Lighting

CS425: Computer Graphics I

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Overview

- Light and shading
- Rendering equation
- Light-material interaction
- Reflection models:
  - Phong,
  - Blinn-Phong
- Shading models:
  - Flat
  - Gouraud
  - Phong

Lighting and shading

- Light is emitted by a light source.
- Light interacts with objects in the scene:
  - Part is absorbed, part is scattered in new directions.
- Finally, light is absorbed by a sensor (e.g., human eye, film).

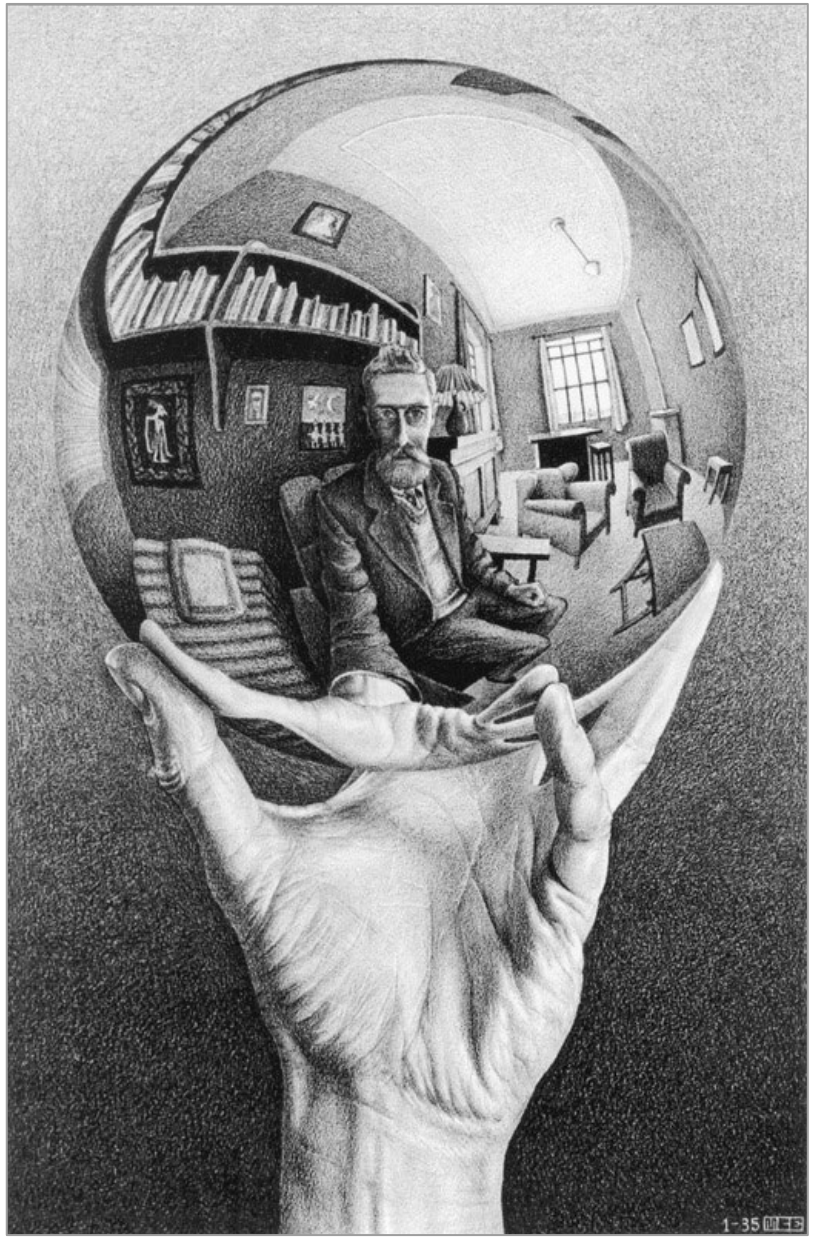
Lighting and shading

- Shading objects so their images appear three-dimensional.

- How can we model light-material interactions?
- We will see how to build a simple reflection model (Phong model) that can be used with real-time graphics hardware.

Why we need shading?

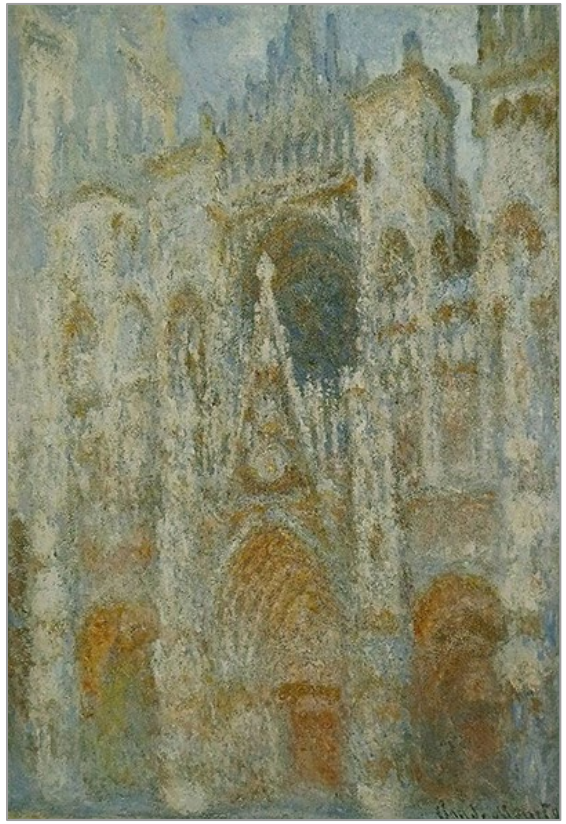
- Appearance of surfaces, taking into account:
  - Surface material
  - Lighting conditions



MC Escher

Why we need shading?

Full Sun



Morning Sun

Setting Sun

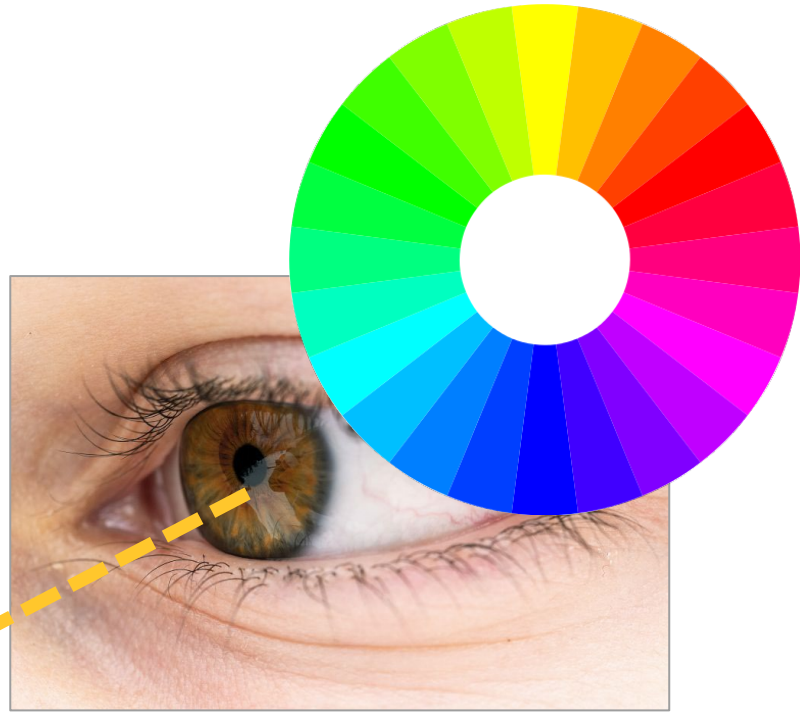
Grey Weather

Rouen Cathedral (Monet series)

Light and shading

1. Light source emits photons

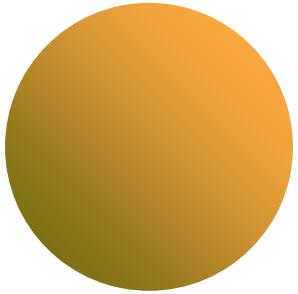
2. Photons interact with the environment: absorption, reflection



