Ray Tracing in Entertainment Industry

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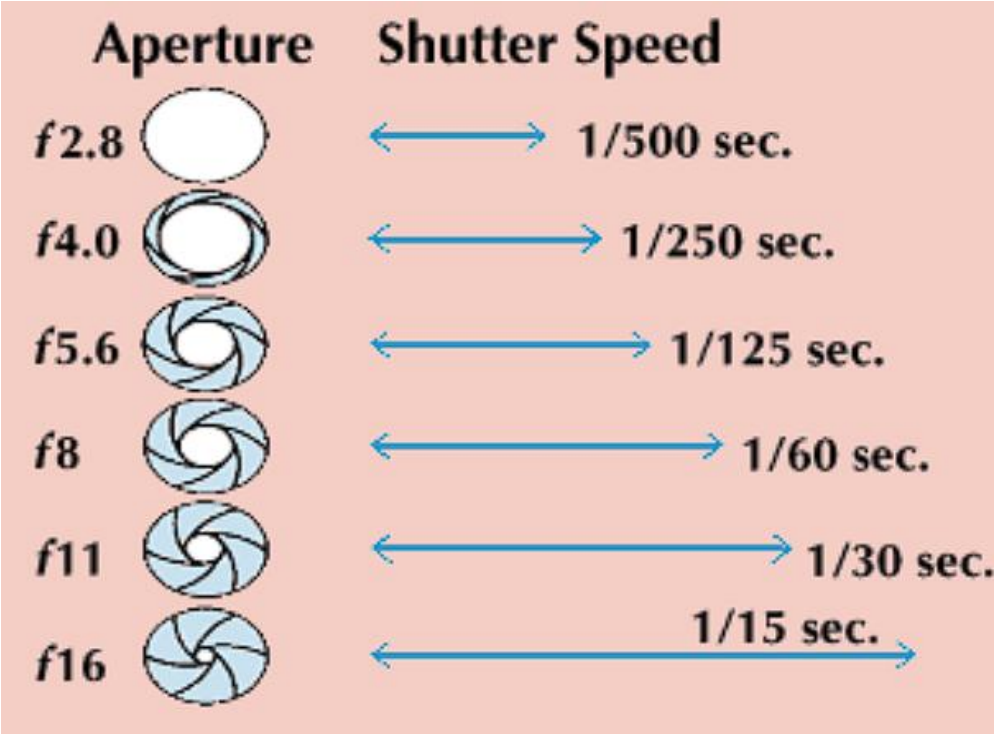
Week 2
Ray tracing components

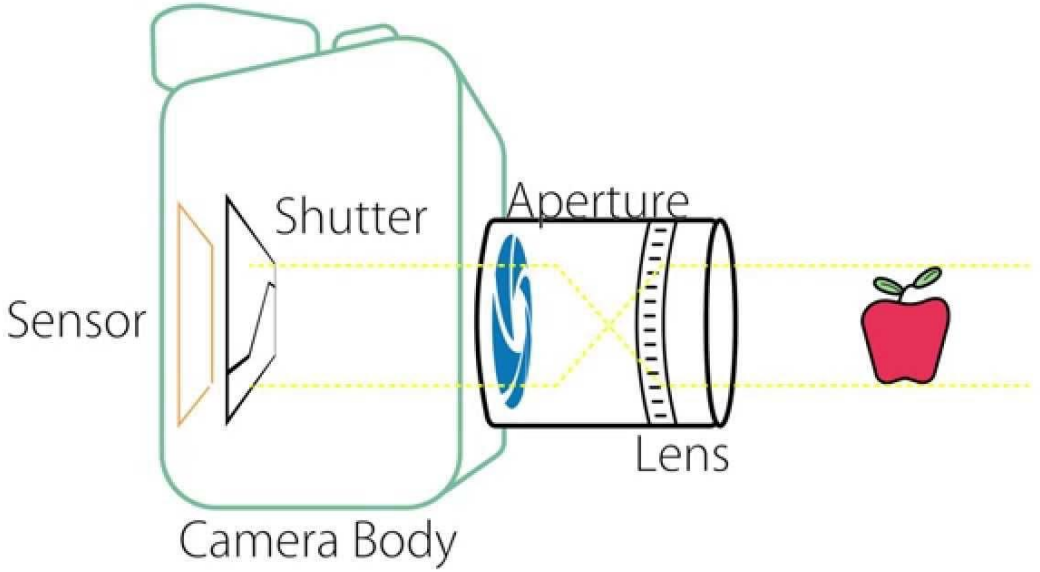
Ray tracing components

- Cameras
- Ray-object intersections
- Light sources
- Visibility
- Surface scattering
- Indirect light transport
- Ray propagation

1. Cameras

- Image plane, sensor : The final output starts from this part
- Shutter : A camera component that controls the amount of light reaching the image plane for a specific duration.
- Aperture : An adjustable opening in a camera lens controlling the amount of light entering the camera and is measured in f-stops.
- Lens : A series of glass elements to focus light from a scene onto an image plane.



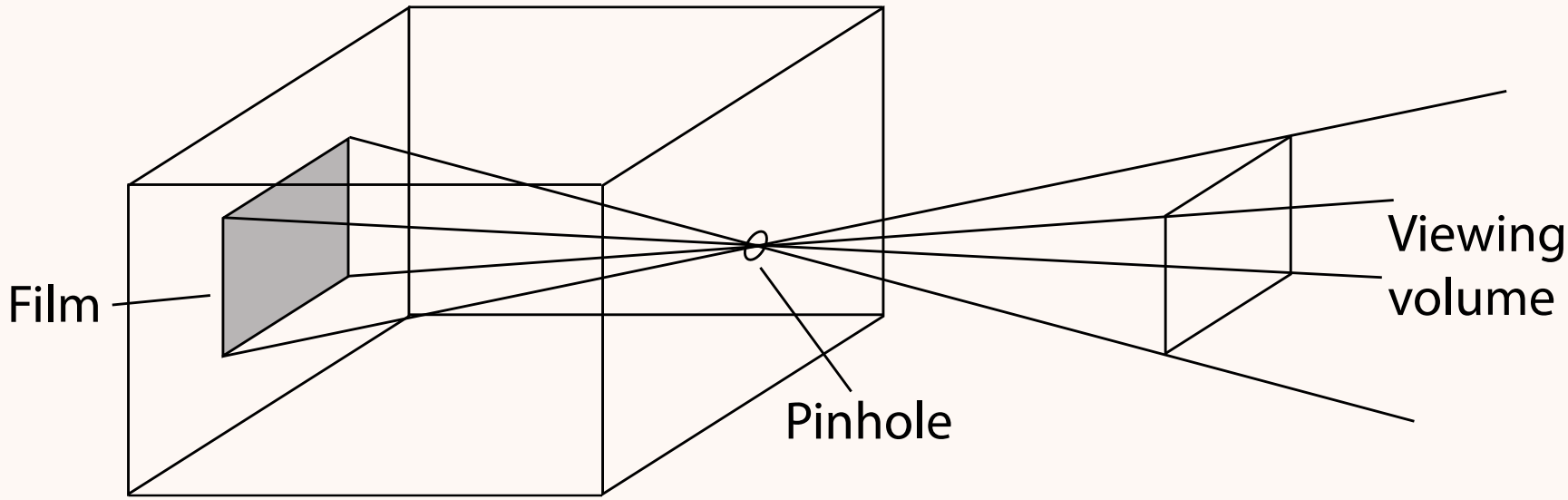


Encyclopædia Britannica, https://www.britannica.com/technology/shutter-photography#/media/1/542395/53797, **Access Date** December 2, 2025.

https://www.youtube.com/watch?app=desktop&v=gB1IrjFQArk

A camera model

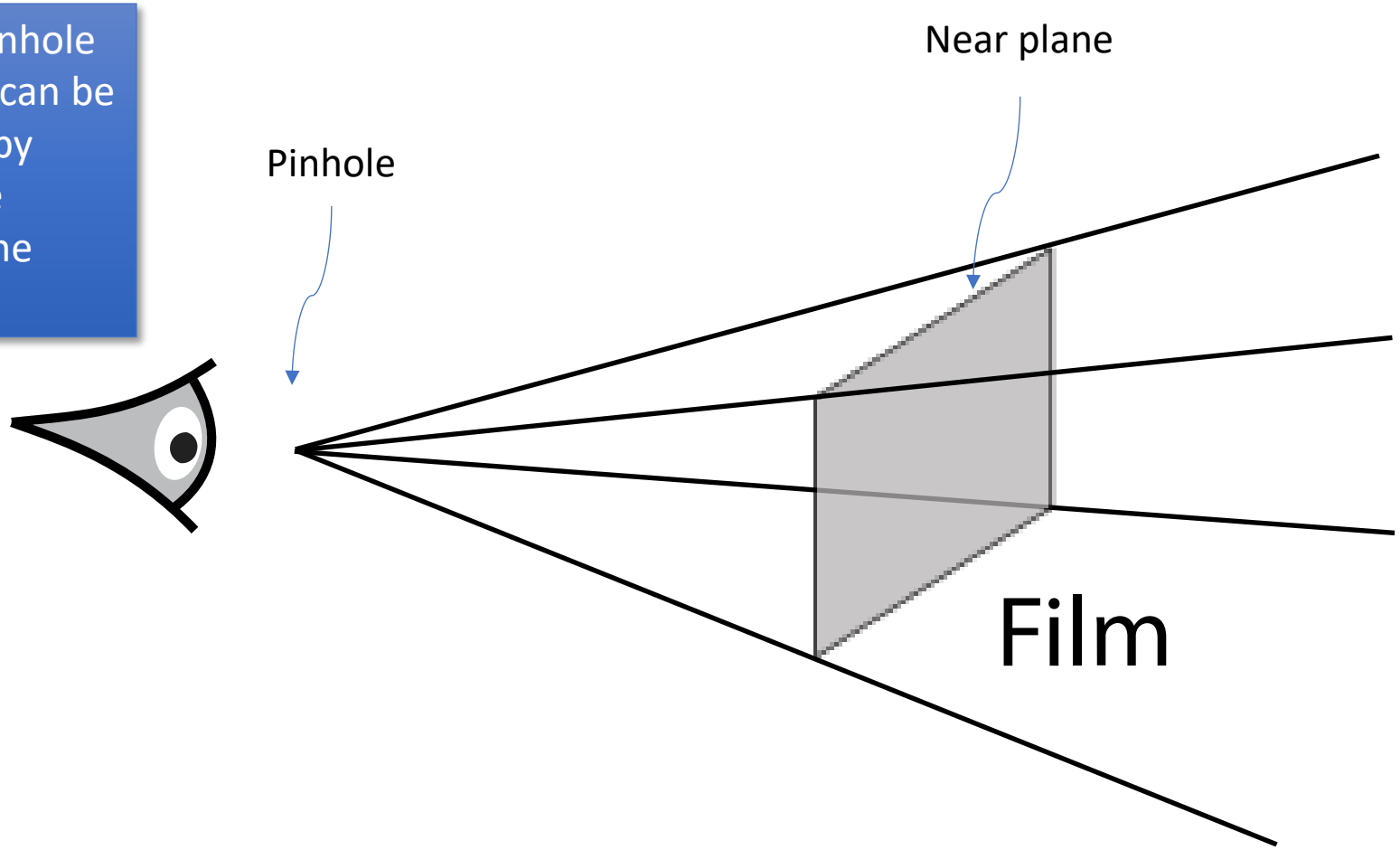
- Pinhole camera



Matt Pharr, Wenzel Jakob, and Greg Humphreys, “Physically Based Rendering: From Theory To Implementation”, https://pbr-book.org/3ed-2018/Introduction/Photorealistic_Rendering_and_the_Ray-Tracing_Algorithm.

