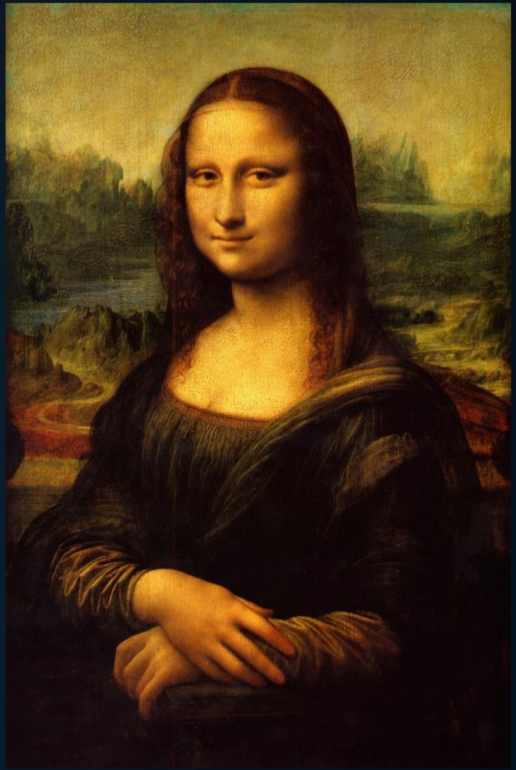
INFOGR – Computer Graphics

J. Bikker - April-July 2016 - Lecture 10: “Shading Models”

Welcome!

Today's Agenda:

- Introduction
- Light Transport
- Materials
- Sensors
- Shading



Introduction

The Quest for (Photo-)Realism

- Objective in modern games
- Important improvements when using ray tracing

The core algorithms of ray tracing and rasterization model light transport (with or without visibility):

$$L(p \rightarrow r) = L_e(p \rightarrow r) + \sum_{i=1}^{N_L} L(q_i \rightarrow p)\, f_r\,(q_i \rightarrow p \rightarrow r)\, G(q_i \leftrightarrow p)$$

Other factors:

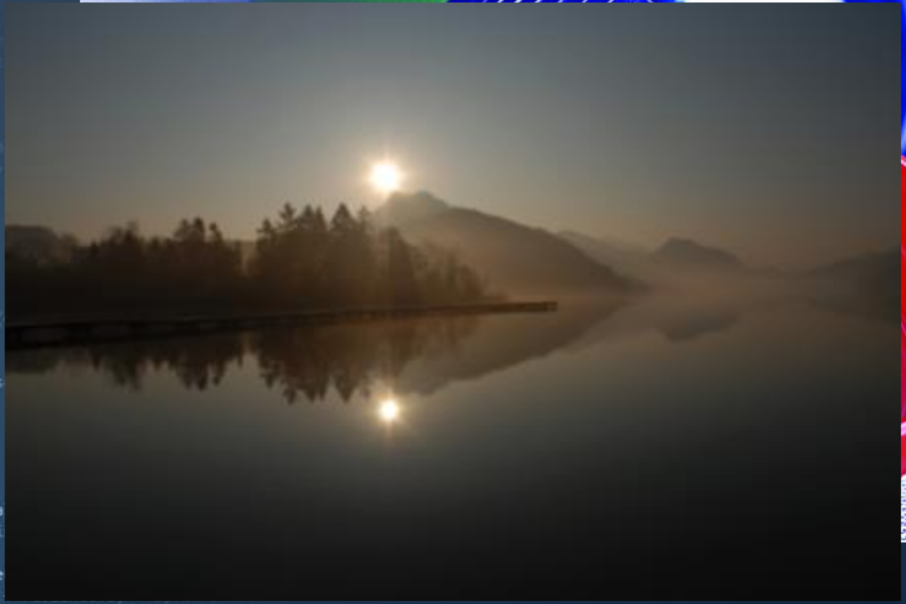
- Material interactions
- Light models
- Sensor models