3. Some are captured by eye / camera

Lighting and shading

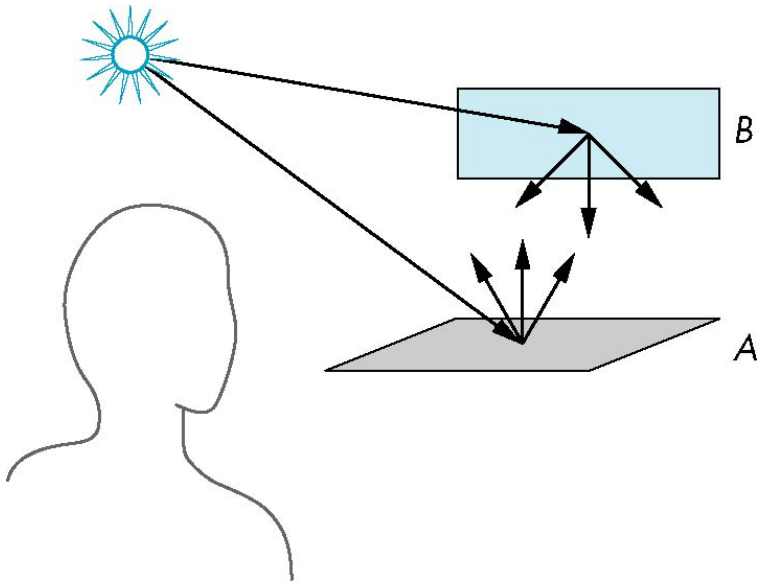
- Light-material interactions cause each point to have a different color or shade.



- We need to consider:
  - Light sources.
  - Material properties.
  - Location of viewer.
  - Surface orientation.

Lighting and shading

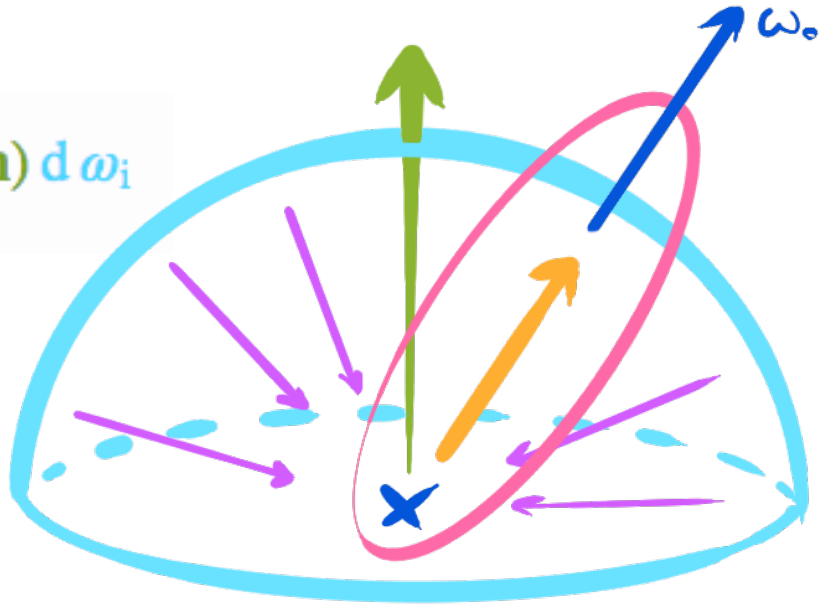
- Light strikes A
  - Some scattered
  - Some absorbed
- Some of scattered light strikes B
  - Some scattered
  - Some absorbed
- Some of this scattered light strikes A and so on…



Rendering equation

- The infinite scattering and absorption of light can be described by the rendering equation:

$$L_o(\mathbf{x}, \omega_o) = L_e(\mathbf{x}, \omega_o) + \int_\Omega f_r(\mathbf{x}, \omega_i, \omega_o) L_i(\mathbf{x}, \omega_i) (\omega_i \cdot \mathbf{n}) \, \mathrm{d}\omega_i$$

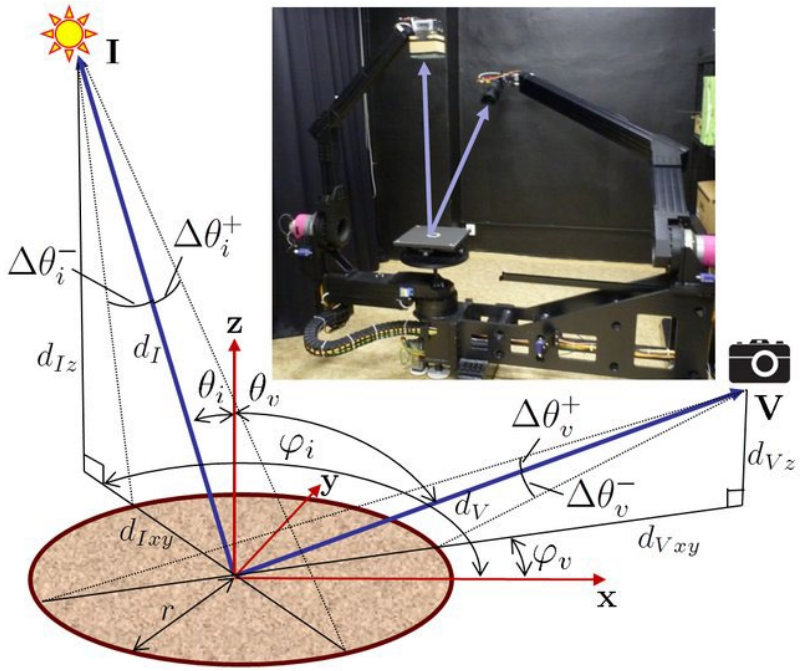


To find the light towards the viewer from a specific point, we sum the light emitted from such point plus the integral within the unit hemisphere of the light coming from a any given direction multiplied by the chances of such light rays bouncing towards the viewer (BRDF) and also by the irradiance factor over the normal at the point.

https://chuckleplant.github.io/2017/05/28/light-shafts.html

Bidirectional reflectance distribution function

- Function that defines how light is reflected at an opaque surface.



"Effective Acquisition of Dense Anisotropic BRDF", Filip et al.