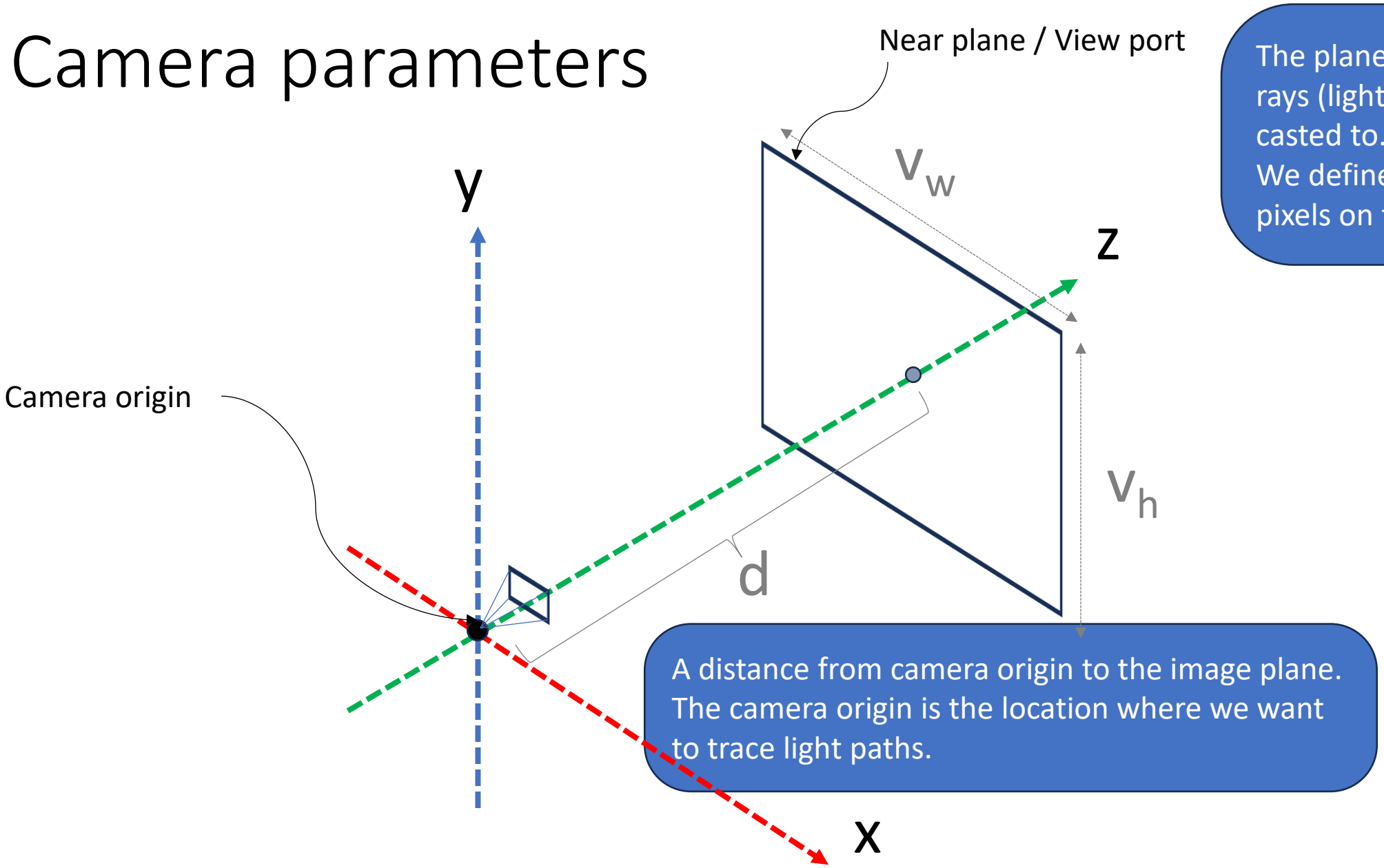
A simplified pinhole camera

Simulating a pinhole camera model can be easily defined by placing the eye (observer) at the pinhole.

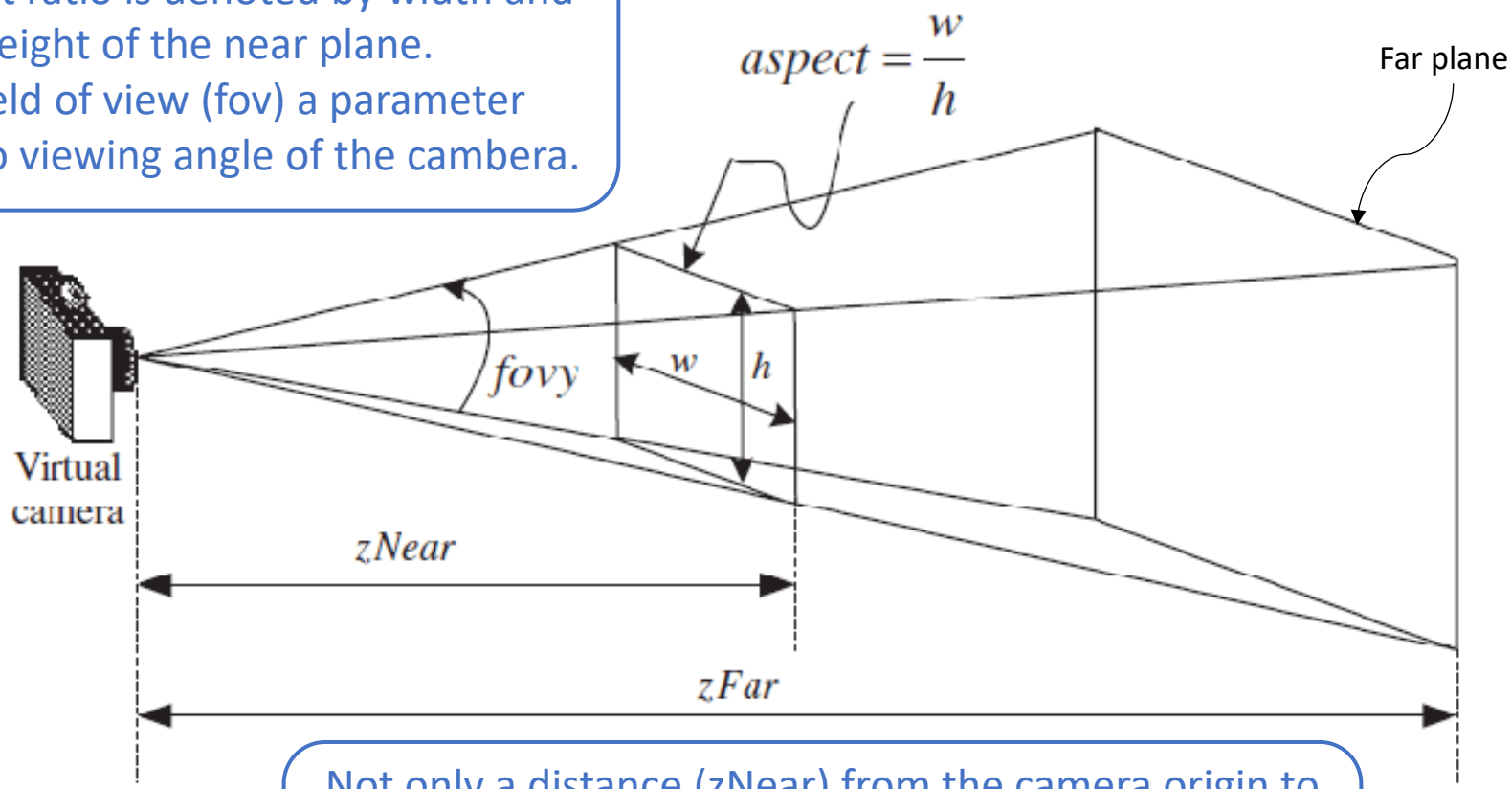


Matt Pharr, Wenzel Jakob, and Greg Humphreys, “Physically Based Rendering: From Theory To Implementation”, https://pbr-book.org/3ed-2018/Introduction/Photorealistic_Rendering_and_the_Ray-Tracing_Algorithm.

Camera parameters



An aspect ratio is denoted by width and height of the near plane.
The field of view (fov) a parameter related to viewing angle of the cambera.



Not only a distance (zNear) from the camera origin to the near plane is defined, but also there is a distance from the camera origin to the far plane (zFar). Both distances can scope a frustum for rendering.

A semi-physical simulation system for binocular vision guided rendezvous, Conference: Control Automation Robotics & Vision (ICARCV), 2012, DOI:10.1109/ICARCV.2012.6485269.

Lens

Types of Lens

- Thin lens (Convex lens)
- Concave lens

Adding lens to the camera can perform some effects.