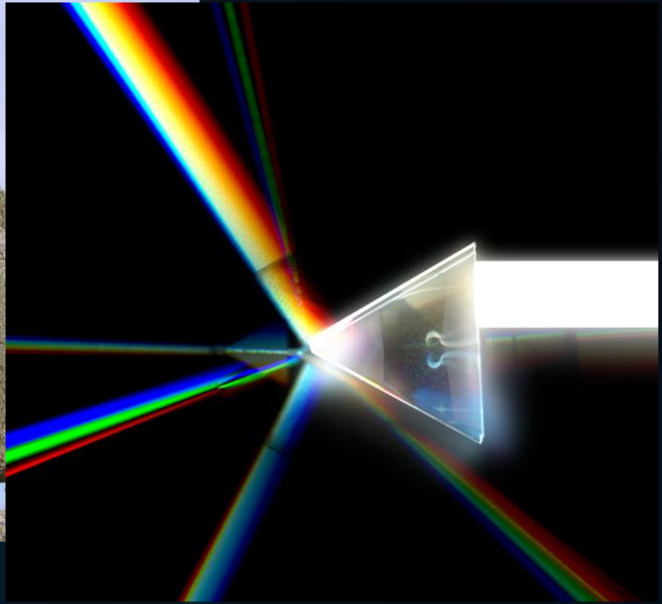
Introduction

Material interactions

Introduction

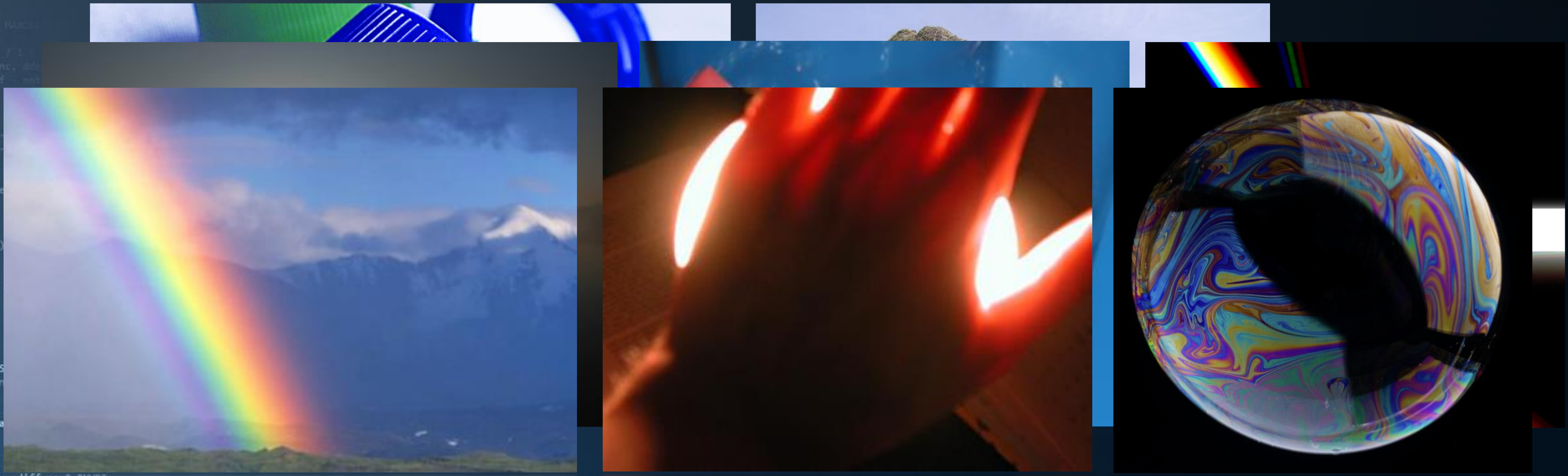
Material interactions





Introduction

Material interactions



Introduction

Light models

Introduction

Light models

crepuscular rays

Introduction

Light models

anticrepuscular rays

Introduction

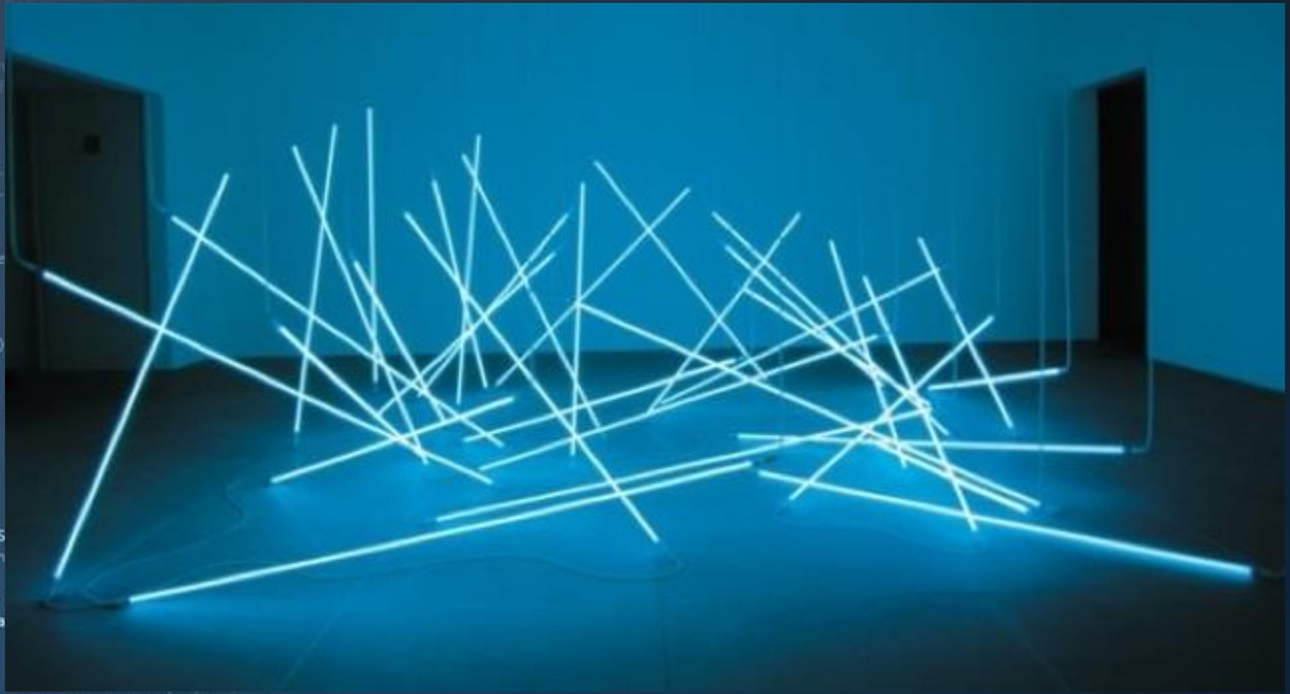
Light models

Introduction

Light models

Introduction

Light models

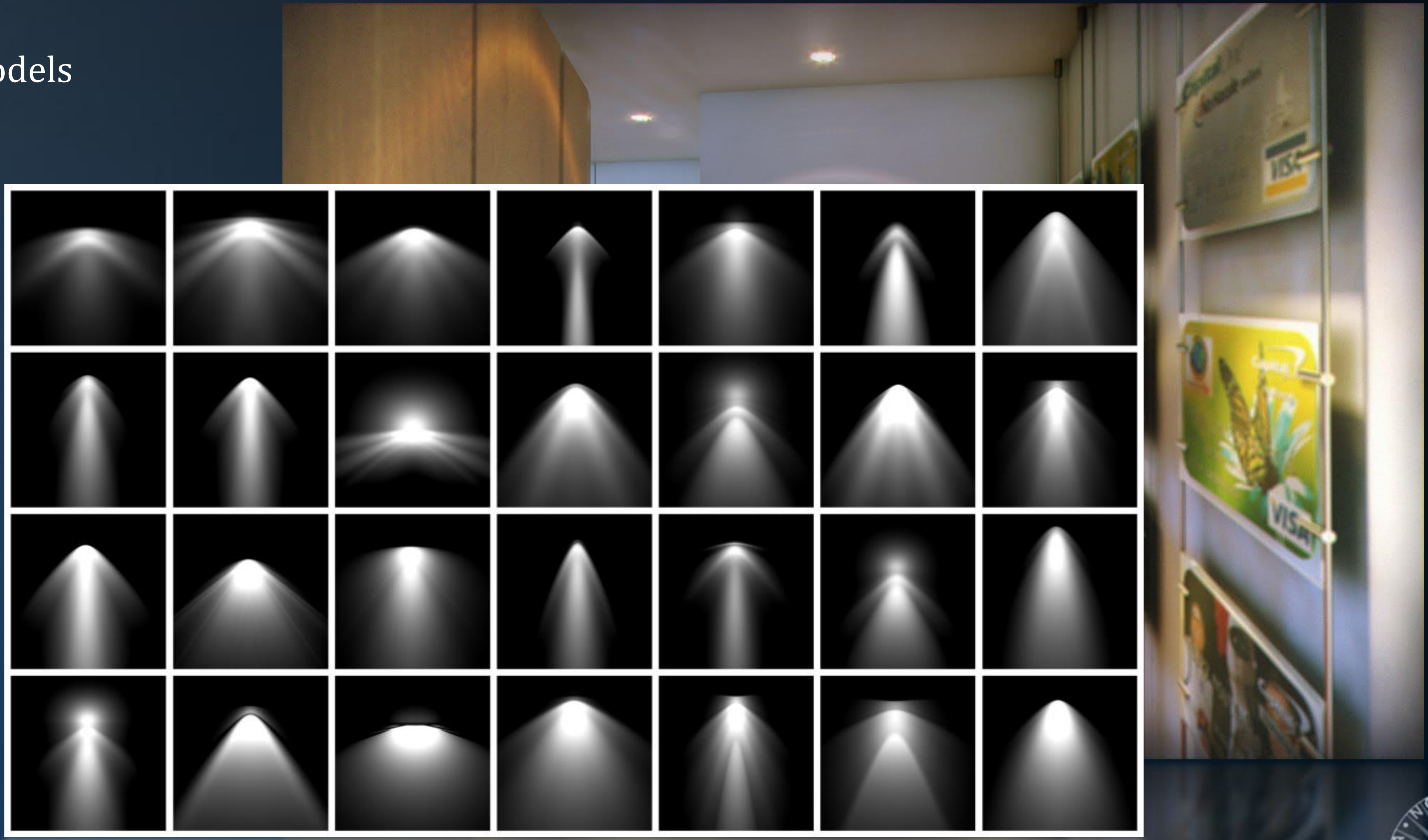


Introduction

Light models

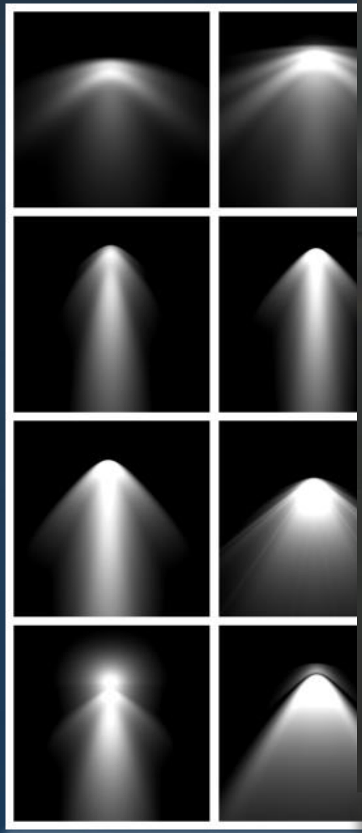
Introduction

Light models



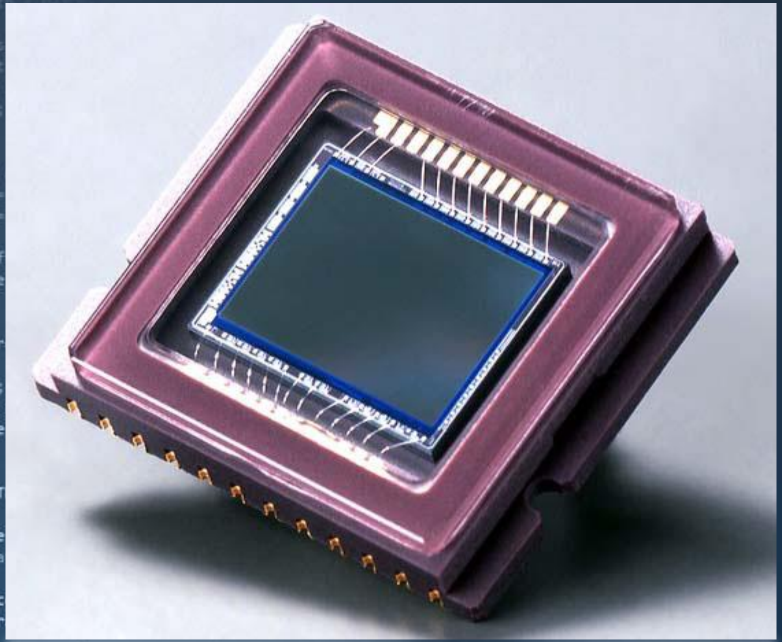
Introduction

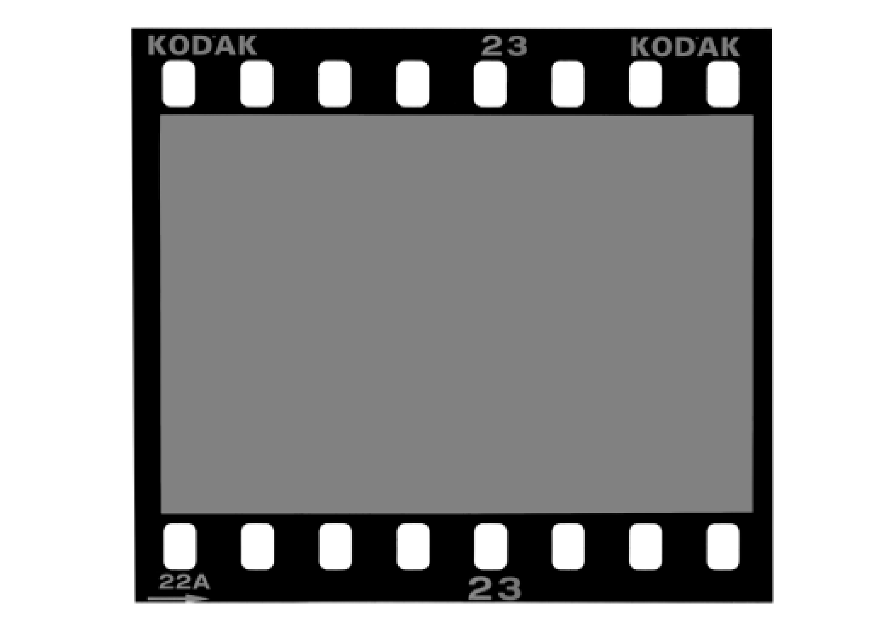
Light models

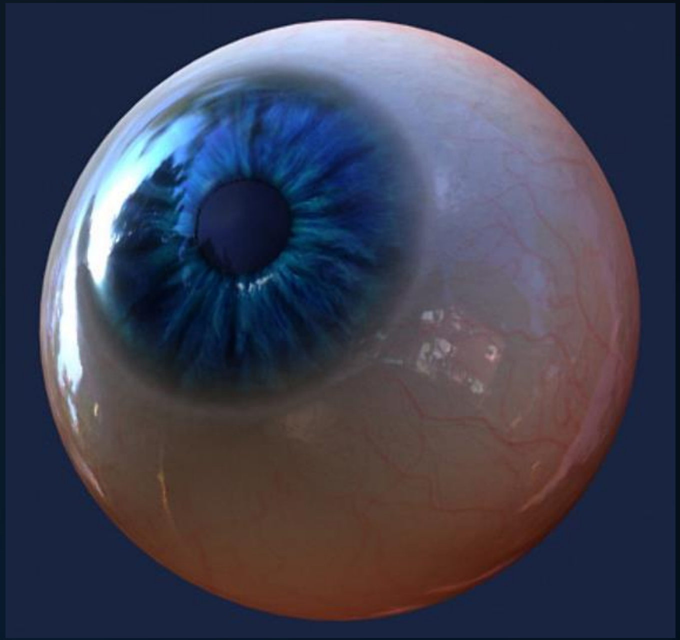


Introduction

Sensor models







Introduction

1. Light is emitted by a light source
2. Light interacts with the scene
3. Light is absorbed by a sensor

Absorption

Scattering

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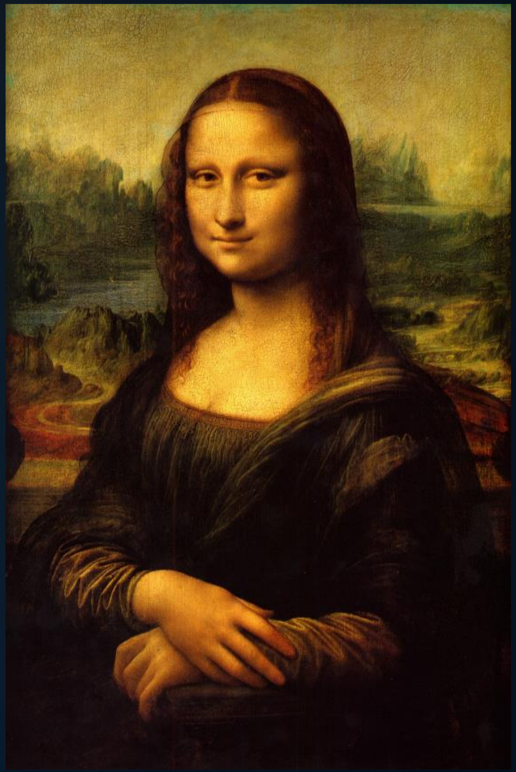
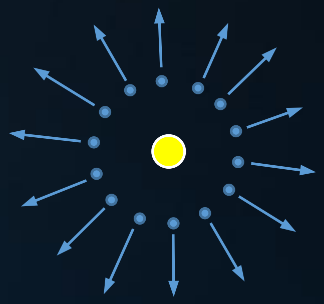


Light Transport

Light Transport Quantities