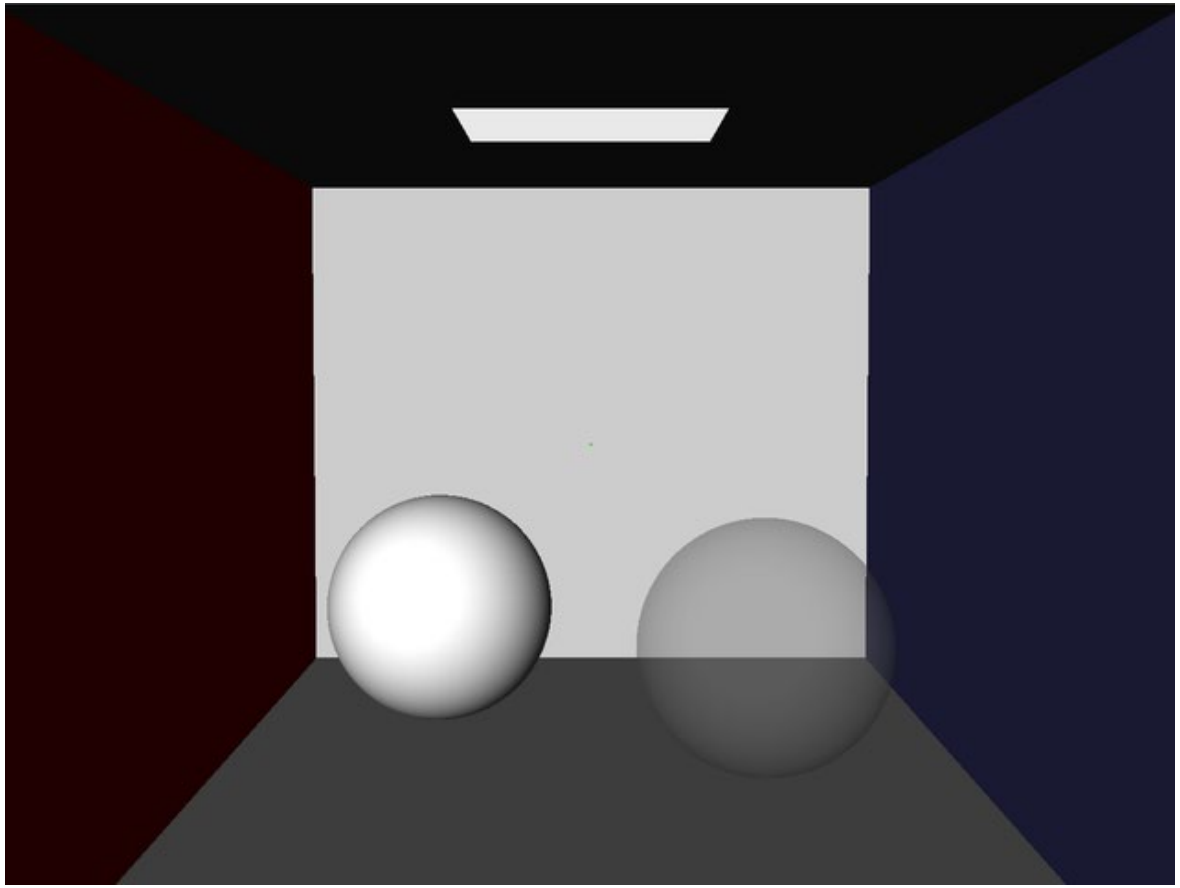
Illumination models

- Global illumination
  - Takes into account light coming from source lights (direct illumination), as well as light reflected by other surfaces (indirect illumination).
  - Takes into account shadow, reflection, refraction.
  - Algorithms:
    - Ray tracing
    - Path tracing
    - Radiosity

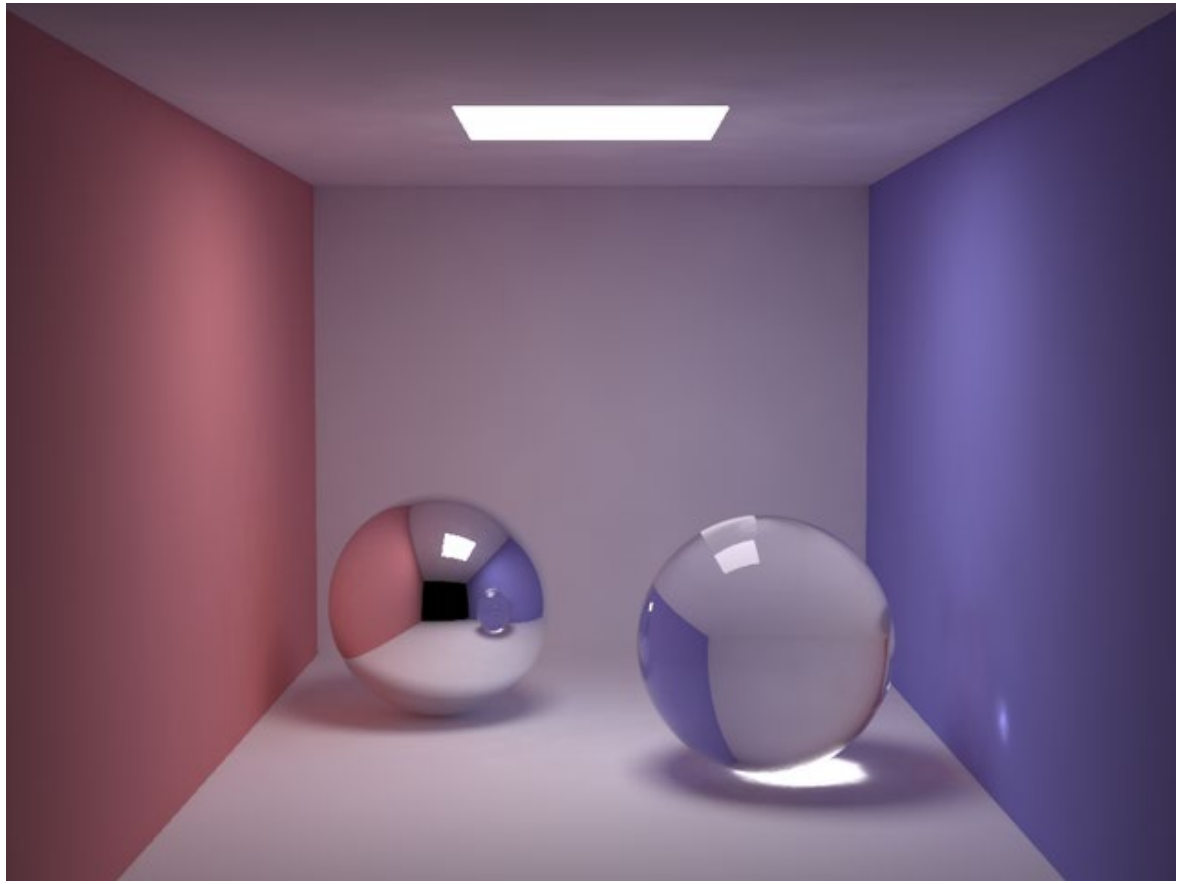
Illumination models

- Local illumination
  - Takes into account light from light sources.
  - Does not consider other objects in the scene (illumination at a point depends only of its own properties).
  - Shadow, reflection, and refraction handled by additional methods.

