Advanced 3D computer graphics for movies and games (NPGR010)

- Spherical integrals, Light & Radiometry – Labs

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Slides of prof. Jaroslav Křivánek, minor edits by Ivo Kondapaneni

Reminders & org

- **Renderings due Oct 16th**
  - Upload to google drive, show on the big screen, 5 minutes per team (how many teams do we have)
- ~~Papers for presentations in the lab – 7.11., 21.11,~~
  - ~~ACM TOG special issue on production rendering~~ ~~https://dl.acm.org/citation.cfm?id=3243123&picked=prox~~
- Reminder – choose papers for the exam
  - http://kesen.realtimerendering.com/
- Log your choices here
  - https://docs.google.com/document/d/1x9wC2n4tnT9H5ttpSVKIK8Xuq1-9f3PQF21YvIhZgyw/edit?usp=sharing
- Decide assignments track vs. individual project track by Wed, Nov 4th 2020.

PEN & PAPER EXERCISES

Surface area of a (subset of a) sphere

- Calculate the surface area of a unit sphere.

- Calculate the surface area of a spherical cap delimited by the angle θ_o measured from the north pole.

- Calculate the surface area of a spherical wedge with angle ϕ_o.

Solid angle

- What is the solid angle under which we observe an (infinite) plane from a point outside of the plane?

- Calculate the solid angle under which we observe a sphere with radius R, the center of which is at the distance D from the observer.

Isotropic point light

- **Q:** What is the emitted power (flux) of an isotropic point light source with intensity that is a constant I in all directions?

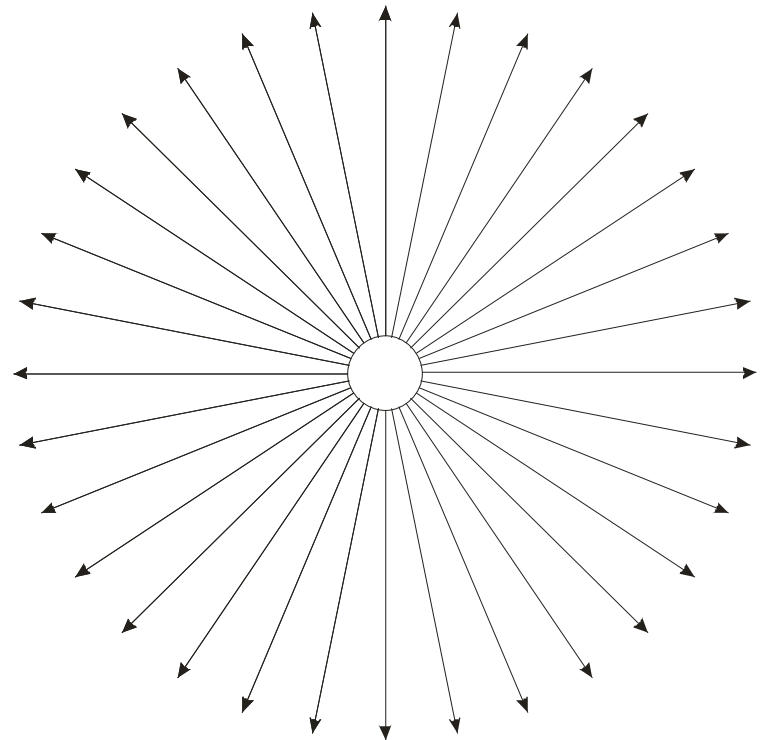# Isotropic point light

- **A:** Total flux:

$$\Phi = \int_\Omega I(\omega)\, d\omega = \left| \begin{array}{c} substitute: \\ d\omega = \sin\theta\, d\theta\, d\varphi \end{array} \right|$$

$$= I \int_{\varphi=0}^{2\pi} \int_{\theta=0}^{\pi} \sin\theta\, d\theta\, d\varphi$$

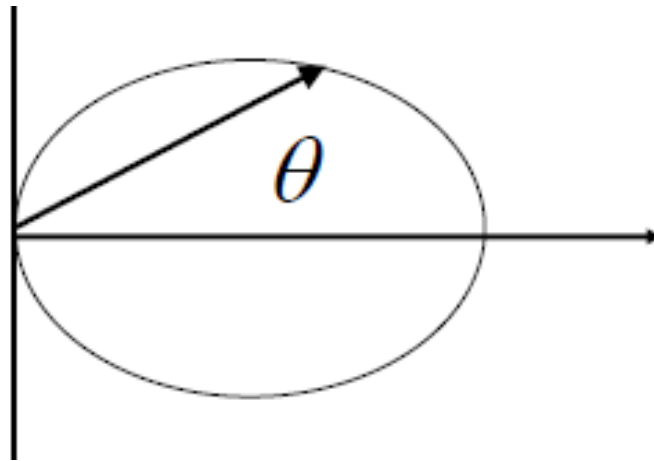$$= I\, 2\pi \left[-\cos\theta \right]_0^\pi$$