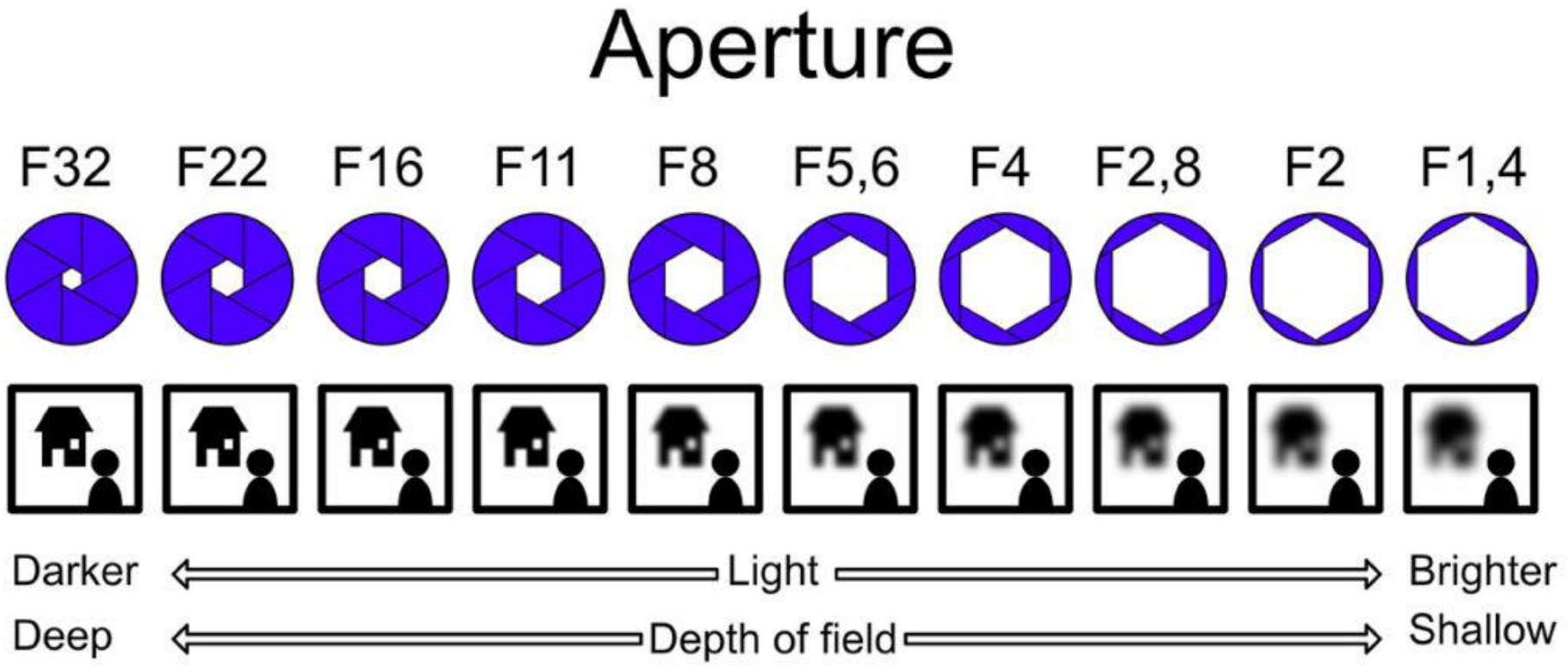
- Bokeh
- Depth of field
- Blurred images

https://blog.demofox.org/2018/07/04/pathtraced-depth-of-field-bokeh/

Convex lens – Concave lens

Feature	Convex Lens (Converging)	Concave Lens (Diverging)
Physical Shape	Thicker at the center, thinner at the edges.	Thinner at the center, thicker at the edges.
Interaction with Light	**Converges** parallel light rays to a real focal point.	**Diverges** parallel light rays as if from a virtual focal point.
Focal Length (f)	**Positive** by sign convention.	**Negative** by sign convention.
Image Formation	Can form both **real, inverted images** (if the object is outside the focal length) and **virtual, upright images** (if the object is inside the focal length).	**Only** forms **virtual, upright, and reduced** images, regardless of the object's position.
Common Applications	Magnifying glasses, cameras, eyeglasses for farsightedness (hyperopia), objective lenses in telescopes.	Eyeglasses for nearsightedness (myopia), peepholes in doors, certain telescope eyepieces.

Depth of Field (DOF)

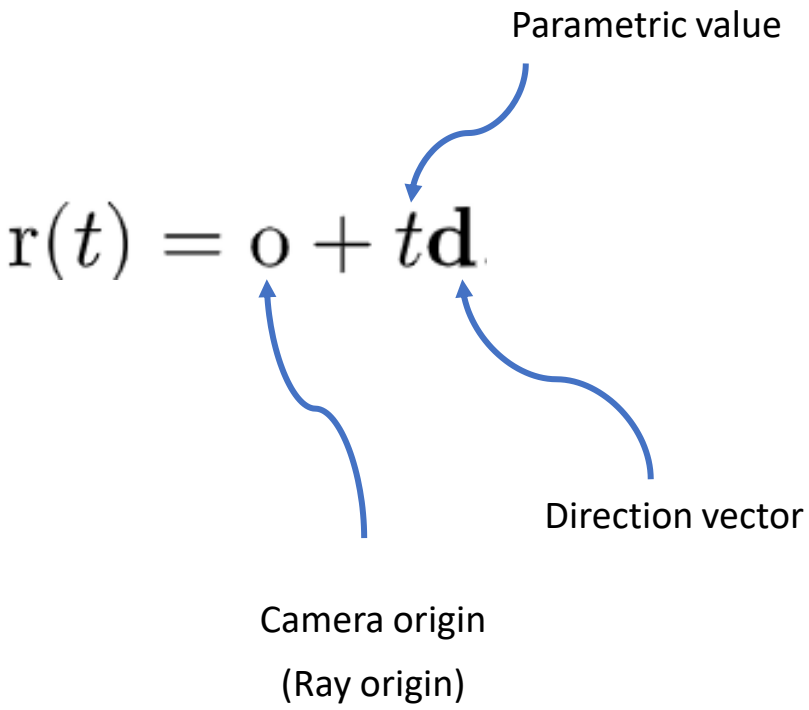


Explanation : https://www.youtube.com/watch?v=bXpTDtU8wgU

Jeff Picoult, https://www.mefoto.com/depth-of-field-in-photography/, June 2024.

2. Ray-object intersections

- Ray equation in a parametric form :



Parametric equations

- Definition
  - Parametric equations are a set of equations that express a set of quantities as explicit functions of a number of independent variables, known as "parameters."

- Note that parametric representations are generally nonunique, so the same quantities may be expressed by a number of different parameterizations. A single parameter is usually represented with the parameter *t*, while the symbols *u* and *v* are commonly used for parametric equations in two parameters.

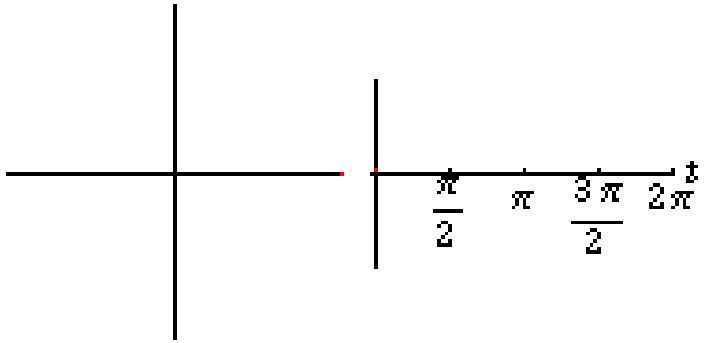
https://mathworld.wolfram.com/ParametricEquations.html

A parametric form of a circle

- A circle is typically defined on the cartesian coordinates.

$$f(t) = f(x(t), y(t))$$

$$x(t) = r_1 \cos t$$
$$y(t) = r_1 \sin t$$



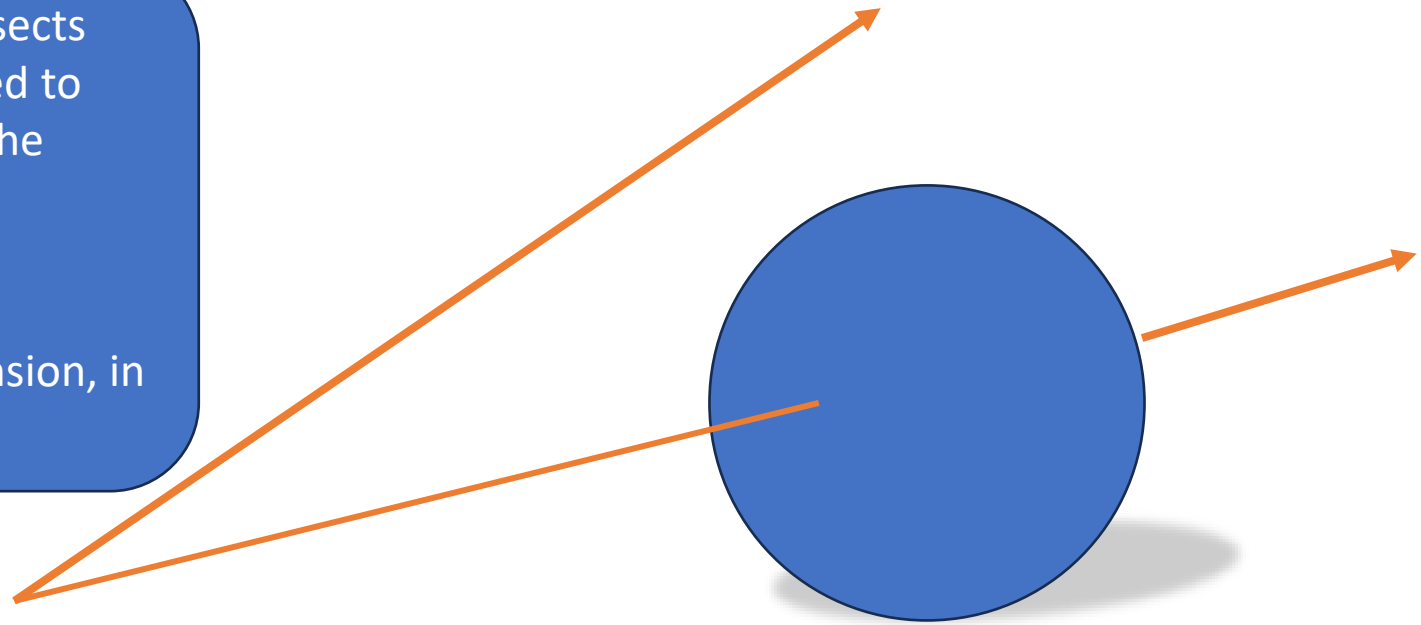
Note that r_1 is a constant and t is in a range of [0, 2pi].

https://mathworld.wolfram.com/ParametricEquations.html

Ray-sphere intersection

In order to find where a ray intersects with an object (a sphere), we need to substitute the ray equation into the object equation.