Illumination models

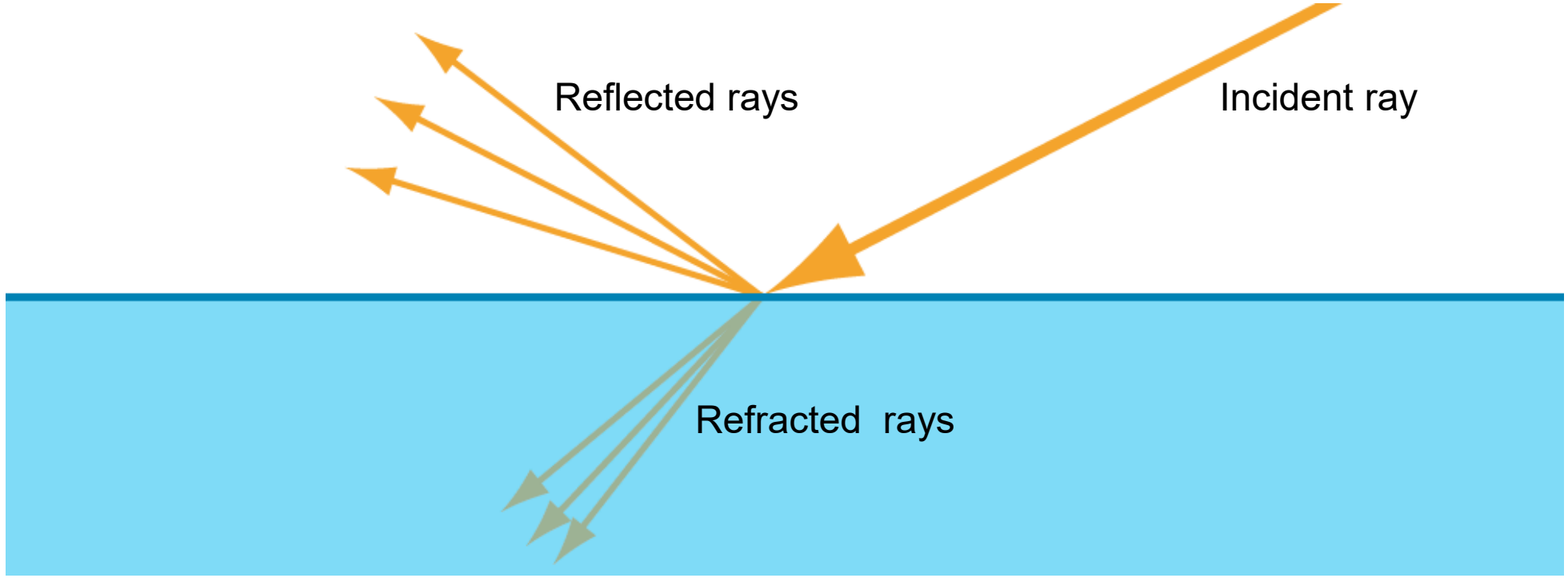


Local illumination

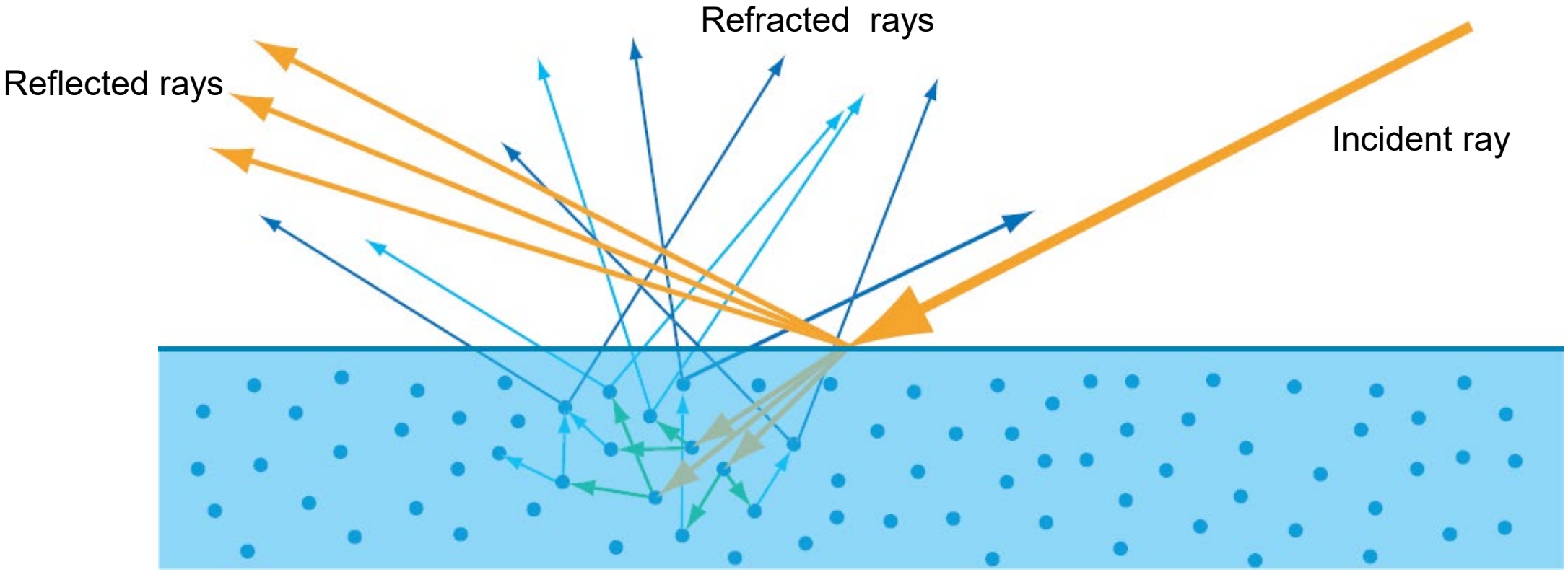


Global illumination

Light-material interaction



Light-material interaction

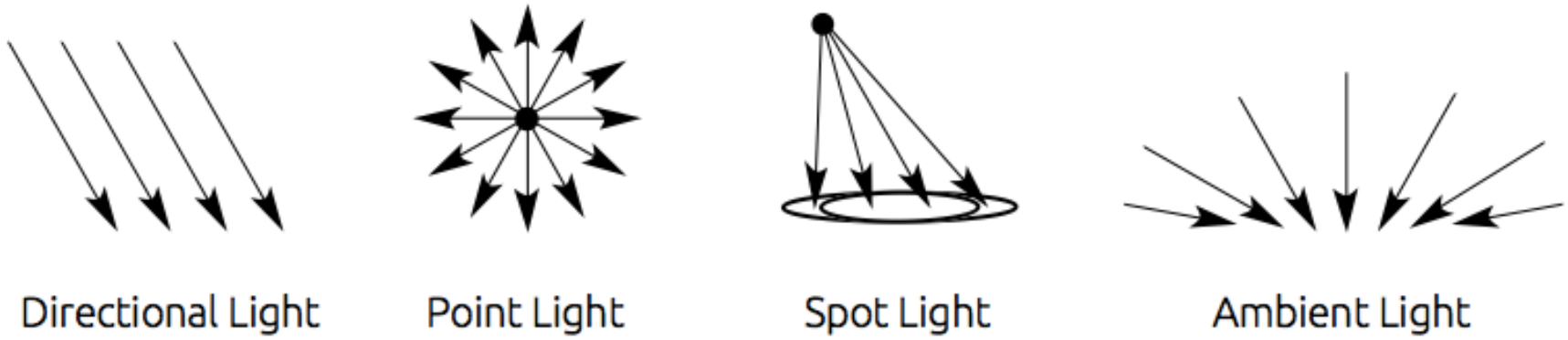


Local illumination

- Light-material interaction is modeled through three components:
- Specular component
  - Reflected rays
- Diffuse component
  - Refracted rays
- Ambient component

Light sources

- Point: position
- Spotlight: position and direction
- Directional: direction

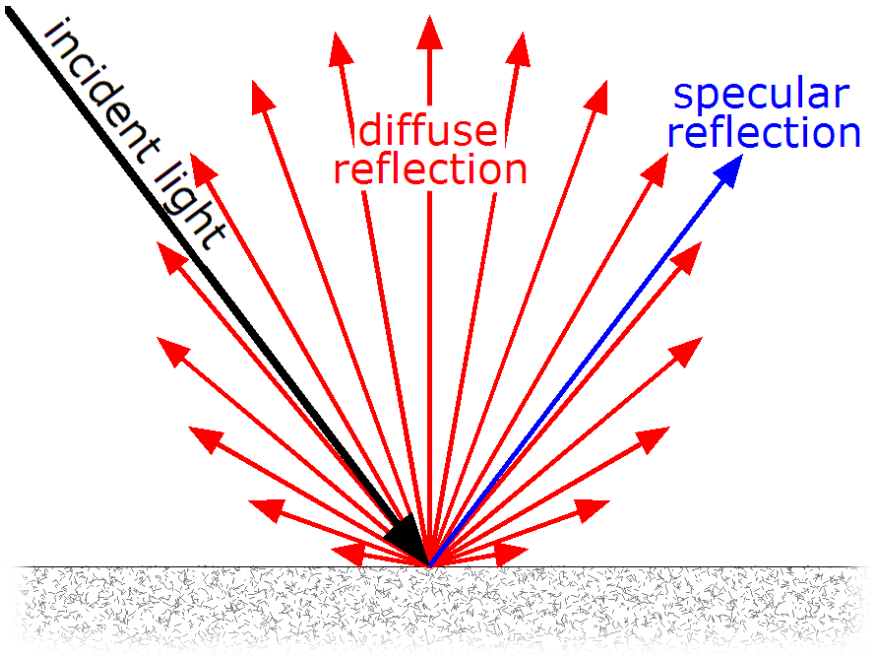


truvis.ch

Phong model

- Computes the local illumination of points on a surface.
- No physical basis. Reflection model.
- Combination of diffuse reflection with specular reflection.
- Rendering equation approximation:
  - Considers direct illumination from light sources
  - Indirect illumination mostly ignored
- Developed by Bui Tuong Phong in his 1975 Ph.D. dissertation.

