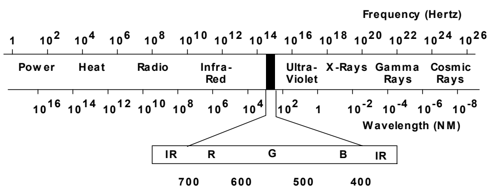
The Light Field

Electromagnetic waves; photons

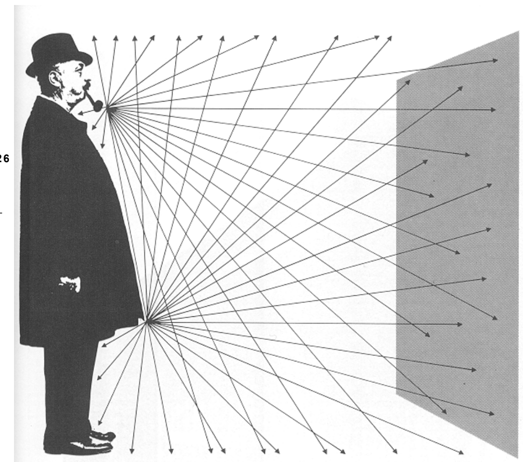
Frequency spectra

and color



Polarization

Spatial distribution



From London and Upton

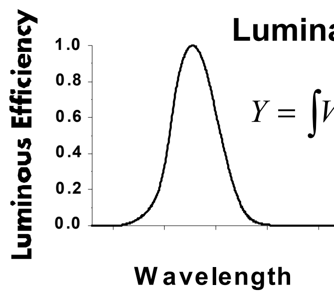
Radiometry

1. How is light measured?
2. How is the spatial distribution of light energy described?
3. How is reflection from a surface characterized?
4. What are the conditions for equilibrium flow of light in an environment?

Radiant Energy and Power

Power: Watts vs. Lumens

- Energy efficiency
- Spectral efficacy



Luminance

$$Y = \int V(\lambda) L(\lambda) d\lambda$$

Energy: Joules vs. Talbot

- Since the velocity of light is so fast, may typically ignore distinction between power and energy
- Exposure - Reaction rates
  - Film response
  - Skin - sunburn

Radiometry vs. Photometry

- Radiance & Radiometry [Units = Watts]

  Physical measurement of electromagnetic energy.

- Luminance & Photometry/Colorimetry [Lumen]

  Perceptual measurement of relative subjective sensation due to light of different wavelengths.

- Brightness [Units = Brils] $B = Y^{1/3}$

  Perceptual measurement of the relative perceived sensation of light of different intensities.

Transport Theory

Transport theory is concerned with calculating how stuff Q *flows* in the environment.

- Mass m
- Charge q
- Radiant energy Φ

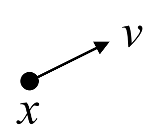
Transport quantities are built around a core of basic geometric ideas. These are tricky!

The easiest way to learn transport theory is to think in terms of particles (photons).

Particle Density

Phase Space

Particle characterized by position and velocity



Particle densities

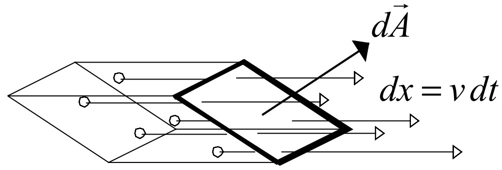
Ratio of number of particles to volumes (phase space)

$$\boxed{d^3x} \times \boxed{d^3v} \qquad n(x,v,t) = \lim_{\Delta^3 x \Delta^3 v \to 0} \frac{N(t)}{\Delta^3 x \, \Delta^3 v}$$

$$\Re^3 \times \Re^3$$

Flows

Count particles crossing a surface



$$d^3x = v\cos\theta\, dA = (\vec{v}\,dt)\bullet d\vec{A}$$

$$Q(x,v) = n(x,v)\,d^3x = n(x,v)\,(\vec{v}\,dt)\bullet d\vec{A}$$

- **Flux [Stuff/Time] (or Rate or Flow)**

$$\Phi = \frac{dQ}{dt} = n(x,v)\,\vec{v}\bullet d\vec{A}$$

- **Flux density [Stuff/(Time•Area)]**

$$\Phi = \frac{d^2Q}{dt\,dA} = n(x,v)\,\vec{v}\bullet d\hat{A} = n(x,v)\,v\cos\theta$$