The Ray parametric equation is independent from object's dimension, in this case a 3-dimensional space.



$$\mathrm{r}(t) = \mathrm{o} + t\mathbf{d}$$

$$x^2 + y^2 + z^2 - r^2 = 0$$

substitute

Ray-sphere intersection solution

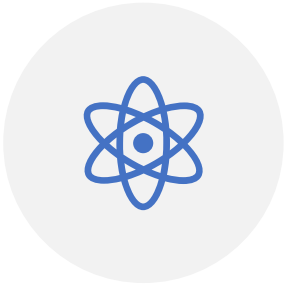
- Solving a quadratic equation to obtain where the ray hits the sphere.

$$(\mathrm{o}_x + t\mathbf{d}_x)^2 + (\mathrm{o}_y + t\mathbf{d}_y)^2 + (\mathrm{o}_z + t\mathbf{d}_z)^2 - r^2 = 0$$

- When there is a solution, there is a hitting point (the least positive value).
- Otherwise, the ray misses the sphere.

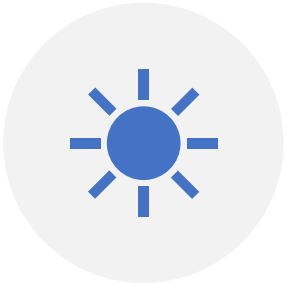
Ray-object intersections

3. Light sources

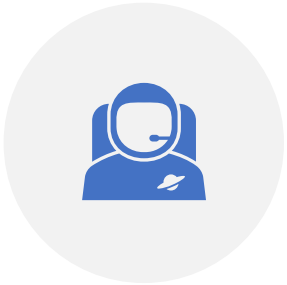


Light is the source of photon distributions in a rendered scene.

Some materials can act as light sources. It can emit light under some conditions.



Light sources have properties such as intensity, color, size and shape.



Light can be measured by using special devices to capture radiance distribution under the environment (advanced topic).

Luminescence

- Luminescence is the emission of light by a substance as a result of a chemical reaction (chemiluminescence) or an enzymatic reaction (bioluminescence).

https://www.moleculardevices.com/technology/luminescence

https://www.leica-microsystems.com/science-lab/life-science/basic-principles-of-luminescence/

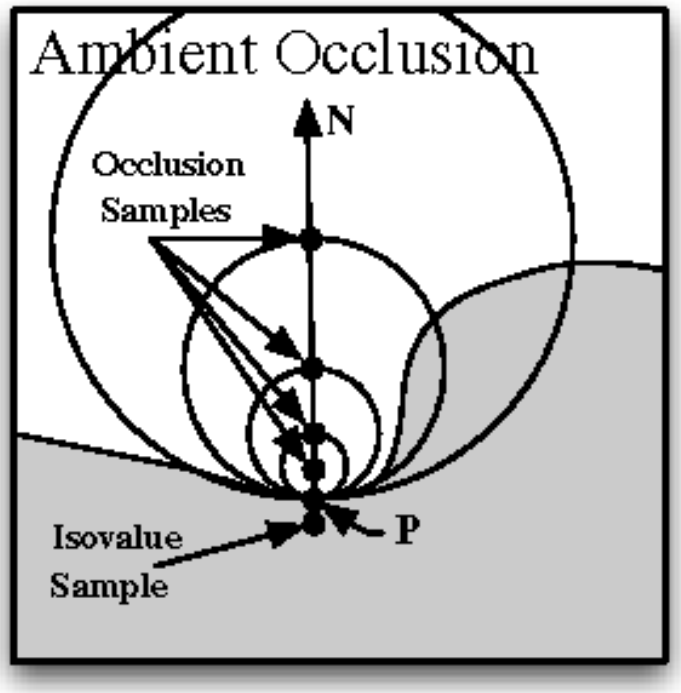
Light-emitting materials

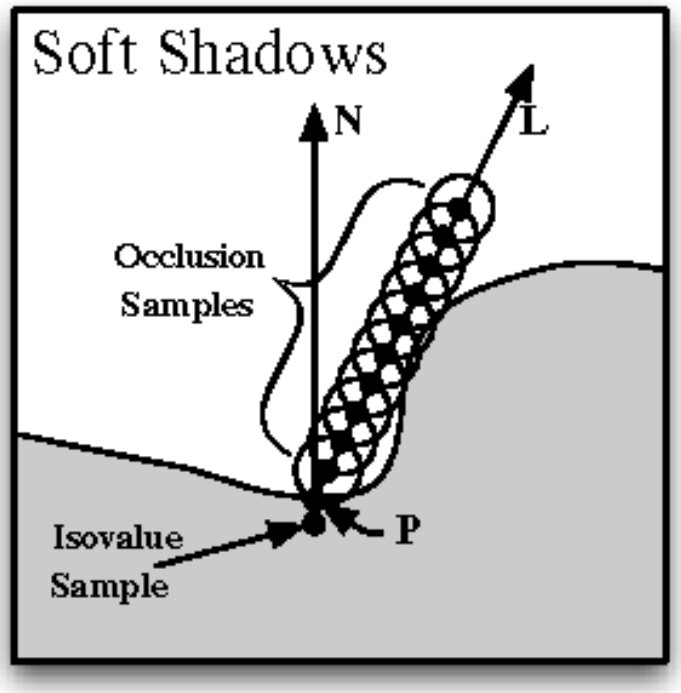
- **Phosphorescent materials**
  - The light emission continues for a period of time (which can be considerable) after the X-ray absorption has taken place.
- **Fluorescent materials**
  - The emission of light is so quickly completed following the X-irradiation that it can be regarded as instantaneous.
- **Thermoluminescent materials**
  - This light emission is associated with heating.

https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/luminescent-material

4. Visibility

- Shadow is a fundamental natural effect related to light and visibility.
- Occlusion : Mostly we talk about geometric occlusion.
- Indirect lighting is process of lighting in which light reaches a surface after bouncing off at least one other surface, rather than coming directly from a light source.





Visibility types

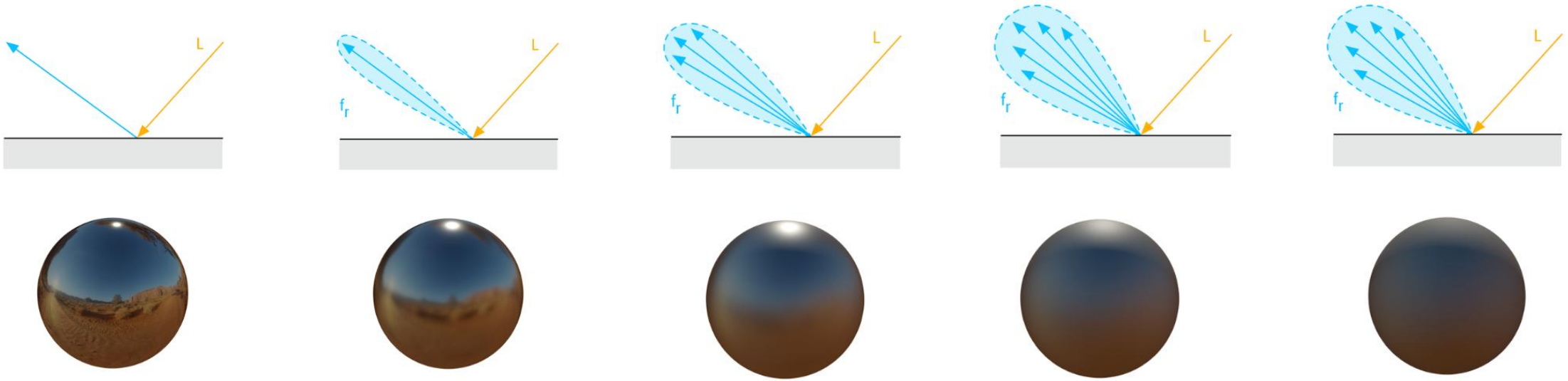
Object – Object

Object – Light

Camera – Object, Light

5. Surface scattering

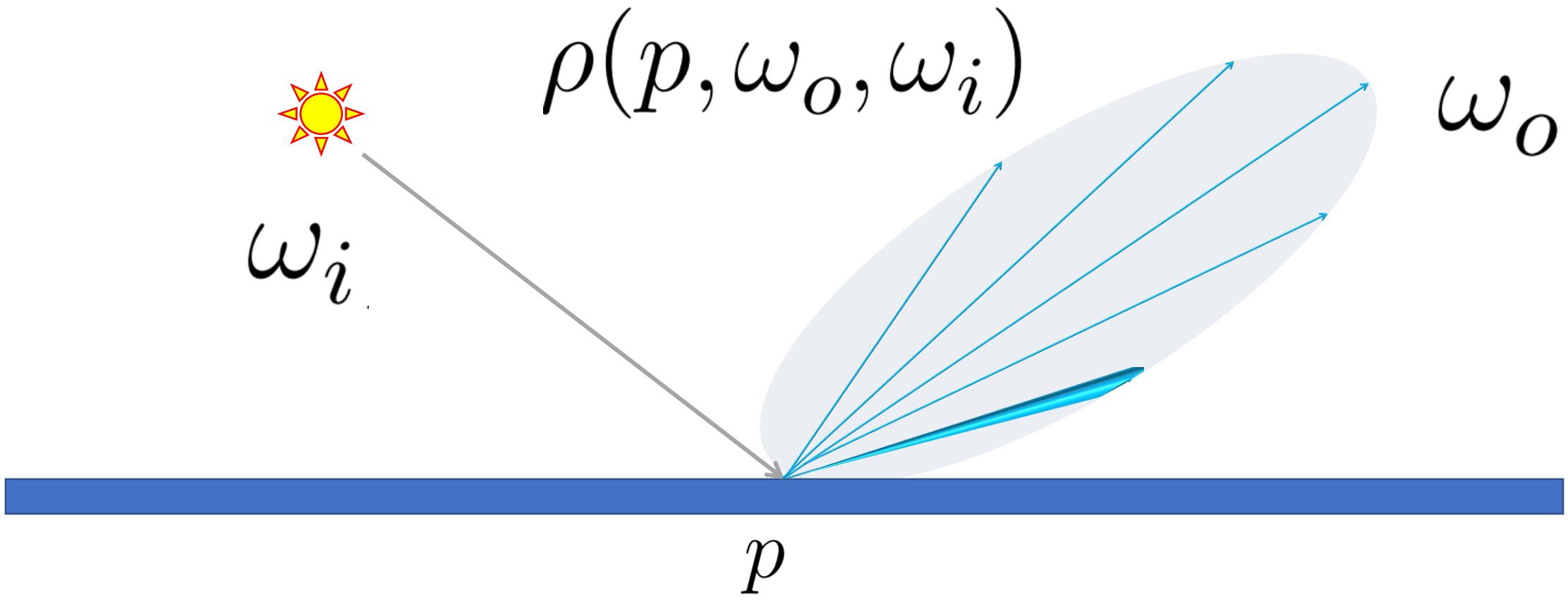
- How light interacts with surface materials.