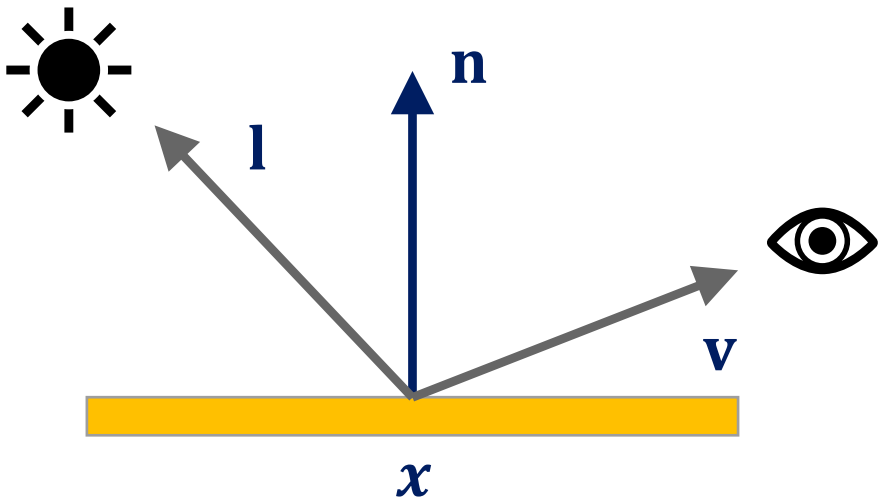
Phong model



$$L(\mathbf{x}, \mathbf{v}) = f_{Phong}(\mathbf{L}_{light}, \mathbf{l}, \mathbf{v}, \mathbf{n})$$

- f_{Phong} computes reflected light into direction $\mathbf{v}$ towards the sensor.

Phong model



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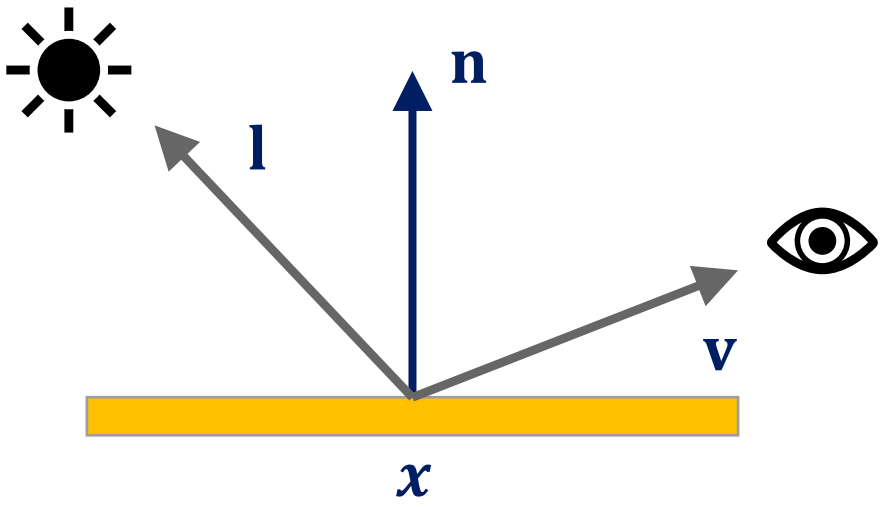
Phong model

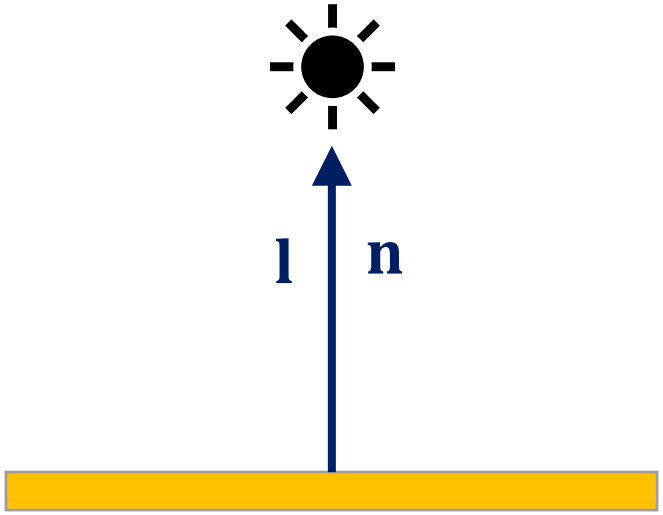


$$L(\mathbf{x}, \mathbf{v}) = f_{Phong}(\mathbf{L}_{light}, \mathbf{l}, \mathbf{v}, \mathbf{n})$$

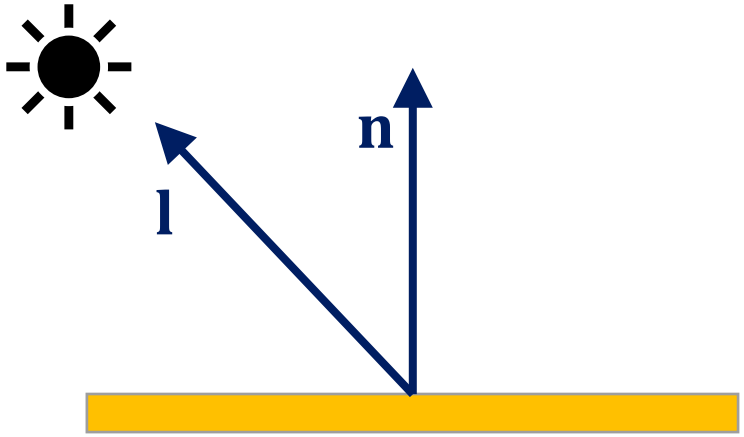
- Light $\mathbf{L}_{light}$ is emitted by a source, with some color and intensity.
- $\mathbf{L}_{diffuse}$ and $\mathbf{L}_{specular}$
  - Depends on angle between $\mathbf{l}$ and $\mathbf{n}$.
  - Depends of material.

Surface illumination

- Angle between surface normal and light surface direction influences the surface brightness.



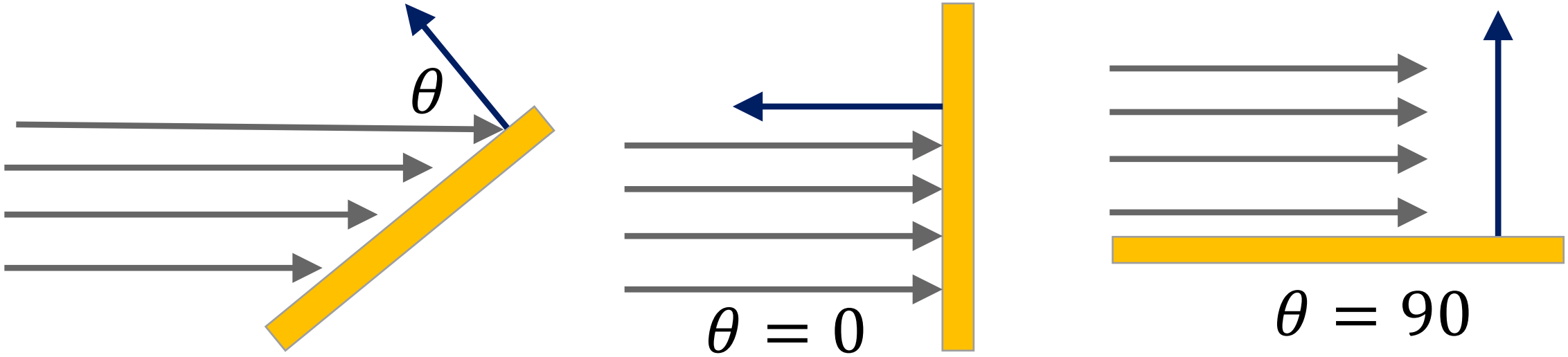
Surface receives more light per area, appears brighter.



Surface receives less light per area, appears darker.

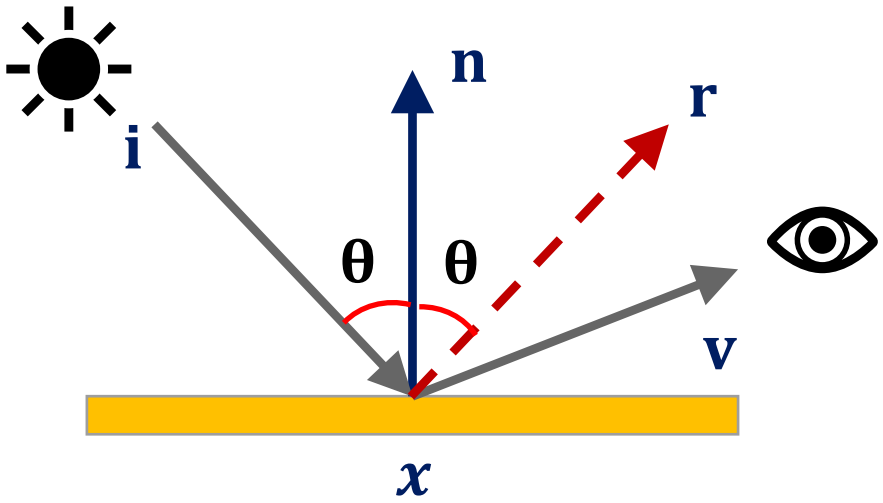
Lambert's cosine law

- Amount of light energy arriving at a surface is proportional to the cosine of the angle between the light direction and the surface normal.



