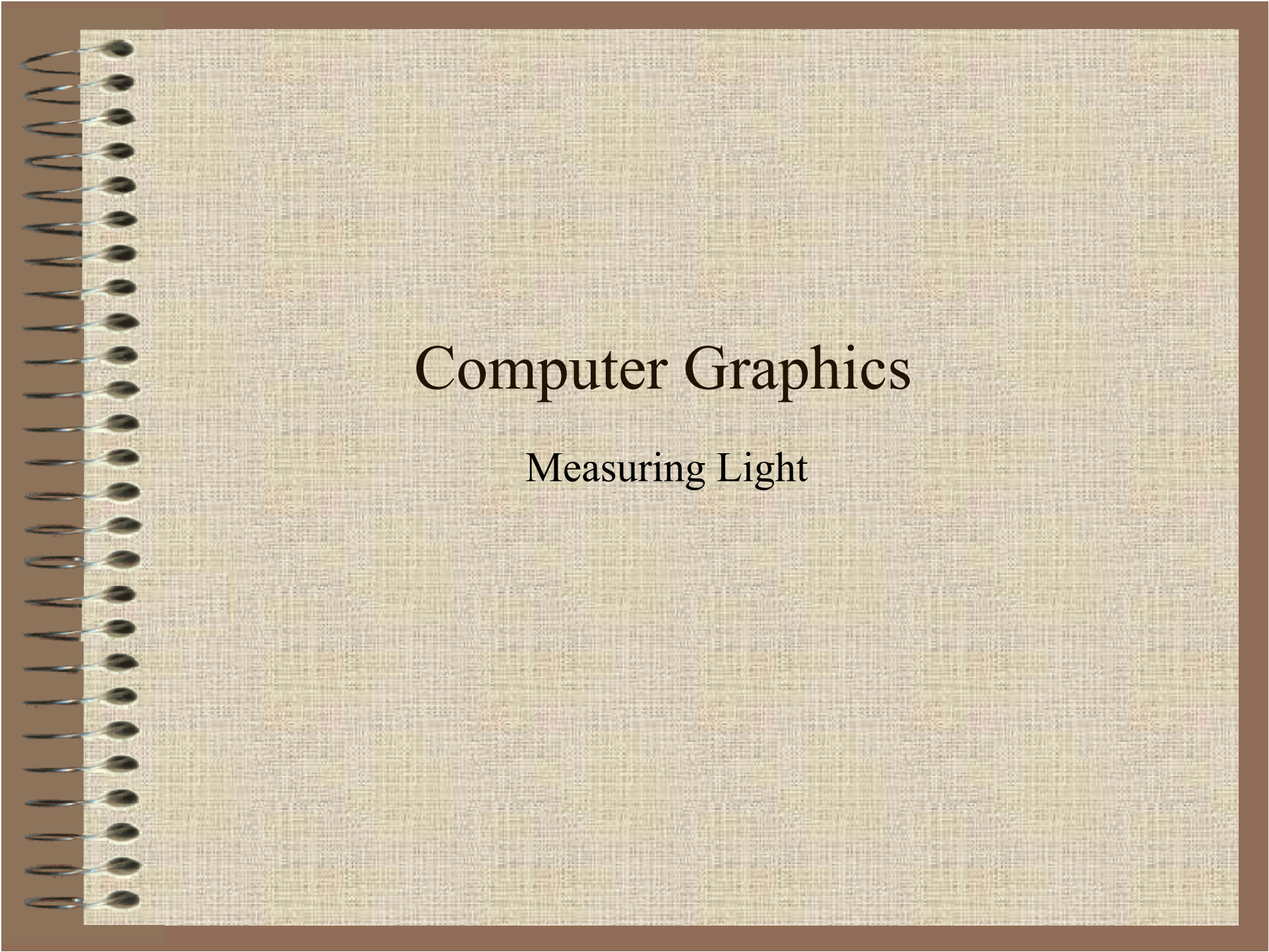




Computer Graphics

Measuring Light

Measuring Light

Radiometry is the measurement of optical radiation, which is electromagnetic radiation within the frequency range between 3×10^{11} and 3×10^{16} Hz. This range corresponds to wavelengths between 0.01 and 1000 micrometres (m m), and includes the regions commonly called the ultraviolet, the visible and the infrared. Two out of many typical units encountered are watts/m² and photons/sec-steradian.

