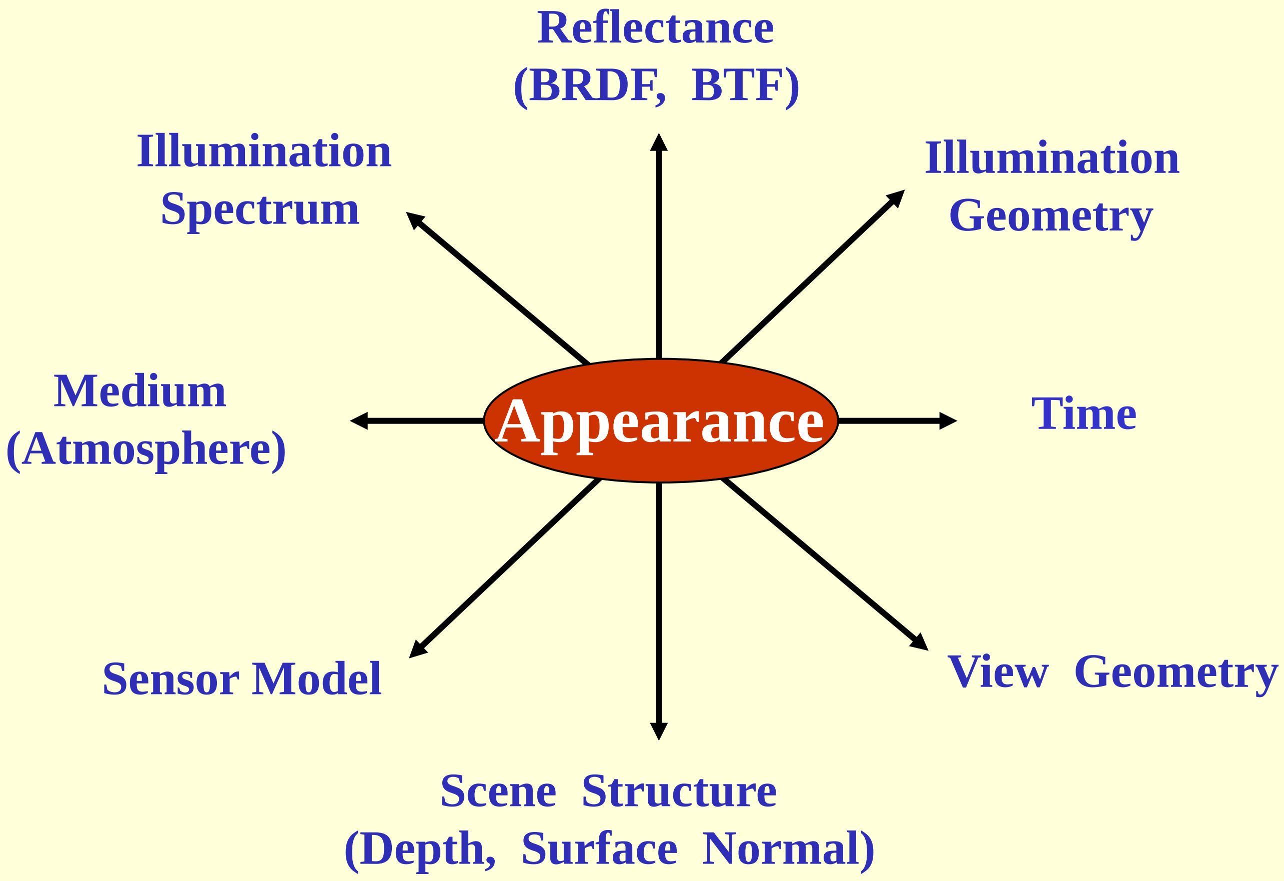
Lighting and Shadows

Lecture #9

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

Appearance of An Outdoor Scene



Reflectance
(BRDF, BTF)

Illumination
Spectrum

Illumination
Geometry

Medium
(Atmosphere)

Appearance

Time

Sensor Model

View Geometry

Scene Structure
(Depth, Surface Normal)

How many Images are Needed to Capture the Complete Variability in Scene Appearance ?

WILD : Weather and Illumination Database

Images of An Outdoor Scene :

- Acquired Every Hour for 9 Months
- Wide Variety of Natural Illuminations
  (Day, Night, Sunny, Cloudy)
- All Weather Conditions and Seasons
  (Clear, Haze, Fog, Rain, Mist) (Fall, Winter, Spring, Summer)
- Weather and Approximate Depth Ground Truth
  (www.nws.noaa.gov) (Satellite OrthoPhotos)
- High Resolution, High Dynamic Range
  (1520 x 1008) (12 bits per Color Channel)
- Registered and Calibrated

Data Acquisition

Sensor :

- Kodak Professional DCS 315 Digital Color Camera
- CCD Resolution 1520 x 1008
- 24 mm - 70 mm Nikkor Zoom Lens

Experiment Setup :

Kodak DCS 315
10-bit Camera

24-70 mm
Zoom Lens

Anti-reflection
Glass

Weather Proof
Enclosure

FireWire
(IEEE 1394)

Pan/Tilt Stage

The Scene

Type : Urban
Location : Uptown Manhattan
Range : 20 Meters to 5 Kilometers

New Jersey

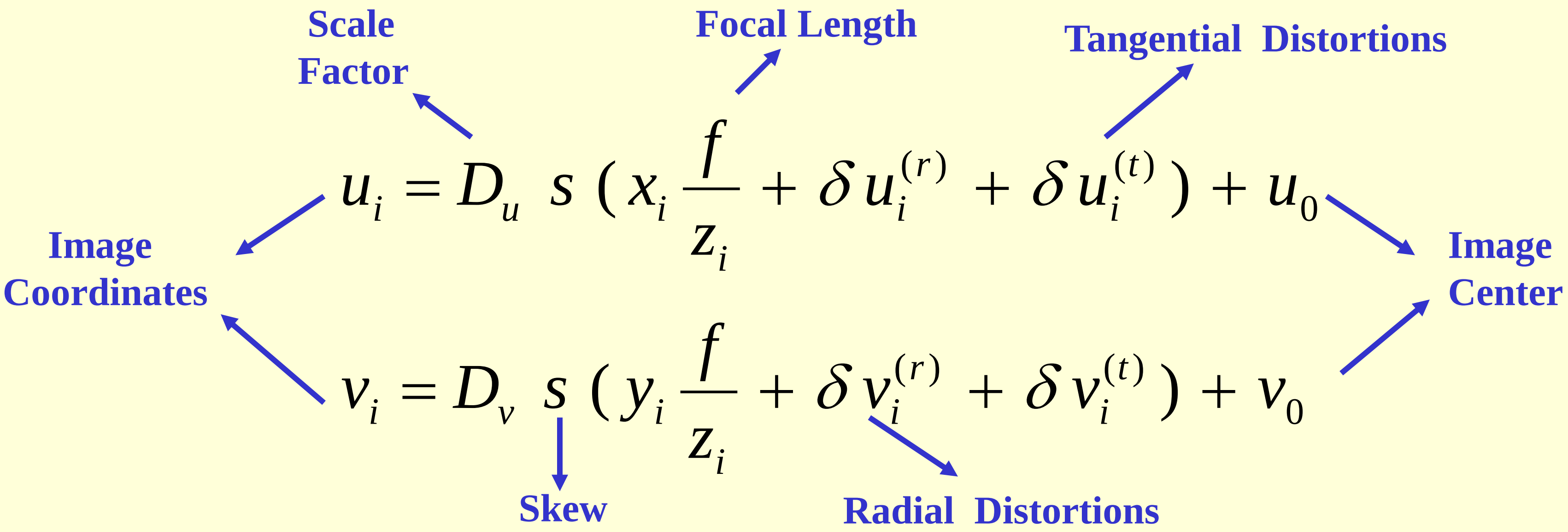
Columbia Medical Center

175th Street

121st Street

Camera Calibration : Geometric

Intrinsic Parameters :