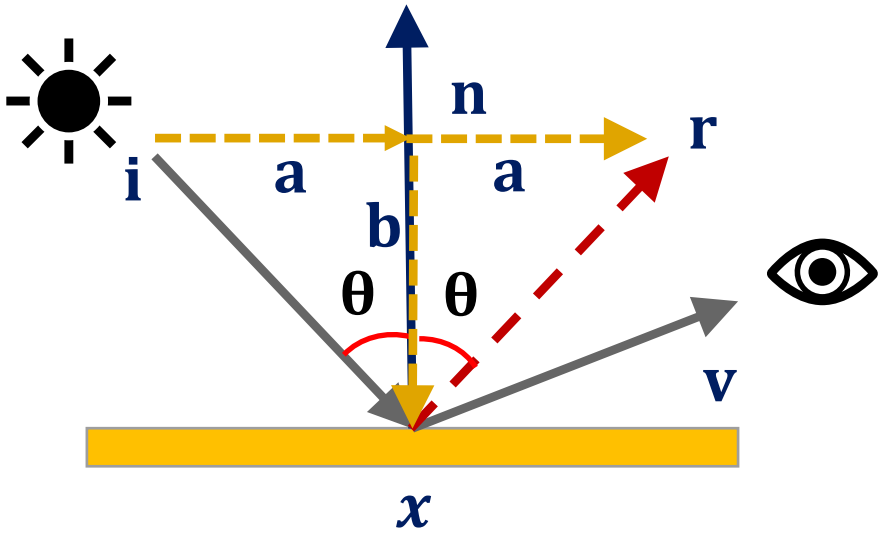
$\mathbf{L}_{surface} = \mathbf{L}_{light} cos(\theta)$ $\mathbf{L}_{surface} = \mathbf{L}_{light} cos(\theta) = \mathbf{L}_{light}$ $\mathbf{L}_{surface} = \mathbf{L}_{light} cos(\theta) = 0$

Law of reflection

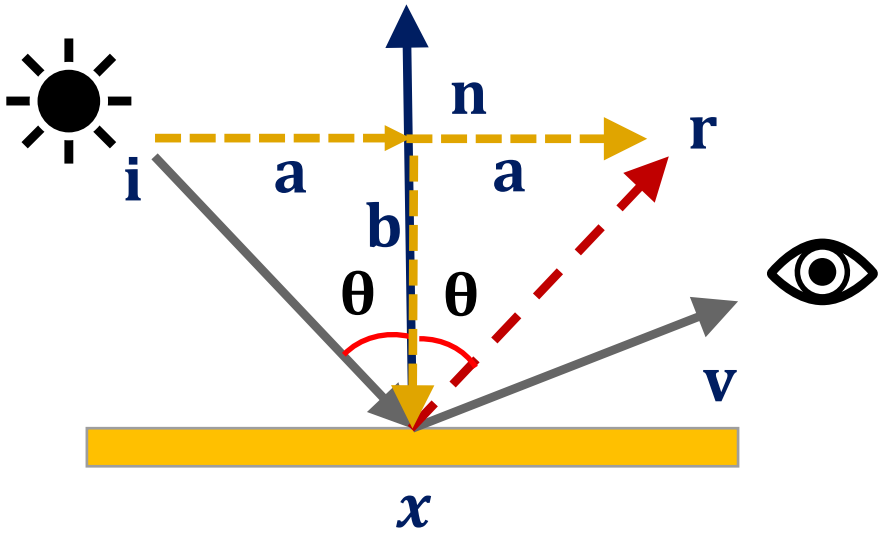


Law of reflection

$$\mathbf{r} = \mathbf{a} - \mathbf{b}$$
$$\mathbf{i} = \mathbf{a} + \mathbf{b}$$



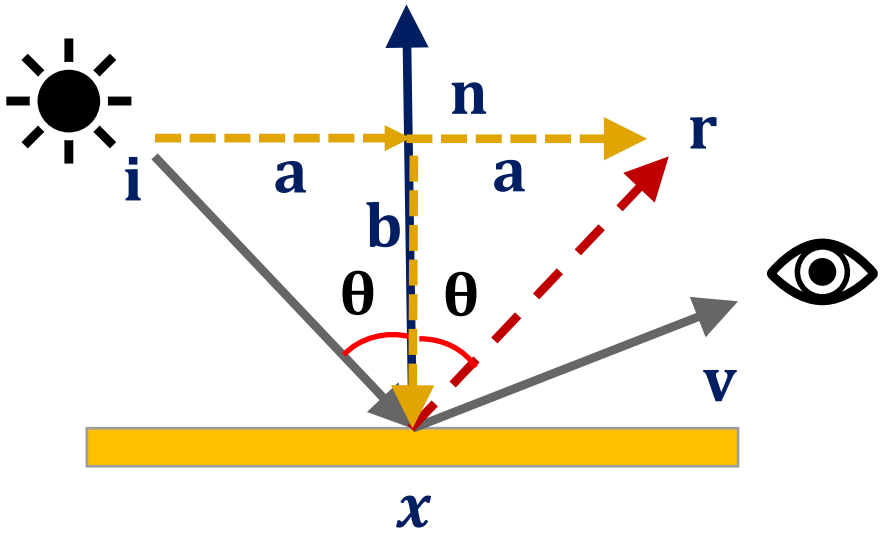
Law of reflection



$$\mathbf{r} = \mathbf{a} - \mathbf{b}$$
$$\mathbf{i} = \mathbf{a} + \mathbf{b}$$

$\mathbf{b} = \mathbf{n}\cos\theta$ (Projection of vector i onto n)

Law of reflection



$$\mathbf{r} = \mathbf{a} - \mathbf{b}$$
$$\mathbf{i} = \mathbf{a} + \mathbf{b}$$

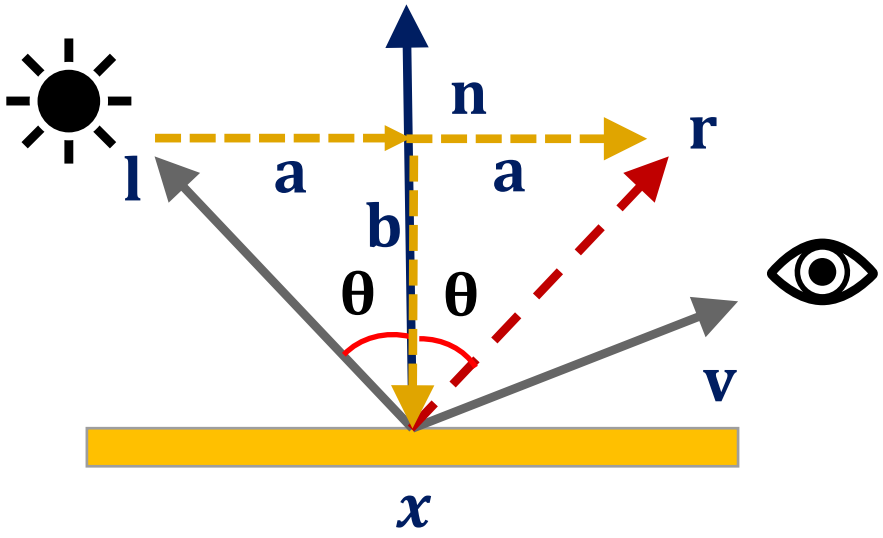
$$\mathbf{b} = \mathbf{n}\cos\theta$$

$$\mathbf{r} = \mathbf{a} - \mathbf{n}\cos\theta$$
$$\mathbf{i} = \mathbf{a} + \mathbf{n}\cos\theta \rightarrow \mathbf{a} = \mathbf{i} - \mathbf{n}\cos\theta$$

$$\mathbf{r} = \mathbf{i} - \mathbf{n}\cos\theta - \mathbf{n}\cos\theta$$
$$\mathbf{r} = \mathbf{i} - 2\mathbf{n}\cos\theta$$
$$\mathbf{r} = \mathbf{i} - 2\mathbf{n}(\mathbf{i} \cdot \mathbf{n})$$

