Real-Time Volume Graphics

[07] Global Volume Illumination

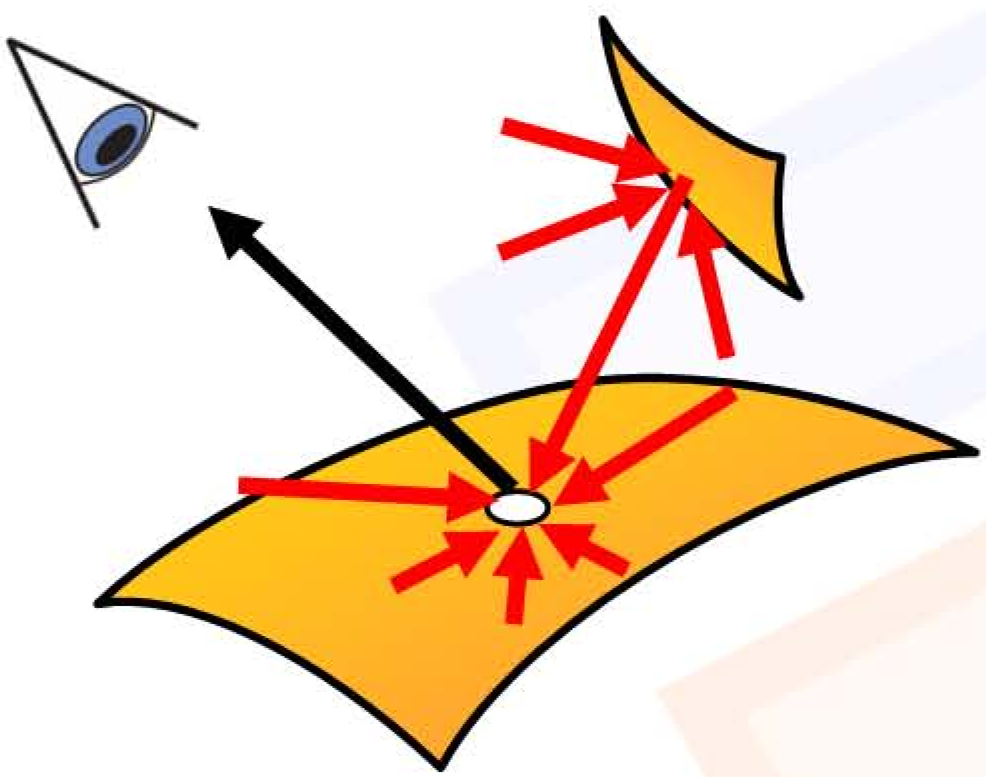
Why Global Illumination

Local illumination

- might sufficient for many application areas in scientific visualization (e.g medicine)
- Not sufficient for visual arts/photorealism!
- Appearance of many common objects is dominated by scattering effects
  - Smoke, clouds
  - Wax, skin, translucent materials

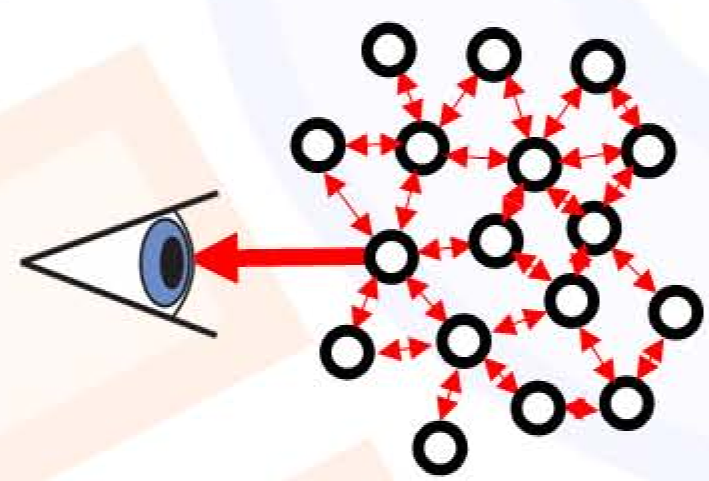
Surface vs Volume Illumination

Surface Lighting



Volume Lighting

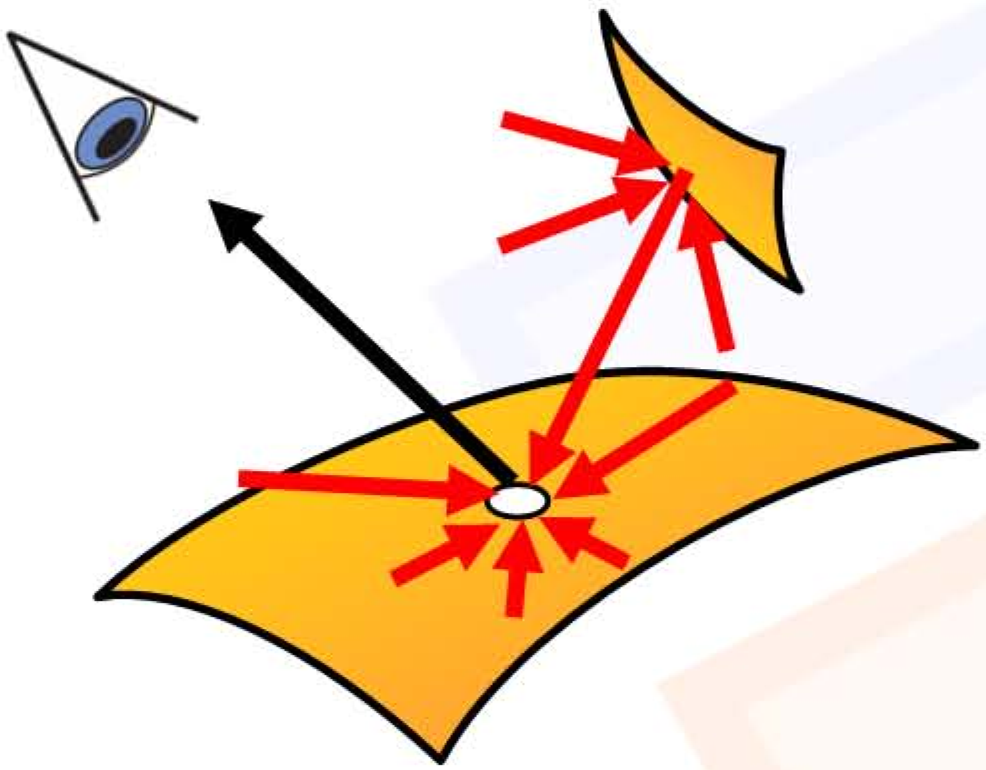
- Light transport in participating medium
- Lighing Calculation at *every* point
- Scattering from *phase function*



Surface vs Volume Illumination

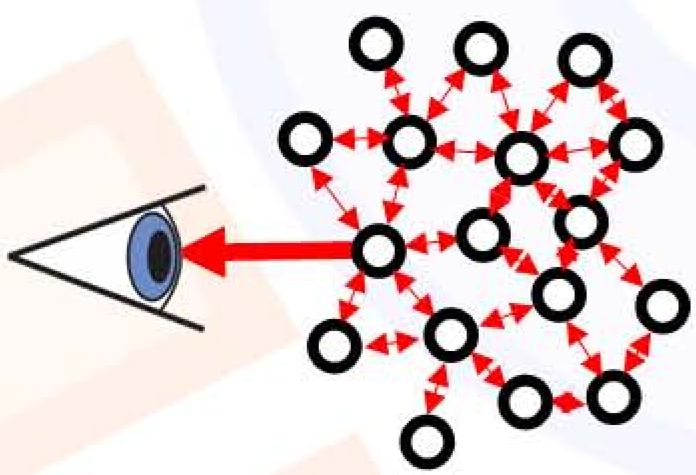
Surface Lighting

- Light transport in vacuum
- Lighting calculation is performed at surface points
- Reflectivity from *BRDF*



