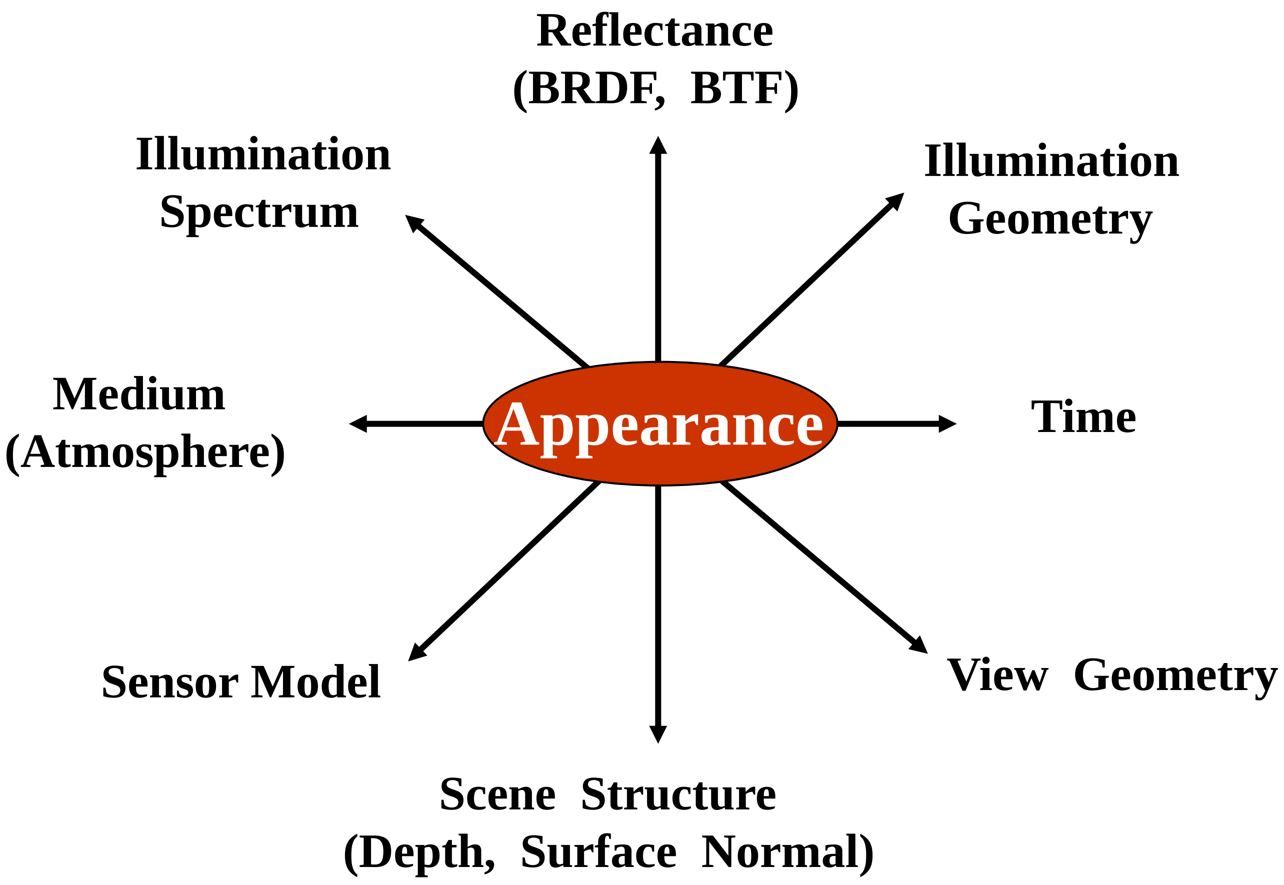
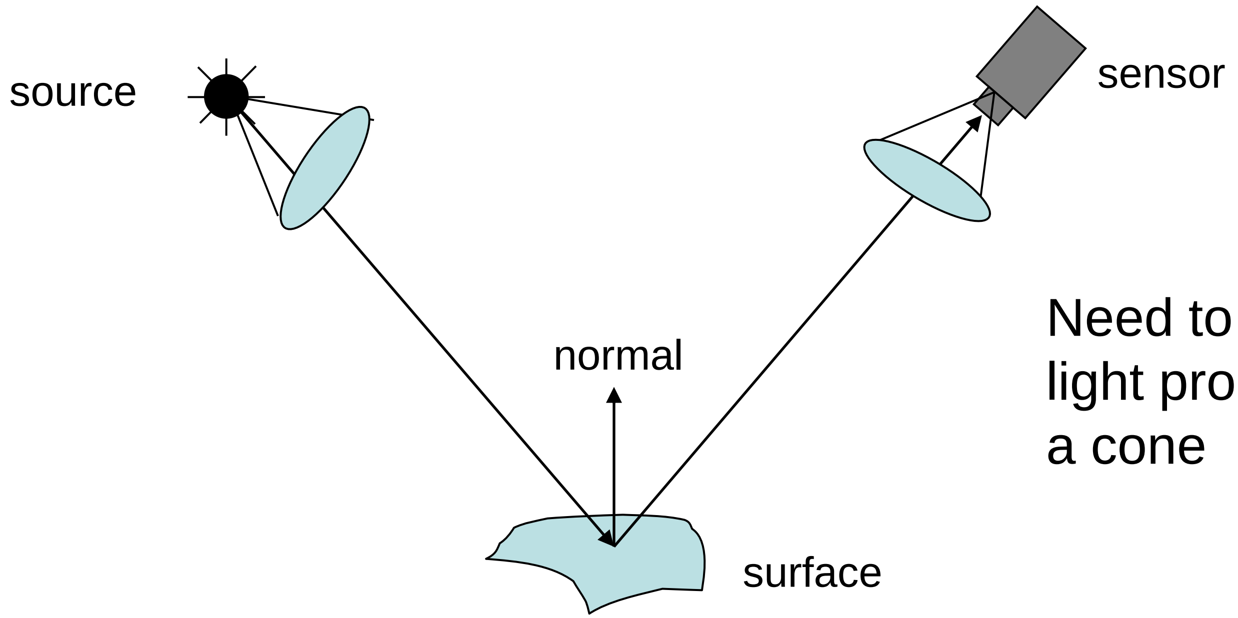
Lighting and Color

Thanks to Langer-Zucker, Henrik Wann Jensen, Ravi Ramamoorthi, Hanrahan, Preetham