Radiant flux - Φ :

“Radiant energy emitted, reflected, transmitted or received, per unit time.”



Units: watts = joules per second

$$W = J\,s^{-1}\,.$$

Simplified particle analogy:
number of photons.

Note: photon energy depends on electromagnetic wavelength: $E = \frac{hc}{\lambda}$*, where h is Planck’s constant, c is the speed of light, and* λ *is wavelength. At* $\lambda = 550\text{nm}$ *(yellow), a single photon carries* $3.6 * 10^{-19}$ *joules.*

Light Transport

Light Transport Quantities

In a vacuum, radiant flux emitted by a point light source remains constant over distance:

A point light emitting 100W delivers 100W to the surface of a sphere of radius r around the light. This sphere has an area of $4\pi r^2$; energy per surface area thus decreases by $1/r^2$.

In terms of photons: the density of the photon distribution decreases by $1/r^2$.

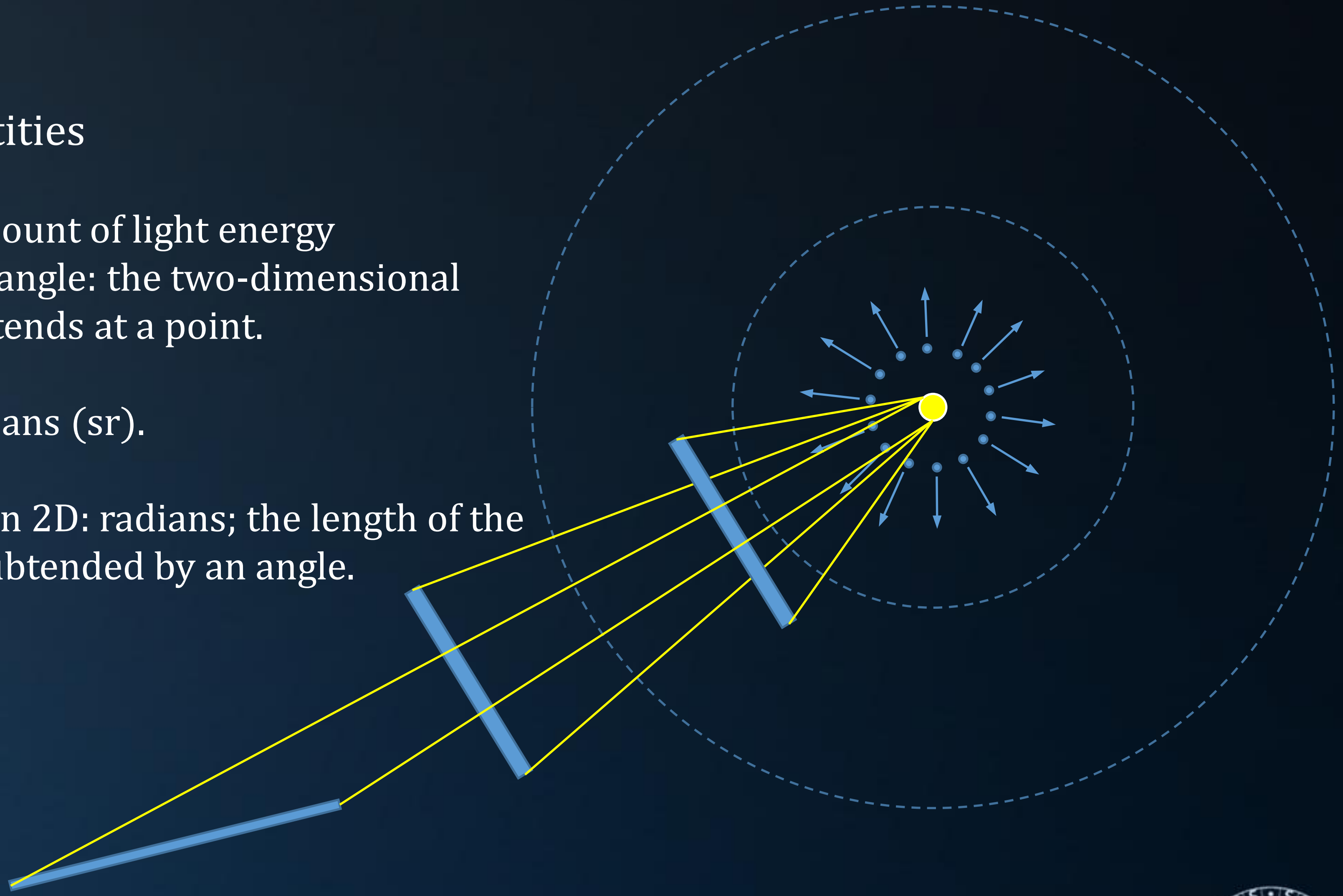
Light Transport

Light Transport Quantities

A surface receives an amount of light energy proportional to its solid angle: the two-dimensional space that an object subtends at a point.