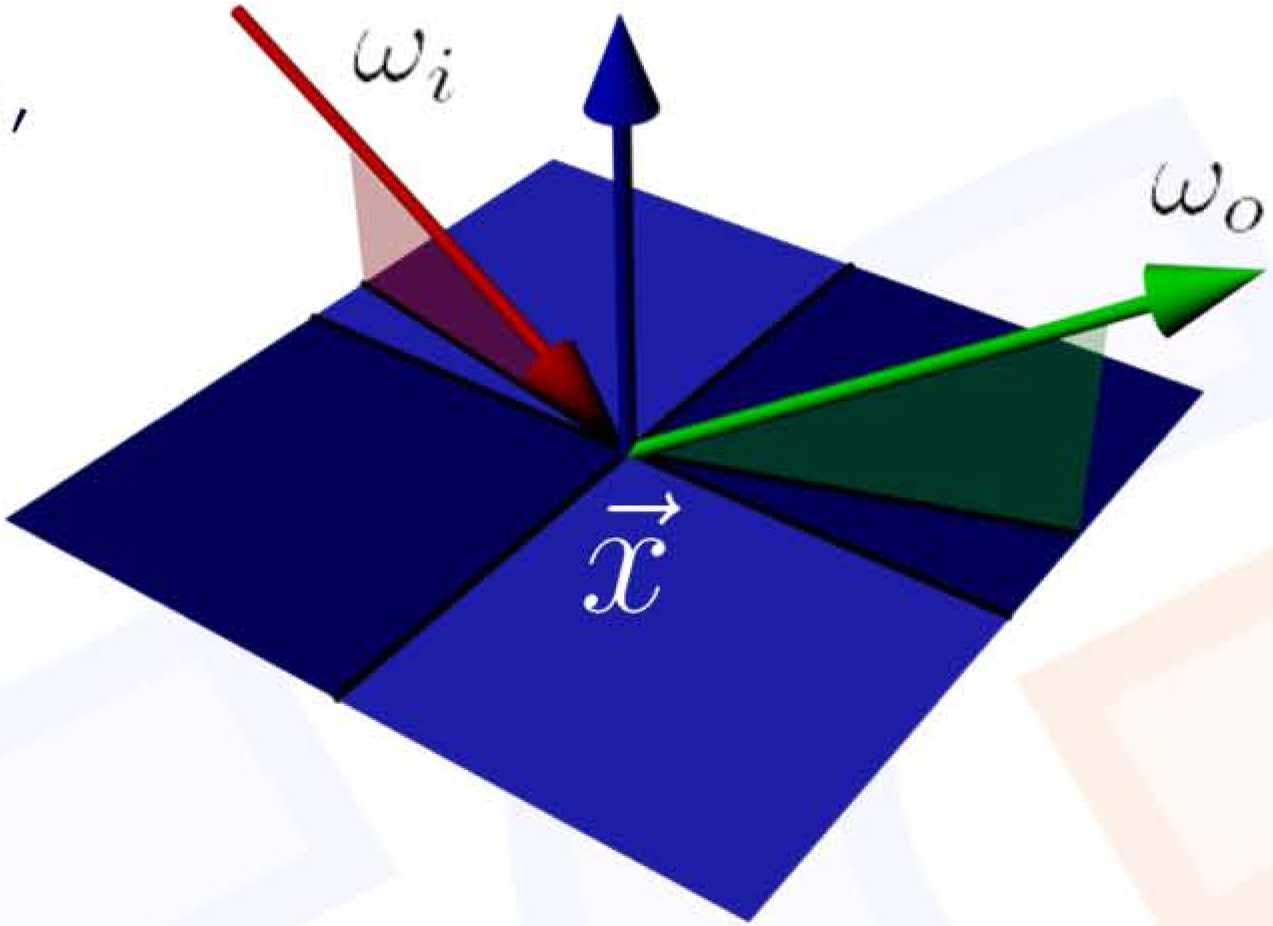
Volume Lighting

- Light transport in participating medium
- Lighing Calculation at *every* point
- Scattering from *phase function*



Surface Illumination

The incoming radiance L_i,
at a point $\vec{x}$
from direction
$\omega_i = (\theta_i, \phi_i)$
will partially be reflected
into direction
$\omega_o = (\theta_o, \phi_o)$

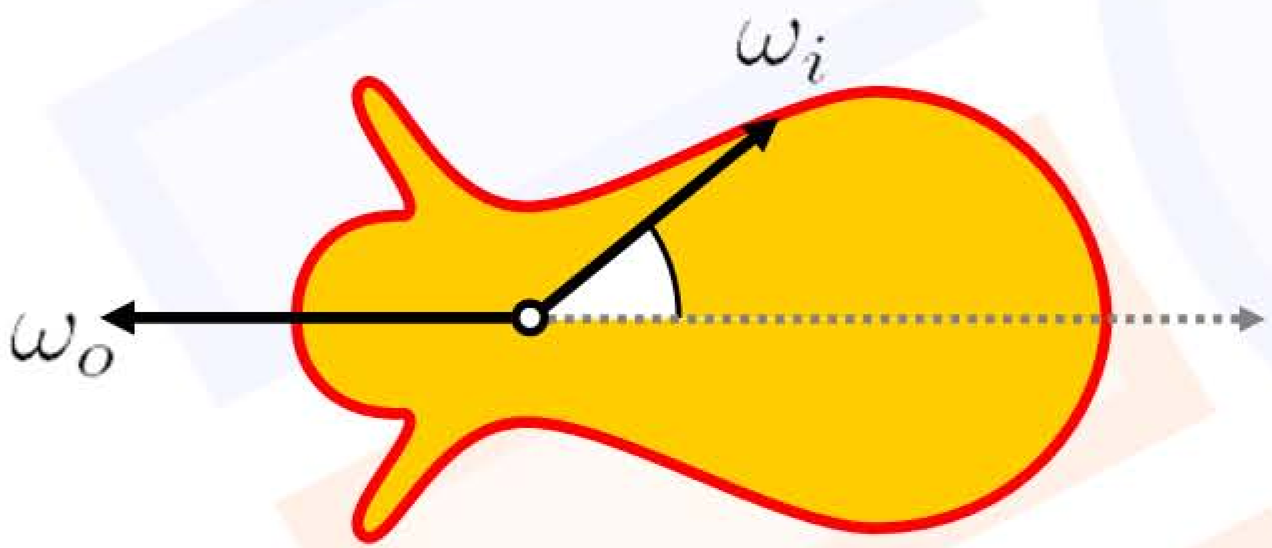


To obtain the radiance at $\vec{x}$, we must account for all possible incoming directions:

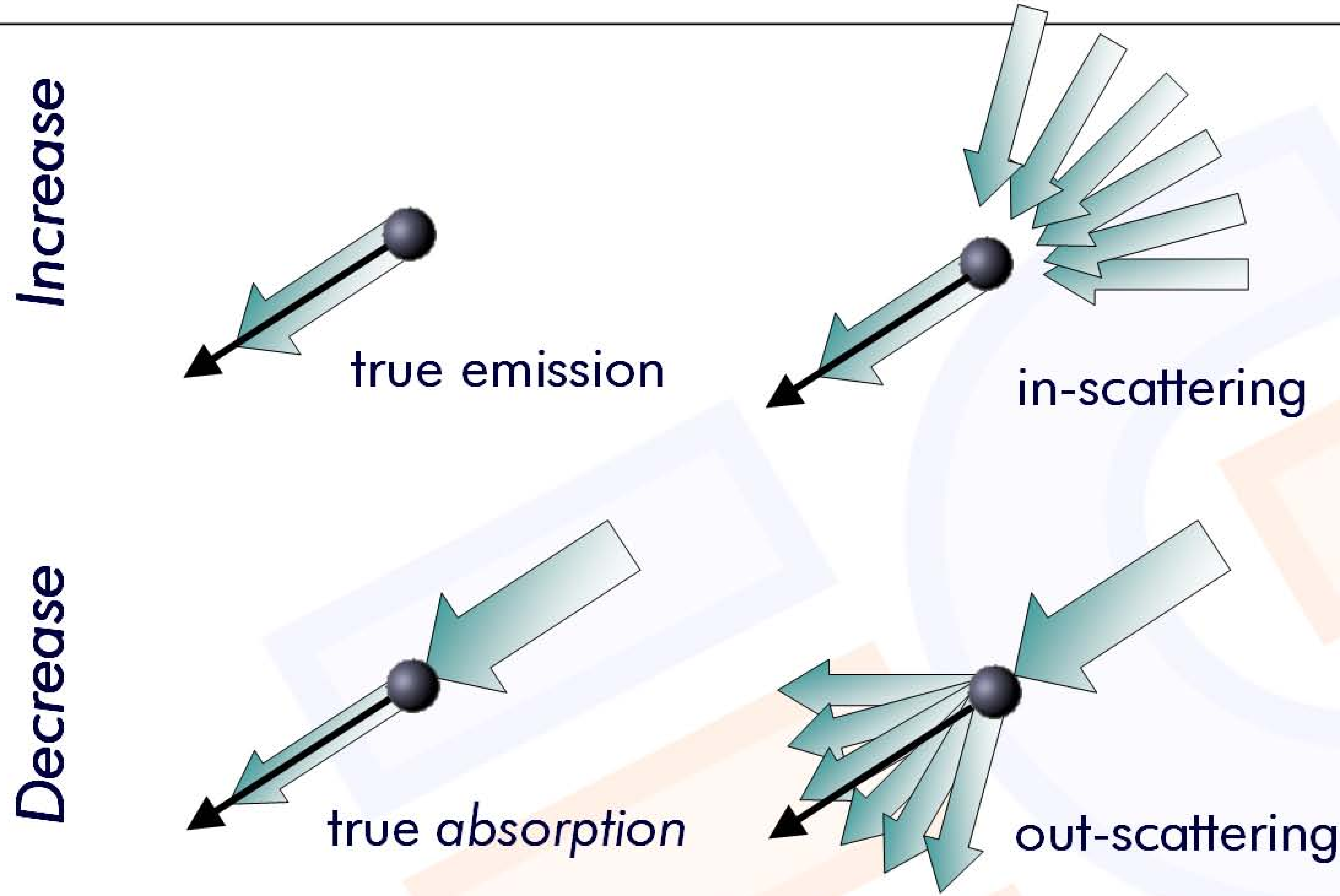
$$L_o(\vec{x}, \vec{\omega}_o) = \int_\Omega f(\vec{x}, \vec{\omega}_i \rightarrow \vec{\omega}_o) L_i(\vec{x}, \vec{\omega}_i) \cos\theta_i \, d\omega_i$$

Phase Functions

- For ***surfaces***, the BRDF describes the probability of light being reflected from one direction ω_i on the hemisphere into another direction ω_o .
- For ***volumes***, the phase function $p(\mathbf{x}, \omega_o, \omega_i)$ describes the probability of light being scattered from direction into direction

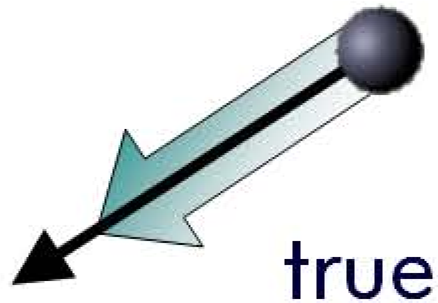


Physical Model of Radiative Transfer

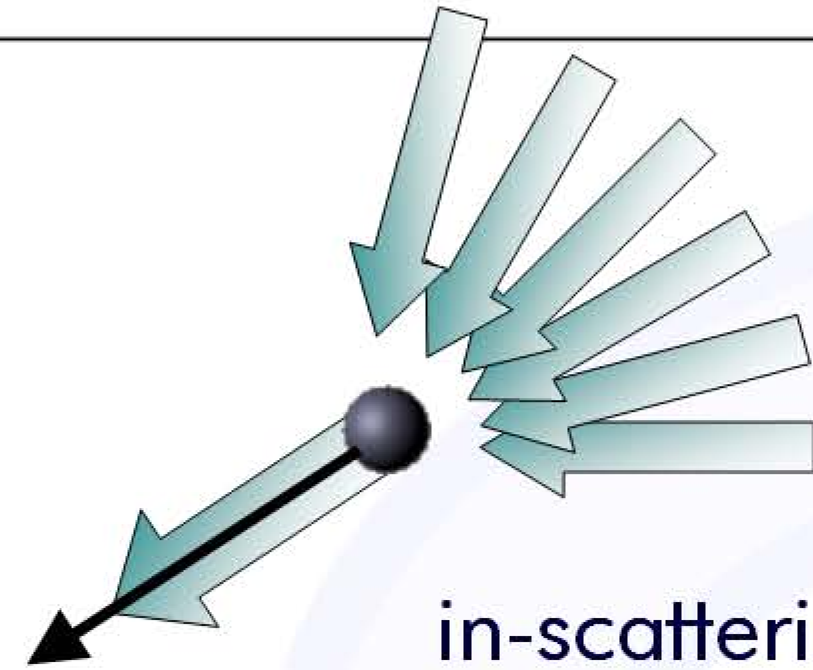


Physical Model of Radiative Transfer

Increase



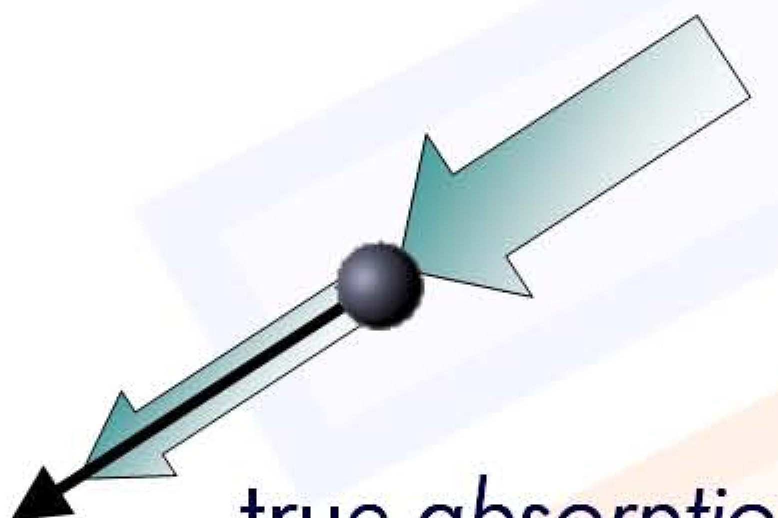
true emission



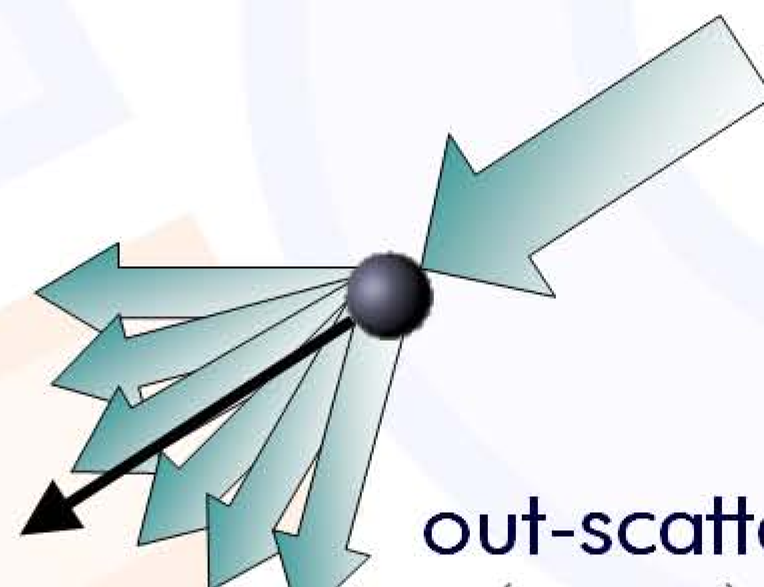
in-scattering

$$\eta(\mathbf{x},\omega) \quad = \quad q(\mathbf{x},\omega) \qquad + j(\mathbf{x},\omega)$$