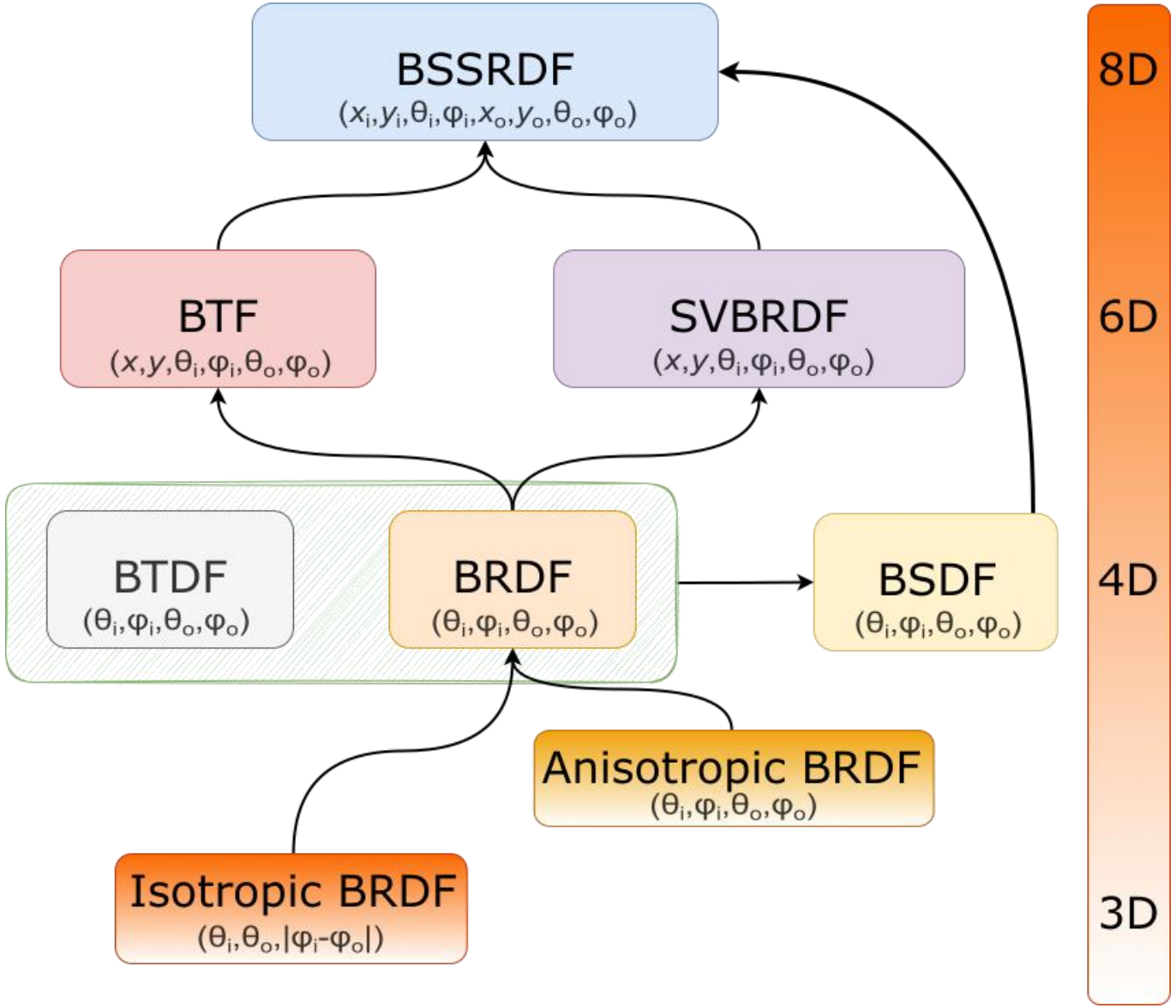
Incoming light
=
reflected light

Reflected light is scattered.

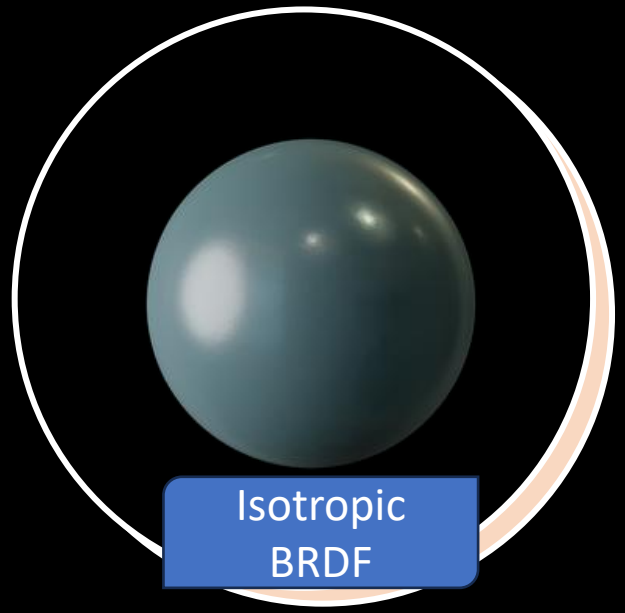
Bidirectional Reflectance Distribution Function (BRDF)