Appearance of An Outdoor Scene

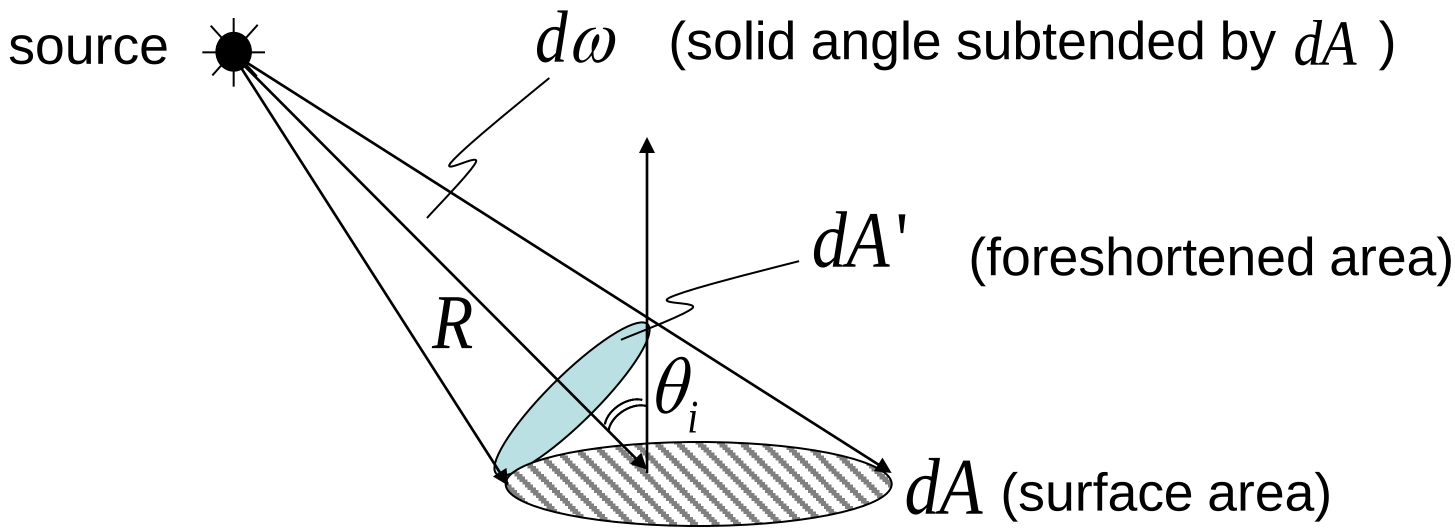


How to quantify light?



Need to consider light propagation in a cone

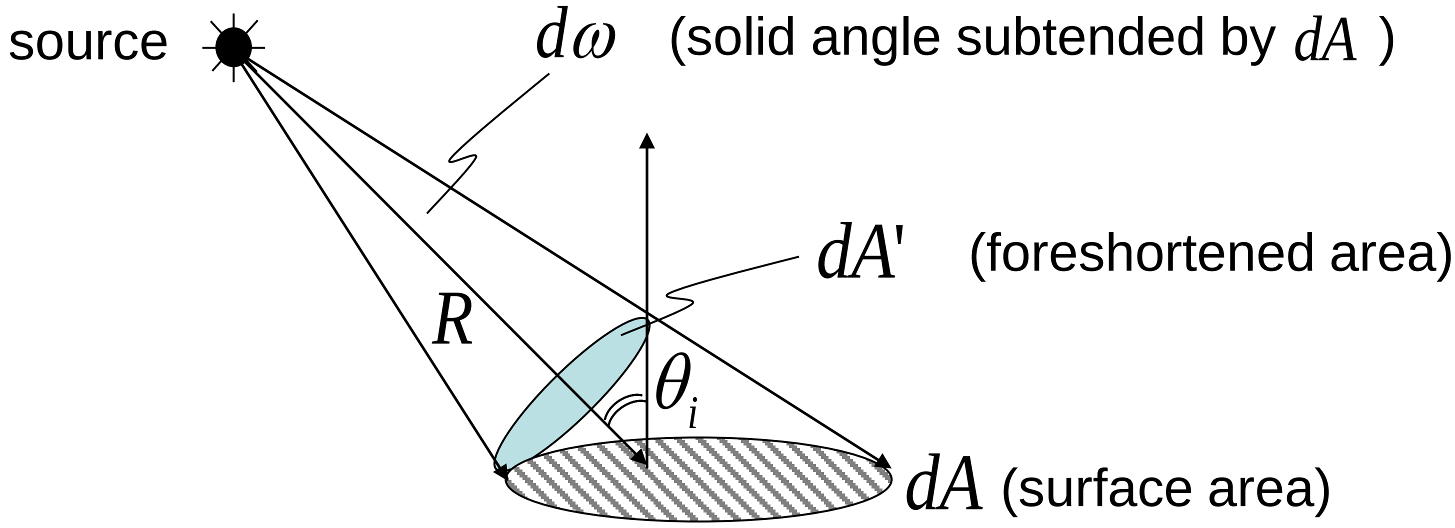
Solid Angle



Solid Angle : $$d\omega = \frac{dA'}{R^2} = \frac{dA \cos\theta_i}{R^2}$$ (steradian)

What is the solid angle subtended by a hemisphere?

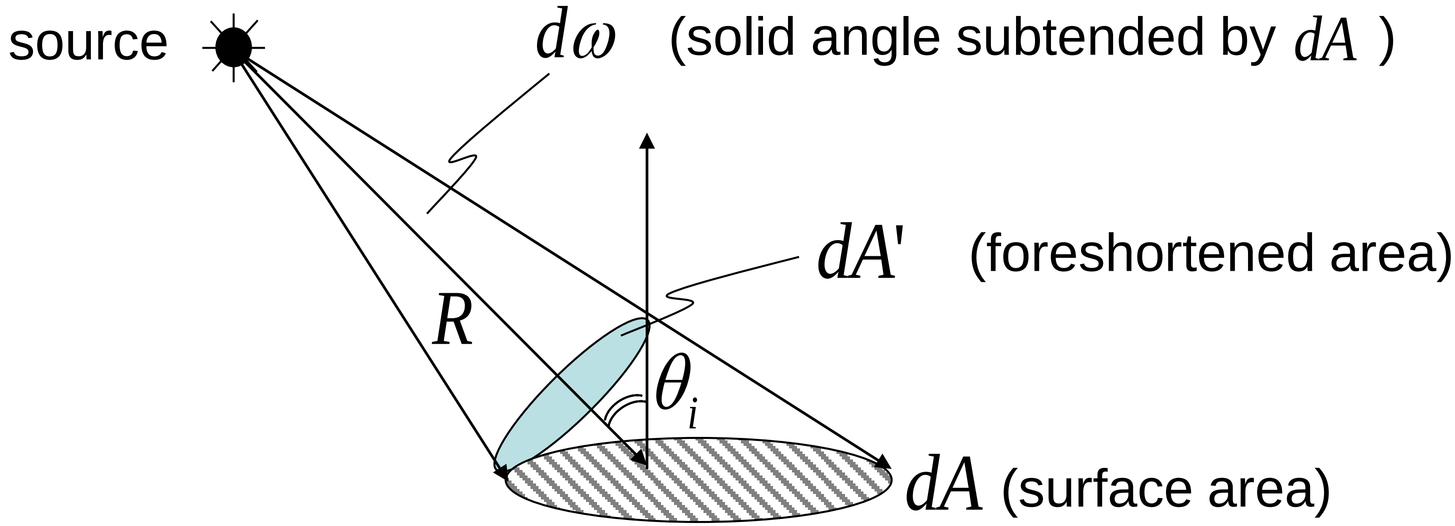
Radiant Intensity of Source



Radiant Intensity of Source : $I = \dfrac{d\Phi}{d\omega}$ (watts / steradian)