Decrease



true *absorption*



out-scattering

$$\chi(\mathbf{x},\omega) \quad = \quad \kappa(\mathbf{x},\omega) \qquad + \sigma(\mathbf{x},\omega)$$

Scattering

- In-scattering

Out-scattering coefficient | Phase function | Incoming radiance

$$j(\mathbf{x},\omega) = \frac{1}{4\pi}\int_{\text{sphere}} \sigma(\mathbf{x},\omega')p(\mathbf{x},\omega',\omega)I(\mathbf{x},\omega')\mathrm{d}\omega'$$

- Volume Rendering Equation:

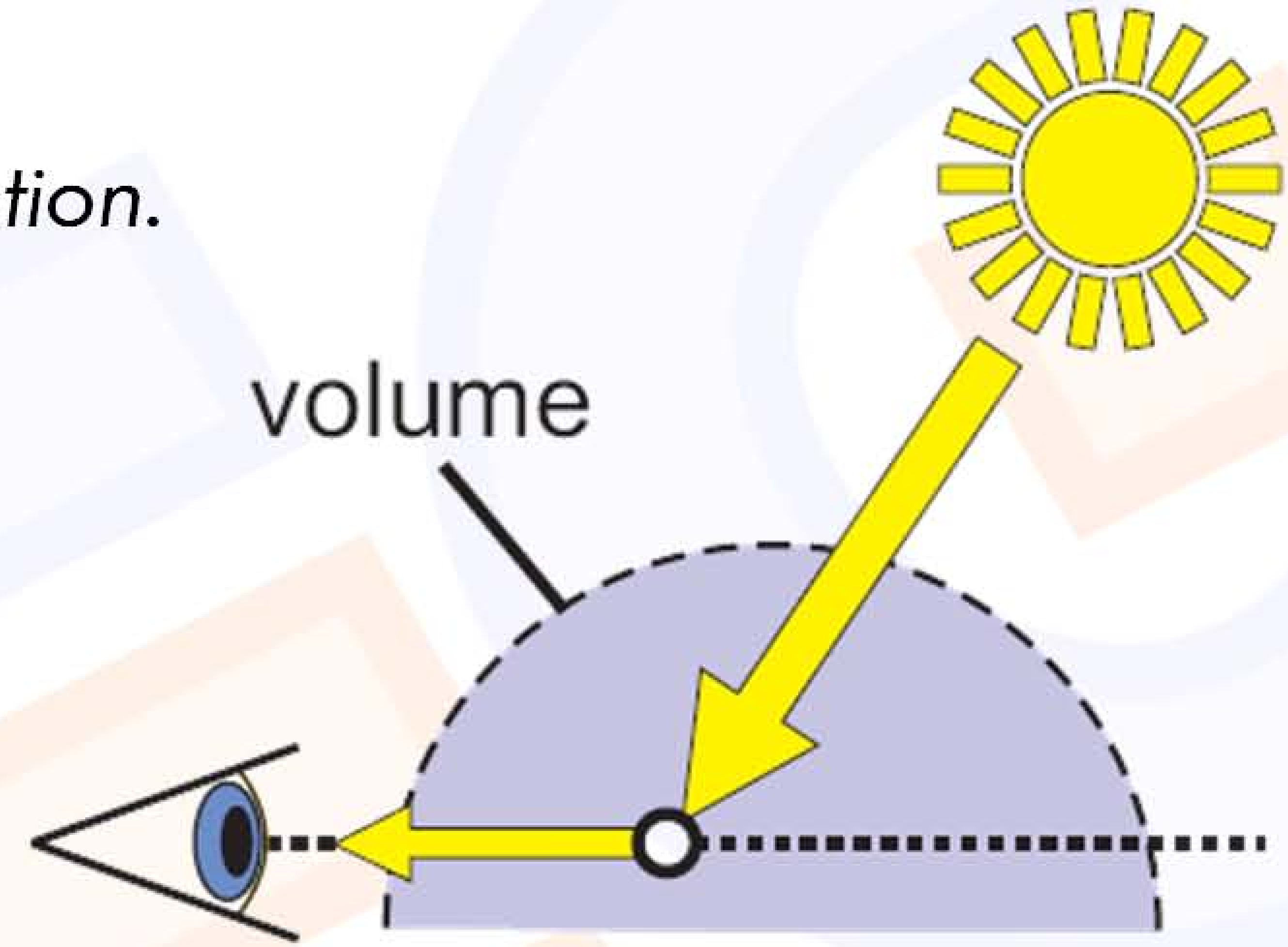
$$\omega \cdot \nabla_{\mathbf{x}} I(\mathbf{x},\omega) = -(\kappa(\mathbf{x},\omega)+\sigma(\mathbf{x},\omega))I(\mathbf{x},\omega) + q(\mathbf{x},\omega) + \int_{\text{sphere}} \sigma(\mathbf{x},\omega')p(\mathbf{x},\omega',\omega)I(\mathbf{x},\omega')\,\mathrm{d}\omega'$$

Volume Illumination

- *Up until now:* External light is not attenuated
- *Now:* Attenuation of light as it travels through the volume

Single scattering, no attenuation.

- Light reaches every point unimpededly
- Light is scattered once before it reaches the eye
- Not physically plausible

