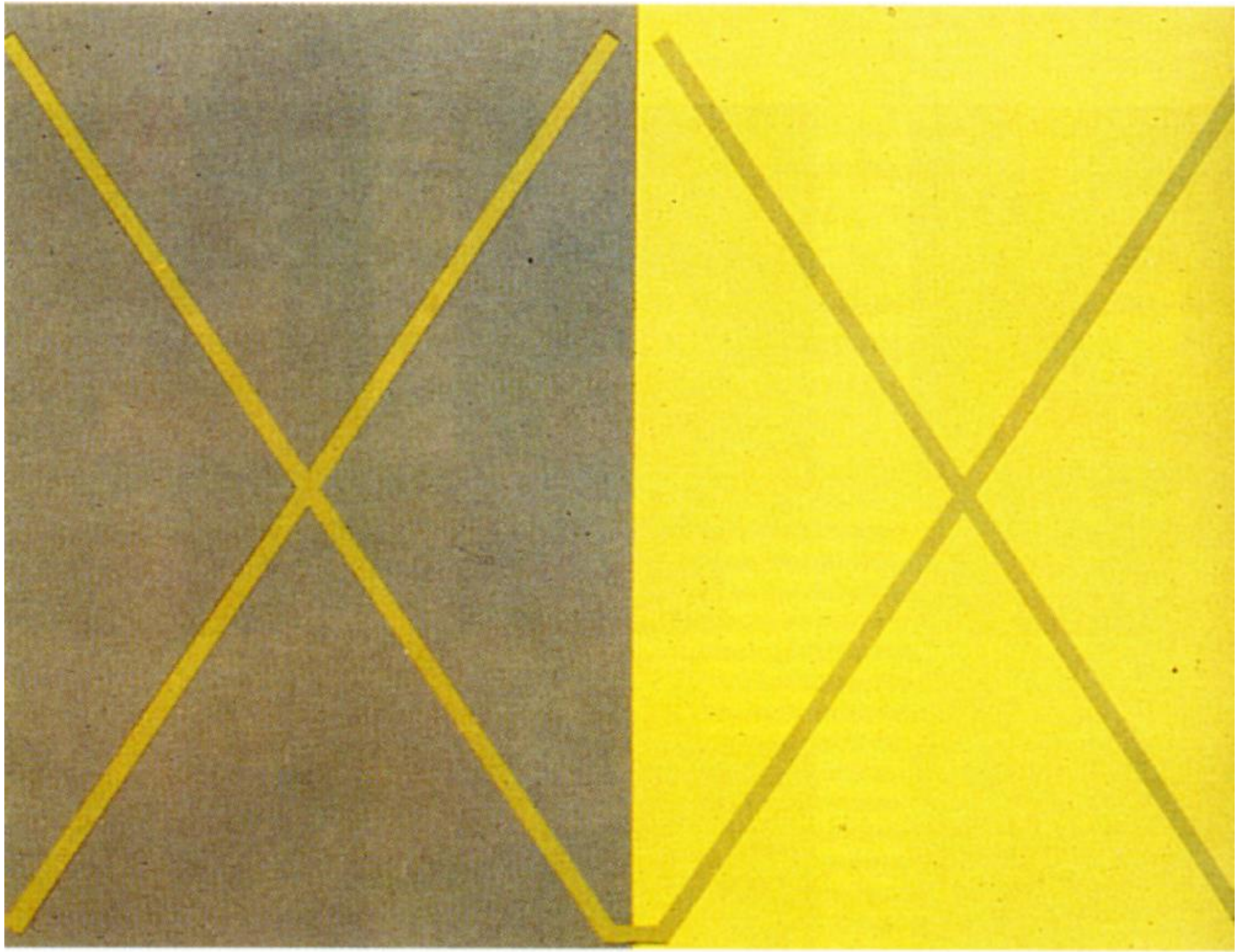
Photos Koenderink slides on image texture and the flow of light

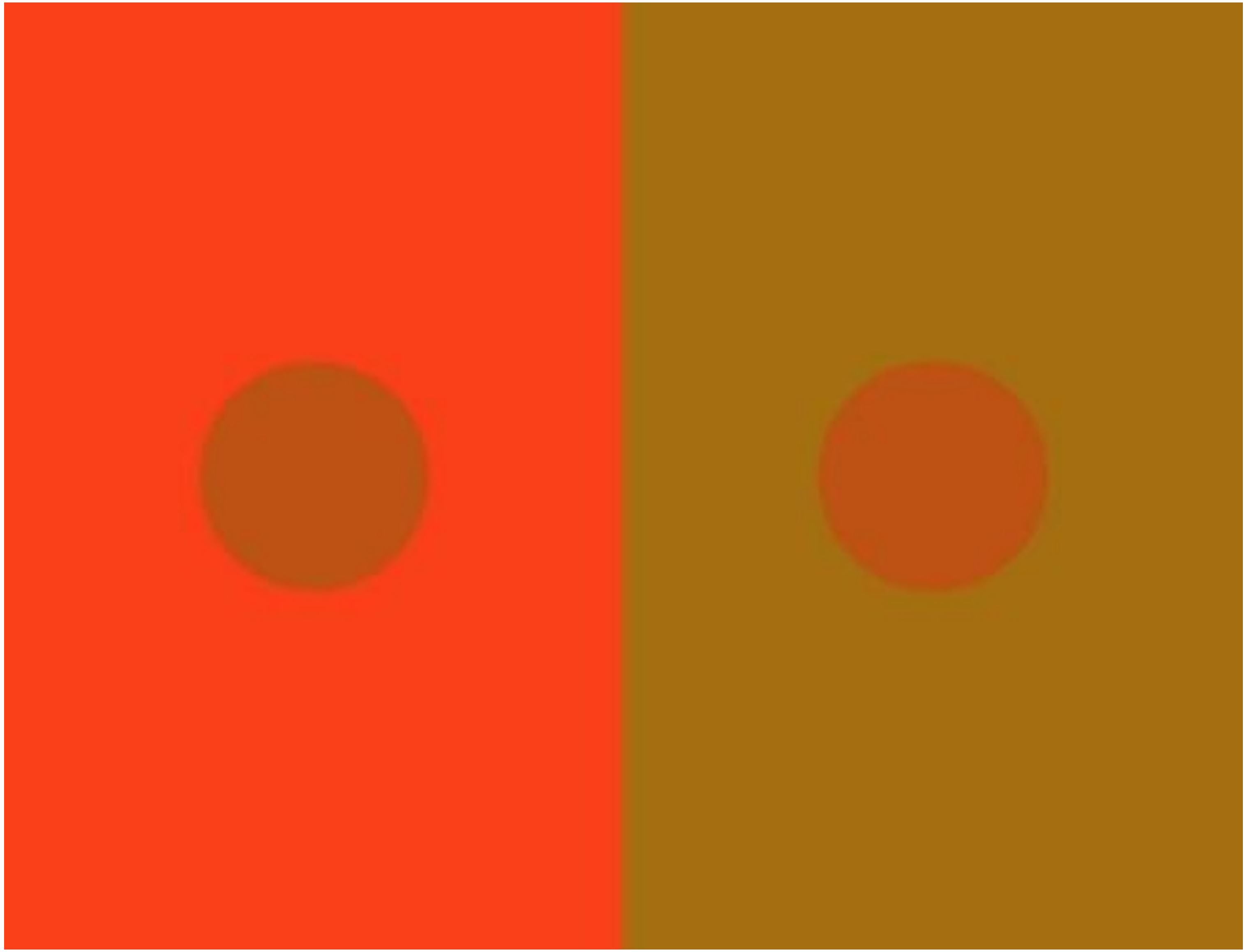