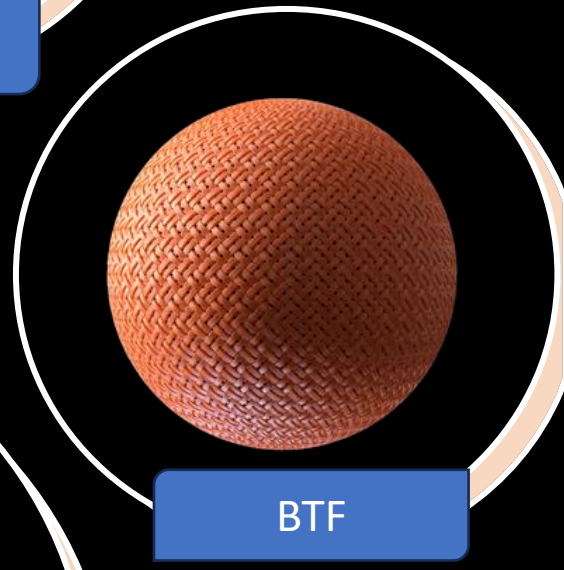


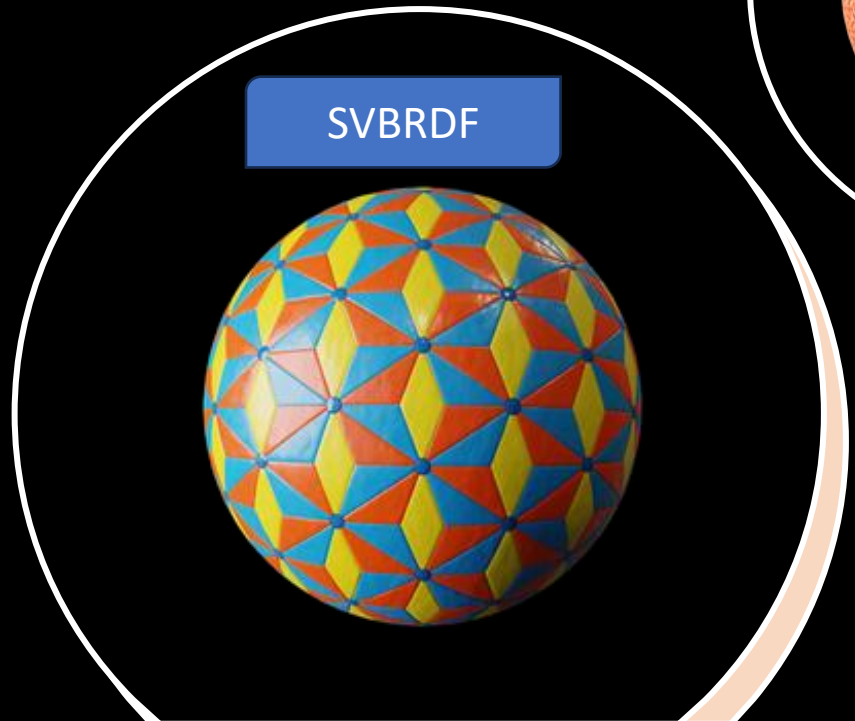
Taxonomy of scattering functions



Examples

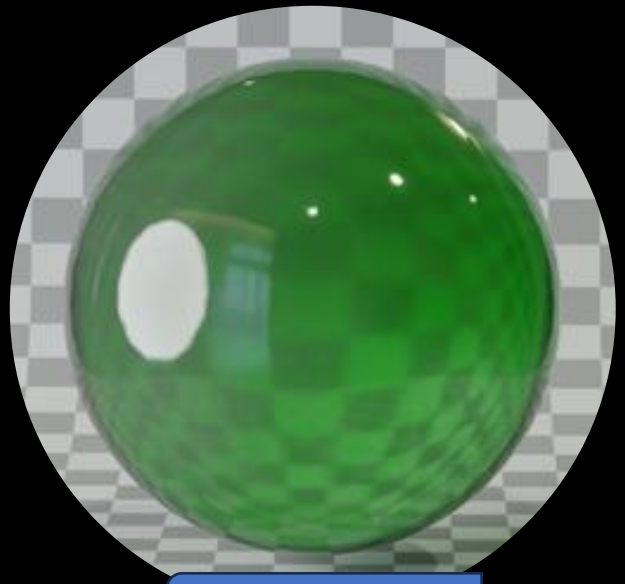




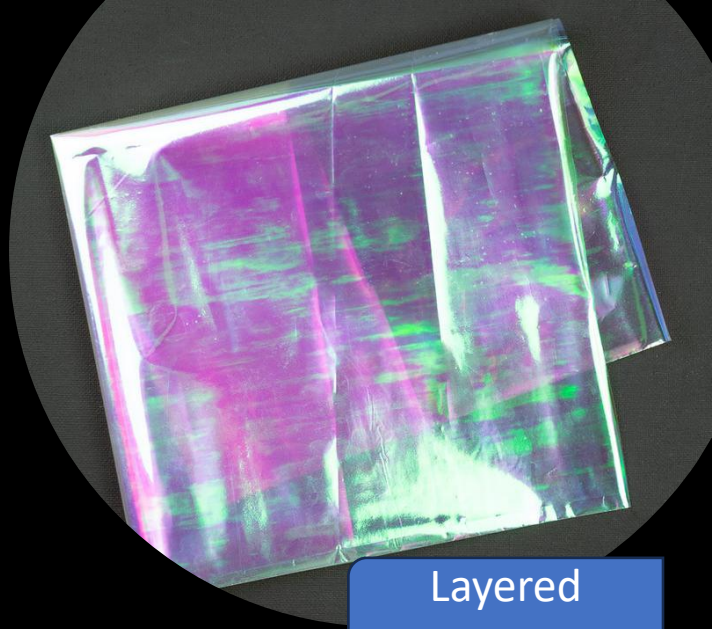


https://www.blenderkit.com/asset-gallery-detail

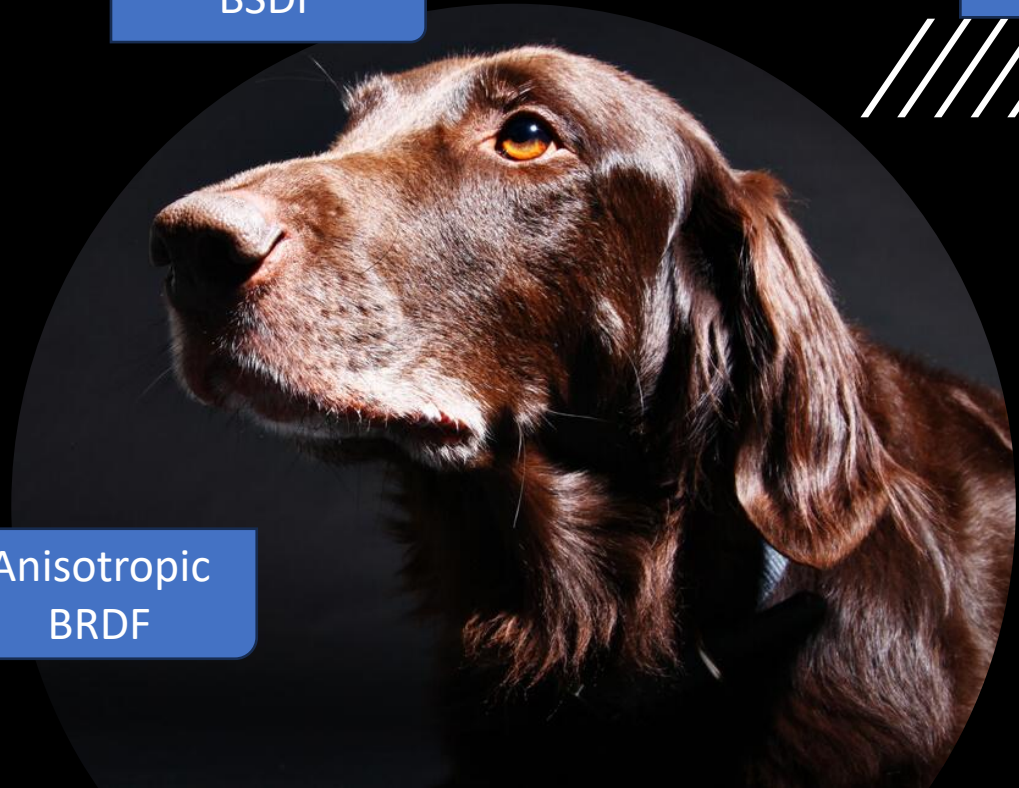
More examples



BSDF

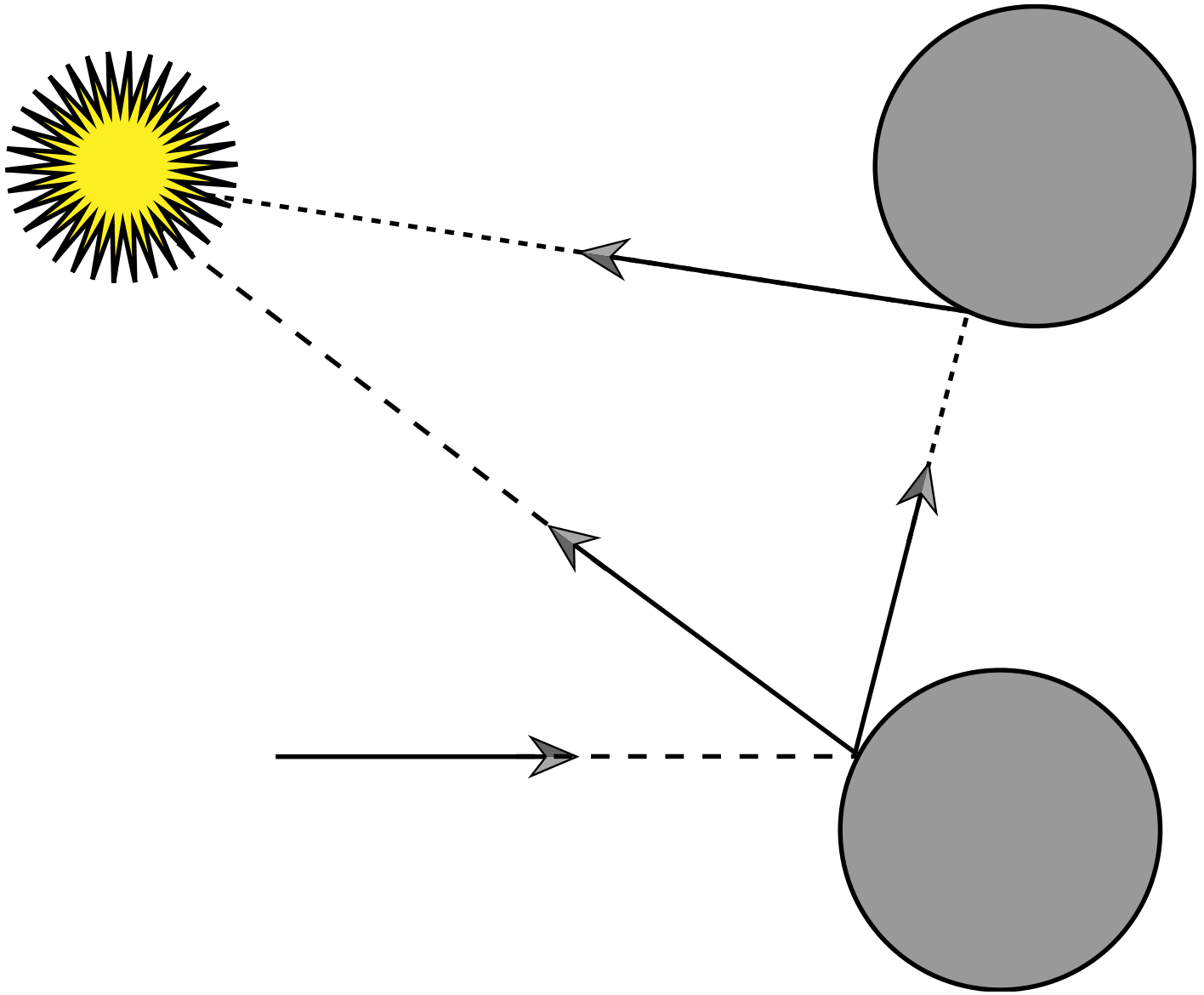


Layered BRDF



Anisotropic BRDF

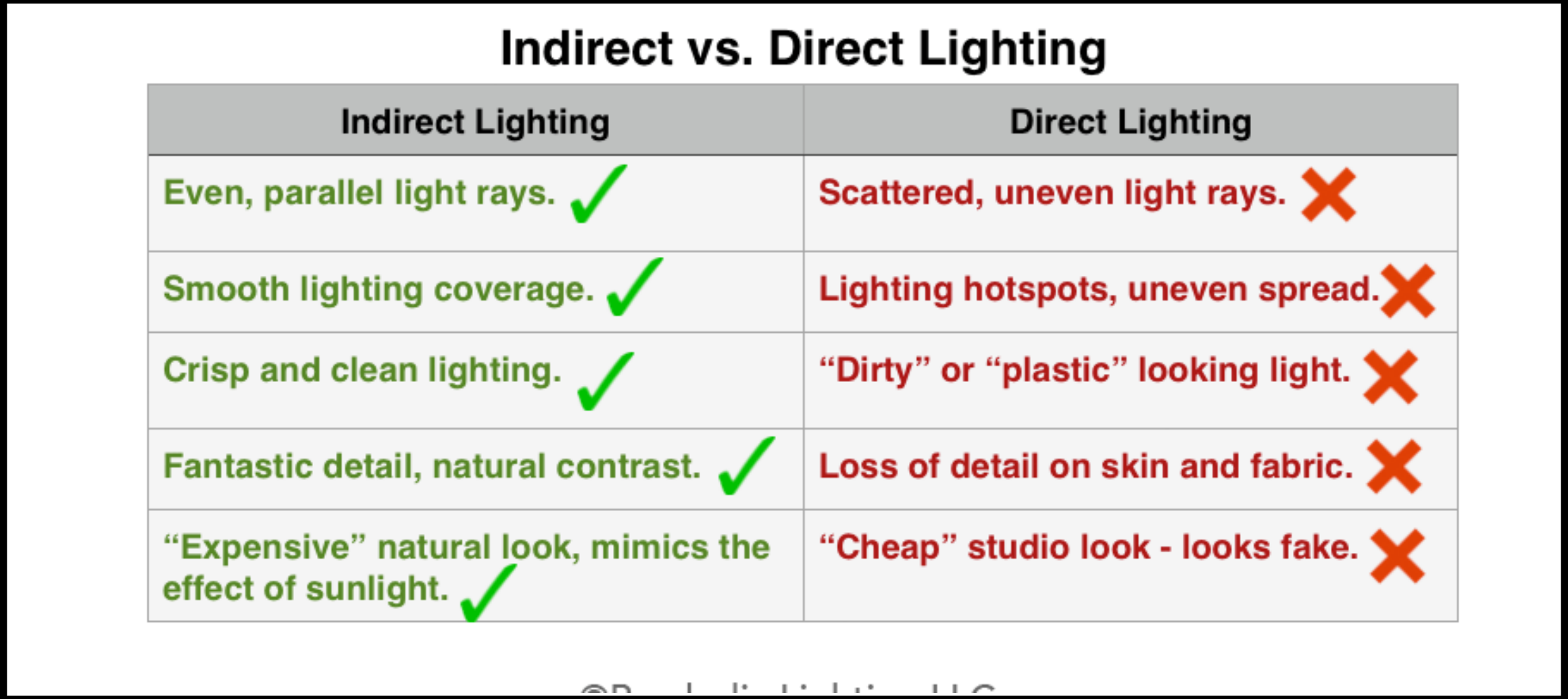
6. Indirect light transport



Indirect lighting effects

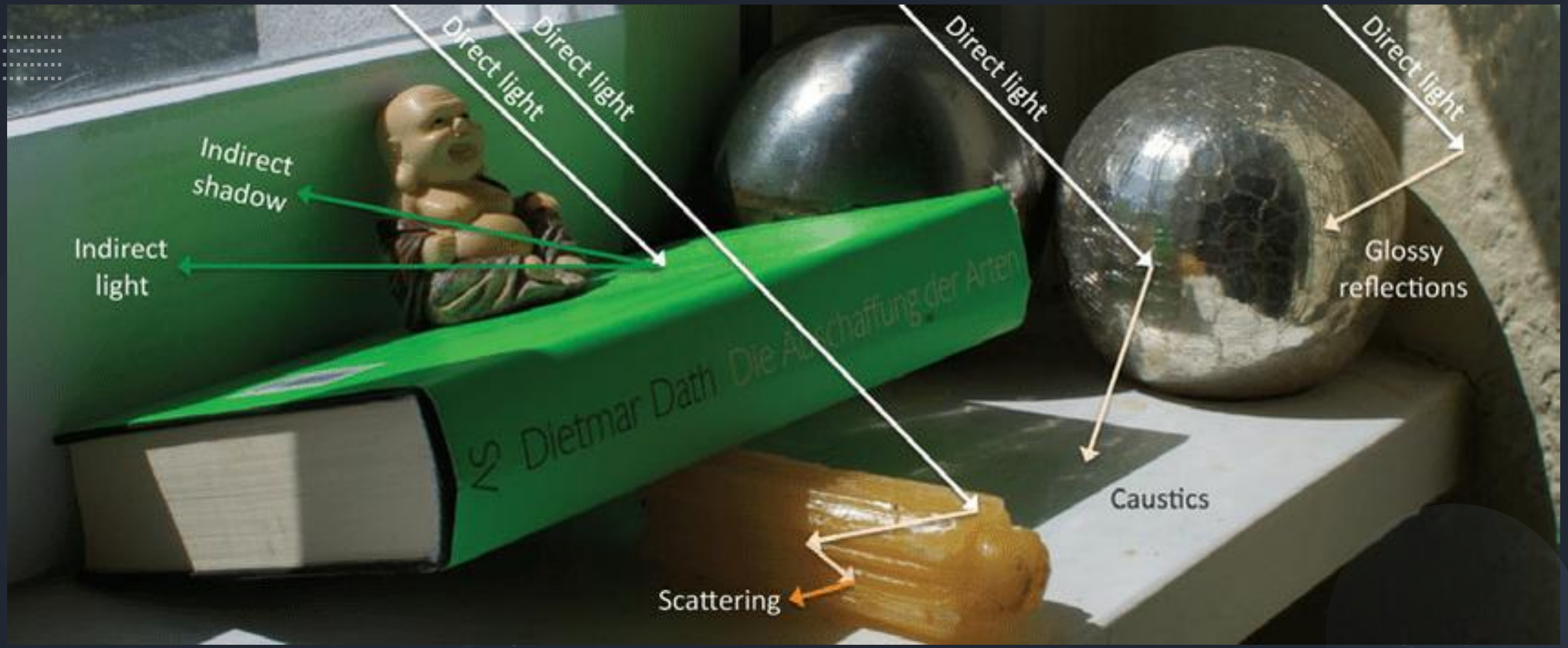
Which one perform indirect lighting better ?
Why ?

- https://blogs.nvidia.com/blog/2022/08/04/direct-indirect-lighting/