Scale Factor

Focal Length

Tangential Distortions

Image Coordinates

$$u_i = D_u \; s \; (x_i \frac{f}{z_i} + \delta u_i^{(r)} + \delta u_i^{(t)}) + u_0$$

Image Center

$$v_i = D_v \; s \; (y_i \frac{f}{z_i} + \delta v_i^{(r)} + \delta v_i^{(t)}) + v_0$$

Skew

Radial Distortions

Camera Calibration Toolbox (Bouguet, Caltech) :

Planar Checkerboard Patterns

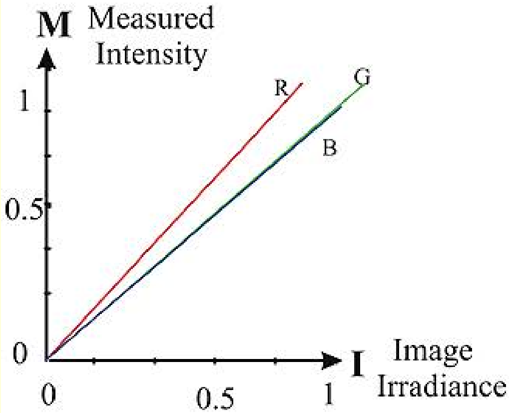
Focal Length	2845 Pixels
$\Delta u_0 , \Delta v_0$	7.2, 9.5 Pixels
Radial Distortion (C_1)	0.07
Reprojection Error	0.18 Pixels

Camera Calibration : Radiometric

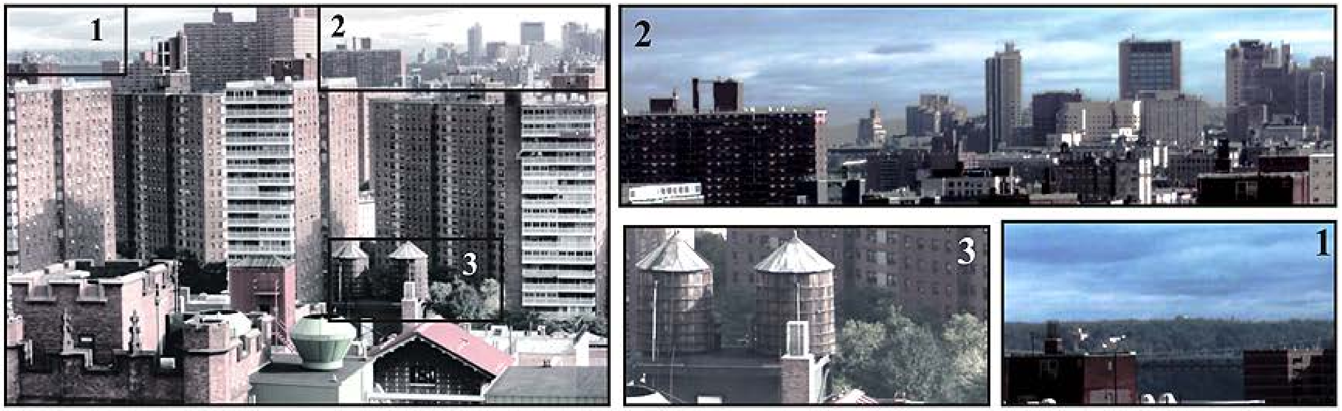
(a) High Exposure

(b) Auto Exposure

(c) Low Exposure



(d) Radiometric Response



(e) Computed High Dynamic Range Image (Histogram Equalized)

Radiometric Response f : Image Irradiance I ⟶ Measured Intensity M

RASCAL : Radiometric Self Calibration [Mitsunaga and Nayar, 99]

High Dynamic Range Image : Linear Combination of Single Exposure Images

Image Registration

- **Camera Weight on the Mount caused Small Misalignments**
- **Registration Transformation : Scale + Rotation + Translation**

Hour – to – Hour Misalignment

$$\begin{pmatrix} 1.0 & -0.0 & 0 \\ 0.0 & 1.0 & 0 \\ -0.0 & -0.0 & 1.0 \end{pmatrix}$$

Day – to – Day Misalignment

$$\begin{pmatrix} 1.0 & -0.0 & 0 \\ 0.0 & 1.0 & 0 \\ -0.1 & -0.3 & 1.0 \end{pmatrix}$$

Week – to – Week Misalignment

$$\begin{pmatrix} 1.0 & -0.0 & 0 \\ 0.0 & 1.0 & 0 \\ -0.3 & -1.3 & 1.0 \end{pmatrix}$$

Month – to – Month Misalignment

$$\begin{pmatrix} 1.0 & -0.0 & 0 \\ 0.0 & 1.0 & 0 \\ -1.2 & -3.8 & 1.0 \end{pmatrix}$$

Ground Truth : Weather Data

Weather Data automatically retrieved from :

http : // www . nws . noaa . gov

Sample Ground Truth File :

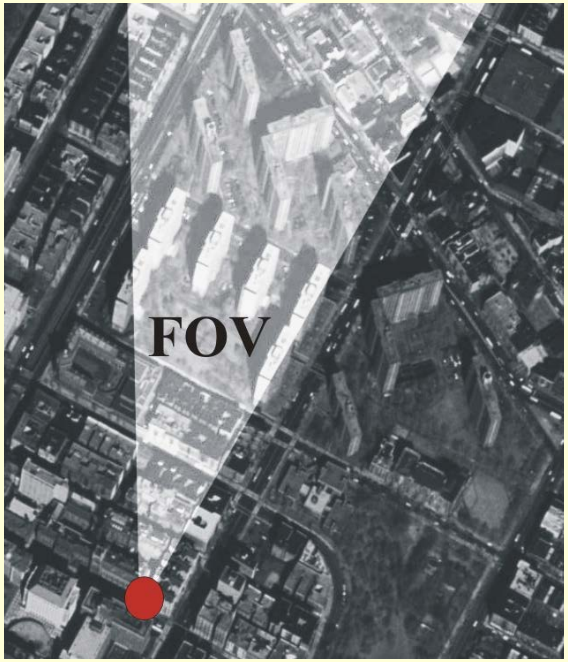
Time	**2001.03.06 11:51am**
Wind	**from the NNW (340 degrees) at 10 MPH gusting to 18 MPH**
Visibility	**1 1/4 mile(s)**
Sky conditions	**Overcast**
Weather	**Light snow, Mist**
Precipitation last hour	**A trace**
Temperature	**32.0 F (0.0 C)**
Dew Point	**32.0 F (0.0 C)**
Relative Humidity	**100%**

Ground Truth : Position and Depth

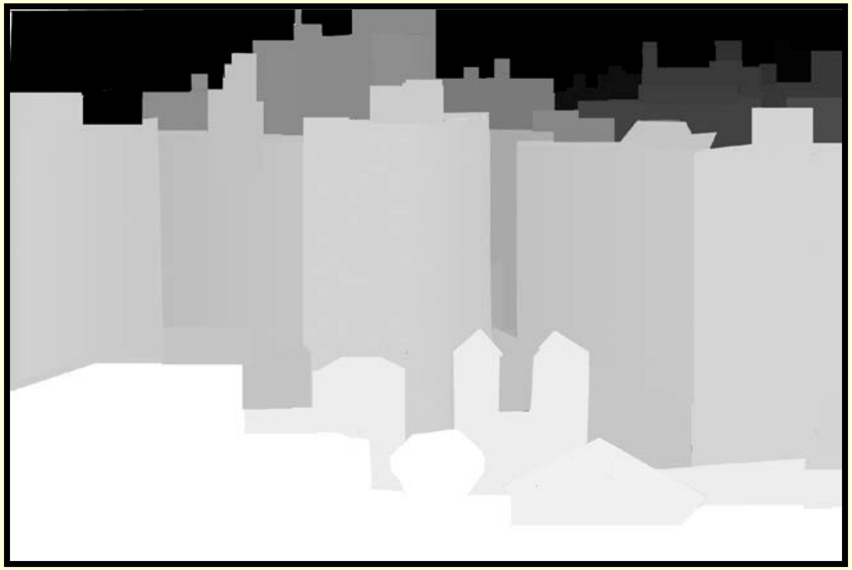
Sensor Position :

$$40° \ 48.5' \ N, \quad 73° \ 57.6' \ W, \quad 76.14 \ m$$

Depth Information :