Light Flux (power) emitted per unit solid angle

Surface Irradiance

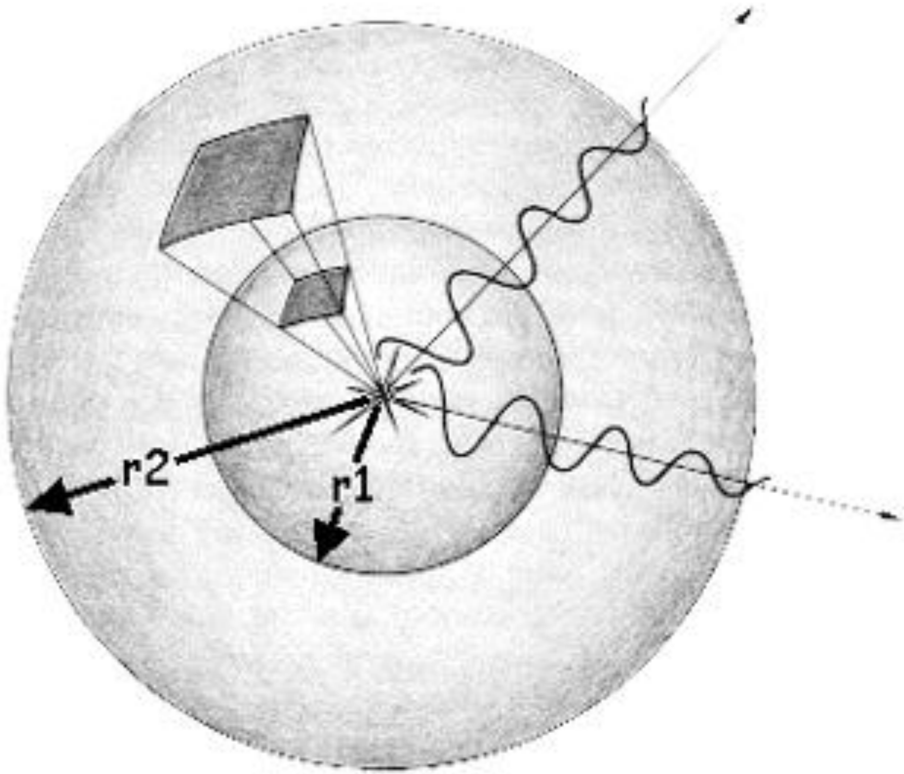


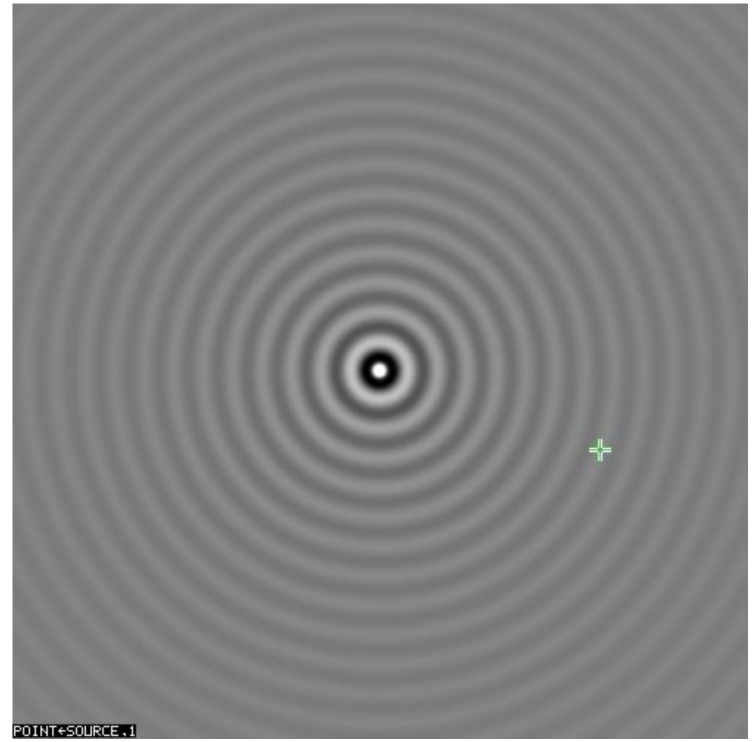
Surface Irradiance : $$E = \frac{d\Phi}{dA}$$ (watts / m^2)

Light Flux (power) incident per unit surface area.

Does not depend on where the light is coming from!