Color constancy

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



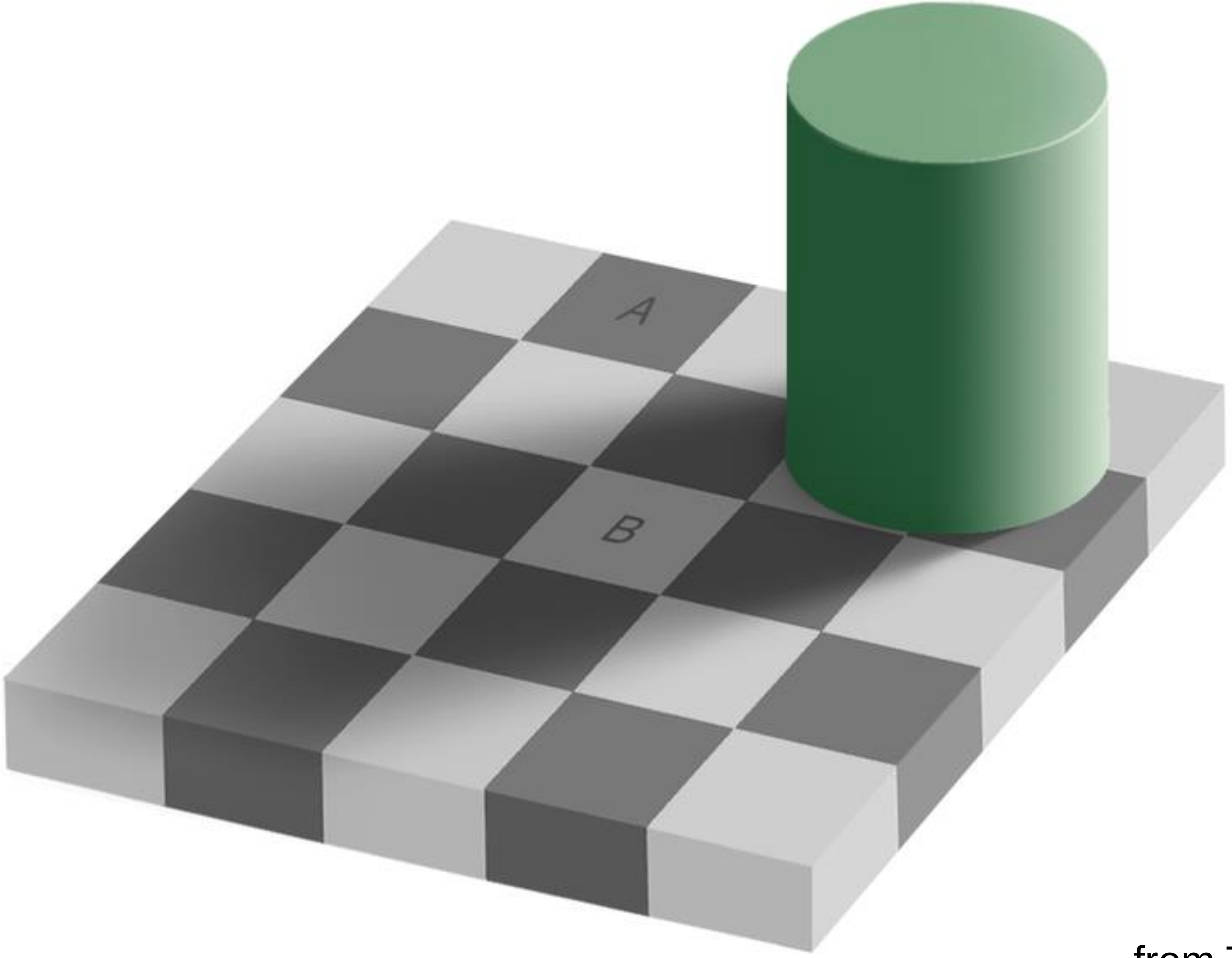