Solid angle units: steradians (sr).

Corresponding concept in 2D: radians; the length of the arc on the unit sphere subtended by an angle.



Light Transport

Light Transport Quantities

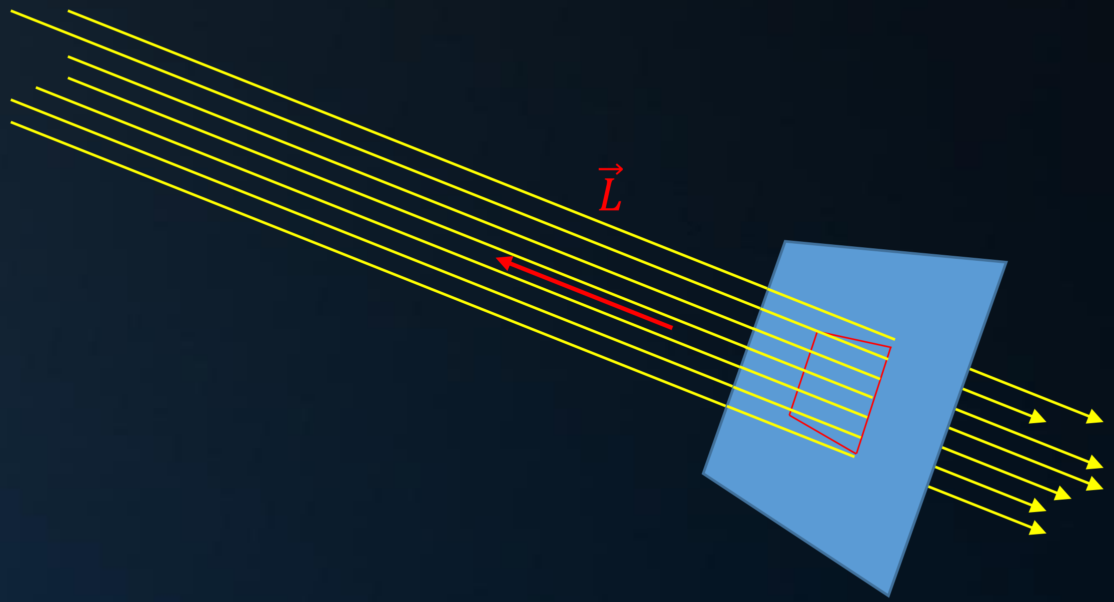
Radiance - L :

“The power of electromagnetic radiation emitted, reflected, transmitted or received per unit projected area per unit solid angle.”

Units: $W sr^{-1} m^{-2}$

Simplified particle analogy:
Amount of particles passing through a pipe with unit diameter, per unit time.

Note: radiance is a continuous value:
while flux at a point is 0 (since both area and solid angle are 0),
we can still define flux per area per solid angle for that point.



Light Transport

Light Transport Quantities

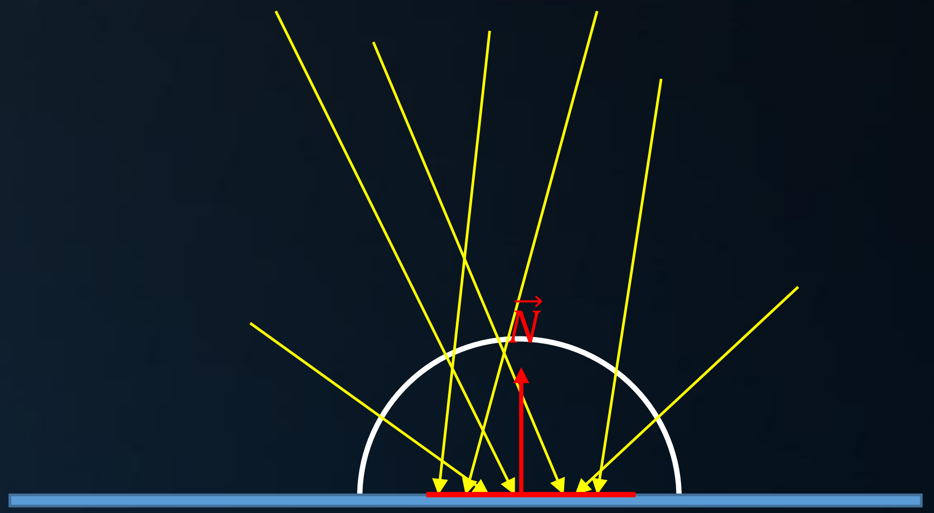
Irradiance - E :

"The power of electromagnetic radiation per unit area incident on a surface."

Units: Watts per m^2 = joules per second per m^2

$$Wm^{-2} = Jm^{-2}s^{-1}\ .$$

Simplified particle analogy:
number of photons arriving per unit area per unit time, from all directions.

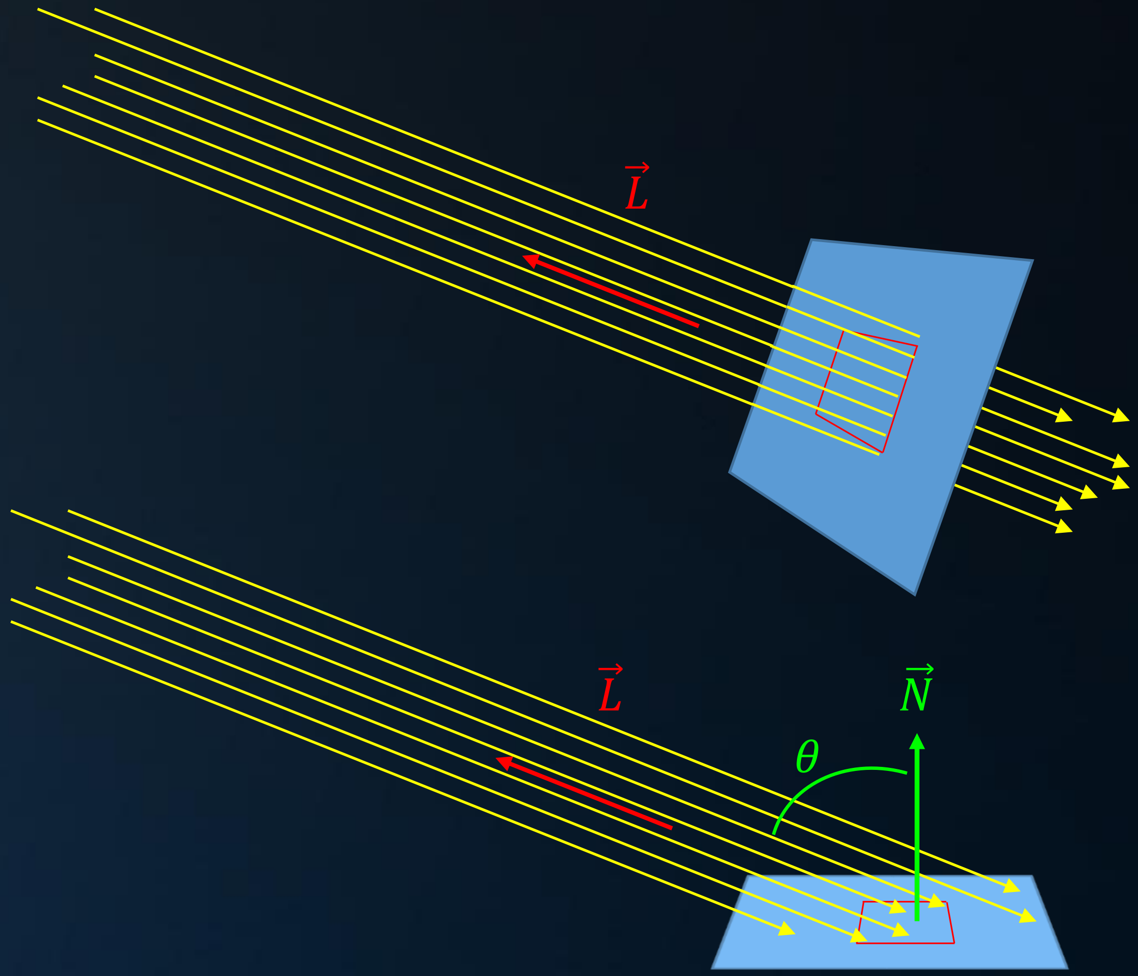


Light Transport

Light Transport Quantities

Converting radiance to irradiance:

$$E = L\cos\theta$$

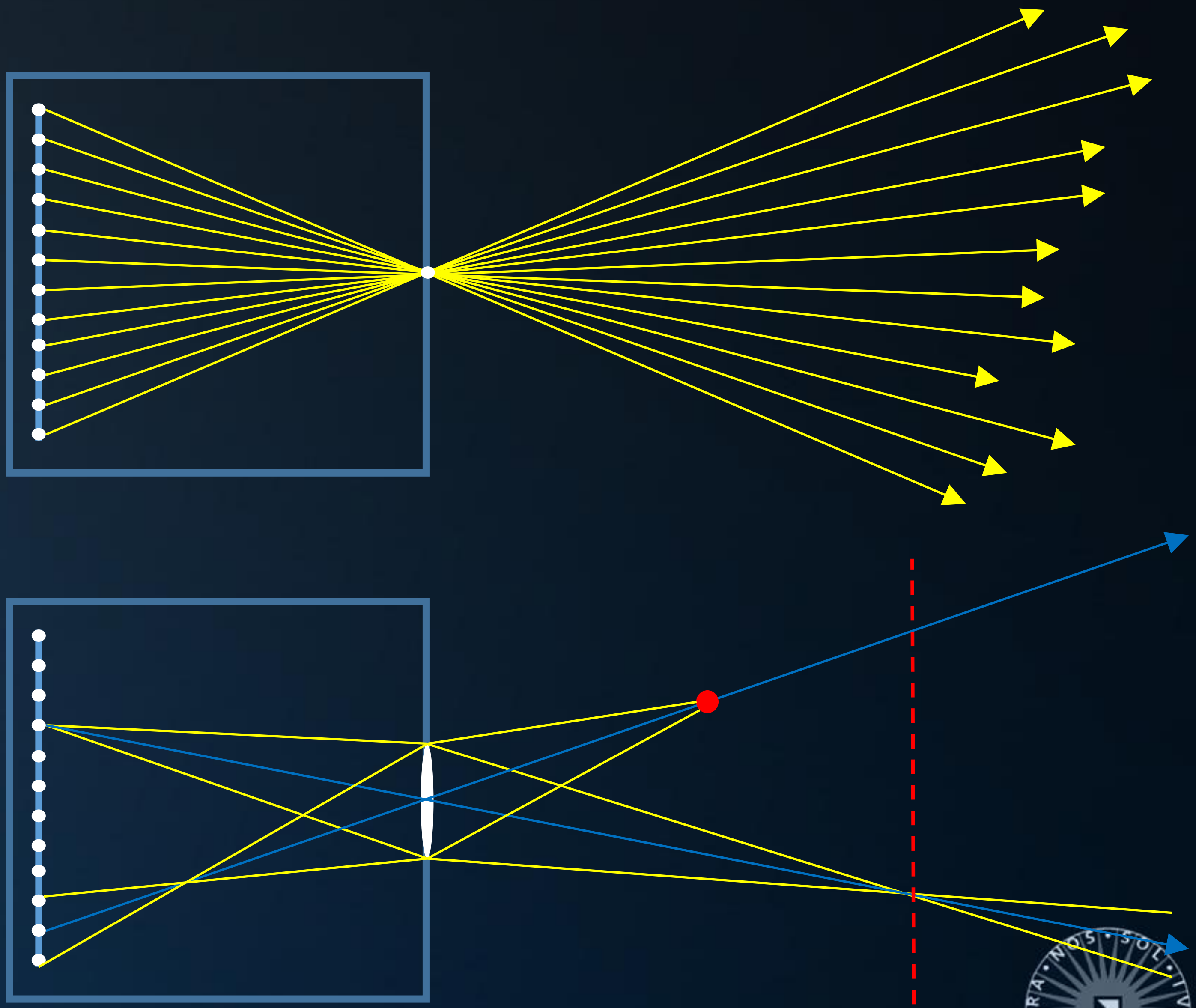


Light Transport

Pinhole Camera

A camera should not accept light from all directions for a particular pixel on the film. A pinhole ensures that only a single direction is sampled.

In the real world, an aperture with a lens is used to limit directions to a small range, but only on the focal plane.



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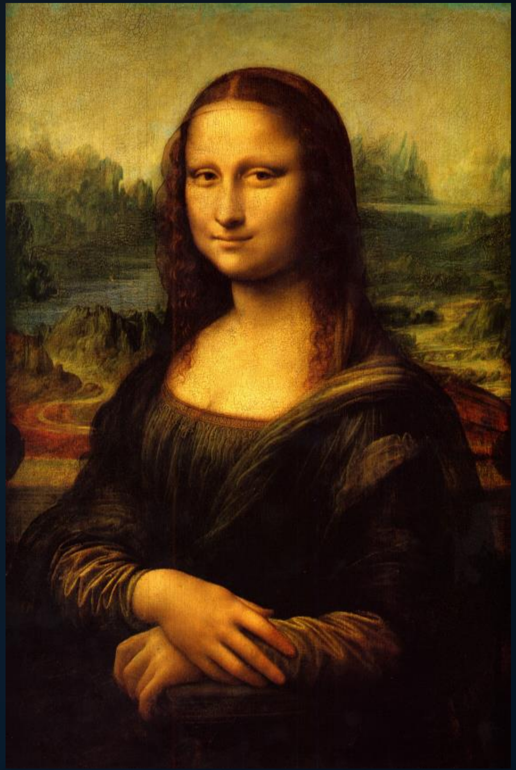


Materials

Material properties:

- Texture + detail texture
- Shader
- Normal map
- Specular map
- Color
- …

Used to simulate the interaction of light with a material.

Interaction:

- Absorption
- Scattering



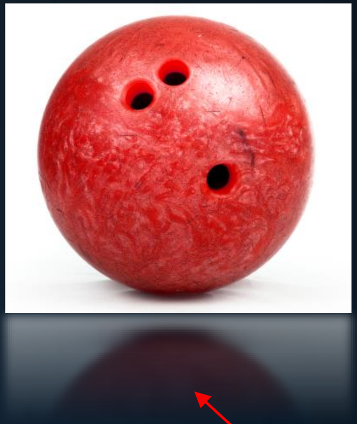

Materials

Absorption:

Happens on ‘optical discontinuities’.

Light energy is converted in other forms of energy (typically heat), and disappears from our simulation.

Materials typically absorb light with a certain wavelength, altering the color of the scattered light. This is how we perceive material color.



Materials

Scattering

Happens on ‘optical discontinuities’.

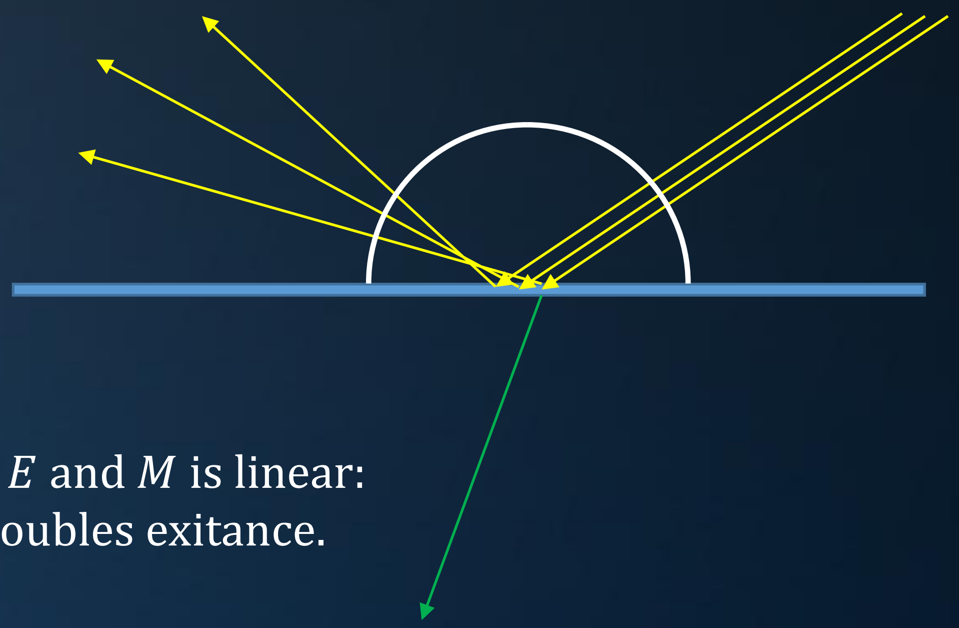
Scattering causes light to change direction. Note that the amount of energy does not change due to scattering.

Light leaving the hemisphere can never exceed light entering the hemisphere, unless the material is emissive.

Materials

Light / surface interaction

In: irradiance (E), from all directions over the hemisphere.
Out: exitance (M), in all directions over the hemisphere.



The relation between E and M is linear: doubling irradiance doubles exitance.

$\frac{M}{E}$ must be in the range 0..1.