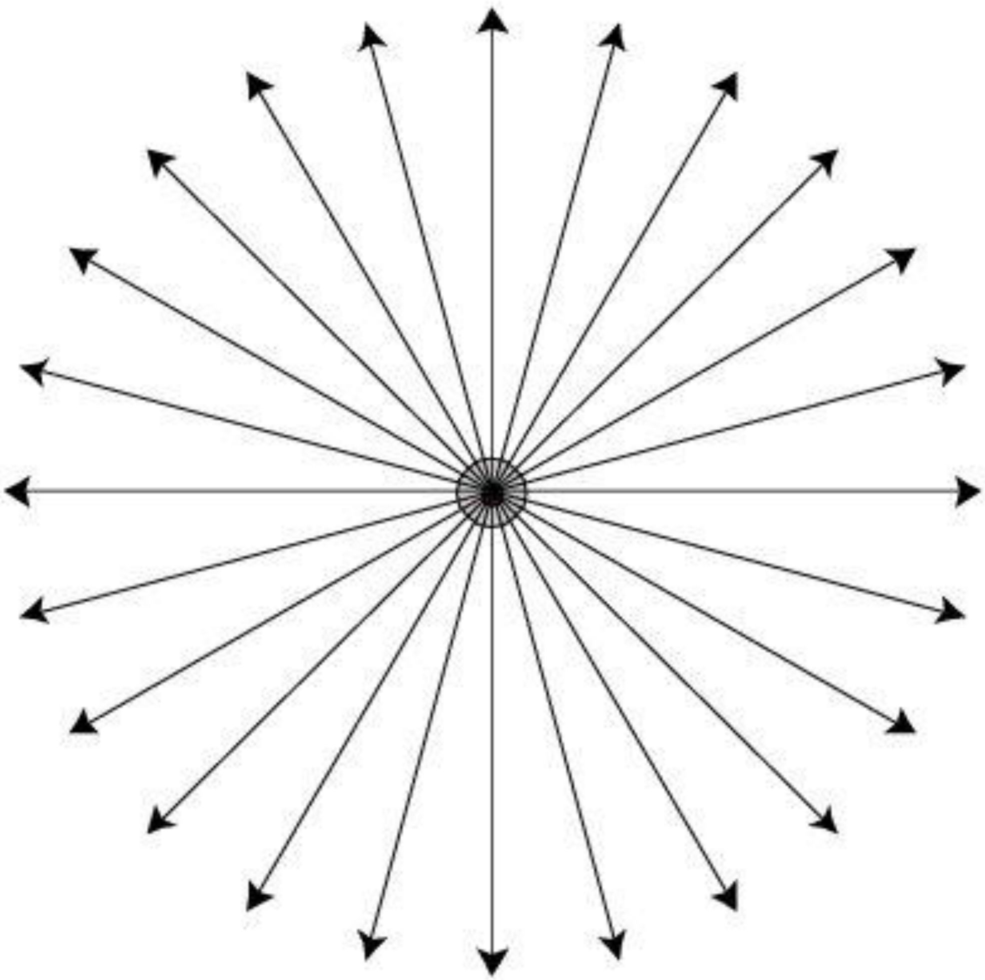
Isotropic Point Light Source





We see an inverse distance squared fall off in intensity.
Here light does not weaken, but only spreads in a sphere.

Isotropic Point Source

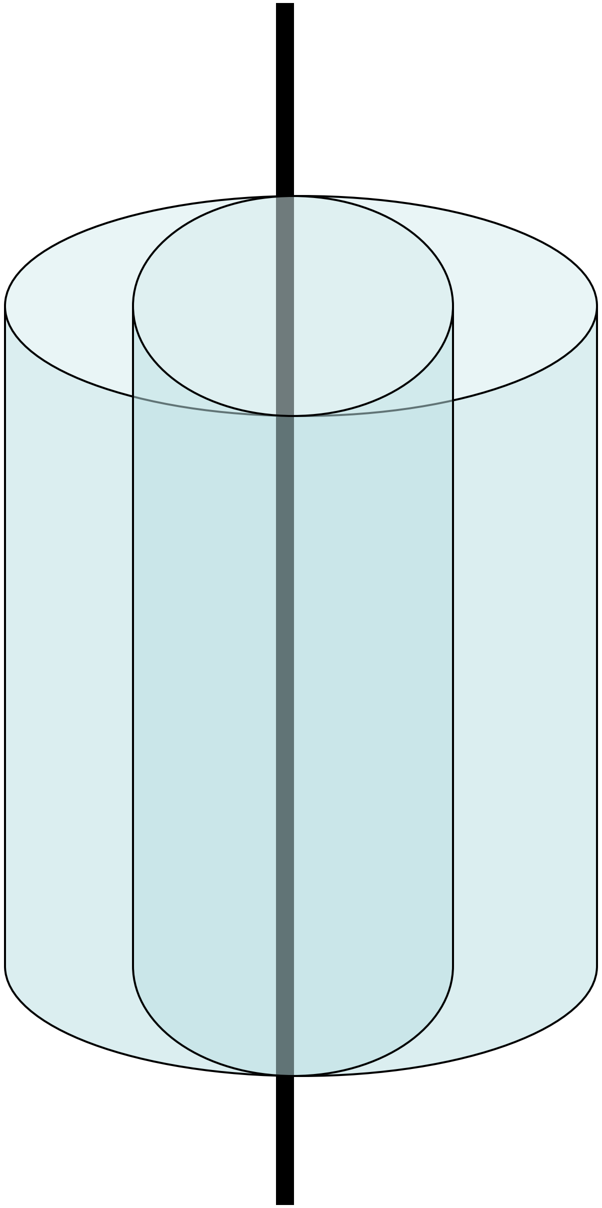


$$\Phi = \int_{S^2} I \, d\omega$$

$$= 4\pi I$$

$$I = \frac{\Phi}{4\pi}$$

Infinite Line Source



Line source shows cylindrical symmetry.

The intensity fall-off is inversely proportional to distance from the line source. Why?

$$d\Phi = I\, d\omega = E\, dA$$

Infinite Planar Area Source

- Assume every point on the plane is an isotropic point light source.
- We saw inverse squared fall off, inverse fall off…so, this must be…
- Intensity CONSTANT with respect to distance! WHY?

As distance increases,

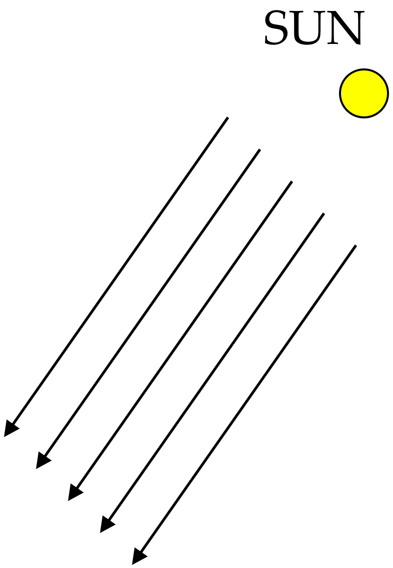
$$d\Phi = I\ d\omega = E\ dA$$

Intensity from one point source decreases

But we add intensities from all point sources on the plane.

Distant and Collimated Lighting

Distant Lighting:



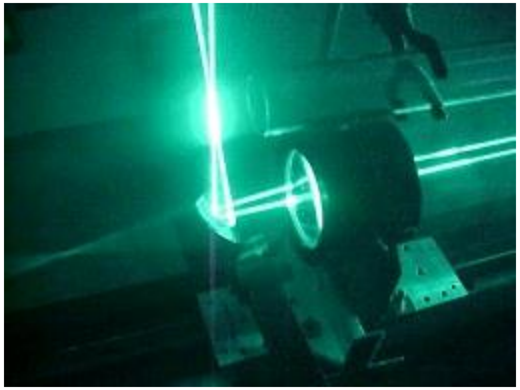
Essentially source at infinity

All surface points receive light from the same direction

Intensity fall must not be ignored!

Most vision and graphics algorithms assume this.