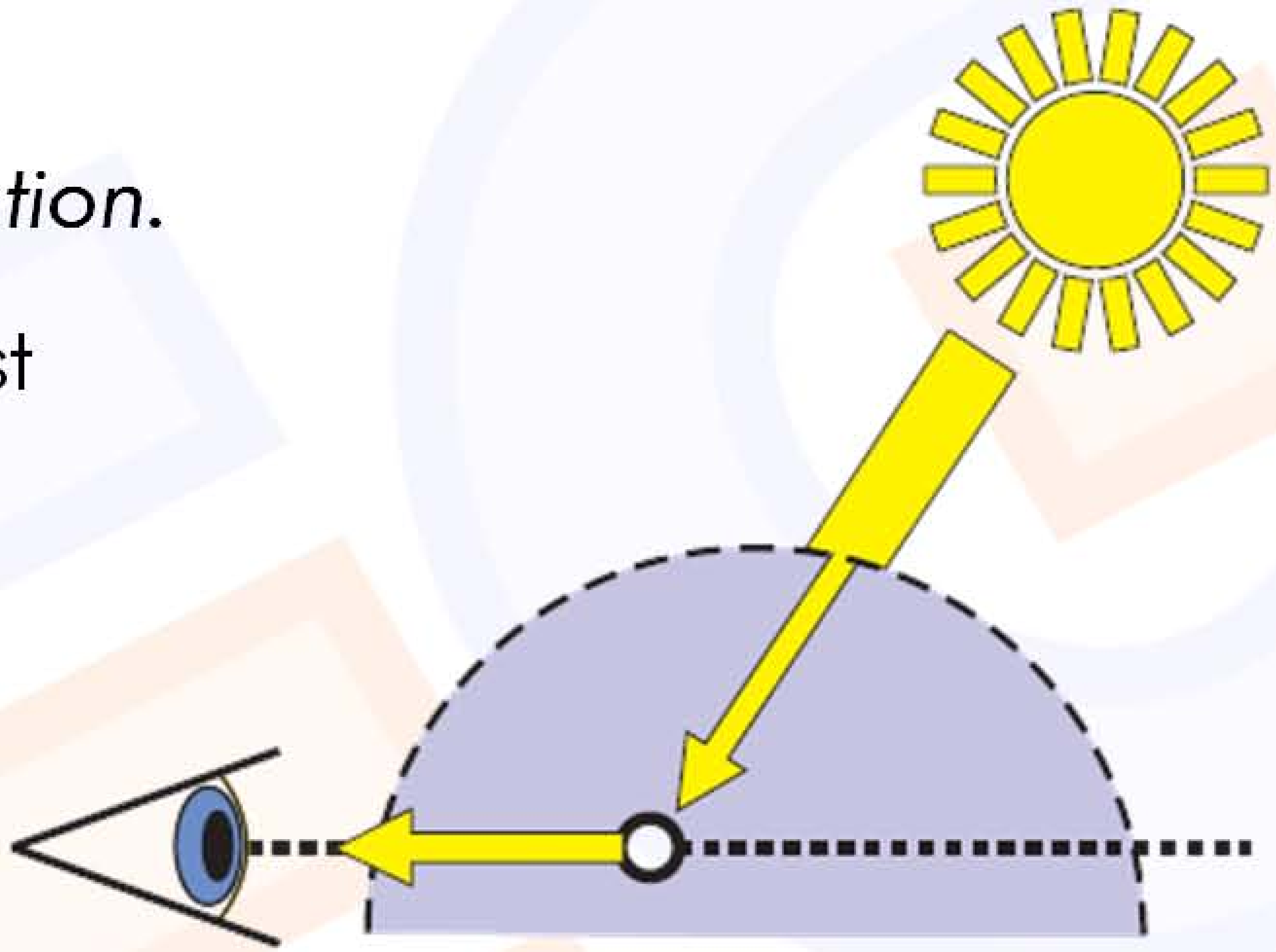


Volume Illumination

- *Up until now:* External light is not attenuated
- *Now:* Attenuation of light as it travels through the volume

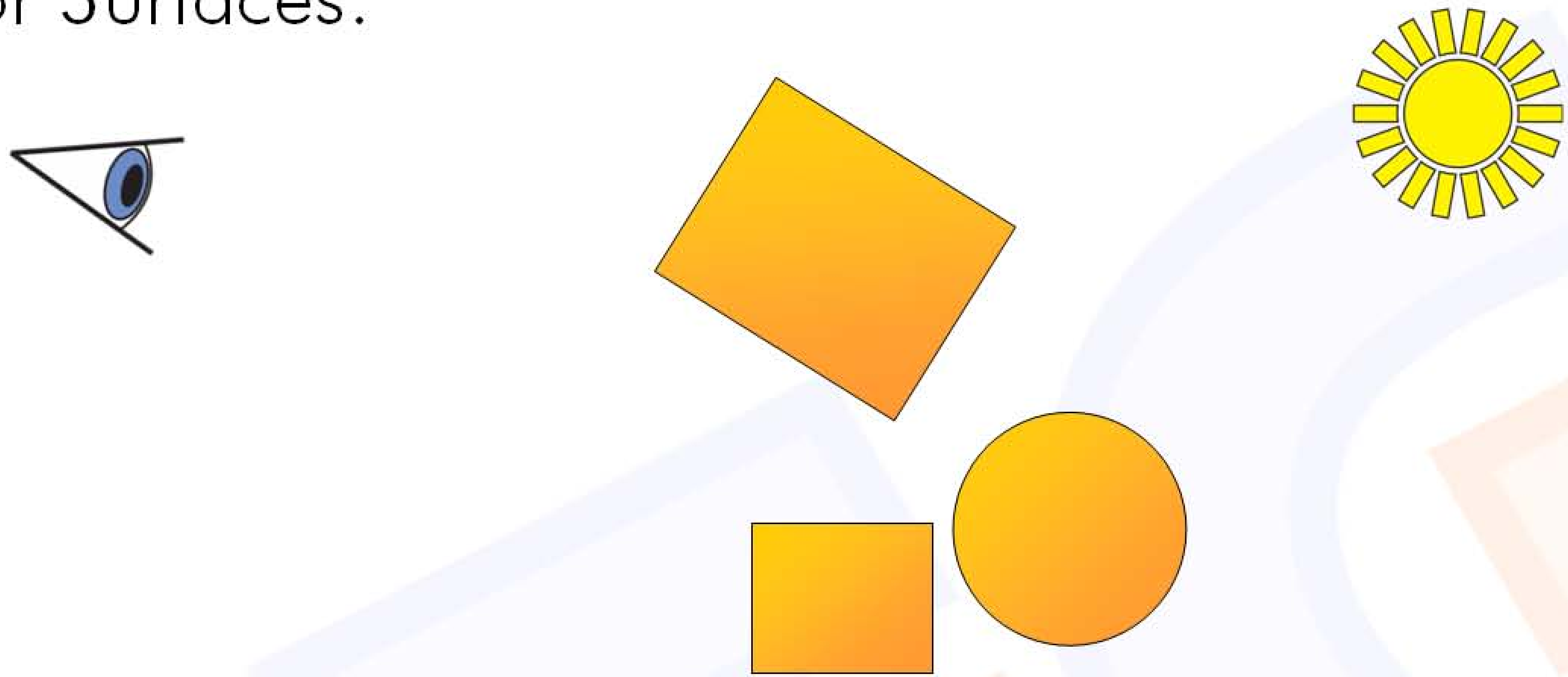
Single scattering with attenuation.

- Light is attenuated along ist way through the volume (*Volumetric shadows*)
- Light is scattered once before it reaches the eye



Shadows Maps

- For Surfaces:



Shadows Maps

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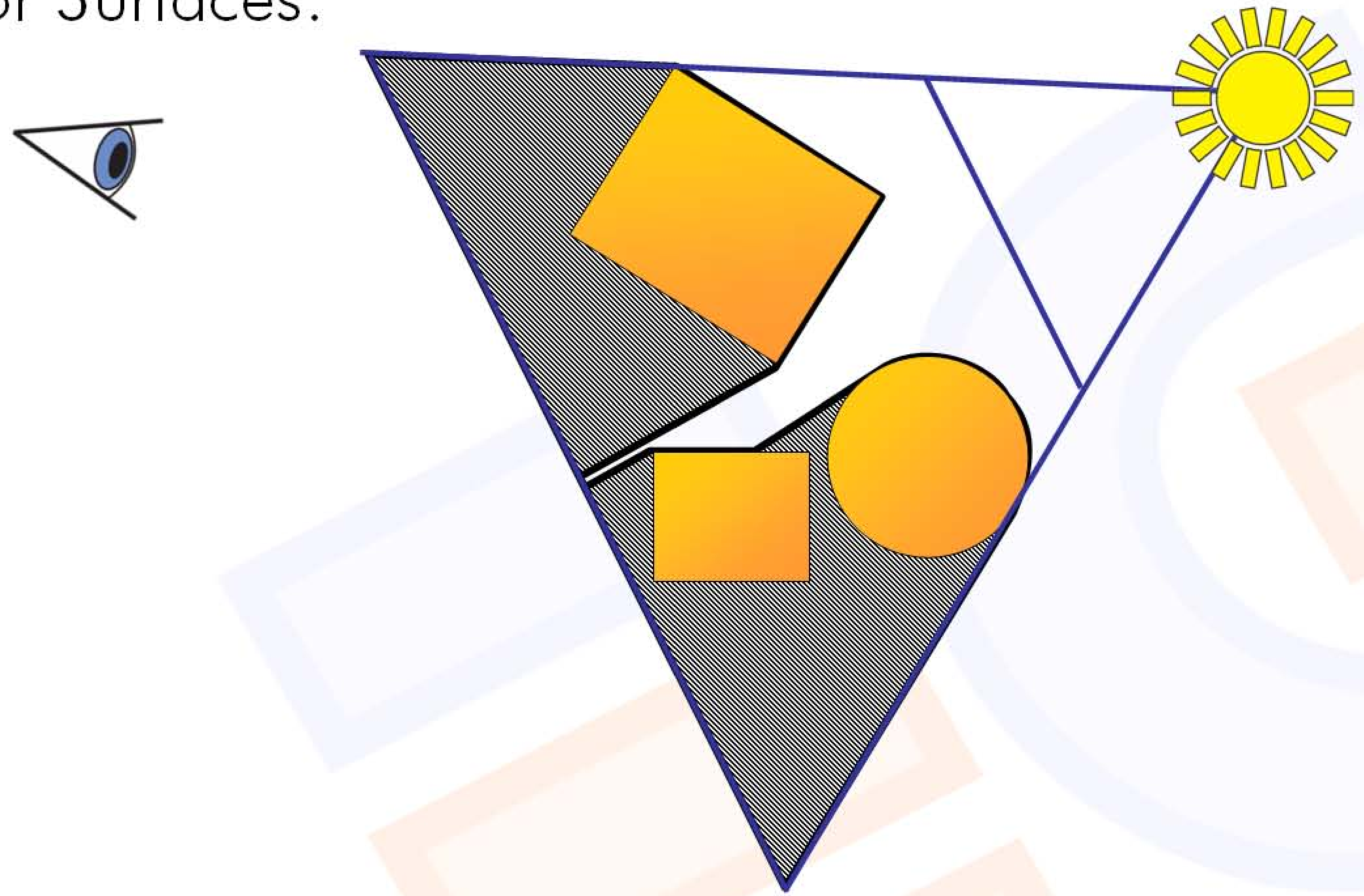