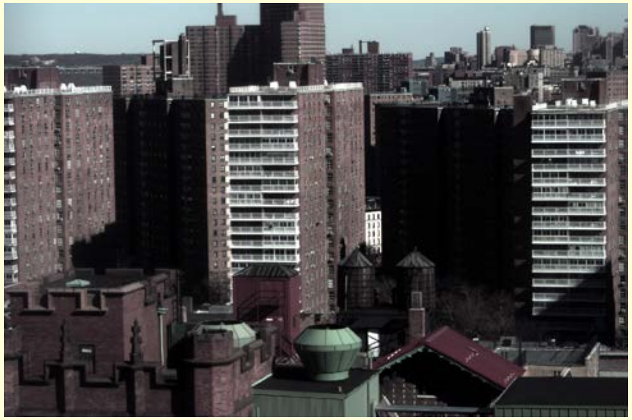


Satellite Digital Ortho-Photo
(1 meter accuracy)



Approximate Depth Map

Illumination Direction

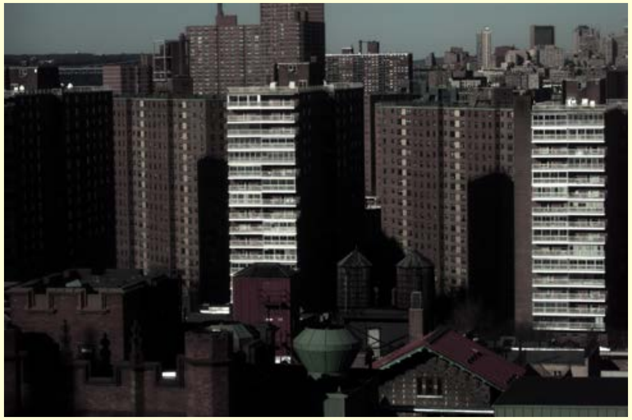


February 18th 2002, 10 AM
Clear and Sunny

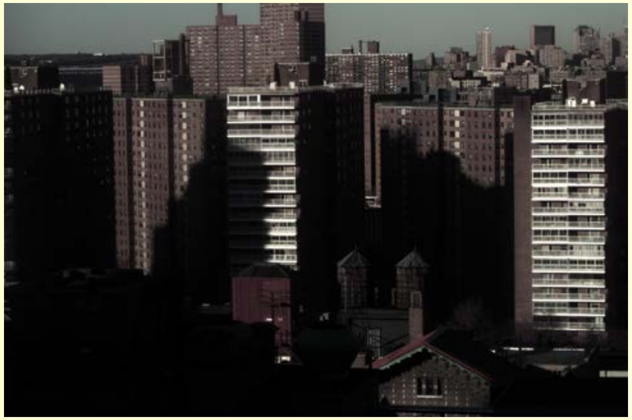
February 18th 2002, 11 AM
Clear and Sunny

February 18th 2002, 12 Noon
Clear and Sunny

February 18th 2002, 2 PM
Clear and Sunny



February 18th 2002, 3 PM
Clear and Sunny



February 18th 2002, 4 PM
Clear and Sunny

Illumination Spectra

May 4th 2002, 6 AM
Clear Day, Sun Rise

May 4th 2002, 12 Noon
Clear Day, Noon

May 4th 2002, 6 PM
Clear Day, Sun Set

May 4th 2002, 9 PM
Clear Night

Cloud Cover

March 22nd 2002, 7 AM
Sunny, No Clouds

March 4th 2002, 7 AM
Partly Sunny, Partly Cloudy

March 13th 2002, 7 AM
Overcast

Sharper Shadows

Decreasing Cloud Cover

Weather Conditions

April 16th 2002, 3 PM
Sunny, Mild Haze

April 12th 2002, 3 PM
Overcast, Light Rain

April 19th 2002, 3 PM
Overcast, Dense Fog

April 28th 2002, 3 PM
Overcast, Dense Mist

Visibility

April 28th 2002, 6 AM
Rain & Mist, Visibility 2.5 miles
0.1 inches Precipitation last hour

April 28th 2002, 9 AM
Rain & Mist, Visibility 1.5 miles
0.23 inches Precipitation last hour

April 28th 2002, 12 Noon
Light Rain & Mist, Visibility 1.25 miles
0.08 inches Precipitation last hour

April 28th 2002, 3 PM
Dense Mist, Visibility 0.75 miles
0.02 inches Precipitation last hour

Four Seasons (New York)

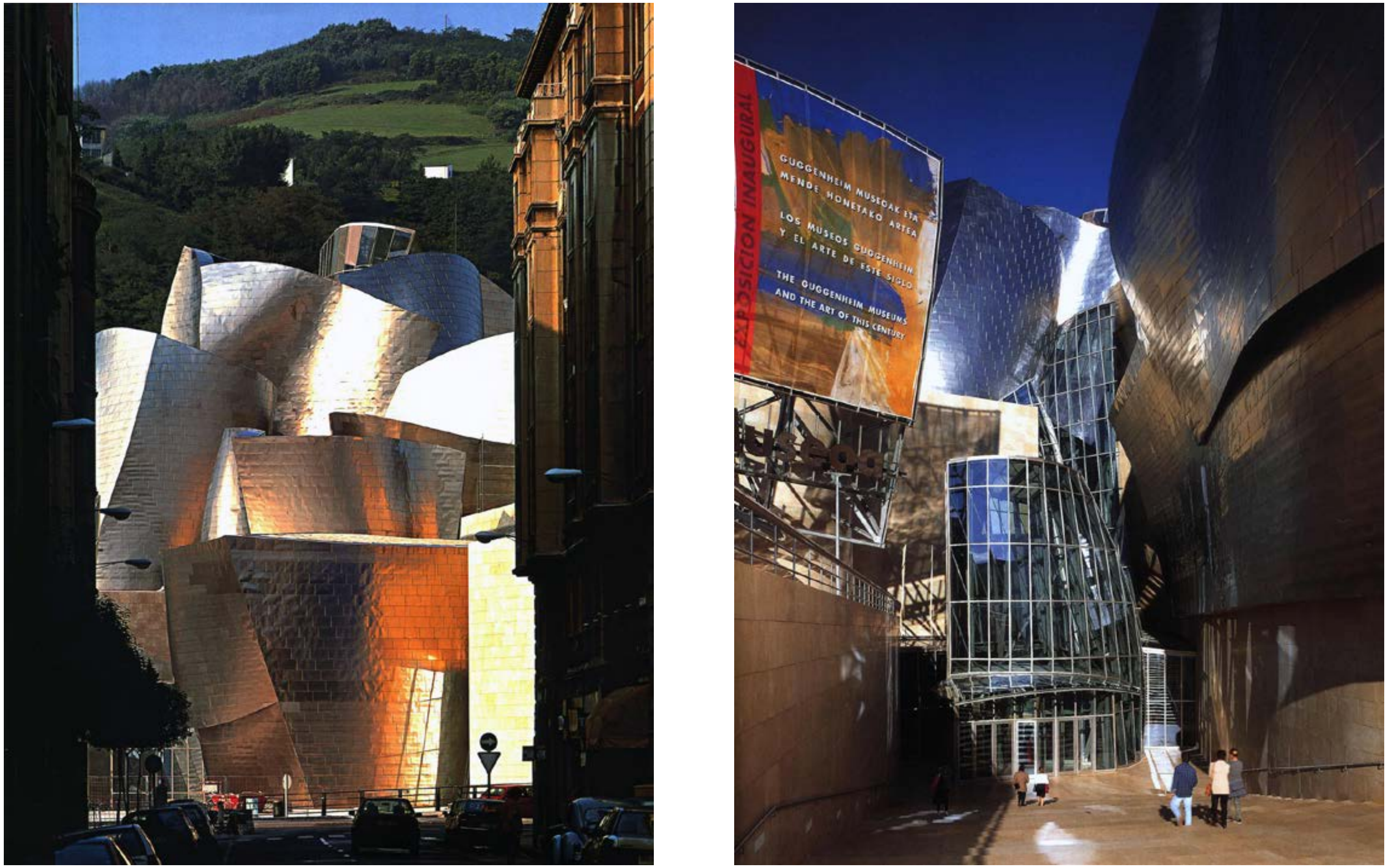
Winter, January 4th 2002, 9 AM
Clear and Sunny