Collimated:

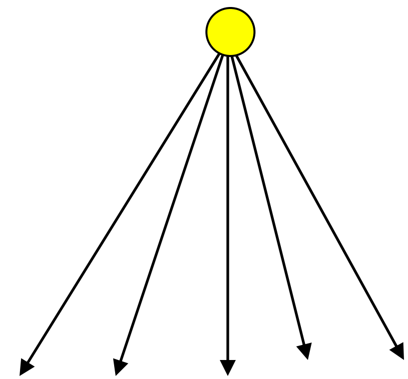


Parallel rays of light on the surface

Lasers (no fall off) - need not be at infinity

Lighting at infinity - (inverse squared fall off)

Divergent and Near-field Lighting



- Every scene point can receive light from a different direction.
- Much harder to model.
- Examples: near by point sources, spot lights
- Assume distant lighting when size of scene is 10% of the distance to the source.

Fluorescent versus Incandescent Lighting

Fluorescent:

Less heat generated.

More efficient lighting for the same brightness.

Flickers continuously.

Shows sparse, spikes in spectrum.

Incandescent:

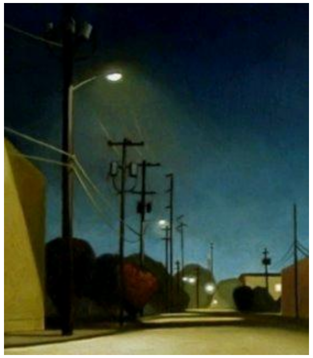
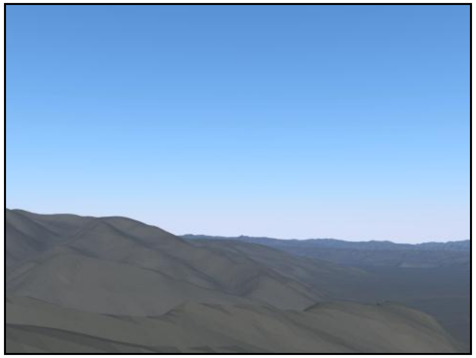
Lots of heat generated.

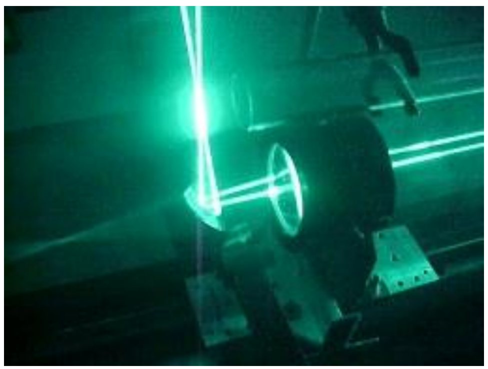
Less efficient lighting for the same brightness.

No flickers.

Shows continuous spectrum.

Is there a unified representation for light sources?

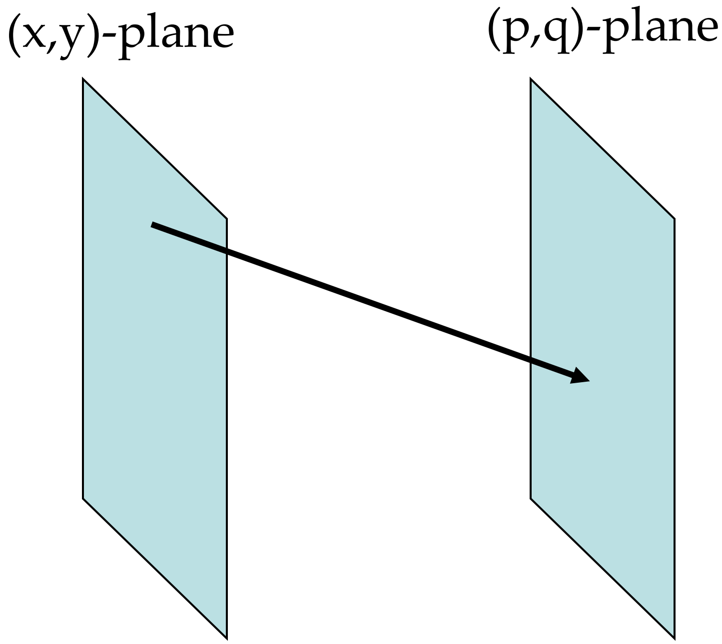



How do we compare the light from a street lamp to that from an overcast sky?

It is important to unify source representation so that algorithms may be developed for all sources instead of one per type of source.

Consider the SPACE of LIGHT RAYS!

4D Hypercube of Rays



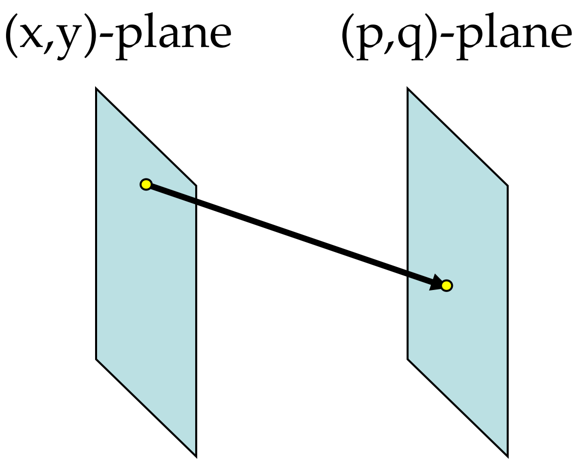
- Assumes vacuum (no absorption or scattering)
- No fluorescence, phosphorescence

$$\mathcal{M}_{src} \equiv \{ (x,y,p,q) \; : \; x \in [-\frac{h_x}{2}, \frac{h_x}{2}],$$
$$y \in [-\frac{h_y}{2}, \frac{h_y}{2}], p \in [-\frac{h_p}{2}, \frac{h_p}{2}], q \in [-\frac{h_q}{2}, \frac{h_q}{2}] \}.$$