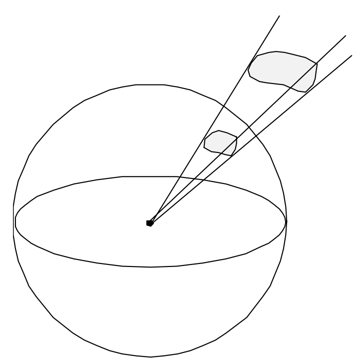
Angles and Solid Angles

- **Angle** $\theta = \dfrac{length}{radius}$

  $\Rightarrow$ **circle has 2π radians**

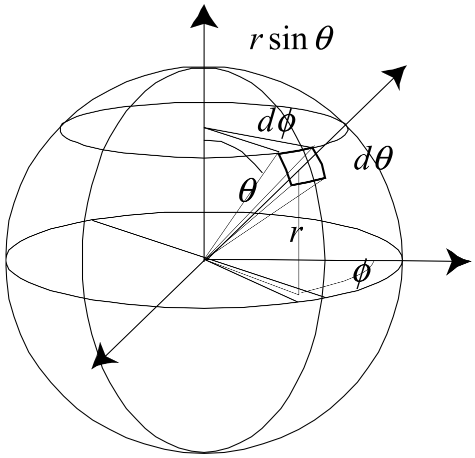
- **Solid angle** $\Omega = \dfrac{area}{radius^2}$

  $\Rightarrow$ **sphere has 4π steradians**



If the area is not on the sphere, then the solid angle subtended by the area is equal to the area projected onto the unit sphere.

Differential Solid Angles



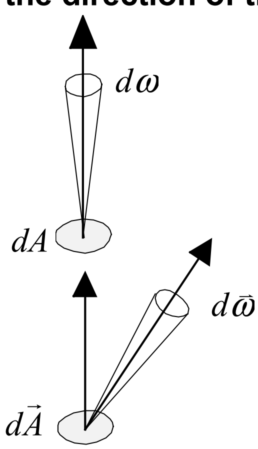
$$dA = (r\,d\theta)(r\sin\theta\,d\phi)$$
$$= r^2\sin\theta\,d\theta\,d\phi$$

$$d\omega = \frac{dA}{r^2} = \sin\theta\,d\theta\,d\phi$$

$$S = \int_0^{\pi}\int_0^{2\pi}\sin\theta\,d\theta\,d\phi = 4\pi$$

Radiance and Luminance

<u>Definition</u>: The *radiance* (*luminance*) is the power per unit projected area perpendicular to the ray per unit solid angle in the direction of the ray.



$$d^2\Phi = L(x,\omega)\,d\vec{\omega}\bullet d\vec{A}$$

$$L(x,\omega) \equiv \frac{d^2\Phi}{d\vec{\omega}\bullet d\vec{A}}$$

$$\left[\frac{W}{m^2 sr}\right]\left[\frac{lm}{m^2 sr} = nit\right]$$

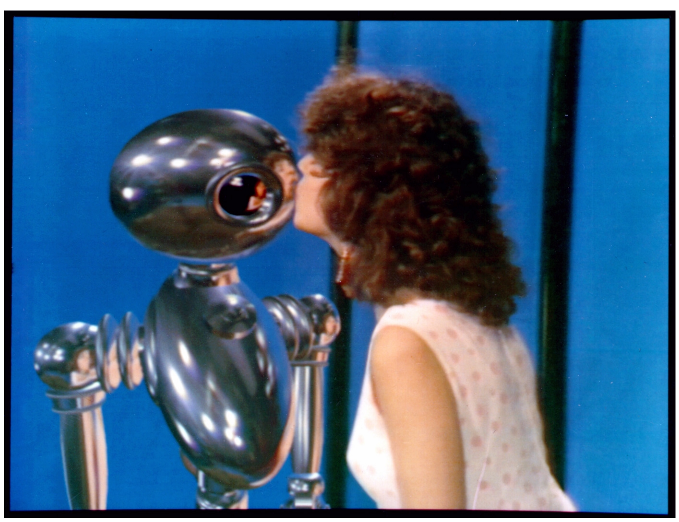
CS348B Lecture 4 Pat Hanrahan, Spring 2001