$\mathbf{r} = \mathbf{i} - 2\mathbf{n}(\mathbf{i} \cdot \mathbf{n})$ (with incident direction)

Law of reflection



$$\mathbf{r} = \mathbf{a} - \mathbf{b}$$
$$\mathbf{i} = \mathbf{a} + \mathbf{b}$$

$$\mathbf{b} = \mathbf{n}\cos\theta$$

$$\mathbf{r} = \mathbf{a} - \mathbf{n}\cos\theta$$
$$\mathbf{i} = \mathbf{a} + \mathbf{n}\cos\theta \rightarrow \mathbf{a} = \mathbf{i} - \mathbf{n}\cos\theta$$

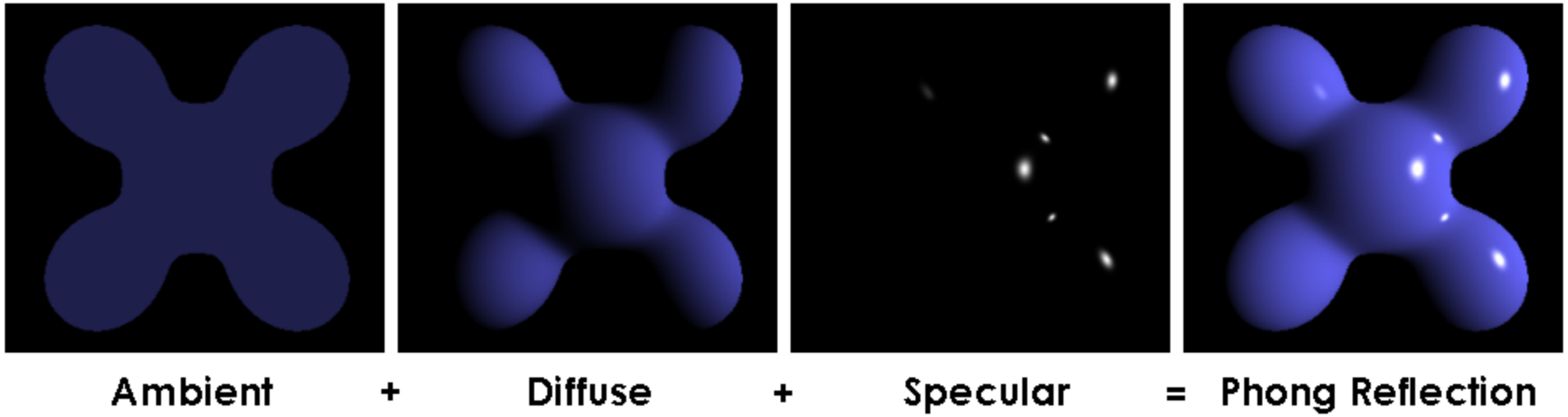
$$\mathbf{r} = \mathbf{i} - \mathbf{n}\cos\theta - \mathbf{n}\cos\theta$$
$$\mathbf{r} = \mathbf{i} - 2\mathbf{n}\cos\theta$$
$$\mathbf{r} = \mathbf{i} - 2\mathbf{n}(\mathbf{i} \cdot \mathbf{n})$$

$\mathbf{r} = \mathbf{i} - 2\mathbf{n}(\mathbf{i} \cdot \mathbf{n})$ (with incident direction)

$\mathbf{r} = 2\mathbf{n}(\mathbf{l} \cdot \mathbf{n}) - \mathbf{l}$ (with light direction)

Phong model

$$f_{Phong}(\mathbf{L}_{light}, \mathbf{l}, \mathbf{v}, \mathbf{n}) = k_{ambient}\mathbf{L}_{ambient} + \sum_{m \in lights} k_{diffuse}(\mathbf{l_m} \cdot \mathbf{n})\mathbf{L}_{m,diffuse} + k_{specular}(\mathbf{r_m} \cdot \mathbf{v})^{\alpha}\mathbf{L}_{m,specular}$$



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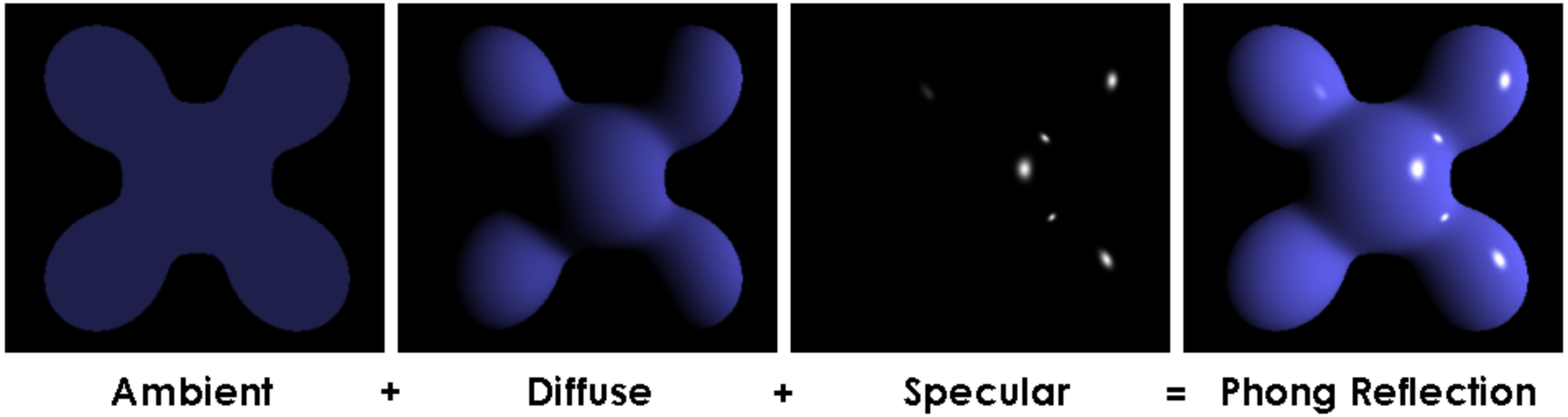
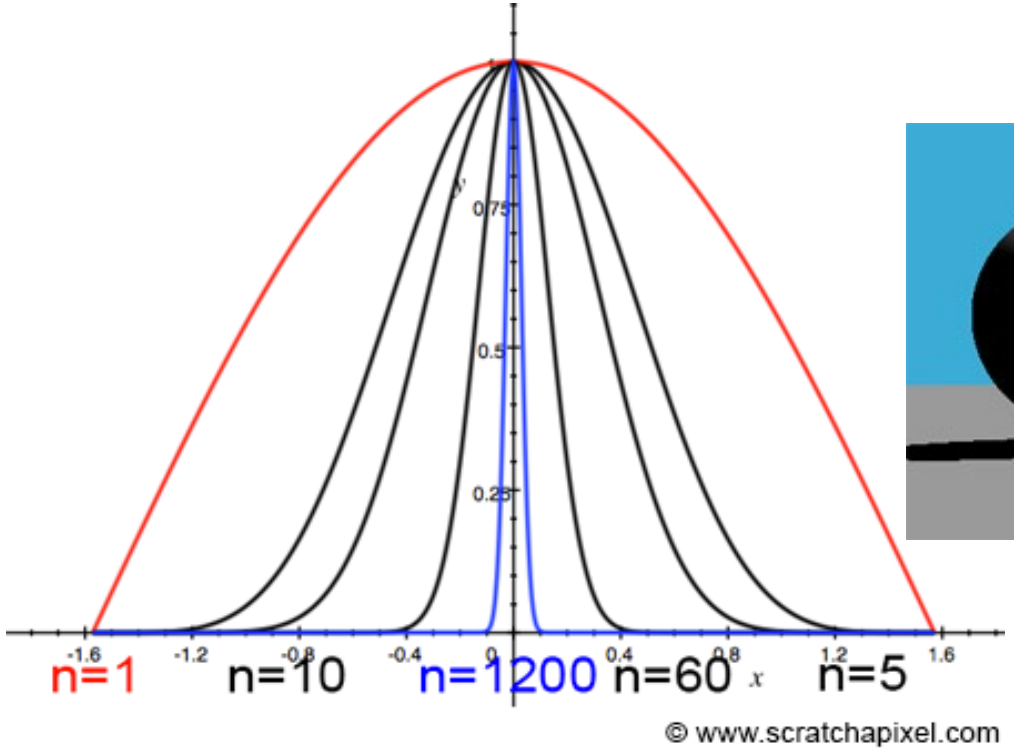
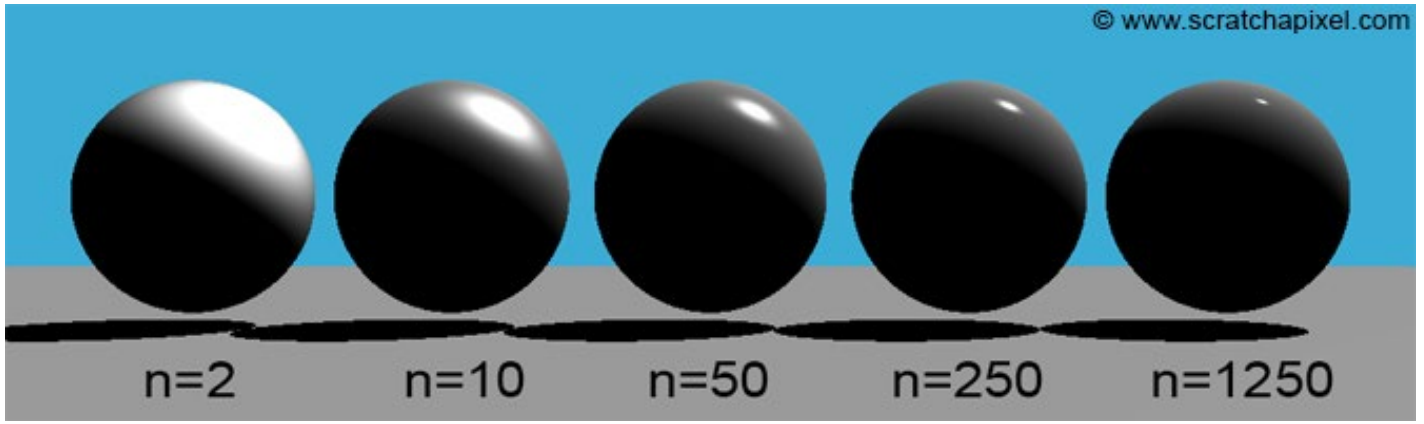
$$\mathbf{r_m} = 2(\mathbf{l_m} \cdot \mathbf{n})\mathbf{n} - \mathbf{l_m}$$