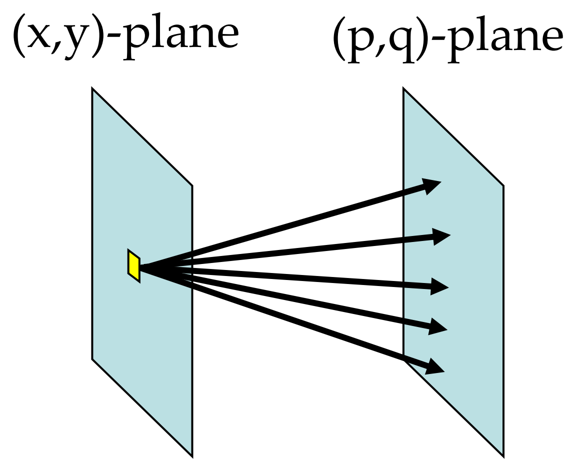
Langer and Zucker, CVPR 97

Representation of Sources

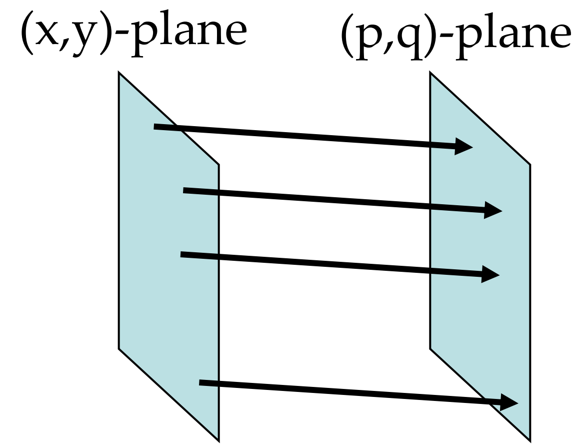
Langer and Zucker, CVPR 97



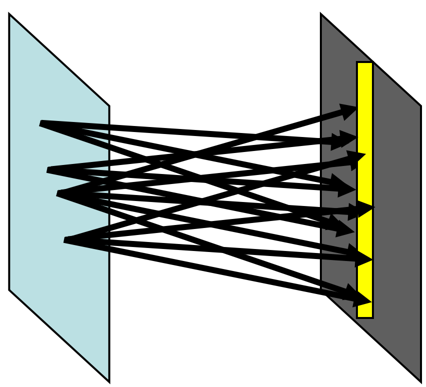
Laser beam – 0D



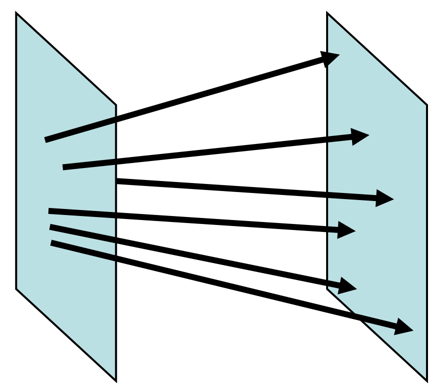
Point source – 2D



Distant Source (Sun) – 2D



Area source (Sky) with
a crack in the door – 3D



Area source (Sky) with
door completely open – 4D

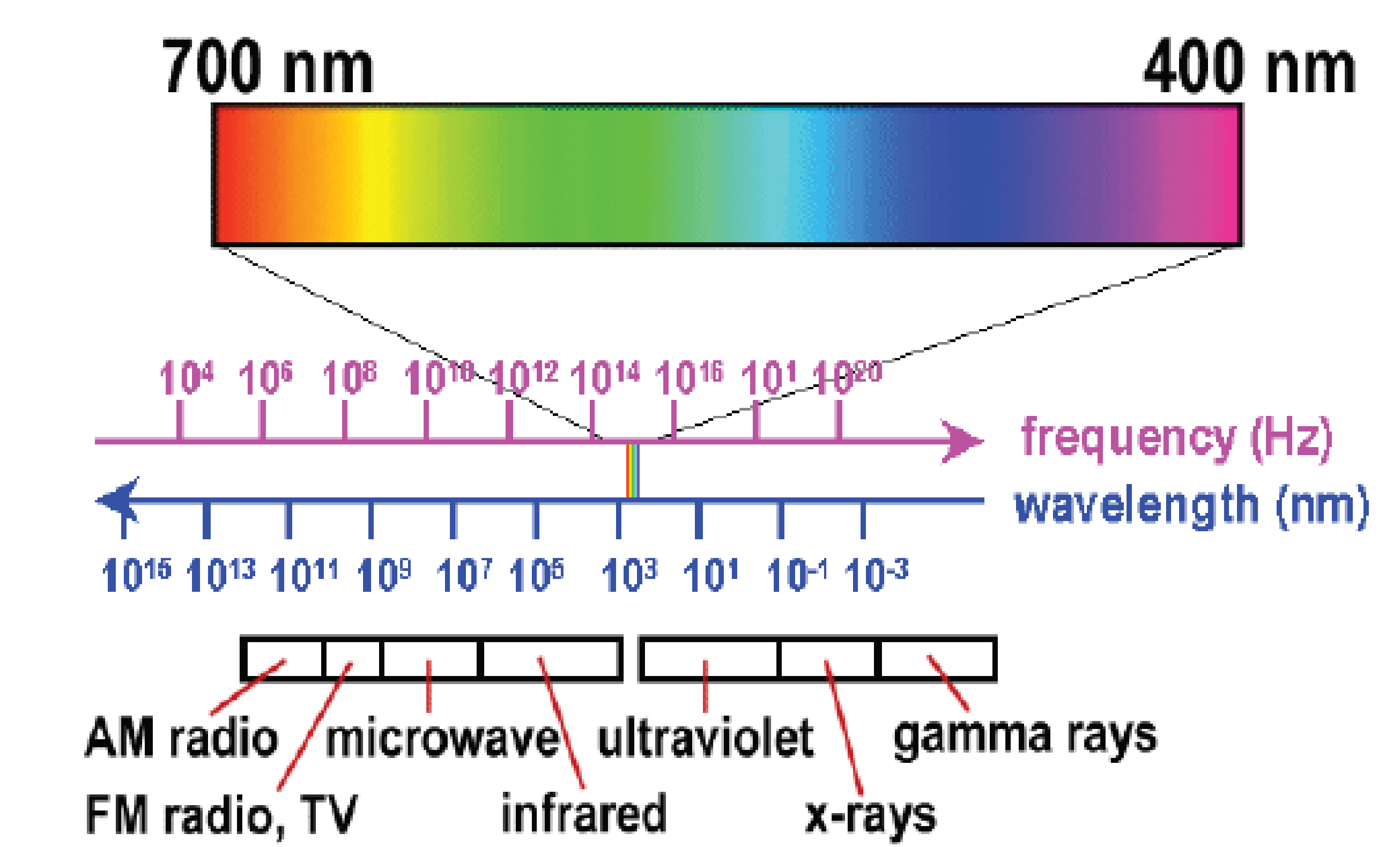
The Rendering Equation

$$L_o(\mathbf{x}, \omega, \lambda, t) = L_e(\mathbf{x}, \omega, \lambda, t) + \int_\Omega f_r(\mathbf{x}, \omega', \omega, \lambda, t) L_i(\mathbf{x}, \omega', \lambda, t)(-\omega' \cdot \mathbf{n}) d\omega'$$