Fall, September 9th 2001, 9 AM
Clear and Sunny

Spring, March 14th 2001, 9 AM
Clear and Sunny

Summer, May 15th 2002, 9 AM
Clear and Sunny

Lighting Design



- From *Frank Gehry Architecture,* Ragheb ed. 2001

Lighting Design

- From *Frank Gehry Architecture*, Ragheb ed. 2001

Nomenclature for Lighting

Size: point
line
area
volume

Distance: infinity
near-field

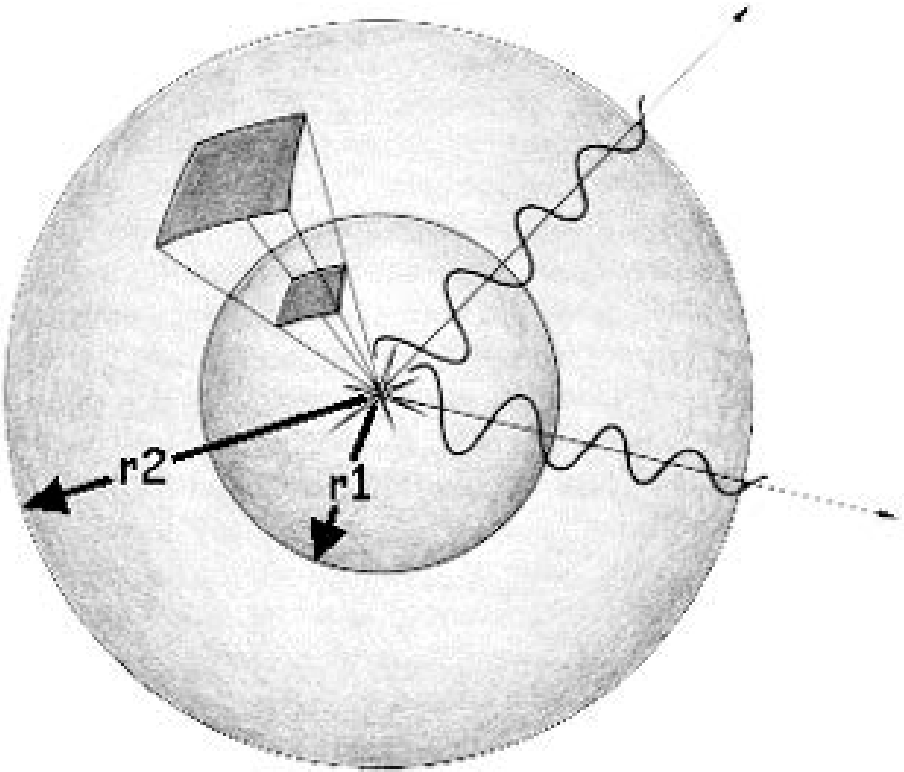
Directionality: collimated
divergent
convergent