Environment Maps = Radiance at a Point

Miller and Hoffman, 1984

CS348B Lecture 4 Pat Hanrahan, Spring 2001

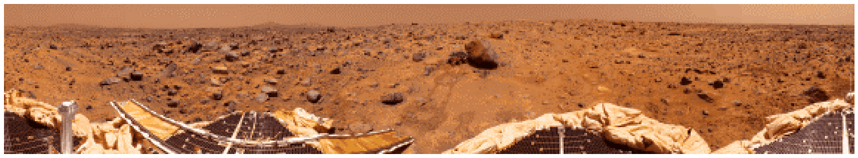
Environment Maps



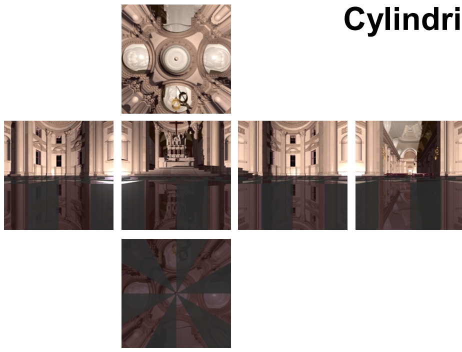
Interface, Chou and Williams (ca. 1985)

CS348B Lecture 4 Pat Hanrahan, Spring 2001

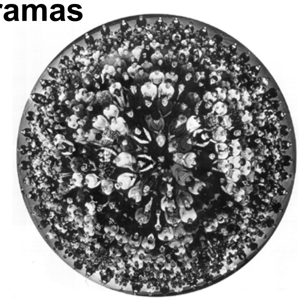
Environment Maps



Cylindrical Panoramas



Cubical Environment Map

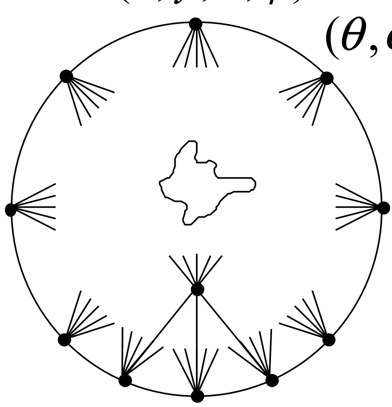


180 degree fisheye
Photo by R. Packo

CS348B Lecture 4 Pat Hanrahan, Spring 2001

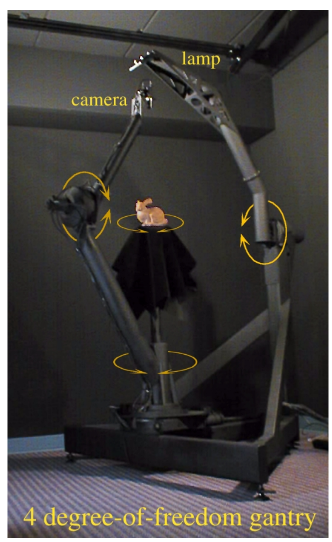
Spherical Light Field

$$L(x, y, \theta, \varphi)$$



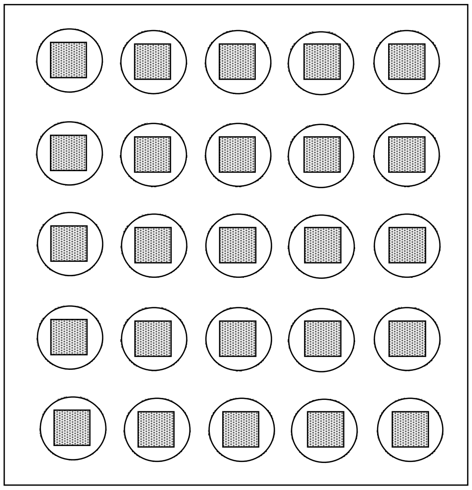
(θ, φ)

Capture all the light leaving an object - like a hologram



CS348B Lecture 4 Pat Hanrahan, Spring 2001

Two-Plane Light Field



2D Array of Cameras

2D Array of Images

Properties of Radiance

1. Fundamental field quantity that characterizes the distribution of light in an environment.

   -> All other quantities are derived from it.