Shadows Maps

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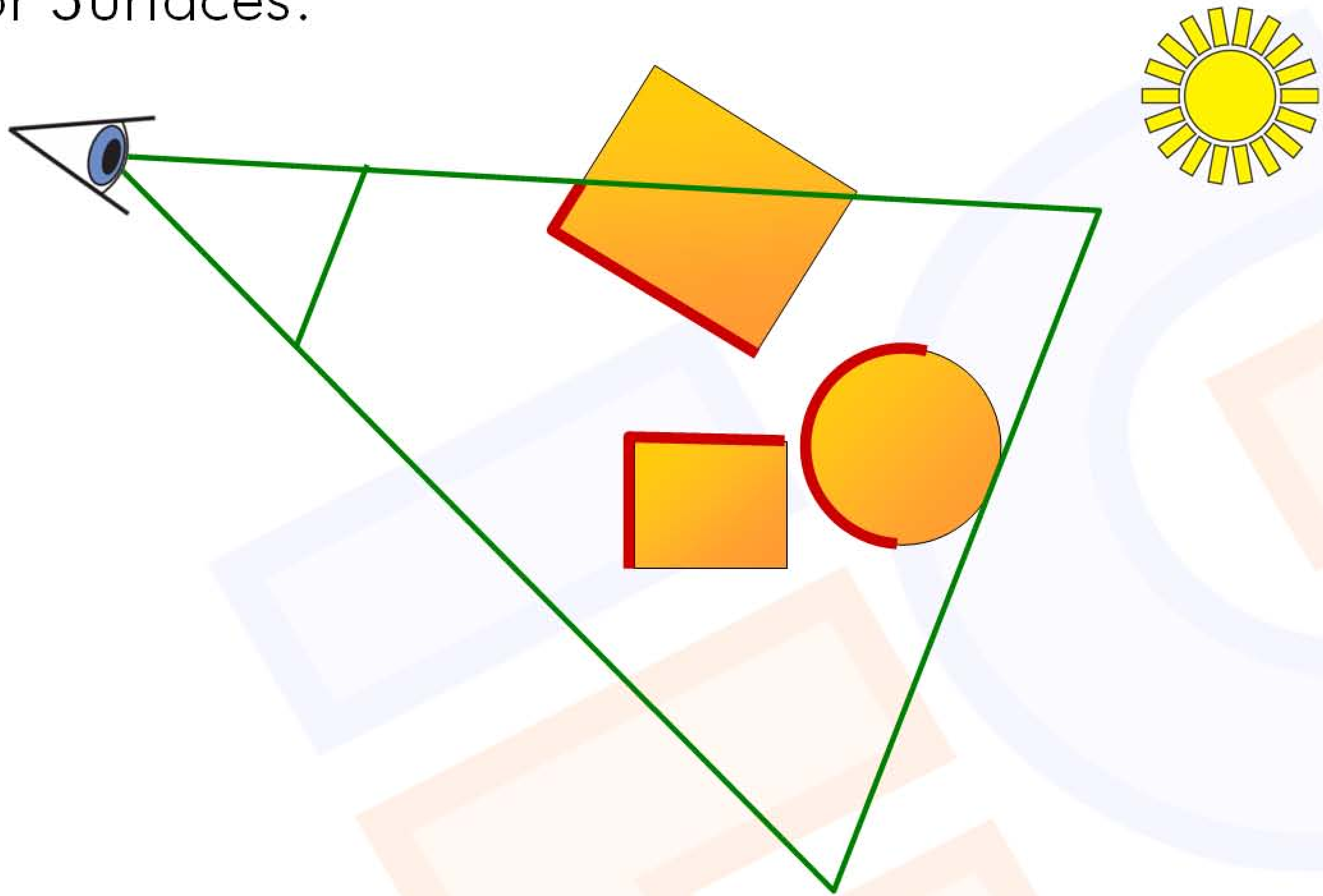