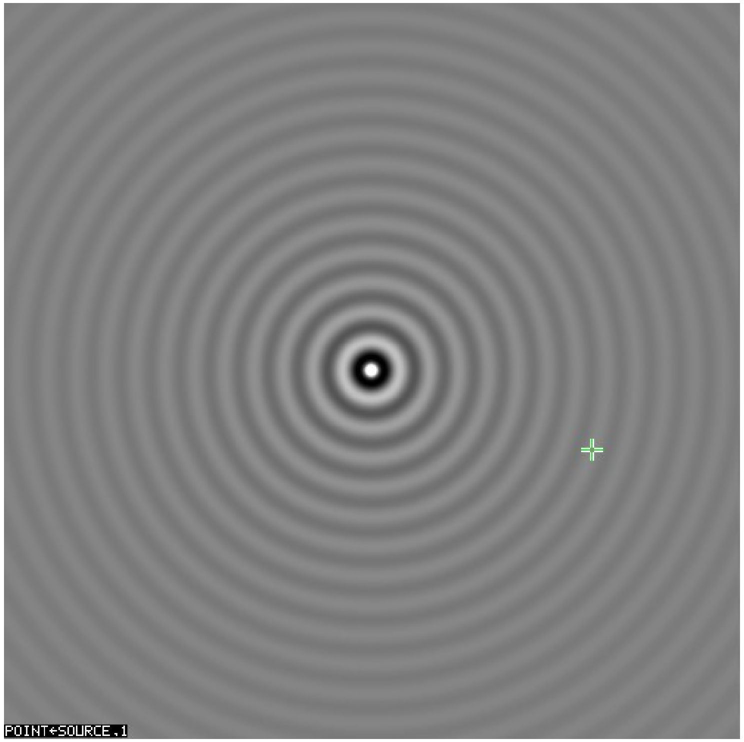
Temporal: static
time-varying

Natural sun
sky
firefly
moon

Artificial halogen
fluorescent
flash
projector
structured light

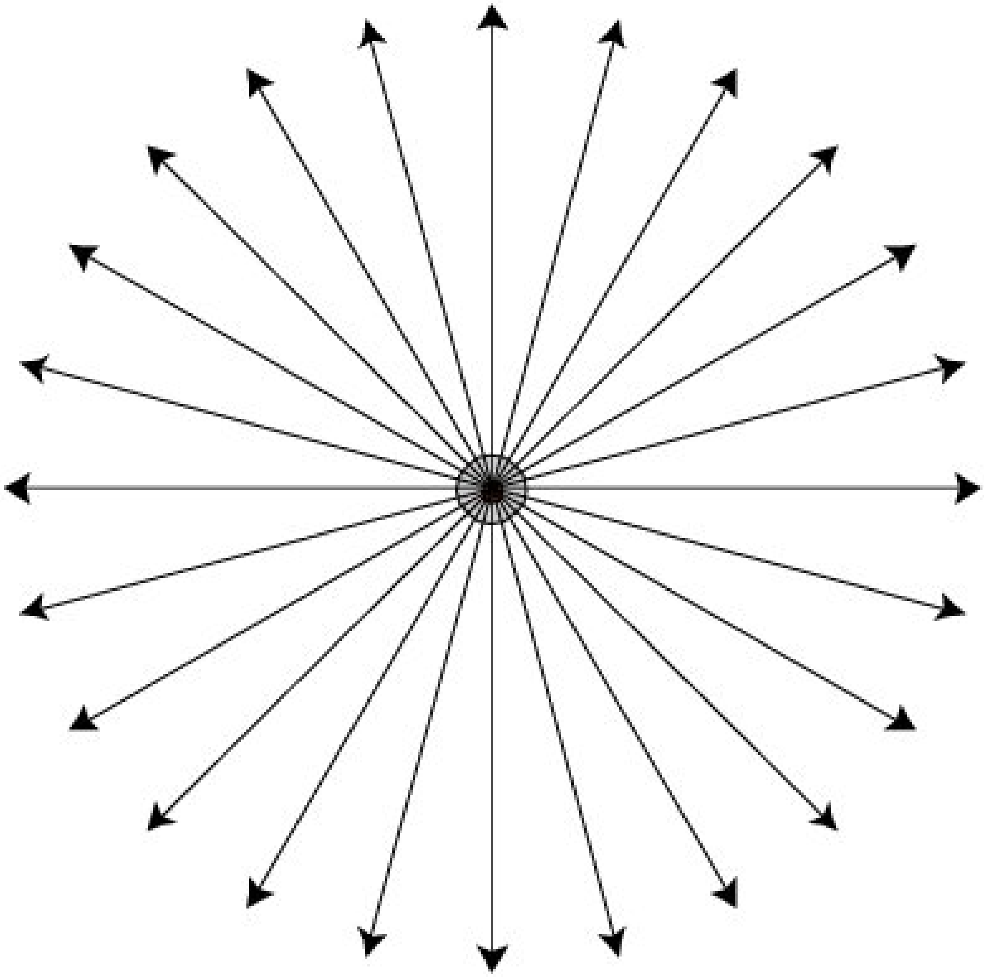
Isotropic Point Light Source





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

Isotropic Point Source



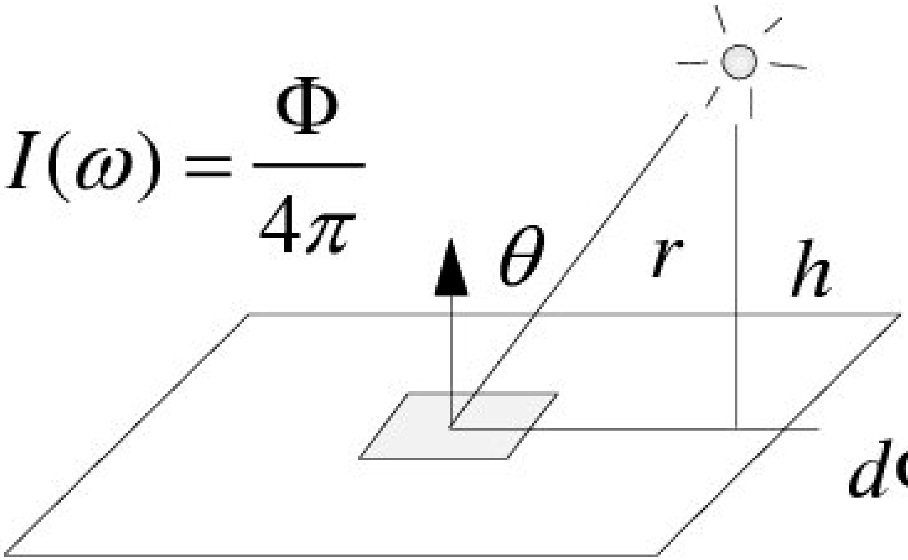
$$\Phi = \int_{S^2} I \, d\omega$$

$$= 4\pi I$$

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

Illumination: Isotropic Point Source

$$I(\omega) = \frac{\Phi}{4\pi}$$



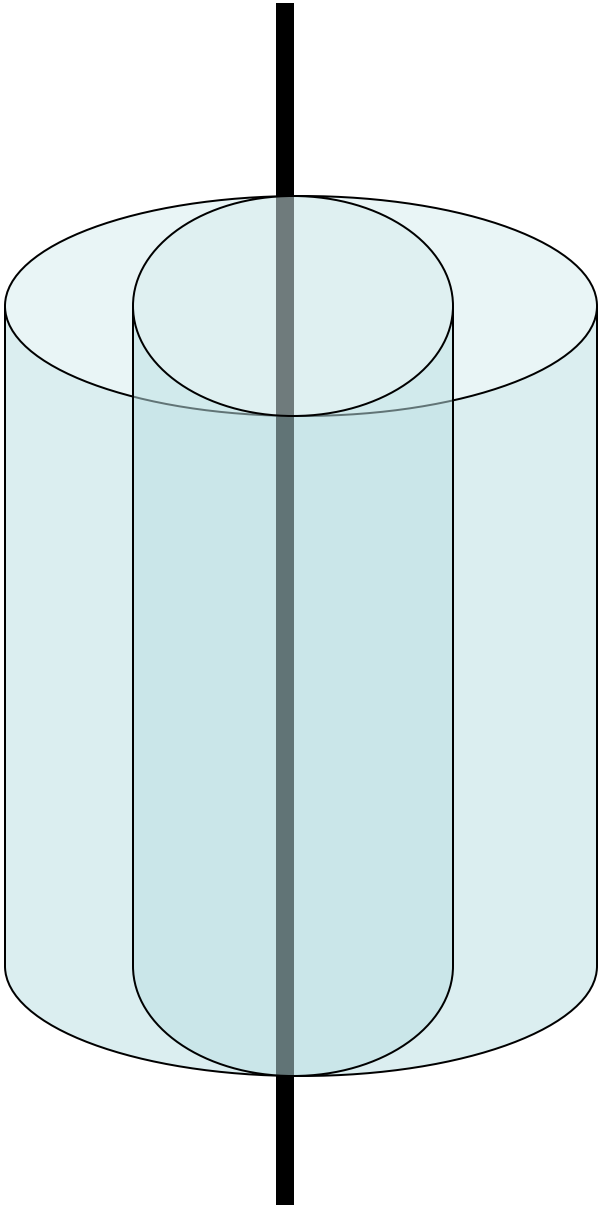
$$d\Phi = I\,d\omega = E\,dA$$

$$I\,d\omega = \frac{\Phi}{4\pi}\frac{\cos\theta}{r^2}dA = E\,dA$$

$$E = \frac{\Phi}{4\pi}\frac{\cos\theta}{r^2}$$

$$\frac{\Phi}{4\pi}\frac{\cos\theta}{r^2} \Rightarrow \frac{\Phi}{4\pi}\frac{\cos^3\theta}{h^2}$$

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,

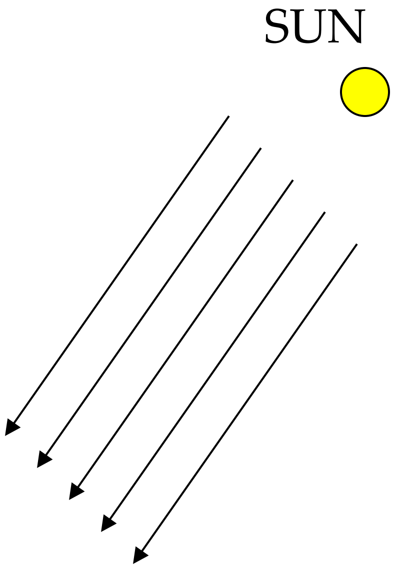
$$d\Phi = I\,d\omega = E\,dA$$

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

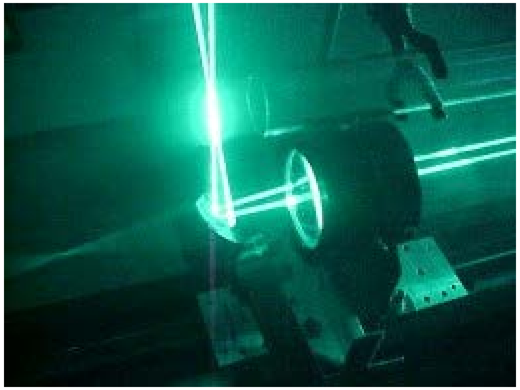
Intensity fall must not be ignored!

Most vision and graphics algorithms assume this.

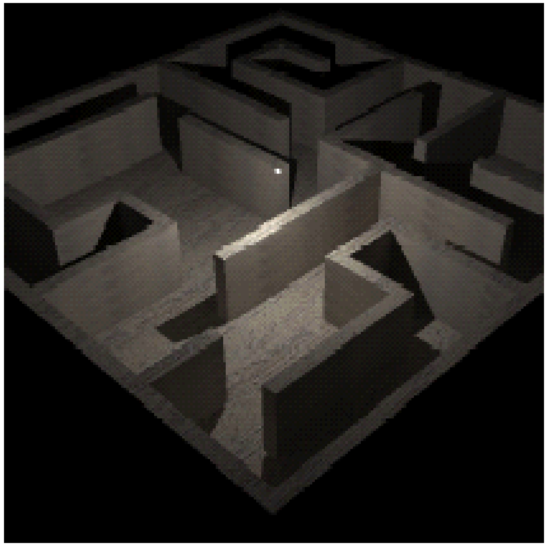
Collimated:

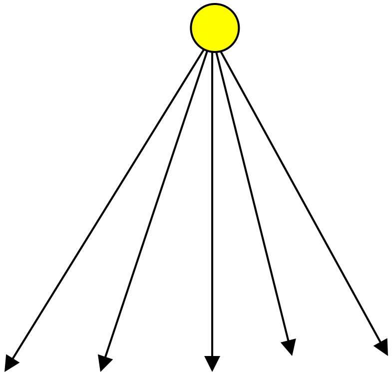
Parallel rays of light on the surface

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



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, not good for vision experiments.
- Shows sparse, spikes in spectrum.