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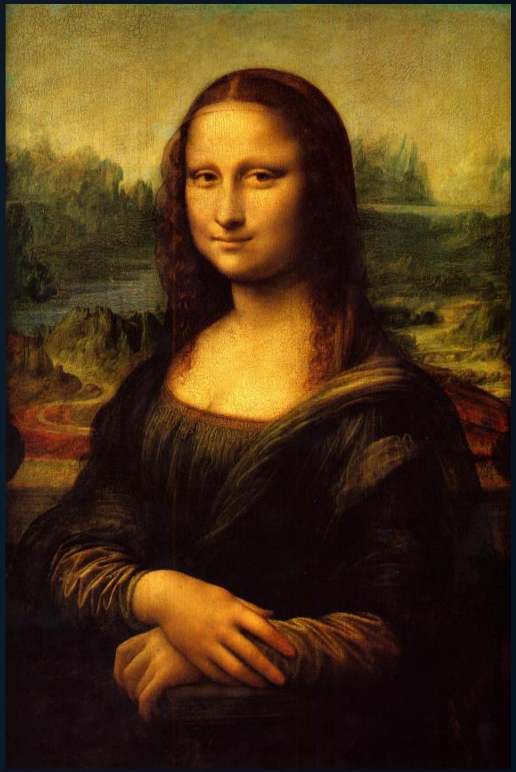
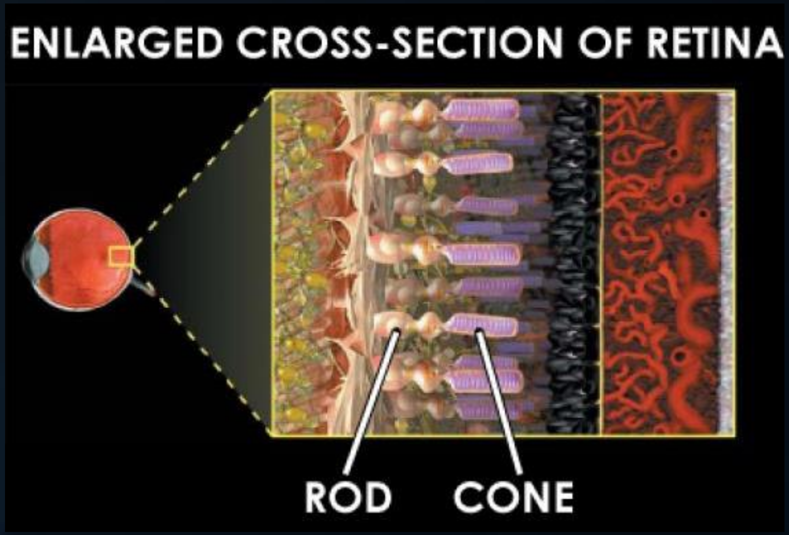


Sensors

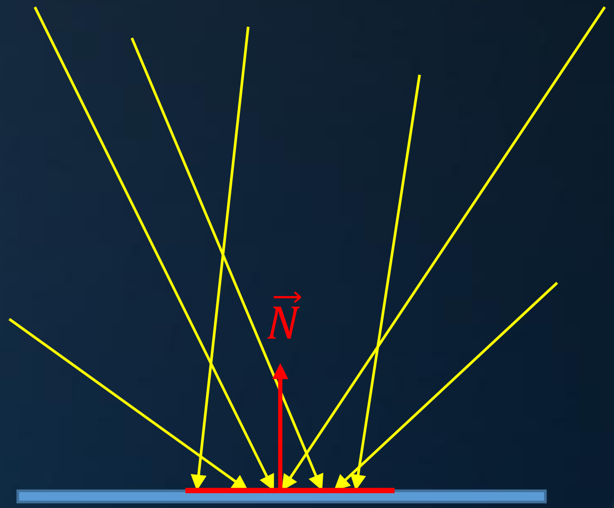


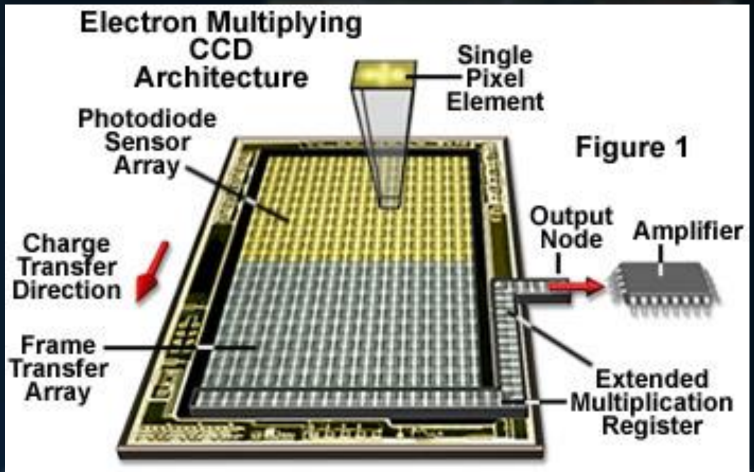
Sensors typically consists of many small sensors:

- Rods and cones in the eye
- Dye particles in the film
- Pixel elements in a CCD
- A ray in a ray tracer
- A fragment in a rasterizer

Note that we cannot use irradiance to generate an image:

irradiance is a measure for light arriving from all directions.

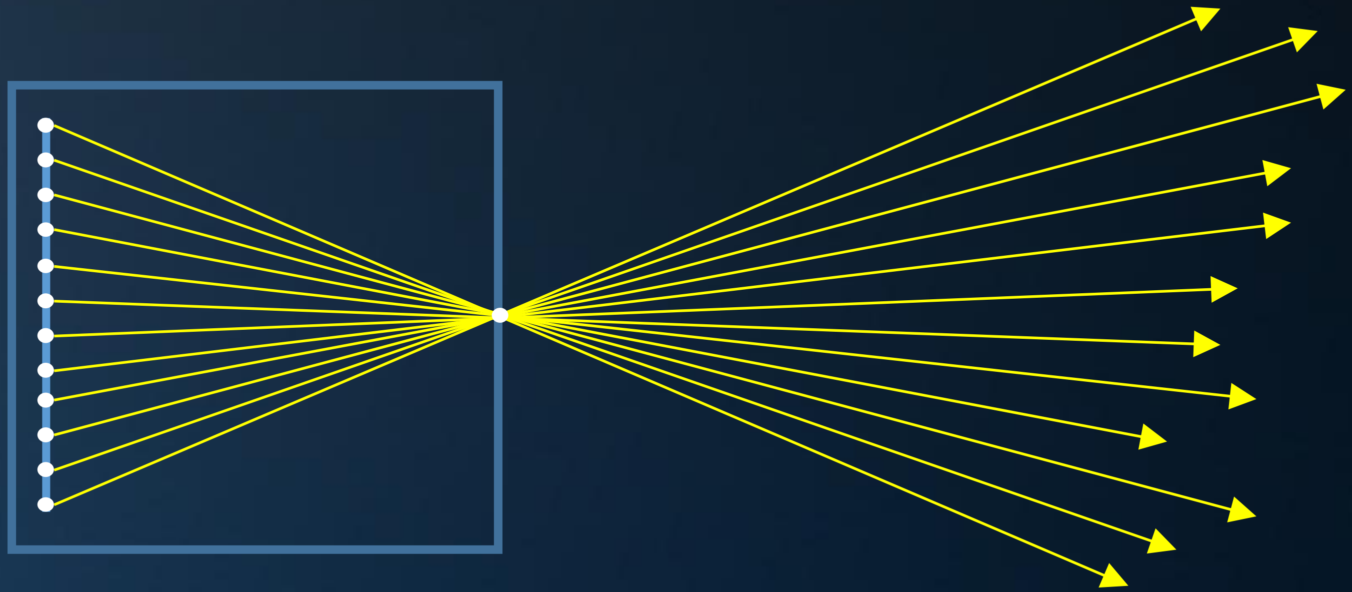




Sensors

Pinhole camera

To capture light from a specific direction, we use a camera with a small opening (the aperture), so that each sensor can ‘see’ a small set of incoming directions.



Sensors

Radiance

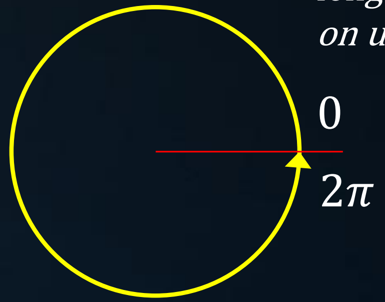
Using a pinhole camera, the sensors become directionally specific:

they average light over a small area, and a small set of incoming directions.

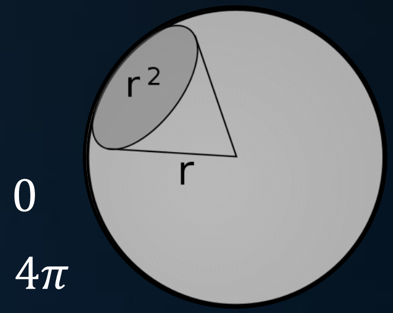
Recall that this is referred to as *radiance (L)*:

The density of light flow per area per incoming direction, in $W\ m^{-2} sr^{-1} s^{-1}$.