Shadows Maps

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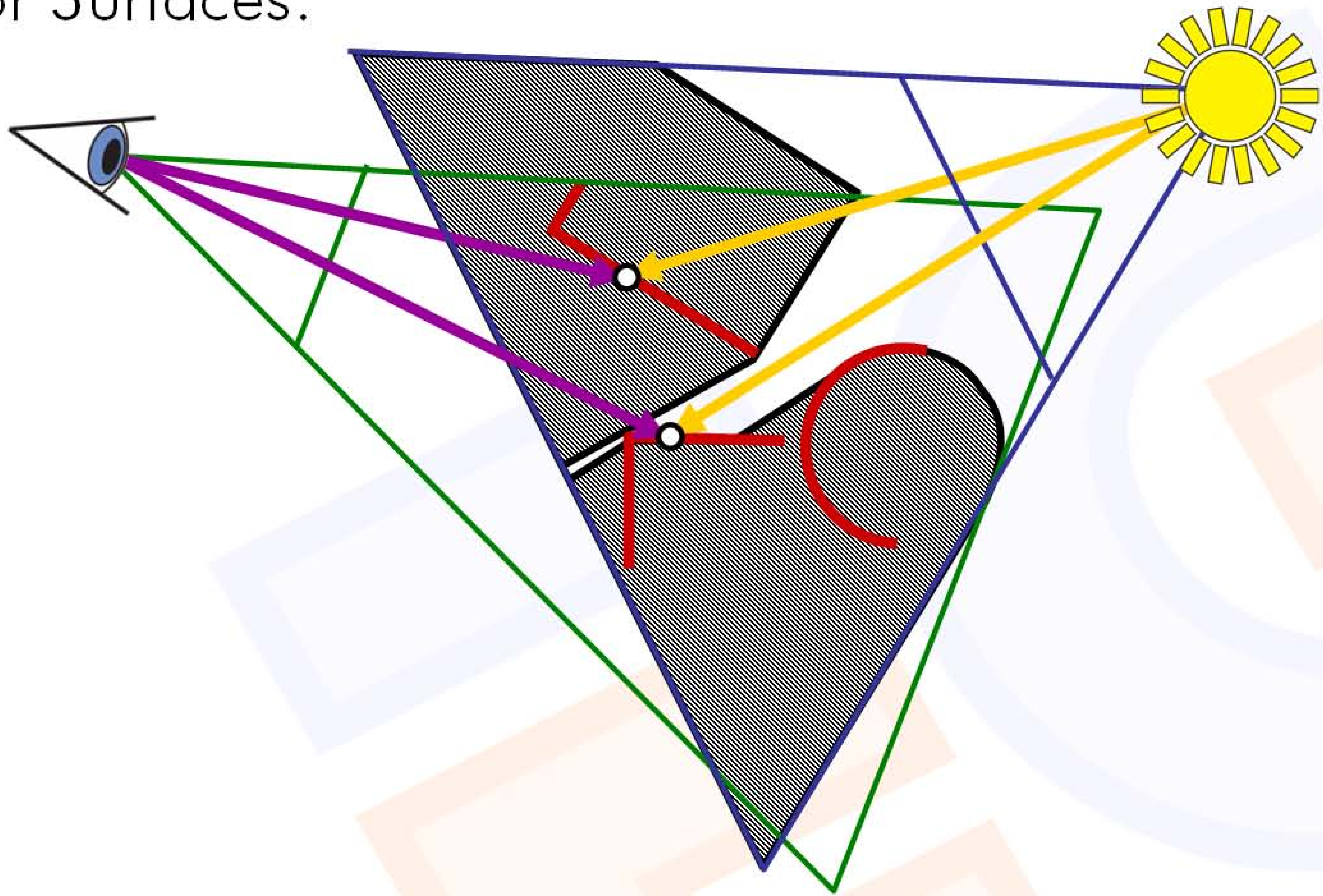
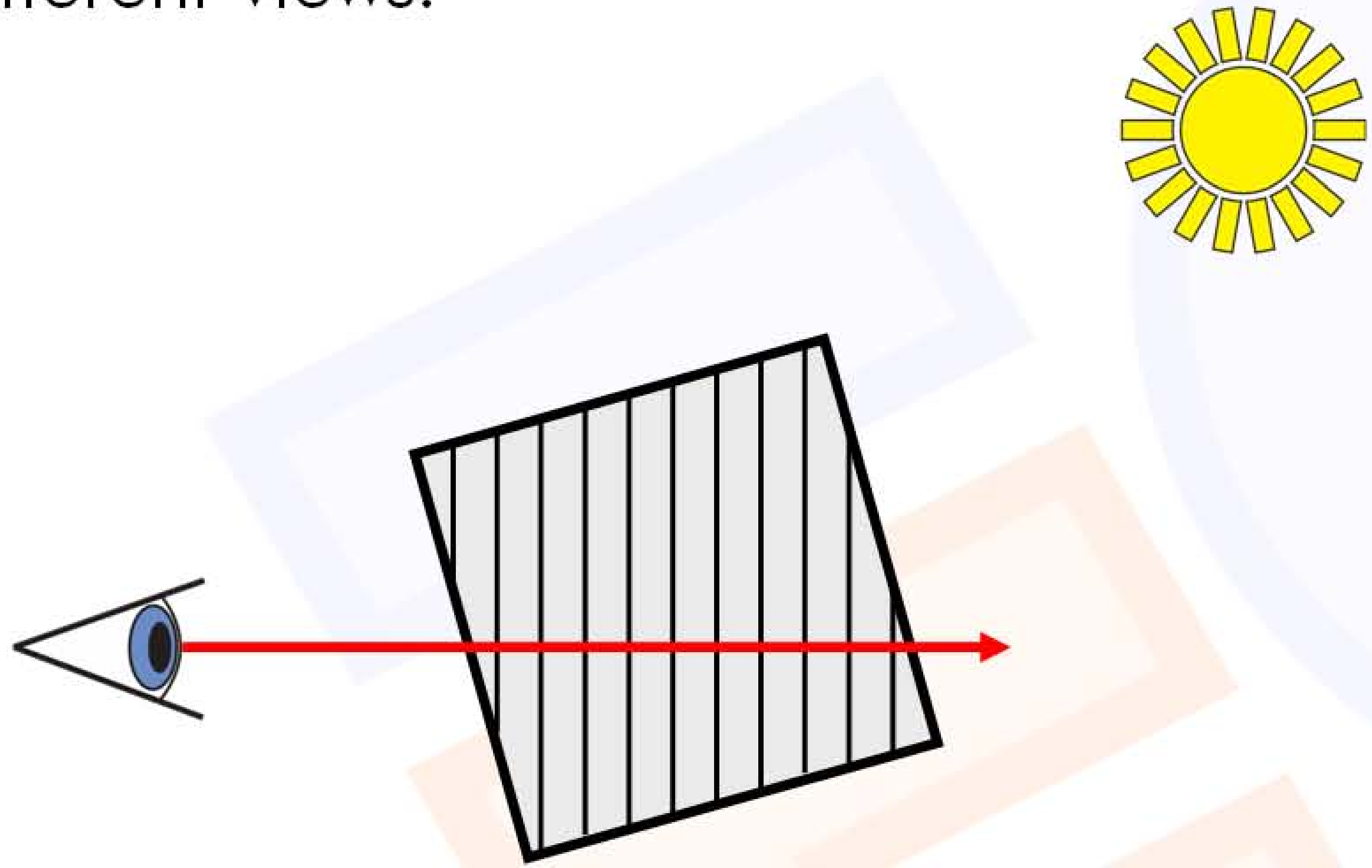


Shadow Maps

- For Volume Rendering:
  - Update image and shadow buffer slice-by-slice
  - Need proxy geometry, that can be rendered from two different views.



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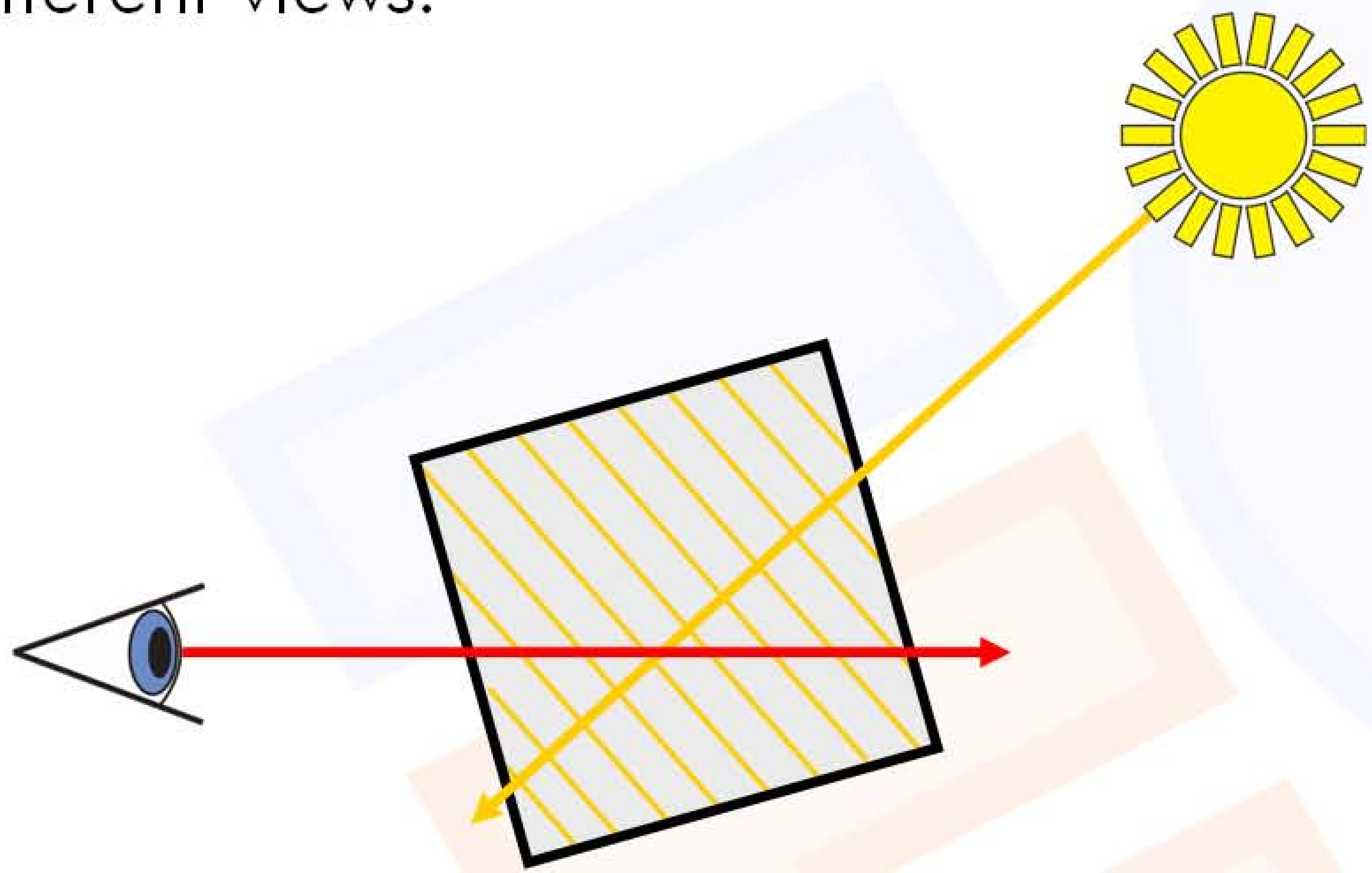