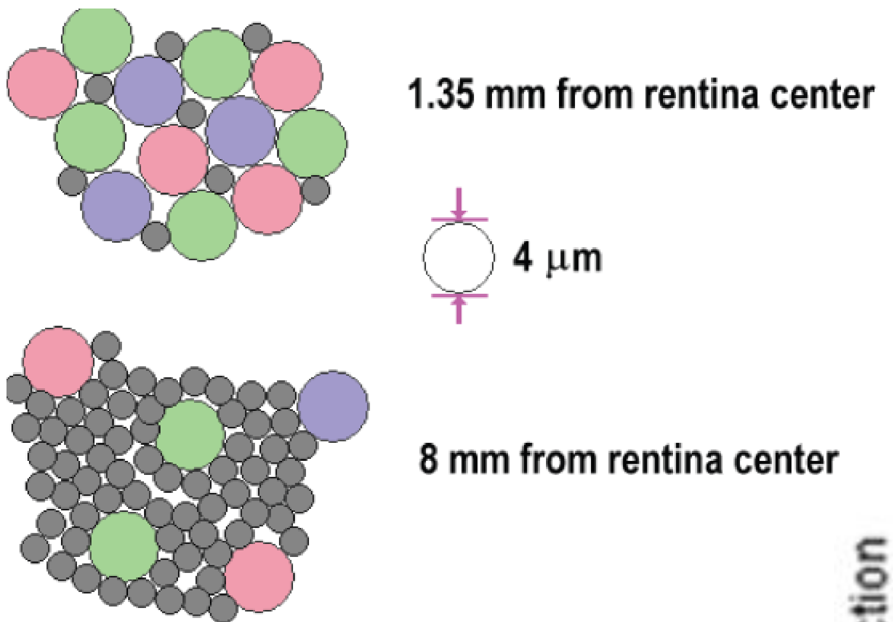
http://en.wikipedia.org/wiki/Rendering_equation

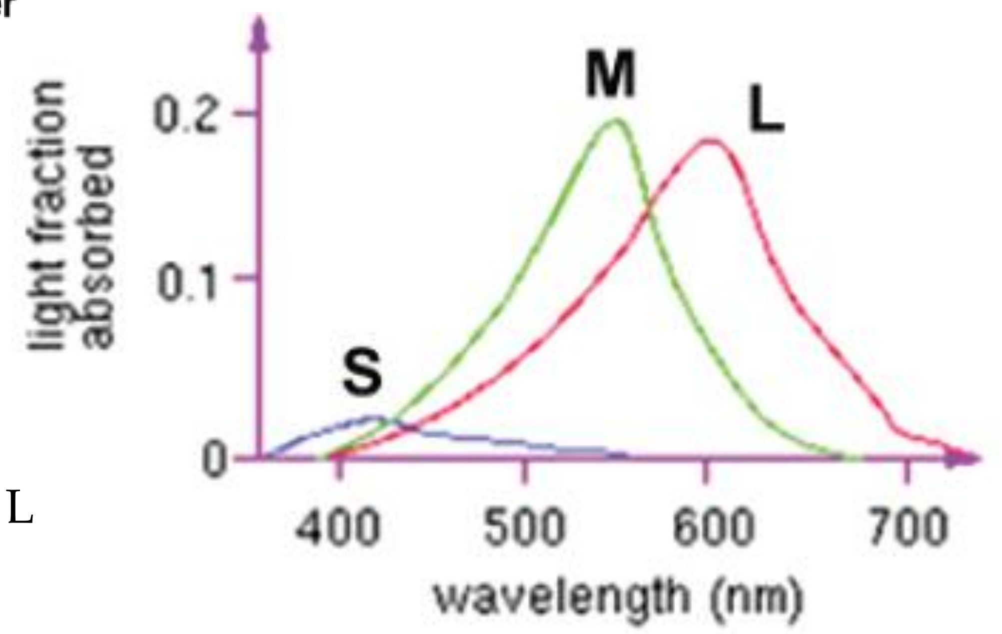
Color

Visible Spectrum



Rods, Cones, and Color Perception





3 types of cones: S, M, and L

Color Models

Spectrum

- allows any radiation (visible or invisible) to be described
- usually unnecessary and impractical

RGB

- convenient for display (CRT uses red, green, and blue phosphors)
- not very intuitive

HSV

- an intuitive color space
- H is hue - what color is it? S is saturation or purity - how non-gray is it? V is value - how bright is it?
- H is cyclic therefore it is a non-linear transformation of RGB

CIE XYZ

- a linear transform of RGB used by color scientists

Better Color Models

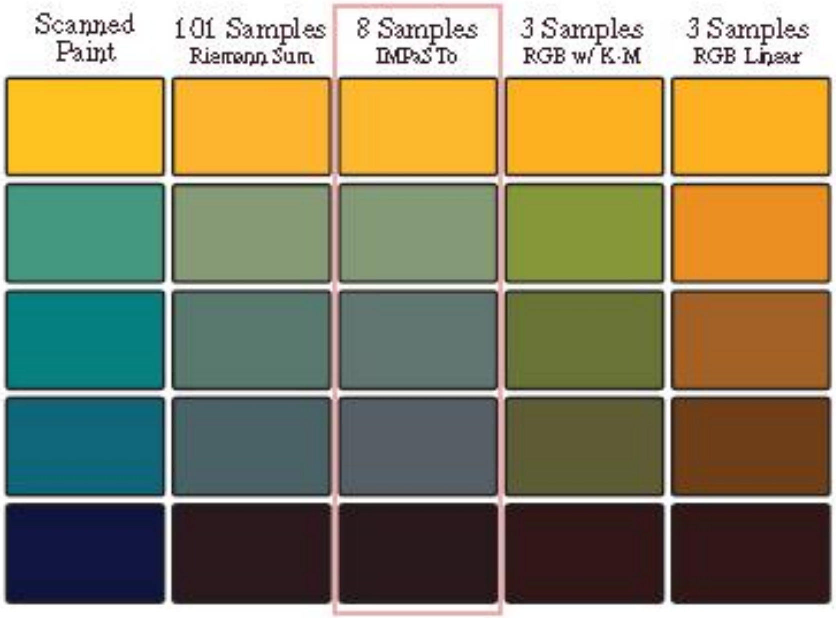


Figure 11: *A painting created with IMPaSTo, after a painting by*

source:
IMPaSTo: a realistic, interactive model for paint
William Baxter, Jeremy Wendt, Ming C. Lin
NPAR 2004, June 2004, pp. 45-56.