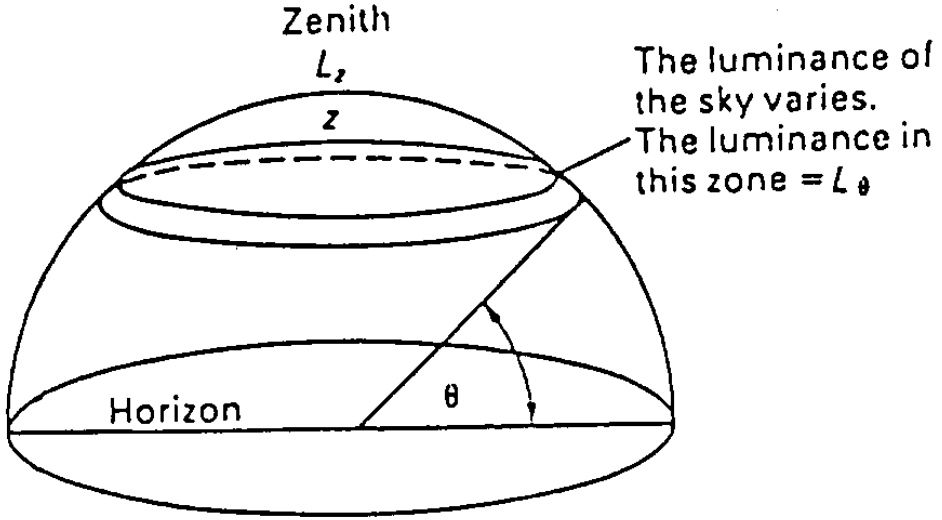
Incandescent:

- Lots of heat generated.
- Less efficient lighting for the same brightness.
- No flickers, good for vision experiments.
- Shows continuous spectrum.

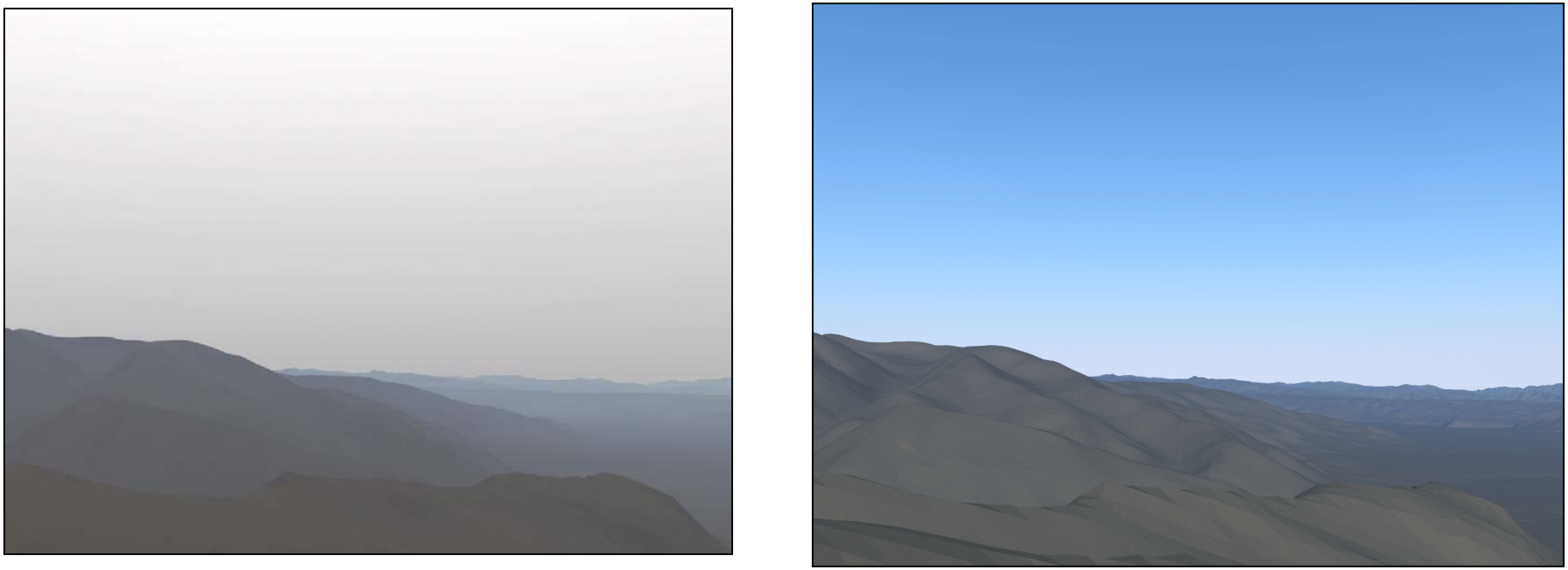
Overcast Sky versus Clear Sky

Which is the brightest region in a overcast sky?
Which is the darkest?

Which is the brightest region in a sunny sky (apart from the sun)?
Which is the darkest?

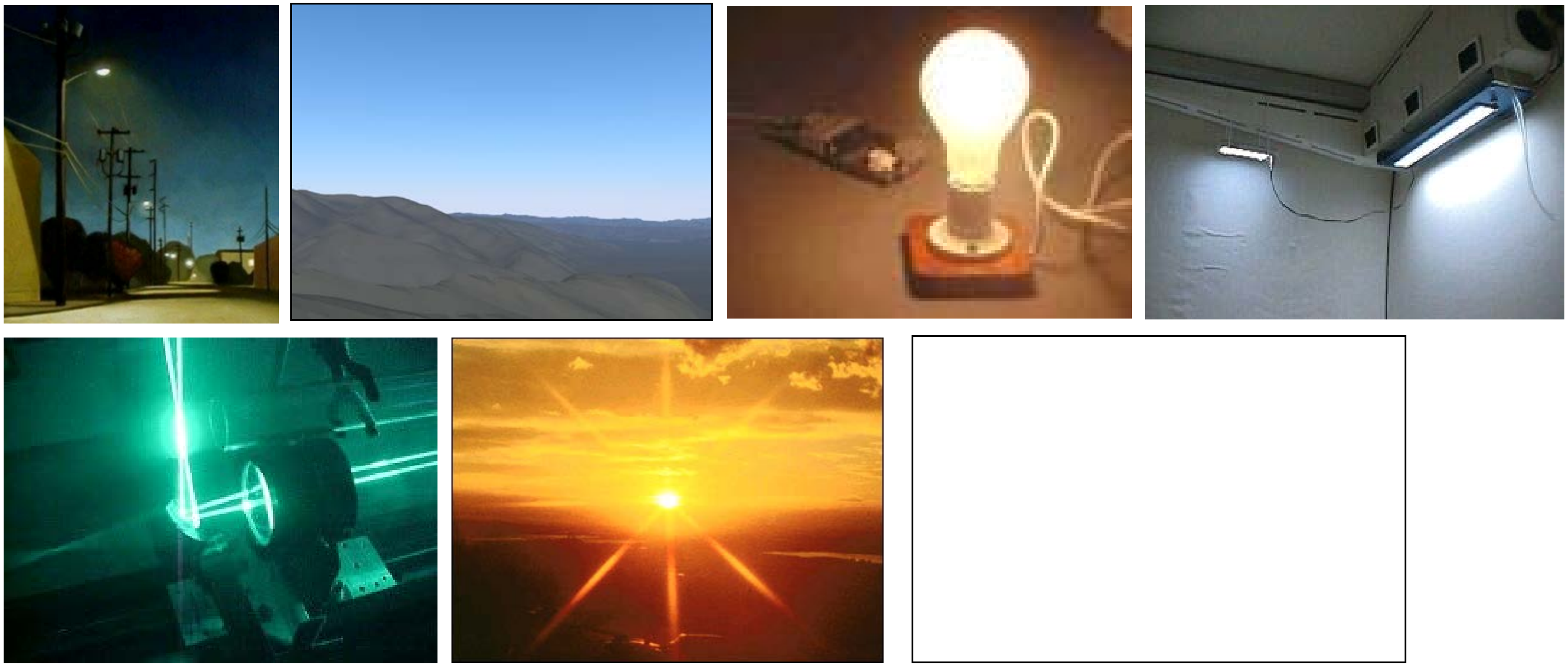


Overcast Sky versus Clear Sky



Notice reversal of brightness in the two skies.