$$= 4\pi I$$

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

Cosine spot light

■ What is the power (flux) of a point source with radiant intensity given by:

$$I(\omega) = I_0 \max\{0, \omega \cdot \vec{d}\}^s$$

θ

Spotlight with linear angular fall-off

- What is the power (flux) of a point light source with radiant intensity given by:

$$I(\theta, \phi) = \begin{cases} I_0 & \theta \leq \alpha \\ I_0 \dfrac{\beta - \theta}{\beta - \alpha} & \alpha < \theta < \beta \\ 0 & \theta \geq \beta \end{cases}$$

Constant part

$$\Phi_1 = \int_0^{2\pi} \int_0^{\alpha} I_0 \sin\theta d\theta d\phi = I_0 2\pi (1 - \cos\alpha).$$

Linear part

$$\Phi_2 = \int_0^{2\pi} \int_{\alpha}^{\beta} I_0 \frac{\beta - \theta}{\beta - \alpha} \sin\theta d\theta d\phi = I_0 \frac{2\pi}{\beta - \alpha} \int_{\alpha}^{\beta} (\beta - \theta) \sin\theta d\theta \tag{1}$$

The last integral is the sum of the following two integrals:

$$\int_{\alpha}^{\beta} \beta \sin\theta d\theta = \beta\cos\alpha - \beta\cos\beta \tag{2}$$

$$-\int_{\alpha}^{\beta} \theta \sin\theta d\theta = \left| \sin\theta - \theta\cos\theta \right|_{\beta}^{\alpha} = \sin\alpha - \alpha\cos\alpha - \sin\beta + \beta\cos\beta \tag{3}$$

Plugging (2) and (3) into (1) and rearranging, we get

$$\Phi_2 = I_0 \frac{2\pi}{\beta - \alpha} \left[(\beta - \alpha)\cos\alpha + \sin\alpha - \sin\beta \right] = I_0 2\pi \left[\cos\alpha - \frac{\sin\beta - \sin\alpha}{\beta - \alpha} \right]. \tag{4}$$
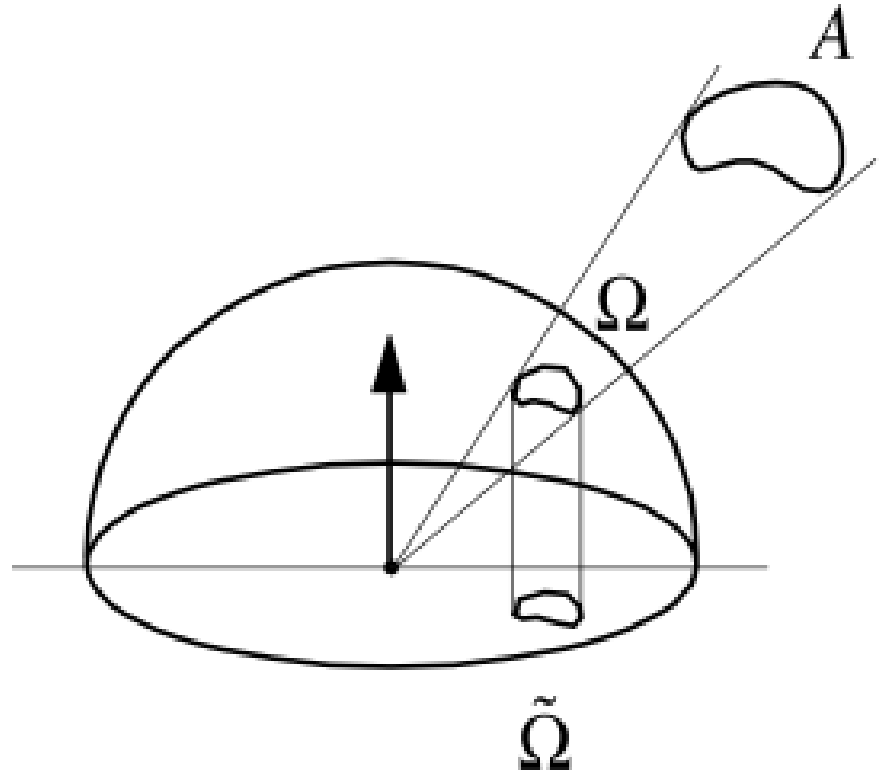
Total flux

$$\boxed{ \Phi = \Phi_1 + \Phi_2 = I_0 2\pi \left[1 - \frac{\sin\beta - \sin\alpha}{\beta - \alpha} \right] } \tag{5}$$

Irradiance due to a Lambertian light source

- What is the irradiance $E(\mathbf{x})$ at point $\mathbf{x}$ due to a uniform Lambertian area source observed from point $\mathbf{x}$ under the solid angle Ω?