Radians:
length of arc on unit circle



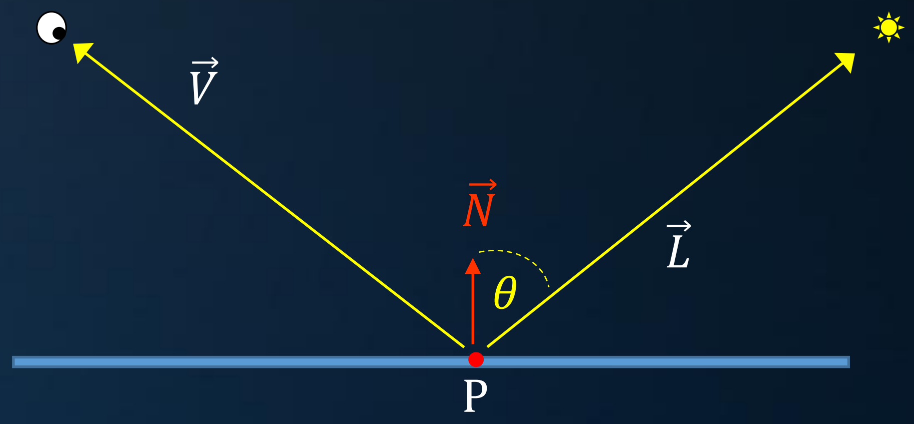
Steradians:
area of surface on unit sphere



Sensors

Summing it up:

- Light arrives from all light sources on point P;
- The energy flow per unit area, perpendicular to $\vec{L}$ is projected on a surface perpendicular to $\vec{N}$. This is *irradiance,* or: E.
- Exitant light M is scattered over all directions on the hemisphere.
- Light scattered towards the eye arrives at a sensor.
- The sensor detects radiance: light from a specific set of directions.



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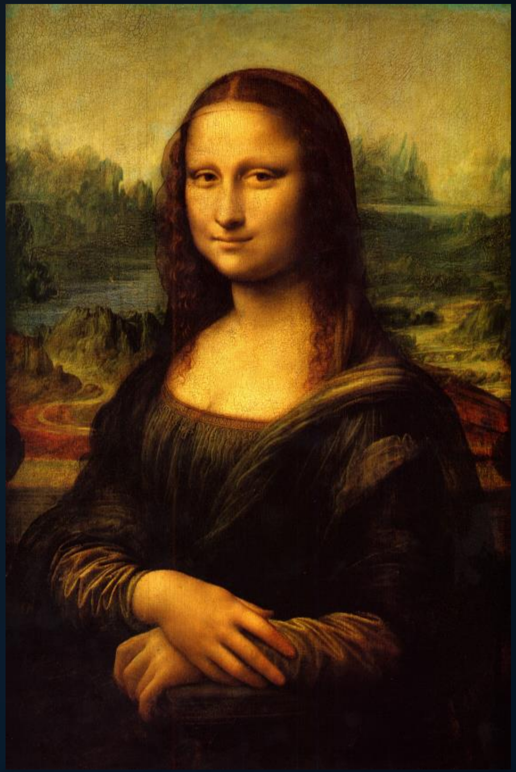
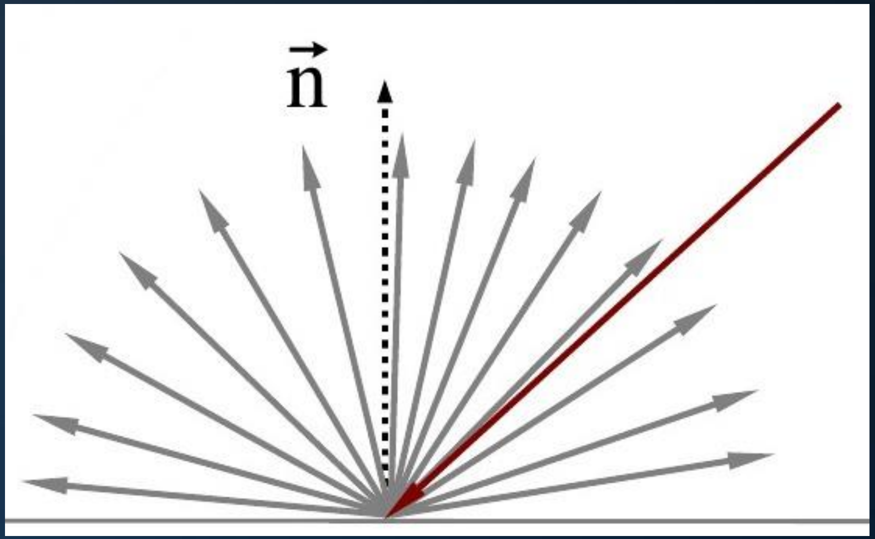


Shading

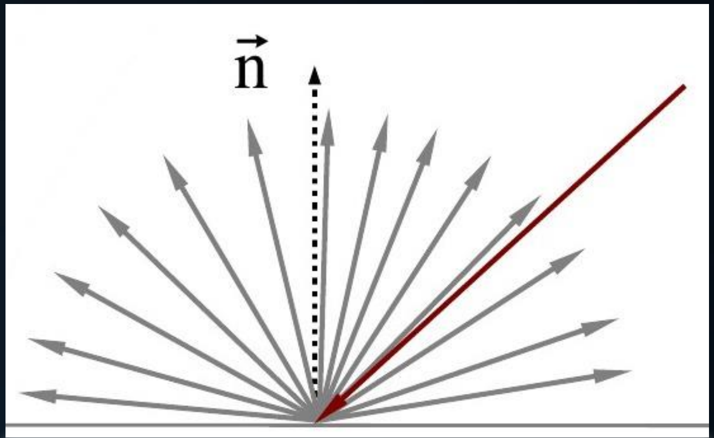
Definition

Shading: the process of using an equation to compute the outgoing radiance along the view ray $\vec{V}$, based on material properties and light sources.



Diffuse or *Lambert* BRDF, also called “N dot L shading”

Shading



Lambert shading model

The diffuse shading model is:

$$M_{diff} = \frac{c_{diff}}{\pi} L \, \overline{cos} \theta_i$$

This takes into account:

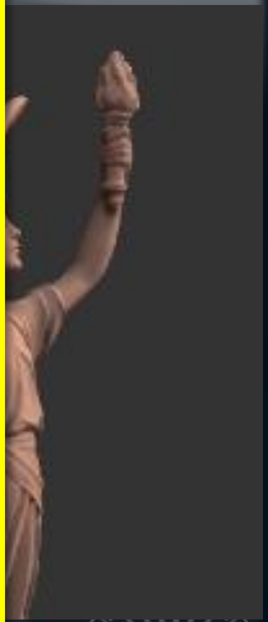
- Projection of the direction of the incoming light on the normal;
- Absorption due to material color c_{diff}.

Distance attenuation is represented in L.

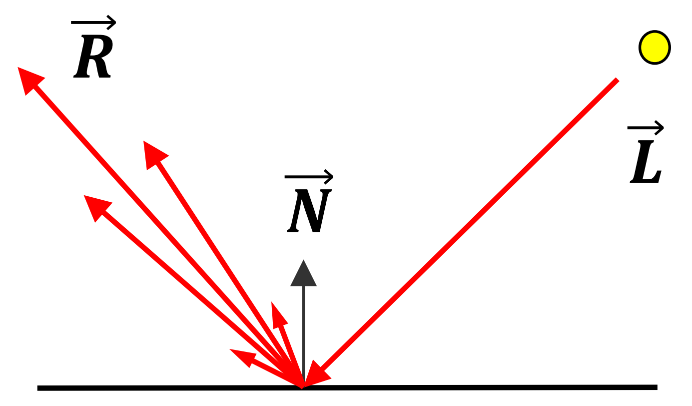
Practical implementation:

```
dist=light.pos-fragment.pos;
L=normalize(light.pos-fragment.pos);
N=fragment_normal; // interpolated
radiance=light.color/(dist*dist);
irradiance=radiance*dot(N,L);
M=(material.color / PI)*irradiance;
```

The reflected energy M is what the camera will receive via the ray arriving at the fragment (i.e., the 'color' of the fragment).



Shading



Phong shading model

The Phong shading model combines a diffuse reflection with a glossy one, and adds an ambient factor.

$$M_{phong} = c_{ambient} + c_{diff}(\vec{N} \cdot \vec{L})L_{diff} + c_{spec}(\vec{V} \cdot \vec{R})^{S}L_{spec}$$

The Phong shading model is an ‘empirical model’, and has many problems:

- It doesn’t guarantee that $M \leq E$;
- It doesn’t take irradiance as input;
- It requires many (unnatural) parameters;
- That ambient factor…

Shading

BRDF – Bidirectional Reflectance Distribution Function

Defines the relation between *irradiance* and *radiance*.

Or, more accurately:

The BRDF represents the ratio of reflected radiance exiting along $\vec{V}$, to the irradiance incident on the surface from direction $\vec{L}$.

Note that the BRDF takes two parameters: an incoming and an outgoing direction.

$$f_r(\vec{L},\vec{V}) = \frac{dL_{reflected}(\vec{V})}{dE_{incoming}(\vec{L})}$$

Shading

BRDF – Bidirectional Reflectance Distribution Function

Diffuse BRDF:

$$f_r(\vec{L},\vec{V}) = \frac{dL_{reflected}(\vec{V})}{dE_{incoming}(\vec{L})} = \frac{material\ color}{\pi}$$

where $E_{incoming}(\vec{L})$ is irradiance arriving from the light source, i.e. light color, times attenuation, times N dot L.