Photometry is the measurement of light, which is defined as electromagnetic radiation which is detectable by the human eye. It is thus restricted to the wavelength range from about 360 to 830 nanometers (nm; 1000 nm = 1 µm). Photometry is just like radiometry except that everything is weighted by the spectral response of the eye. Visual photometry uses the eye as a comparison detector, while physical photometry uses either optical radiation detectors constructed to mimic the spectral response of the eye, or spectroradiometry coupled with appropriate calculations to do the eye response weighting. Typical photometric units include lumens, lux, candelas, and a host of other bizarre ones.

The only real difference between radiometry and photometry is that radiometry includes the entire optical radiation spectrum, while photometry is limited to the visible spectrum as defined by the response of the eye. In my forty years of experience, photometry is more difficult to understand, primarily because of the arcane terminology, but is fairly easy to do, because of the limited wavelength range. Radiometry, on the other hand, is conceptually somewhat simpler, but is far more difficult to actually do.

Source: Radiometry and photometry, by James M. Palmer

Radian and Steradian

- *"The radian is the plane angle between two radii of a circle that cuts off on the circumference an arc equal in length to the radius."*
- The abbreviation for the radian is **rad**. Since there are 2π radians in a circle, the conversion between degrees and radians is $1 \text{ rad} = (180/\pi) \text{ degrees}$.
- A solid angle extends the concept to three dimensions.
- *"One steradian (sr) is the solid angle that, having its vertex in the center of a sphere, cuts off an area on the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere."*
- The solid angle is thus ratio of the spherical area to the square of the radius. The spherical area is a projection of the object of interest onto a unit sphere, and the solid angle is the surface area of that projection. If we divide the surface area of a sphere by the square of its radius, we find that there are 4π steradians of solid angle in a sphere. One hemisphere has 2π steradians.

Source: Radiometry and photometry, by James M. Palmer

Radiometry

Radiometric units can be divided into two conceptual areas: those having to do with power or energy, and those that are geometric in nature. The first two are:

Energy is an SI derived unit, measured in joules (J).

Power is another SI derived unit. It is the derivative of energy with respect to time, dQ/dt , and the unit is the watt (W).

Even though we patronize the power utility, what we are actually buying is energy in watt-hours. Now we become more specific and incorporate power with the geometric quantities area and solid angle.

Irradiance (a.k.a. flux density) is another SI derived unit and is measured in W/m^2 . Irradiance is power per unit area incident from all directions in a hemisphere onto a surface that coincides with the base of that hemisphere. A similar quantity is **radiant exitance**, which is power per unit area leaving a surface into a hemisphere whose base is that surface.

Radiant intensity is another SI derived unit and is measured in W/sr . Intensity is power per unit solid angle.

Radiance is the last SI derived unit we need and is measured in $W/m^2\text{-sr}$. Radiance is power per unit projected area per unit solid angle. The integral of radiance over area and solid angle is power.

Measuring Light

QUANTITY	RADIOMETRIC	PHOTOMETRIC
power	watt (W)	lumen (lm)
power per unit area	W/m^2	$\text{lm/m}^2 = \text{lux (lx)}$
power per unit solid angle	W/sr	$\text{lm/sr} = \text{candela (cd)}$
power per area per solid angle	$\text{W/m}^2\text{-sr}$	$\text{lm/m}^2\text{-sr} = \text{cd/m}^2 = \text{nit}$

Source: Radiometry and photometry, by James M. Palmer

Measuring Light Radiometry

Radiometry units deal with measuring light power at all wavelengths.