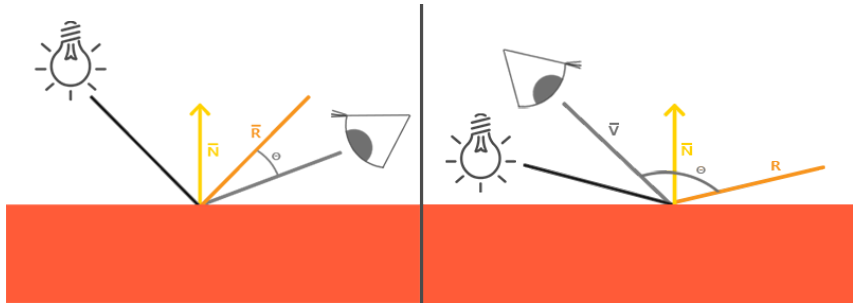
Specular exponent





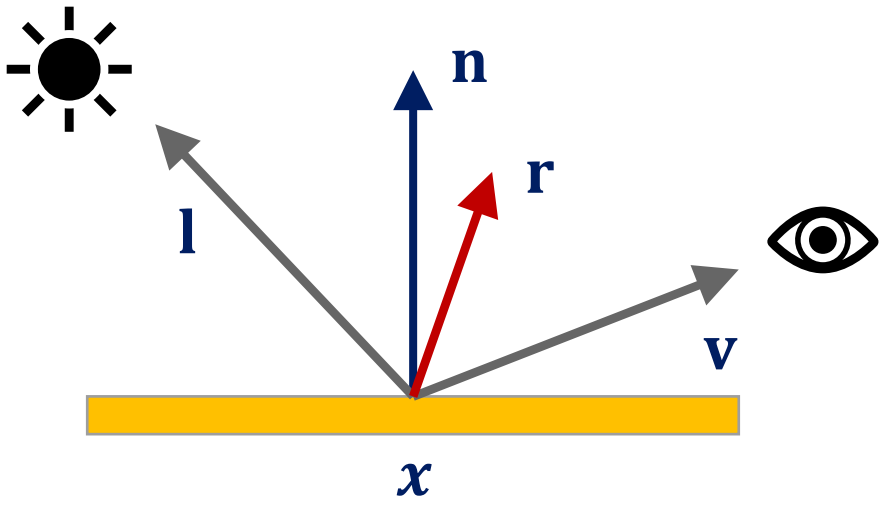
Blinn-Phong model

- A slight modification of the Phong reflection model.
- Purpose is to speed up the computation (not relevant today), and account for $\mathbf{v}$ and $\mathbf{r}$ greater than 90 degrees.
- Modification only affects specular reflection.
- Main goal: avoid computation of the reflected direction $\hat{\mathbf{r}}$.



Blinn-Phong model

- Half-way vector:



$$\mathbf{h} = \frac{\mathbf{l} + \mathbf{v}}{\|\mathbf{l} + \mathbf{v}\|}$$

Blinn-Phong model

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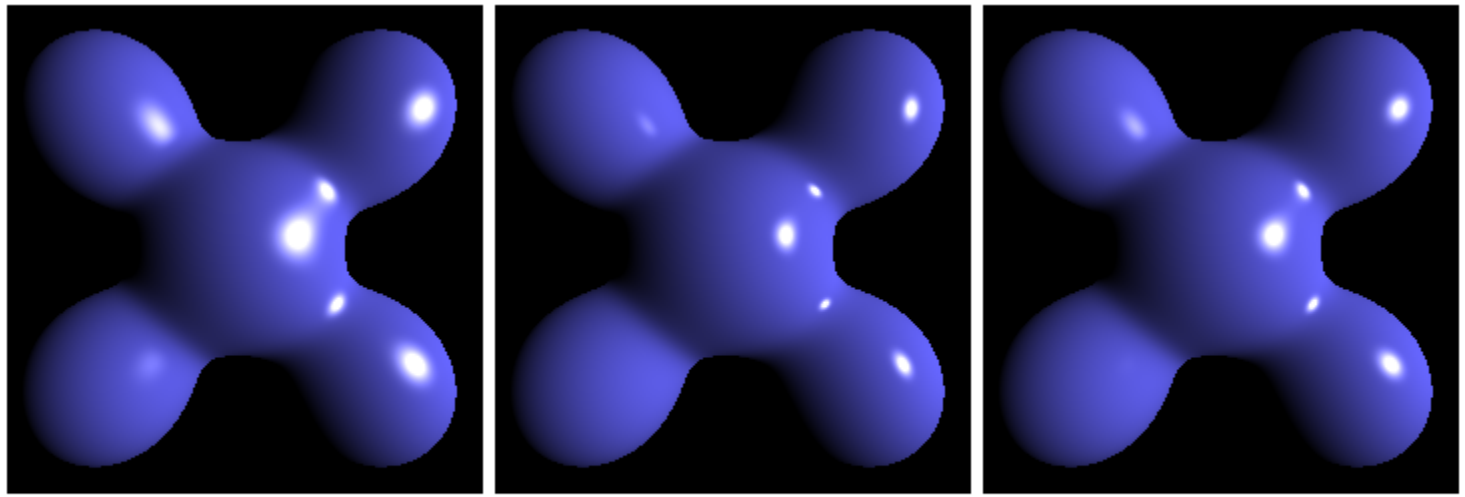

Different components