Metamers

http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/spectrum/metamers_java_browser.html

Color Constancy

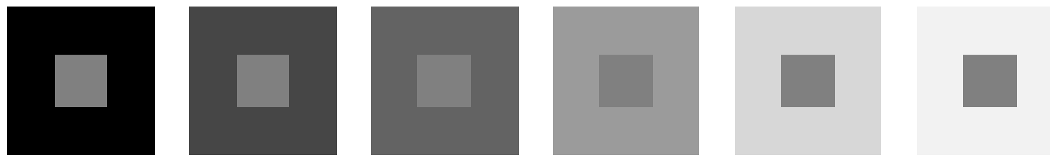


Figure 5.4: All the center squares have the same lightness; the apparently lightness, however, is profoundly influenced by the surrounding squares.

fig:lightness-squares

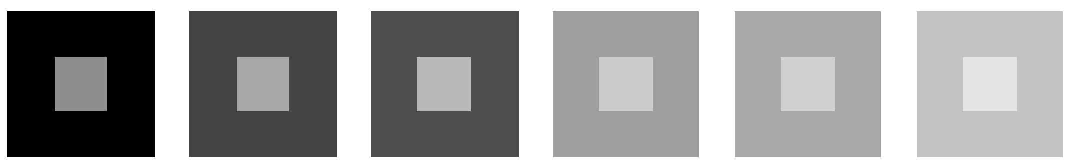
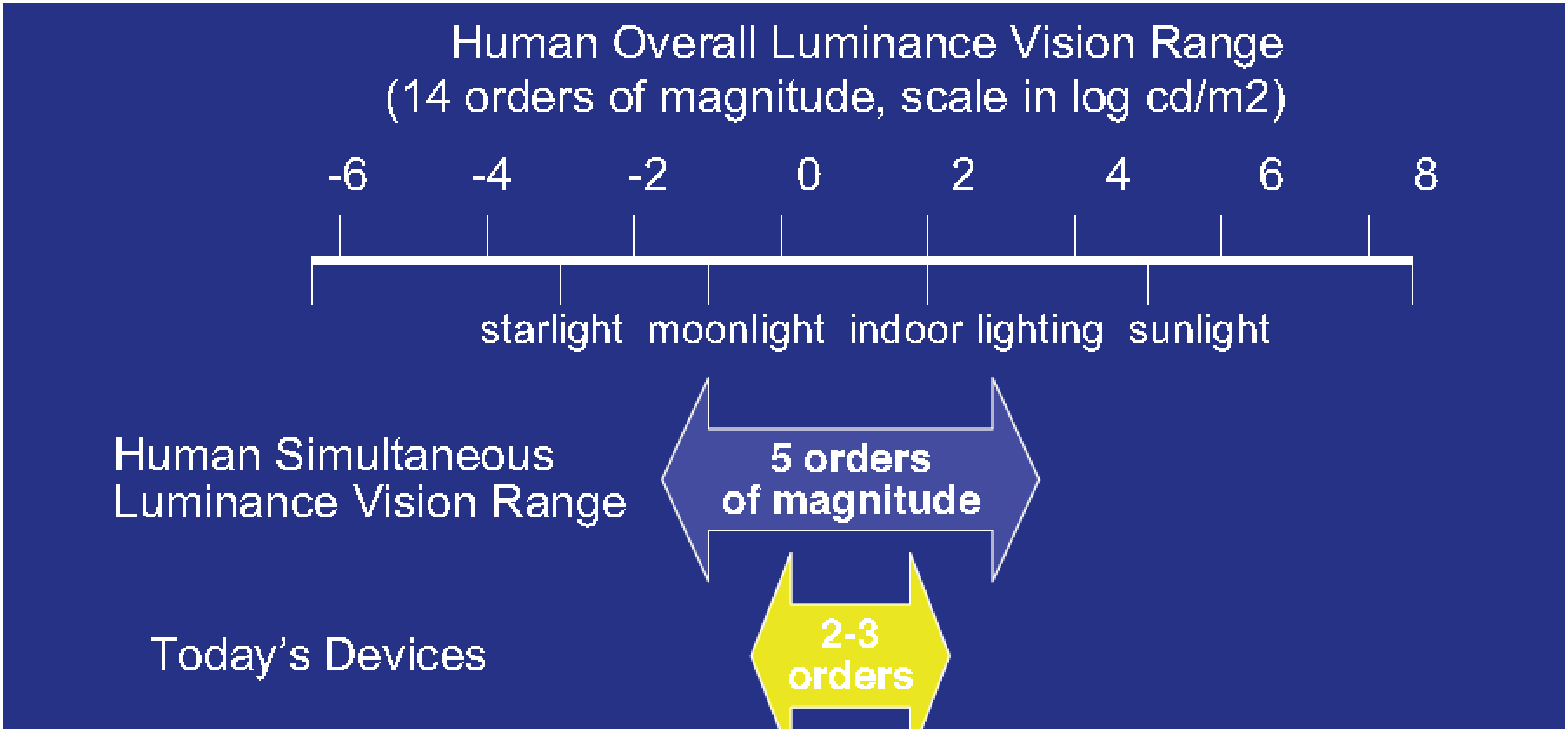


Figure 5.5: The ratio of the center square's darkness to the surrounding square's darkness is approximately the same in each example; we tend to see the center squares as exhibiting far less variation in lightness than those in the previous figure.

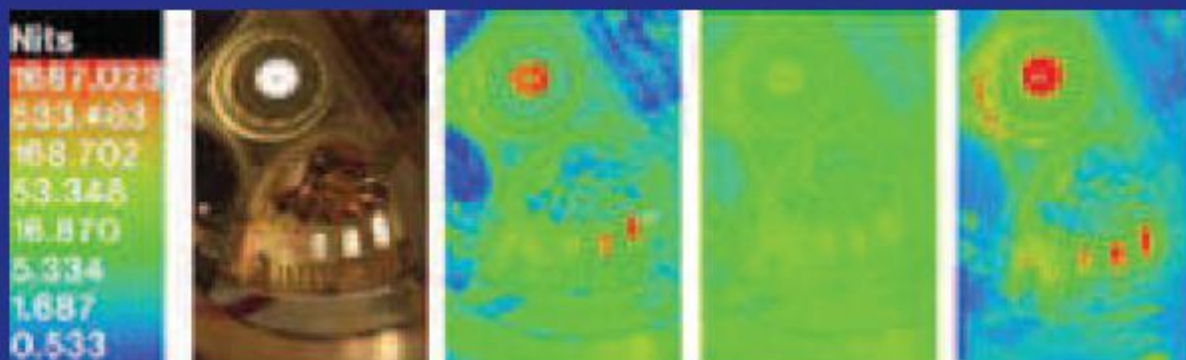
Hughes et al., Computer Graphics: Principles and Practice (3rd Edition)

Visible Range of Intensities



Visible Range of Intensities

Conventional CRTs have 600:1 dynamic range
Flat-panel LCDs are 500:1.



HDR image, range, conventional display, HDR display

Goal for displays: 1,000,000 : 1 contrast or better!