Quantity	S.I Unit
Radiant energy	Joule (J)
Radiant flux	Watt (W)
Spectral power	Watt per meter (W/m)
Radiant Intensity	Watt per Steradians (W/Sr)
Spectral Intensity	Watt per Steradians per meter (W/Sr/m)
Radiance	Watt per steradian per square meter (W/Sr/m²)
Spectral radiance	Watt per steradian per meter cube (W/Sr/m³) or (W/Sr/m²/Hz)
Irradiance	Watt per square meter (W/m²)
Spectral Irradiance	Watt per meter cube (W/m³) or (W/m²/Hz)
Radiance exitance / Radiant emittance	Watt per square meter
Spectral radiant exitance/ Spectral radiant emittance	Watt per meter cube (W/ m³) or Watt per square meter per hertz (W/m²/Hz)
Radiosity	Watt per square meter (W/m²)
Radiant exposure	Joule per square meter (J/m²)
Radiant energy	Joule per meter cube (J/m³)

Measuring Light Photometry

Photometry units deal with measurement of visible light wavelength

Quantity	S.I Unit
Radiant energy	Joule (J)
Radiant flux	Watt (W)
Spectral power	Watt per meter (W/m)
Radiant Intensity	Watt per Steradians (W/Sr)
Spectral Intensity	Watt per Steradians per meter (W/Sr/m)
Radiance	Watt per steradian per square meter (W/Sr/m²)
Spectral radiance	Watt per steradian per meter cube (W/Sr/m³) or (W/Sr/m²/Hz)
Irradiance	Watt per square meter (W/m²)
Spectral Irradiance	Watt per meter cube (W/m³) or (W/m²/Hz)
Radiance exitance / Radiant emittance	Watt per square meter
Spectral radiant exitance/ Spectral radiant emittance	Watt per meter cube (W/ m³) or Watt per square meter per hertz (W/m²/Hz)
Radiosity	Watt per square meter (W/m²)
Radiant exposure	Joule per square meter (J/m²)
Radiant energy	Joule per meter cube (J/m³)

Measuring Light

- **Candela (cd)**

Unit of luminous intensity of a light source in a specific direction. Also called *candle*. Technically, the radiation intensity in a perpendicular direction of a surface of $1/600000$ square metre of a black body at the temperature of solidification platinum under a pressure of 101,325 newtons per square metre.

- **Footcandle (fc or ftc)**

Unit of light intensity, measured in lumens per square foot. The brightness of one candle at a distance of one foot. Approximately 10.7639 lux.

- **Lumen (lm)**

Unit of light flow or luminous flux. The output of artificial lights can be measured in lumens.

- **Lux (lx)**

Unit of illumination equal to one lumen per square metre. The metric equivalent of foot-candles (one lux equals 0.0929 footcandles). Also called metre-candle.

Measuring Light

Illuminance:

1 metre-candle = 1 lux

1 phot = $1 \text{ lm/cm}^2 = 10^4 \text{ lux}$

1 foot-candle = $1 \text{ lumen/ft}^2 = 10.76 \text{ lux}$

1 milliphot = 10 lux

Luminance:

Here we have two classes of units. The first is conventional, easily related to the SI unit, the cd/m^2 (nit).

1 stilb = $1 \text{ cd/cm}^2 = 10^4 \text{ cd/m}^2 = 10^4 \text{ nit}$

1 $\text{cd/ft}^2 = 10.76 \text{ cd/m}^2 = 10.76 \text{ nit}$

The second class was designed to "simplify" characterization of light reflected from diffuse surfaces by including in the definitions the concept of a perfect diffuse reflector ([lambertian](#), reflectance $r = 1$). If one unit of illuminance falls upon this hypothetical reflector, then 1 unit of luminance is reflected. The perfect diffuse reflector emits $1/\pi$ units of luminance per unit illuminance. If the reflectance is r , then the luminance is r times the illuminance. Consequently, these units all have a factor of $(1/\pi)$ built in.

1 lambert = $(1/\pi) \text{ cd/cm}^2 = (10^4/\pi) \text{ cd/m}^2$

1 apostilb = $(1/\pi) \text{ cd/m}^2$

1 foot-lambert = $(1/\pi) \text{ cd/ft}^2 = 3.426 \text{ cd/m}^2$

1 millilambert = $(10/\pi) \text{ cd/m}^2$

1 skot = 1 milliblondel = $(10^{-3}/\pi) \text{ cd/m}^2$