Photography perspectives

https://www.parabolixlight.com/indirect-vs-directlighting



Lighting effects

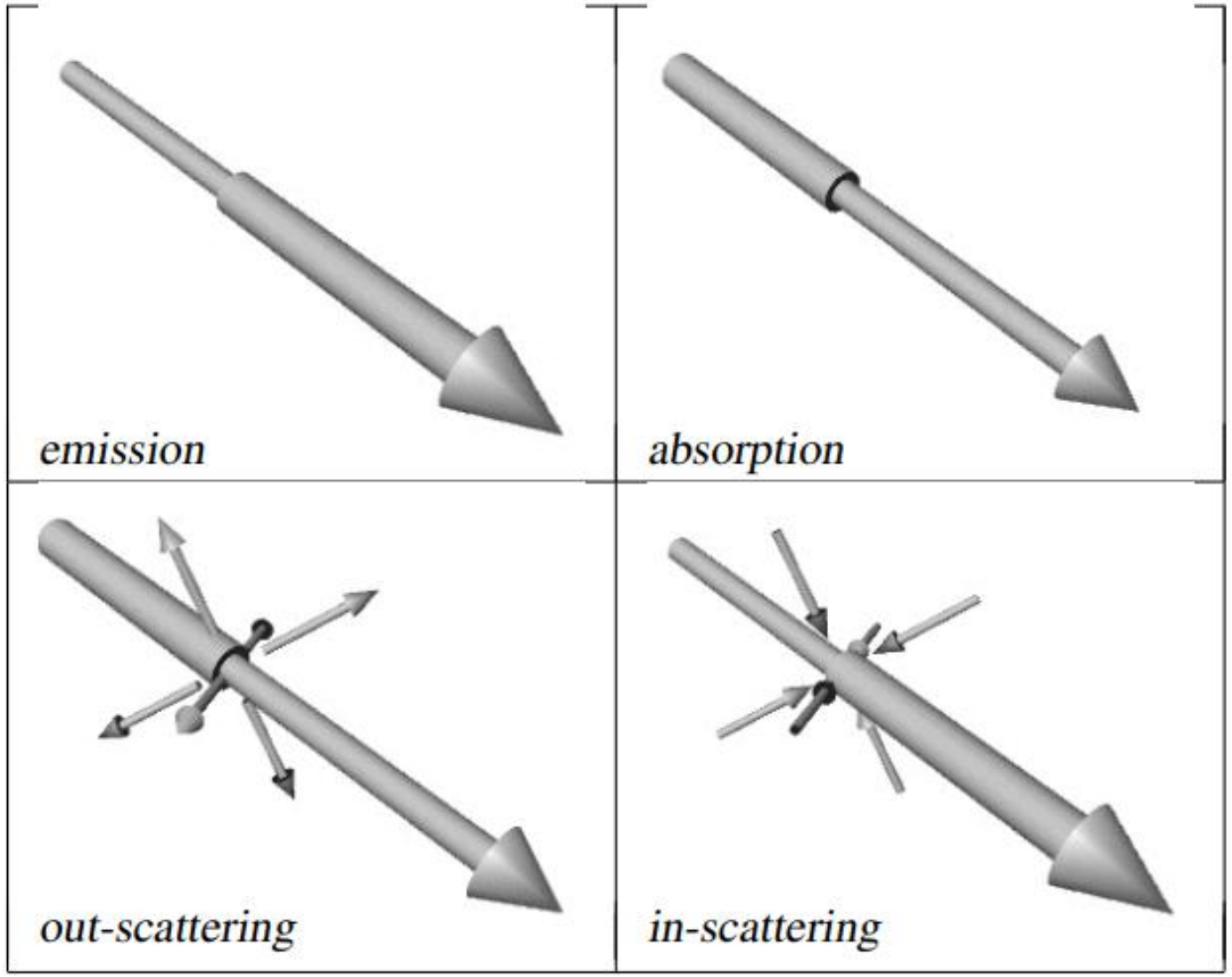
- Rauwendaal, Randall. (2013). Voxel Based Indirect Illumination using Spherical Harmonics. 10.13140/2.1.1300.6403.

7. Ray propagation

- How light travels and is distributed through out the scene.
  - Light attenuation along the distance.
  - Light travels through participating medium.
    - Attenuation
    - Multiple scattering
  - Light propagates in a straight direction or wave directions.

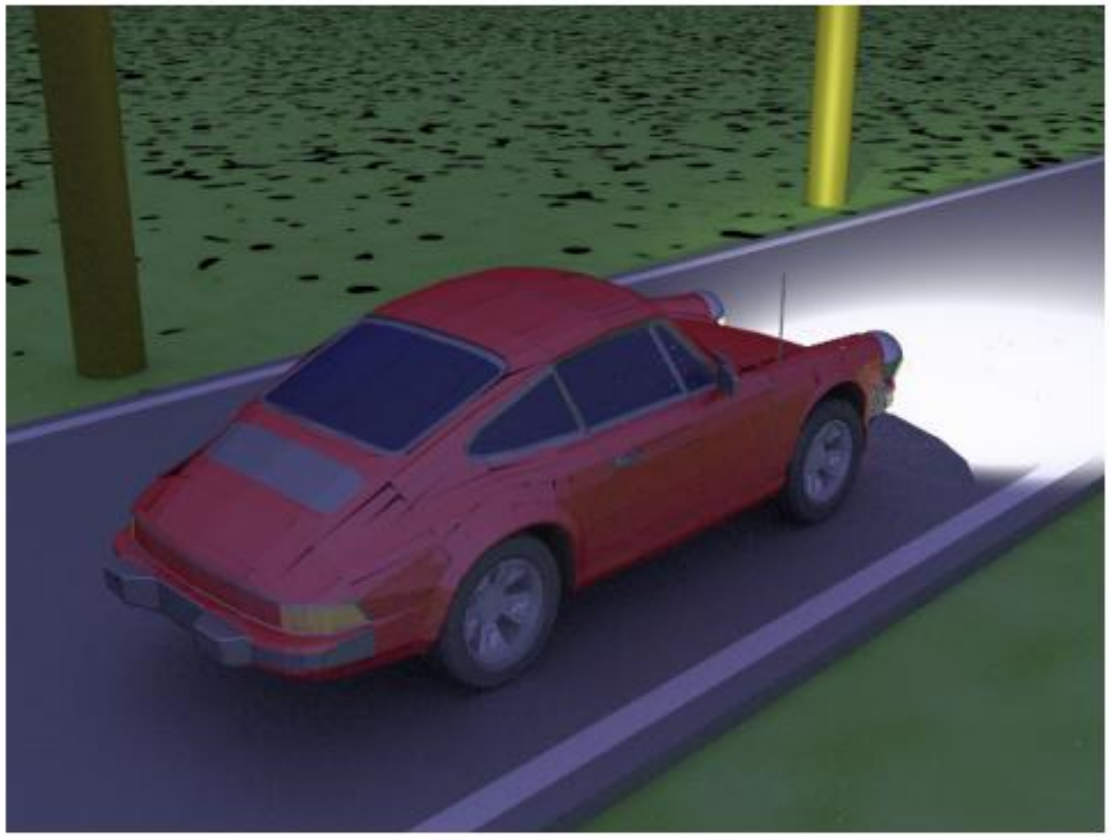
http://graphics.ucsd.edu/~henrik/papers/radiance_caching/