Uniform Area Source

$$E(x) = \int\limits_{H^2} L \cos\theta \, d\omega$$

$$= L \int\limits_{\Omega} \cos\theta \, d\omega$$

$$= L \tilde{\Omega}$$

CG III (NPGR010) - J. Křivánek

How dark are outdoor shadows?

- ✦ luminance arriving on a surface from a full (overhead) sun is 300,000 × luminance arriving from the blue sky, but the sun occupies only a small fraction of the sky

- ✦ illuminance on a sunny day = 80% from the sun + 20% from blue sky, so shadows are 1/5 as bright as lit areas (2.3 f/stops)

(Marc Levoy)

mean = 7

mean = 27

Based in these hints, calculate the solid angle under which we observe the Sun. (We assume the Sun is at the zenith.)
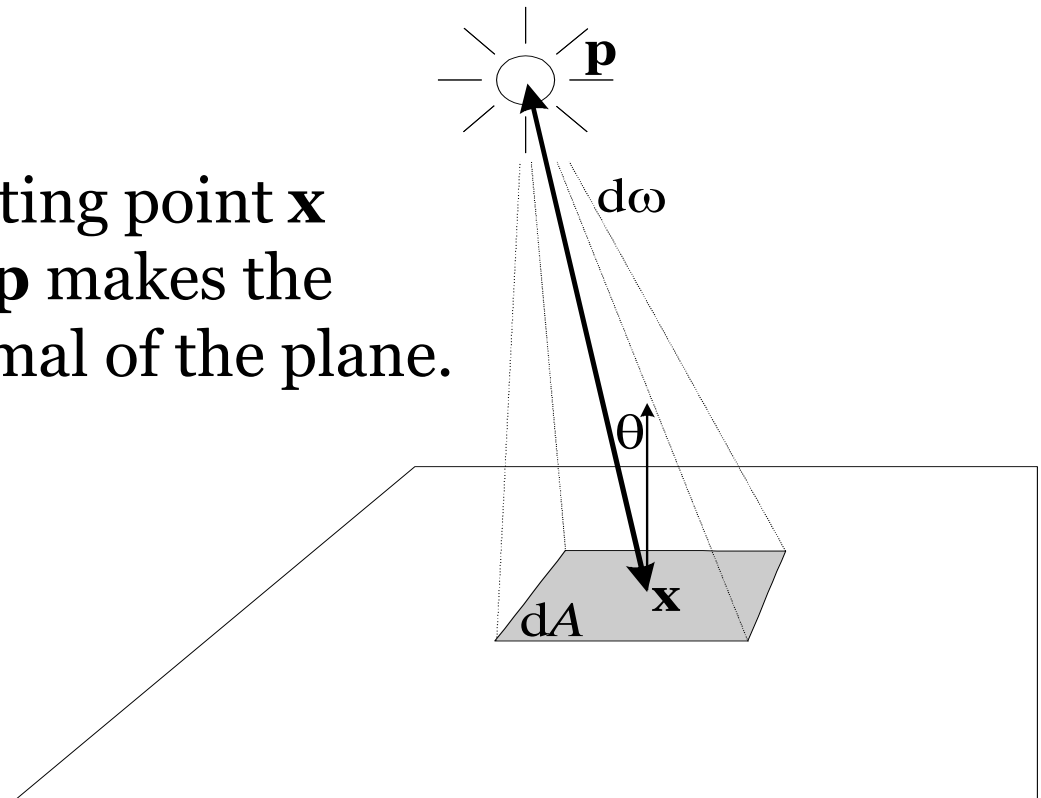
JPEG file