Is there a unified representation for light sources?



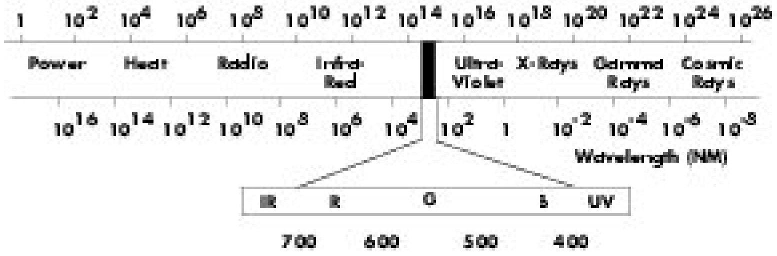
How do we compare the light from a street lamp to that from an overcast sky?

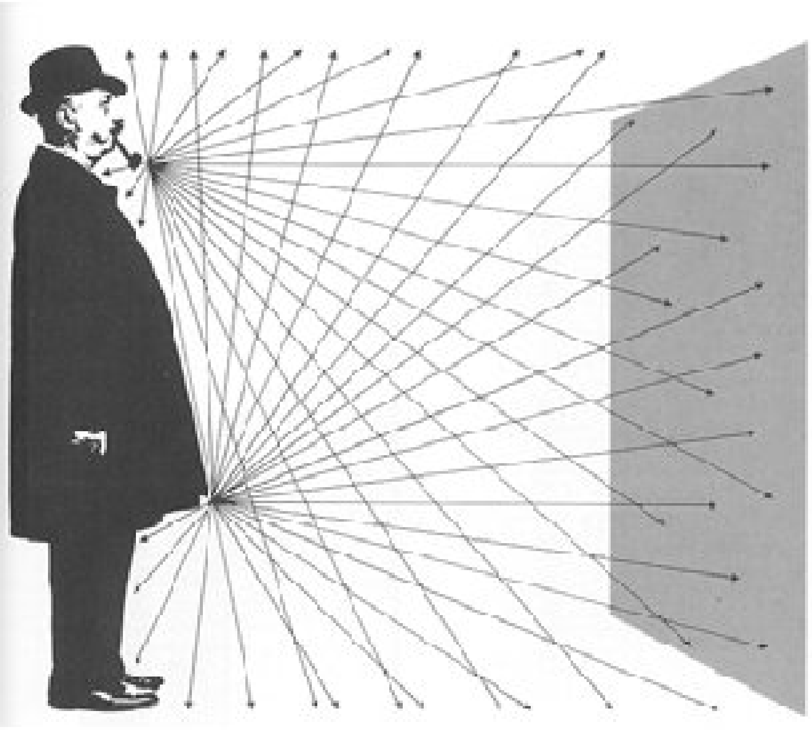
It is important to unify source representation so that algorithms may be developed for all sources instead of one per type of source.

Consider the SPACE of LIGHT RAYS!

The Light Field

Electromagnetic waves and power spectrum





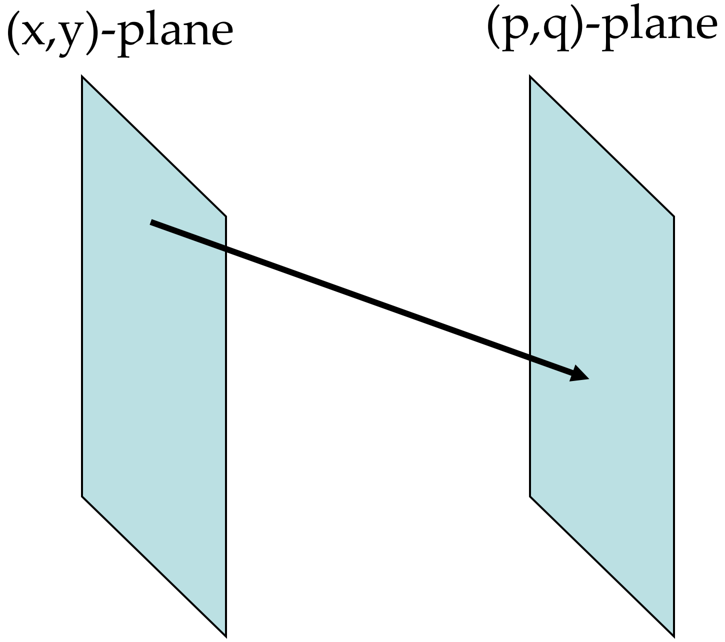
Ignore polarization

Ignore photons

Spatial distribution

From London and Upton

4D Hypercube of Rays



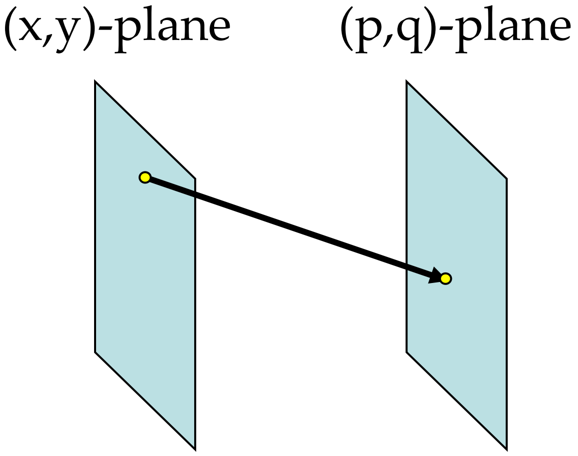
- Assumes vacuum (no absorption or scattering)
- No fluorescence, phosphorescence