2. Radiance invariant along a ray.

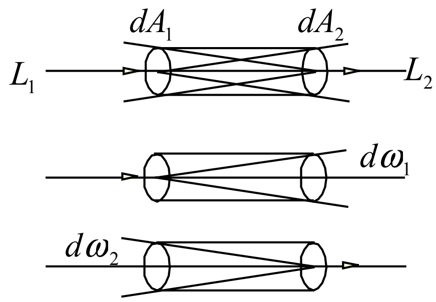
   -> Radiance is what is propagated in a ray tracer

3. Response of a sensor proportional to radiance.

   -> Image is a 2D set or rays

Radiance: 1st Law

The radiance in the direction of a light ray remains constant as the ray propagates.



$$d\Phi_1 = L_1 d\omega_1 dA_1 = L_2 d\omega_2 dA_2 = d\Phi_2$$

$$d\omega_1 = dA_2 / r^2$$
$$d\omega_2 = dA_1 / r^2$$

$$d\omega_1 dA_1 = \frac{dA_1 dA_2}{r^2} = d\omega_2 dA_2$$

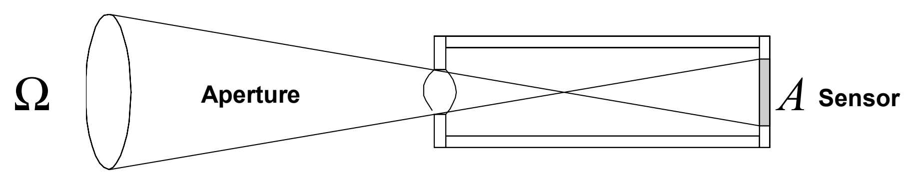
$$\therefore L_1 = L_2$$

L is the numeric quantity that should be associated with rays in ray tracers.

Radiance: 2nd Law

The response of a sensor is proportional to the radiance of the surface visible to the sensor.

L is what should be computed and displayed.



$$R = \int_A \int_\Omega L \cos\theta \, d\omega \, dA = L \int_A \int_\Omega \cos\theta \, d\omega \, dA = LT$$

Throughput $T = \int_A \int_\Omega \cos\theta \, d\omega \, dA$

Throughput

Throughput: $$T = \int_A \int_\Omega d^2T = \int_A \int_\Omega d\vec{\omega} \bullet d\vec{A}$$

Properties:

1. **Throughput measures or counts the number of lines or rays in beam of light.**
2. **Throughput is conserved in an optical system; that is, throughput is unchanged under the lays of geometric optics (straight lines, reflection, refraction, mirages).**

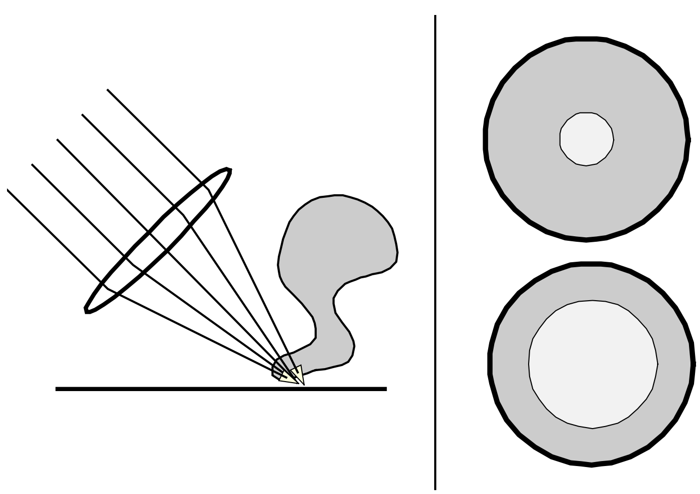
Radiance = energy [conserved] / throughput [conserved[

$$L(x,\omega) \equiv \frac{d^2\Phi}{d\vec{\omega} \bullet d\vec{A}}$$ **[Conserved]**

Quiz 1

Does radiance increase under a magnifying glass?

<u>NO!!</u>



Quiz 2

Does the brightness that a wall appears to the eye depend on the distance of the viewer to the wall?

<u>NO!!</u>