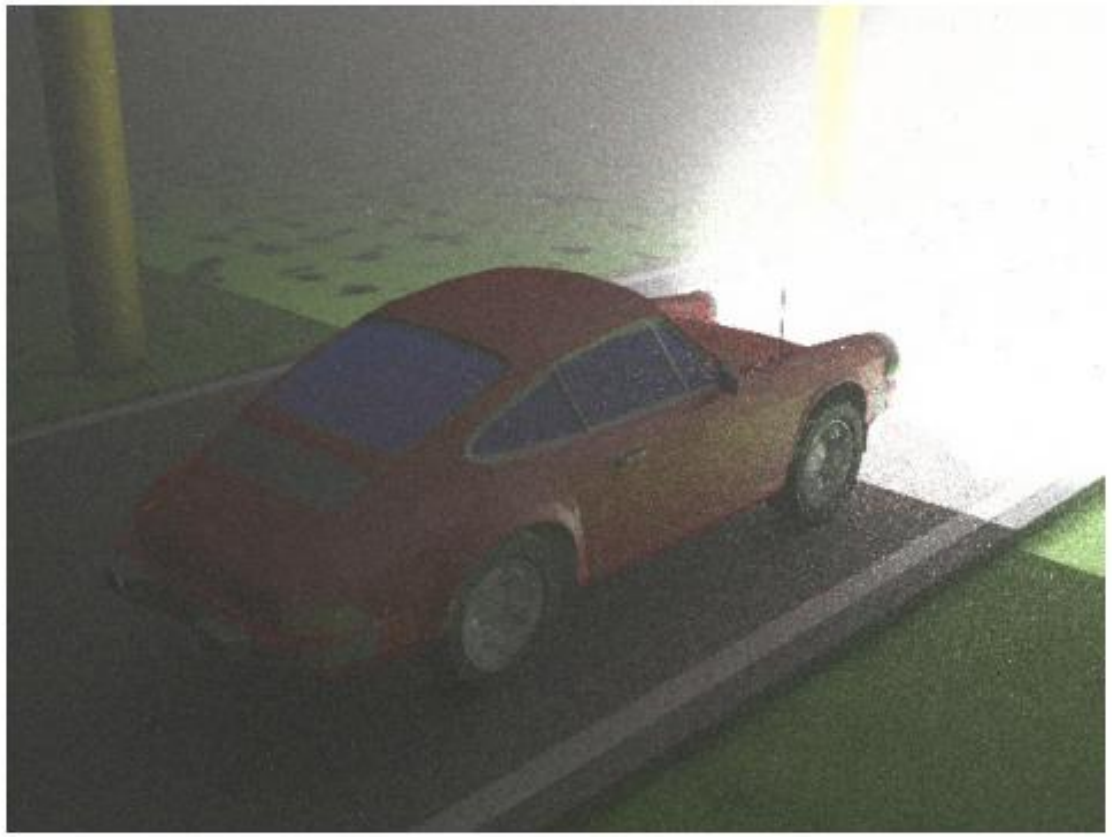
Light interactions in a participating medium



Eva Cerezo, Frederic Perez-Cazorla, Xavier Pueyo, Francisco Seron, François X. Sillion. A Survey on Participating Media Rendering Techniques. The Visual Computer, 2005.

Example





With and Without participating media

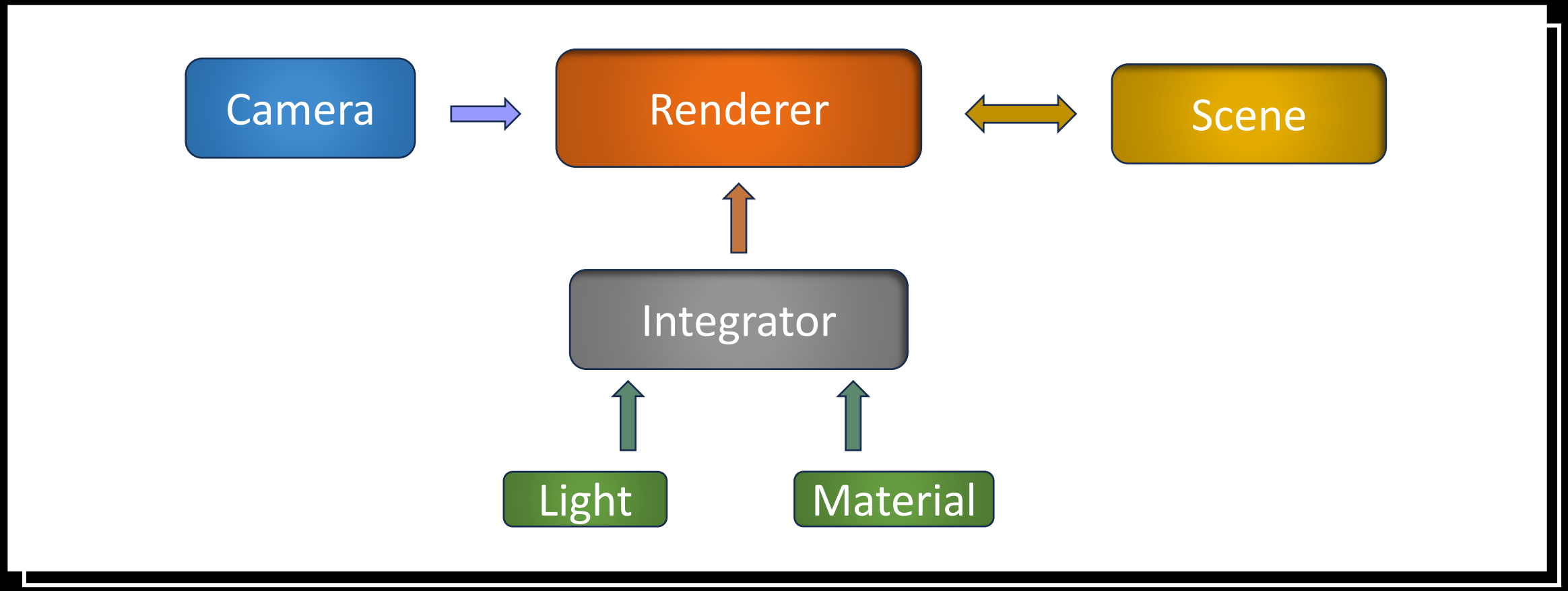
Fog

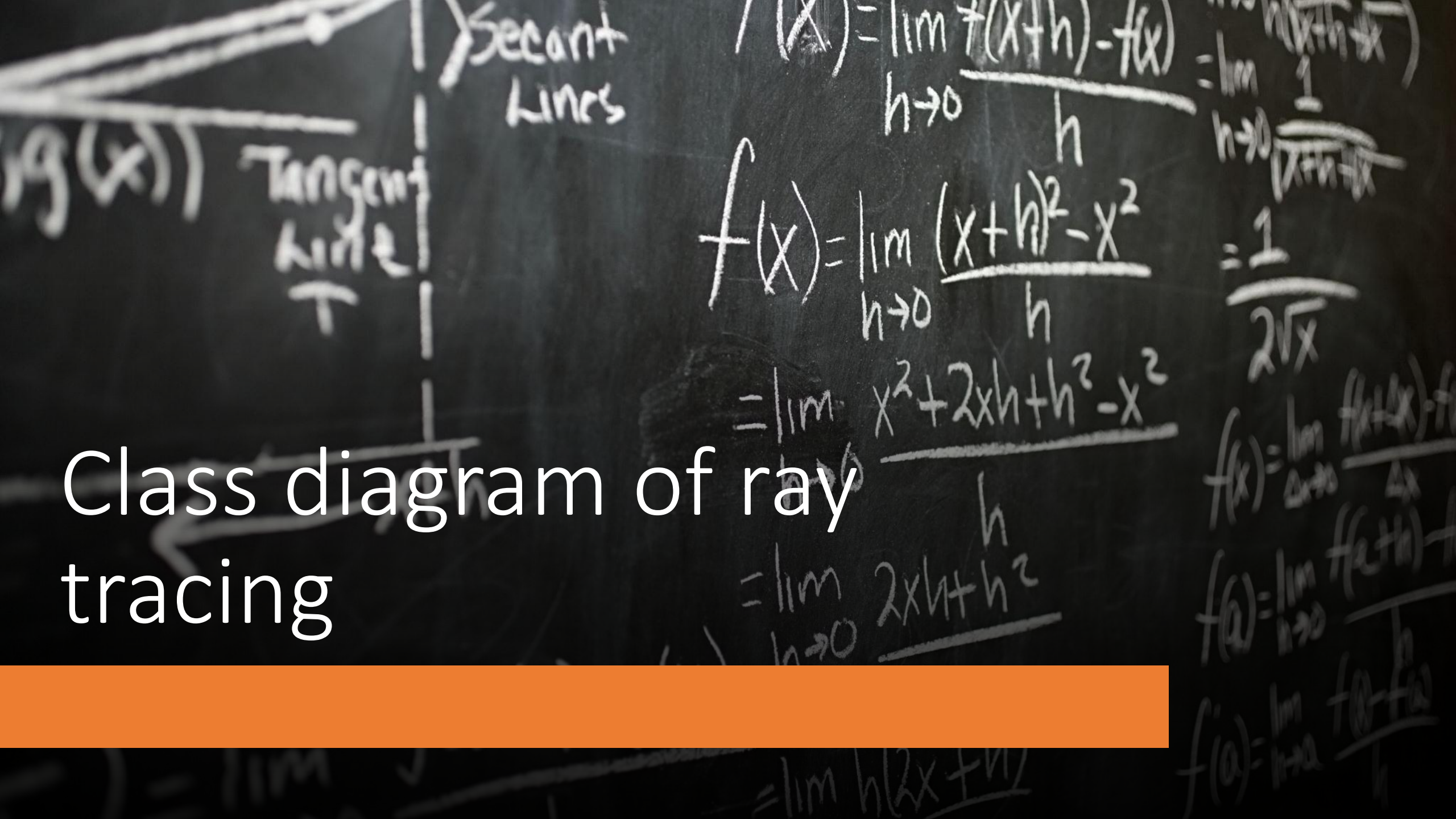
Smoke and Fire

The ray tracing rendering pipeline

- Renderer
- Integrator
- Object
  - Shape – Geometry
  - Appearance – Material properties
- Light
- Camera

Ray tracing pipeline





Class diagram of ray tracing