RAW, linearly boosted ©2009 Marc Levoy
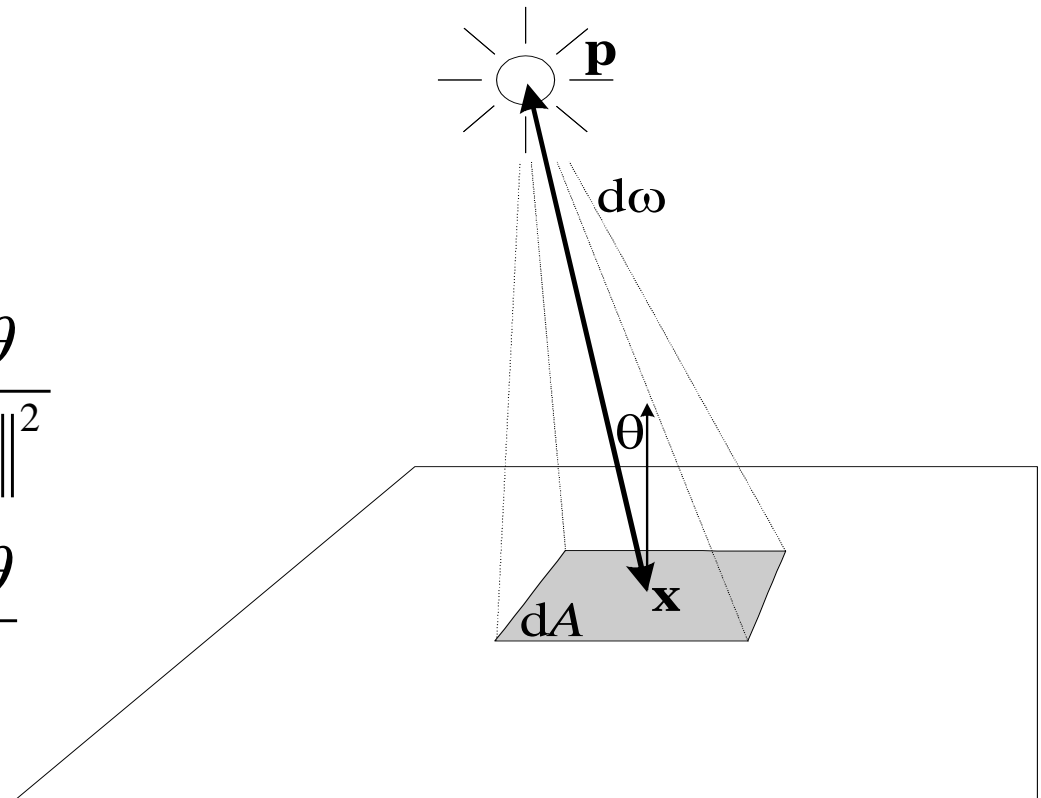
Irradiance due to a point source

- What is the irradiance at point **x** on a plane due to a point source with intensity $I(\omega)$ placed at the height h above the plane.

- The segment connecting point **x** to the light position **p** makes the angle θ with the normal of the plane.

p

dω

θ

x

dA

Irradiance due to a point source

- Irradiance of a point on a plane lit by a point source:

$$E(\mathbf{x}) = \frac{d\Phi(\mathbf{x})}{dA}$$

$$= \frac{I(\mathbf{p} \to \mathbf{x})d\omega}{dA}$$

$$= I(\mathbf{p} \to \mathbf{x})\frac{\cos\theta}{\|\mathbf{p} - \mathbf{x}\|^2}$$

$$= I(\mathbf{p} \to \mathbf{x})\frac{\cos^3\theta}{h^2}$$

Area light sources

- Emission of an area light source is fully described by the emitted radiance $L_e(\mathbf{x},\omega)$ for all positions on the source $\mathbf{x}$ and all directions ω.

- The total emitted power (flux) is given by an integral of $L_e(\mathbf{x},\omega)$ over the surface of the light source and all directions.

$$\Phi = \int\limits_{A} \int\limits_{H(\mathbf{x})} L_e(\mathbf{x},\omega)\cos\theta \, \mathrm{d}\omega \, \mathrm{d}A$$

Diffuse (Lambertian) light source

- What is the relationship between the emitted radiant exitance (radiosity) $B_e(\mathbf{x})$ and emitted radiance $L_e(\mathbf{x}, \omega)$ for a Lambertian area light source?

Lambertian source =

emitted radiance does not depend on the direction ω

$$L_e(\mathbf{x}, \omega) = L_e(\mathbf{x}).$$

Diffuse (Lambertian) light source

- $L_e(\mathbf{x}, \omega)$ is constant in ω

- Radiosity: $B_e(\mathbf{x}) = \pi L_e(\mathbf{x})$

$$B_e(\mathbf{x}) = \int_{H(\mathbf{x})} L_e(\mathbf{x}, \omega) \cos\theta \, \mathrm{d}\omega$$

$$= L_e(\mathbf{x}) \int_{H(\mathbf{x})} \cos\theta \, \mathrm{d}\omega$$

$$= \pi \, L_e(\mathbf{x})$$

Uniform Lambertian light source

- What is the total emitted power (flux) Φ of a **uniform** Lambertian area light source which emits radiance L_e

  - Uniform source – radiance does not depend on the position, $L_e(\mathbf{x}, \omega) = L_e$ = const.

Uniform Lambertian light source

- $L_e(\mathbf{x}, \omega)$ is constant in $\mathbf{x}$ and ω

$$\Phi_e = \mathbf{A}\,\mathbf{B}_e = \pi\,\mathbf{A}\,L_e$$