One source of constancy: local comparisons





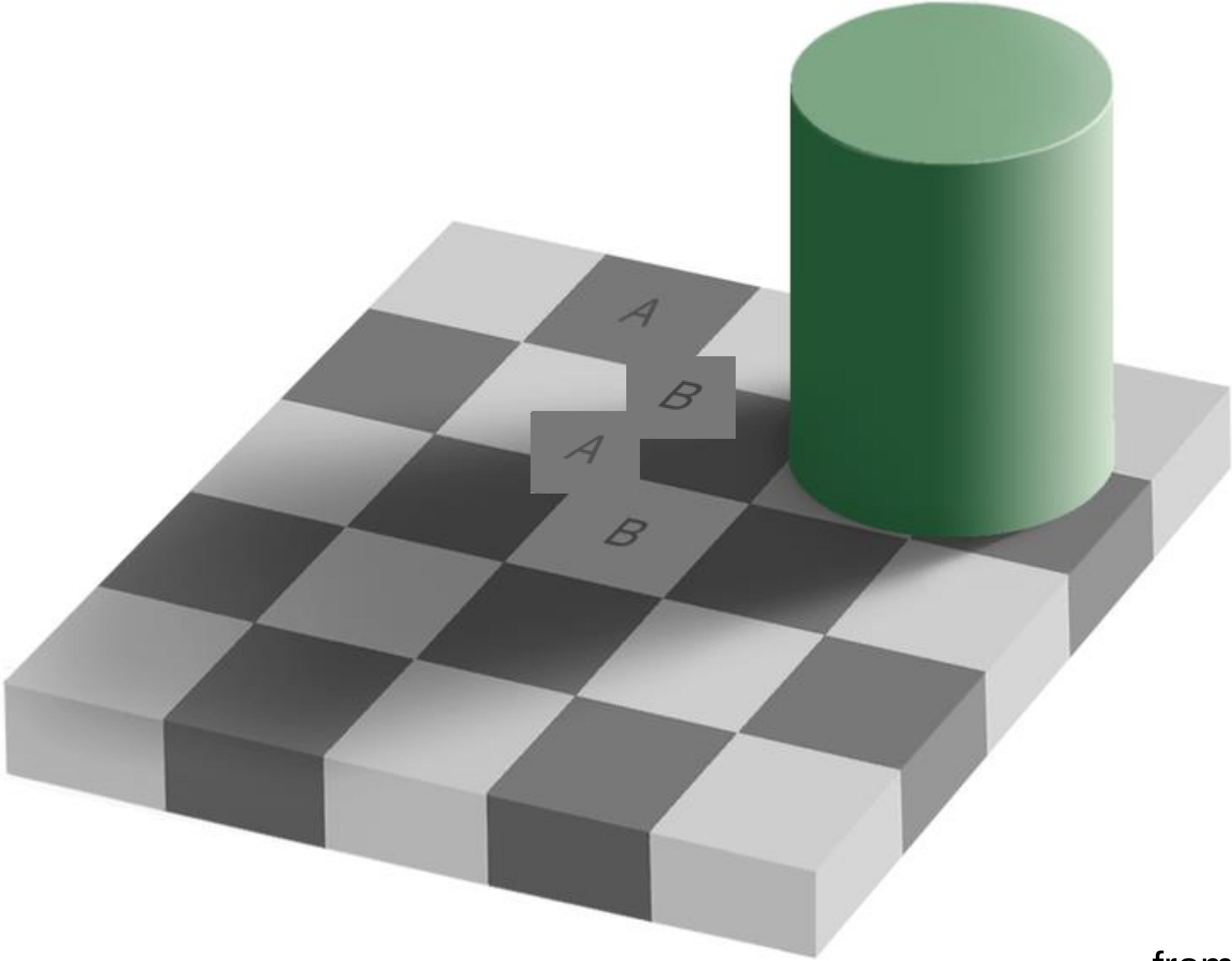
http://www.echalk.co.uk/amusements/OpticalIllusions/colourPerception/colourPerception.html

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

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