The diffuse BRDF scatters light equally in all directions. $\vec{V}$ *is not used in the equation*. The diffuse BRDF is *view independent*.

Also note that $\vec{N}$ and $\vec{L}$ do not occur in this equation: N dot L is simply used to convert from radiance to irradiance.

Practical use of the BRDF:

Input for a BRDF is irradiance. This means that we already have processed attenuation and N dot L.

The fragment color, using a BRDF and a point light at distance r is thus:

$$M = f_r(\vec{L},\vec{V})\ \overline{\cos\theta_i}\ \frac{light\ color}{r^2}$$

Shading

BRDF – Bidirectional Reflectance Distribution Function

Phong BRDF:

$$f_r(\vec{L},\vec{V}) = \frac{dL_{reflected}(\vec{V})}{dE_{incoming}(\vec{L})} = color + color\,\overline{\cos\alpha}^m$$

Where α is the angle between $\vec{V}$ and $\vec{R}$, $\vec{R}$ is $\vec{L}$ reflected in $\vec{N}$, and m is the Phong exponent.

Note that the division by π is missing; it doesn’t make sense for the specular reflection…

Also note that the ambient color is missing: this factor is constant and does not depend on irradiance.

Shading

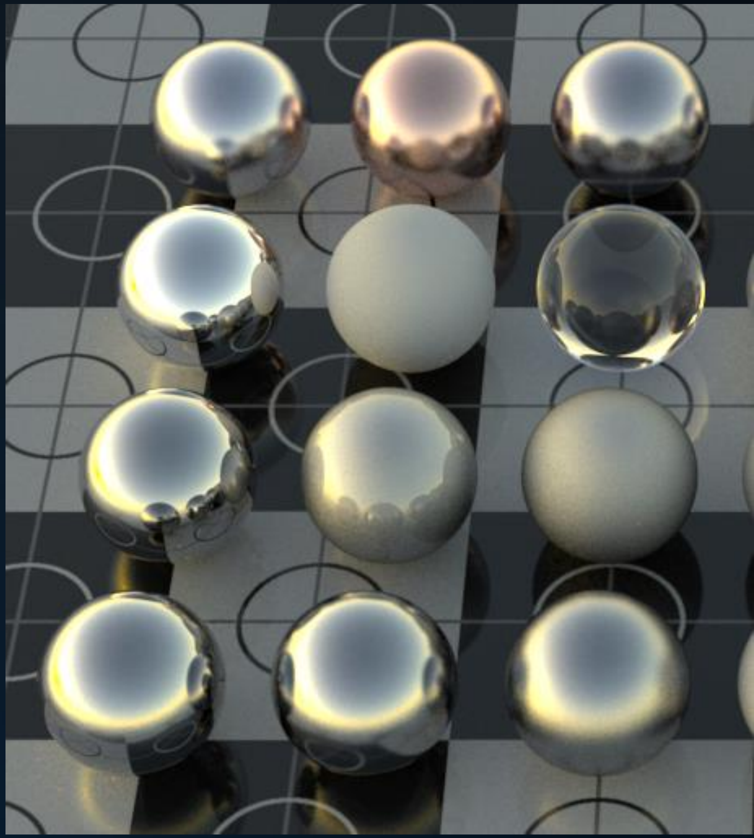
BRDF – Bidirectional Reflectance Distribution Function

BRDFs formalize the interaction of light / surface interaction, and allow us to do so in a physically correct way.

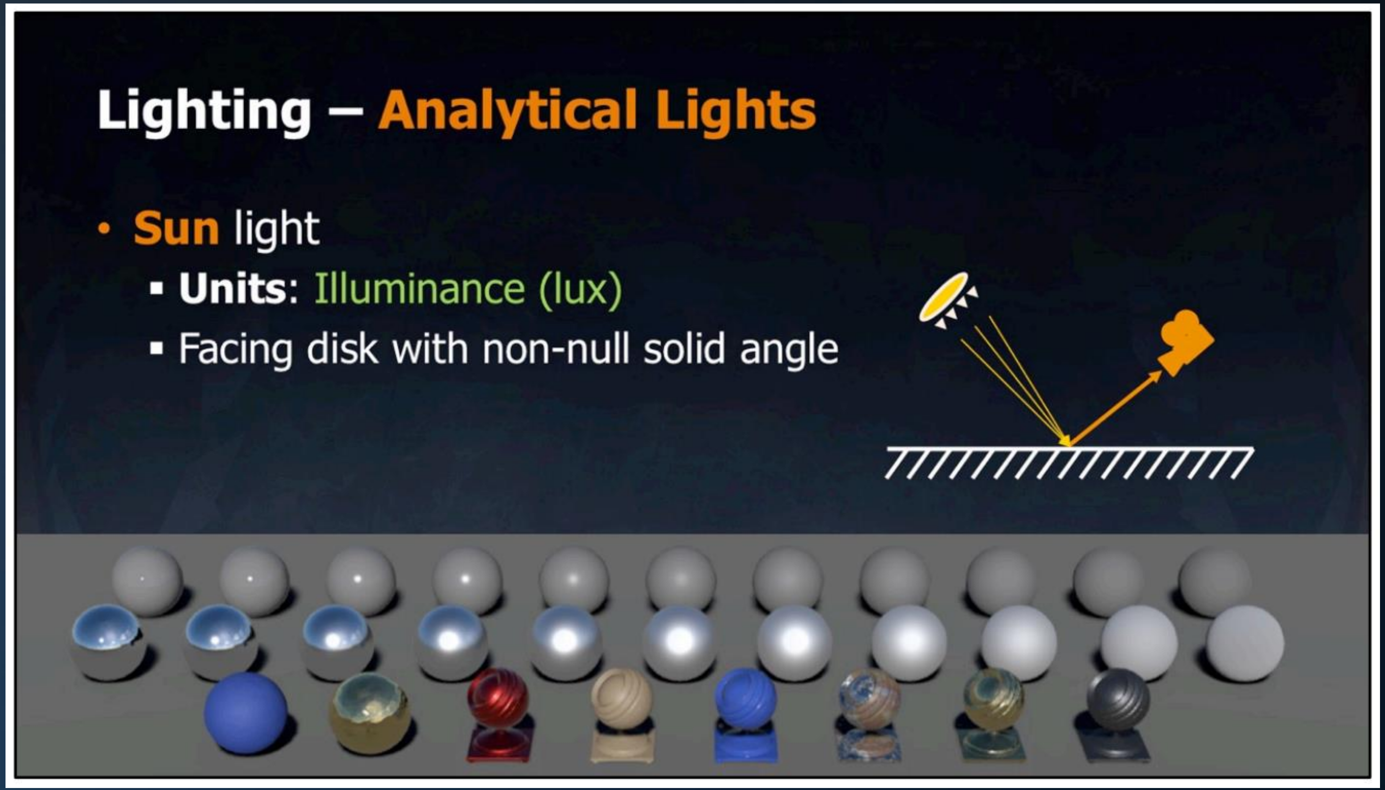
Games are switching to physically based models rapidly:

- To increase realism;
- To reduce the number of parameters in shaders;
- To have uniform shaders for varying lighting conditions.

More on this in Advanced Graphics!



Shading



"Moving Frostbite to PBR"
http://www.frostbite.com/wp-content/uploads/2014/11/s2014_pbs_frostbite_slides.pdf

Shading

“Lighting Killzone : Shadow Fall”
http://www.guerrilla-games.com/presentations/Drobot_Lighting_of_Killzone_Shadow_Fall.pdf

Shading

“Physically Based Shading in Unity”
http://aras-p.info/texts/files/201403-GDC_UnityPhysicallyBasedShading_notes.pdf

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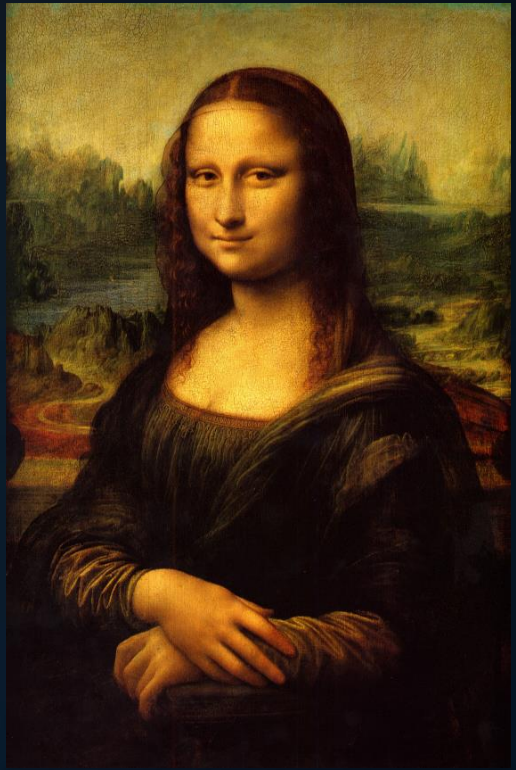

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END of "Shading Models"

next lecture: "Visibility"