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

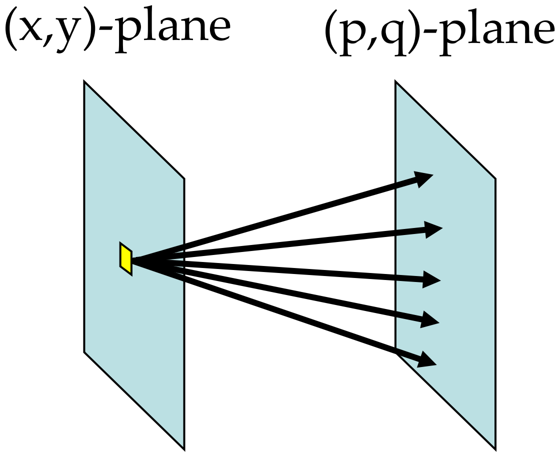
Langer and Zucker, CVPR 97

Representation of Sources

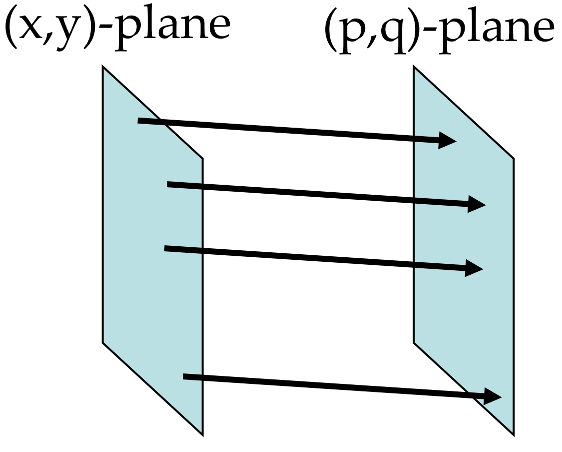
Langer and Zucker, CVPR 97



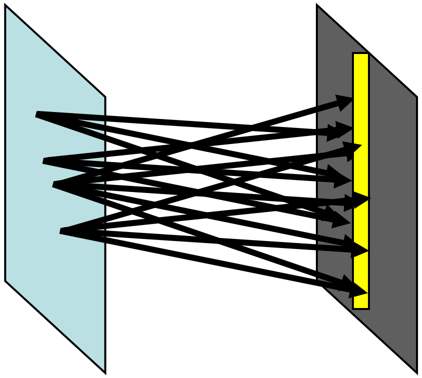
Laser beam – 0D



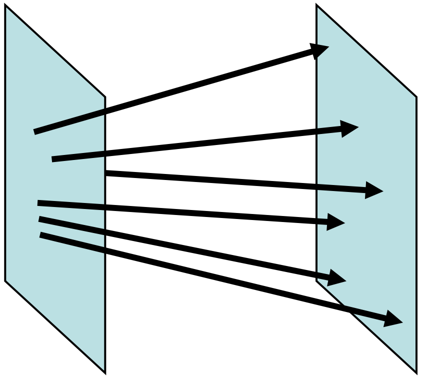
Point source – 2D



Distant Source (Sun) – 2D



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



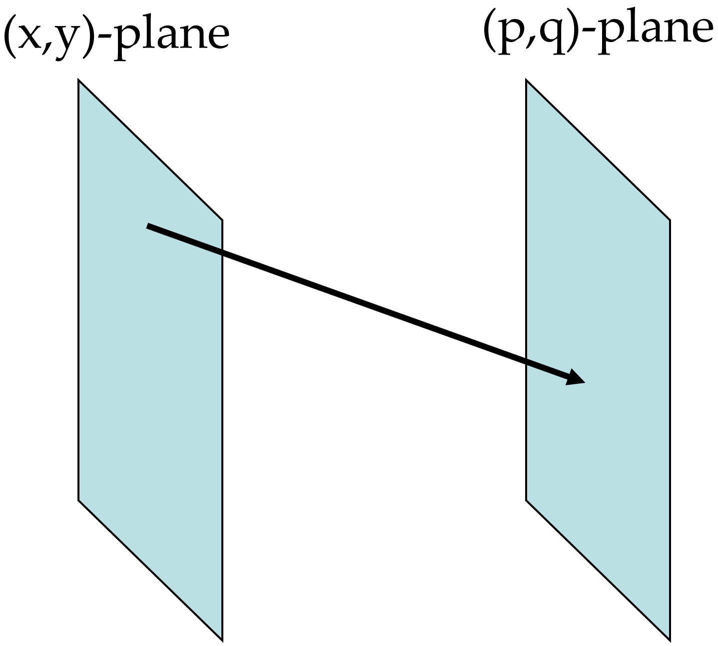
Area source (Sky) with
door completely open – 4D

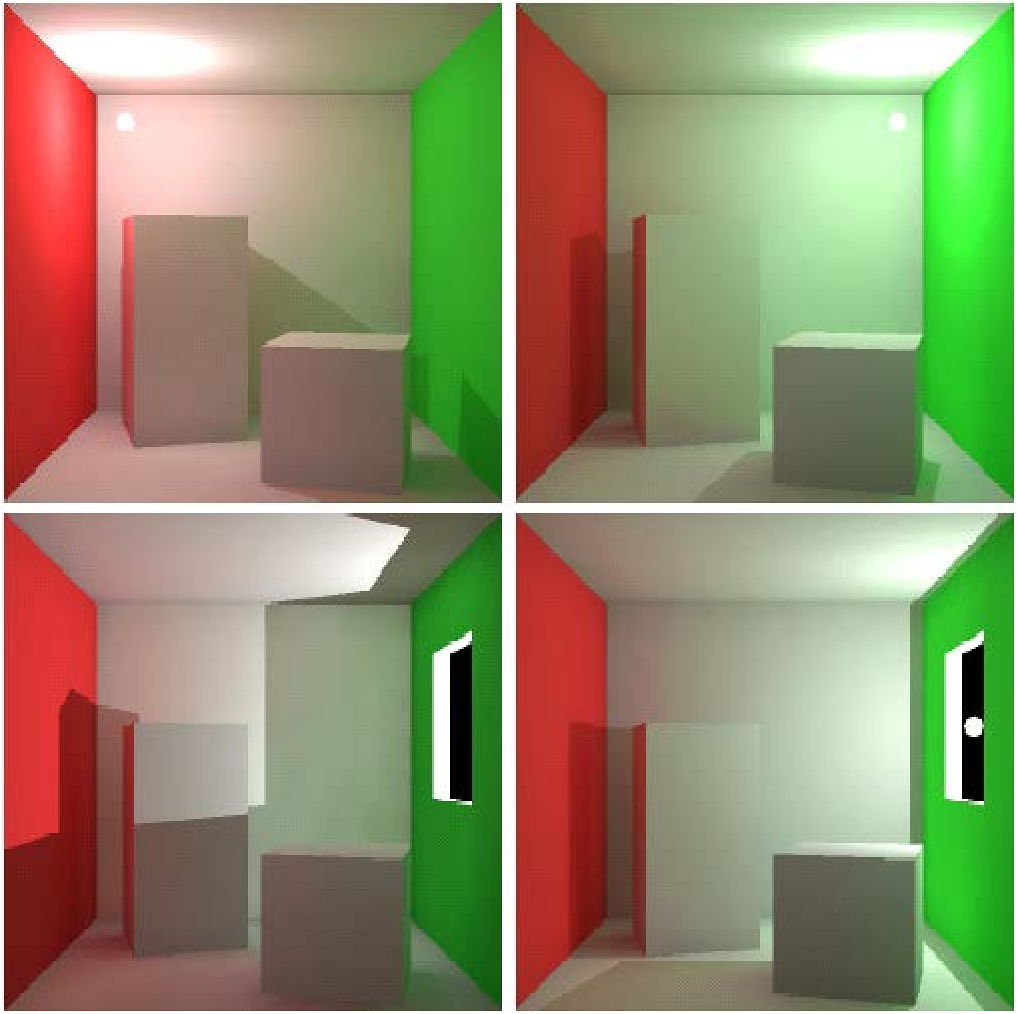
Corners of the 4D Hypercube

Non-ideal example	*Ideal model*	h_x	h_y	h_p	h_q	dimension
overcast sky	uniform source	∞	∞	∞	∞	4
Cyberware^{TM} scanner		∞	∞	∞	0	3
		∞	∞	0	∞	
fluorescent tube	linear source	∞	0	∞	∞	3
		0	∞	∞	∞	
sunlight	point source at infinity	∞	∞	0	0	2
	uniform distribution of rays in a plane	∞	0	∞	0	2
		0	∞	0	∞	
louvered linear source (see text)	fan of rays perpendicular to a linear source	∞	0	0	∞	2
		0	∞	∞	0	
small panel light	point source	0	0	∞	∞	2
sunlight through crack in doorway	parallel rays in a plane	∞	0	0	0	1
		0	∞	0	0	
rotating spotlight	fan of rays	0	0	0	∞	1
		0	0	∞	0	
spotlight or laser	single ray	0	0	0	0	0

Langer and Zucker, CVPR 97

Examples of sources





What is a Light Source?

Is sky a source? If so, why not a white piece of paper?

Is a translucent object a source?

How to differentiate between source rays and non-source rays?

> Define a minimum set of absorbants at the ends of rays so that the whole ray space is dark.