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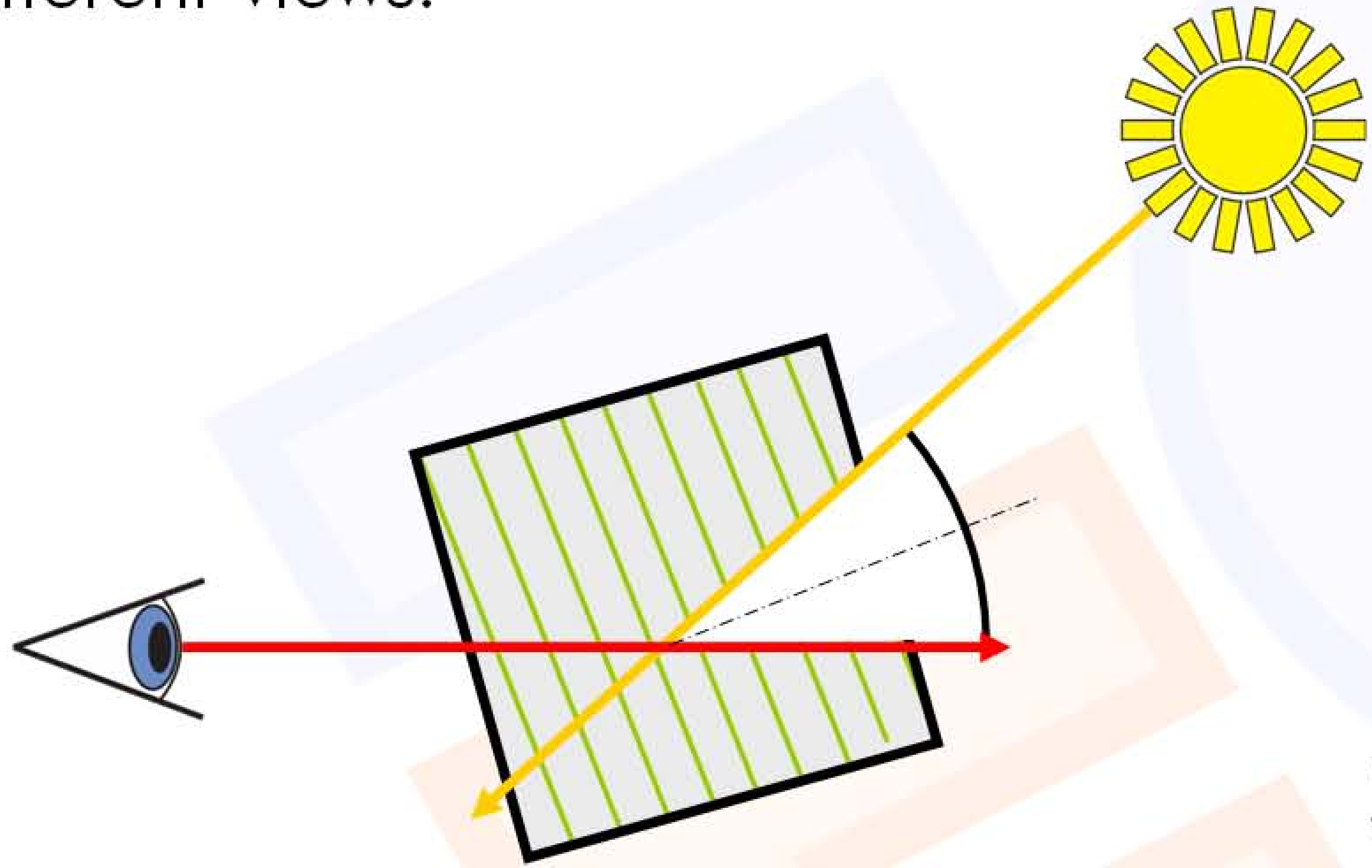
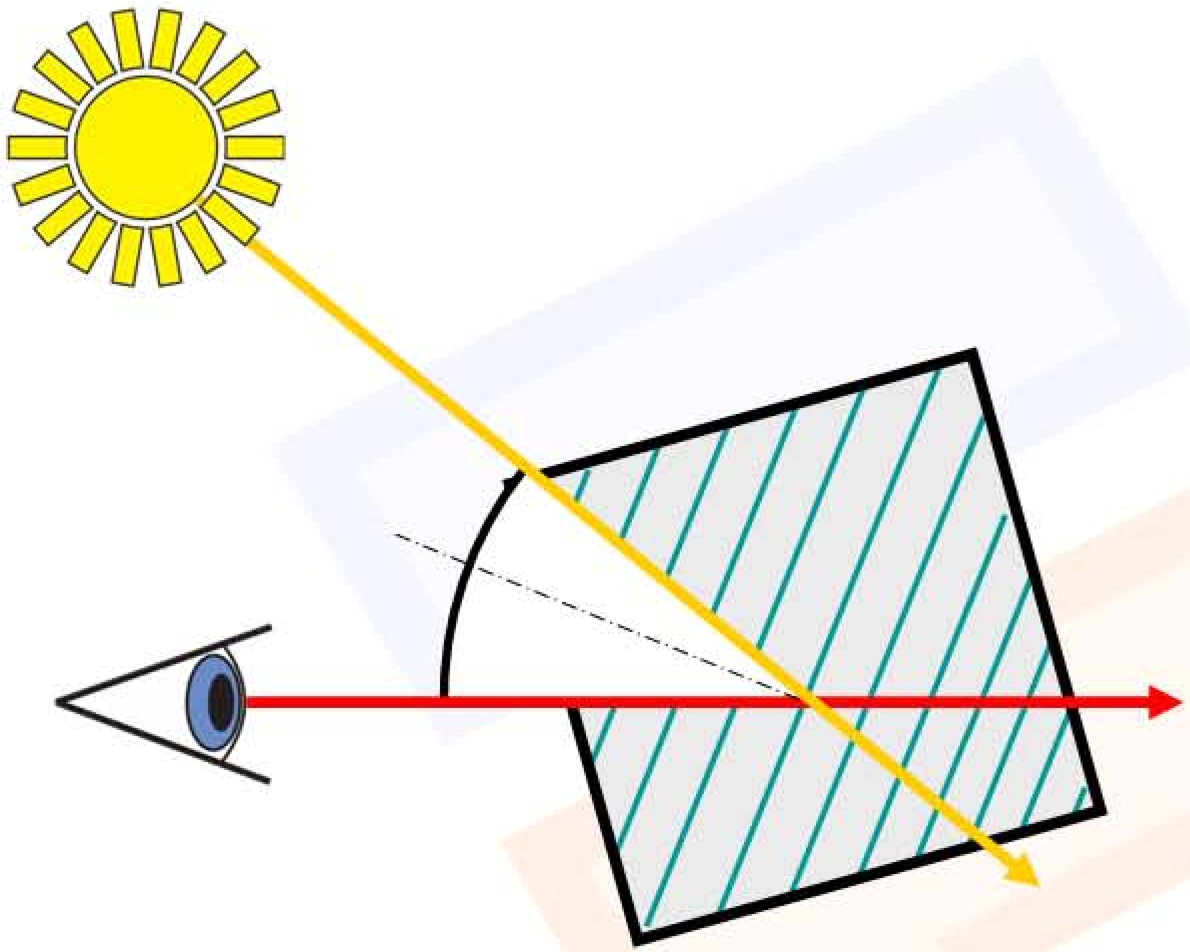


Half Angle Slicing

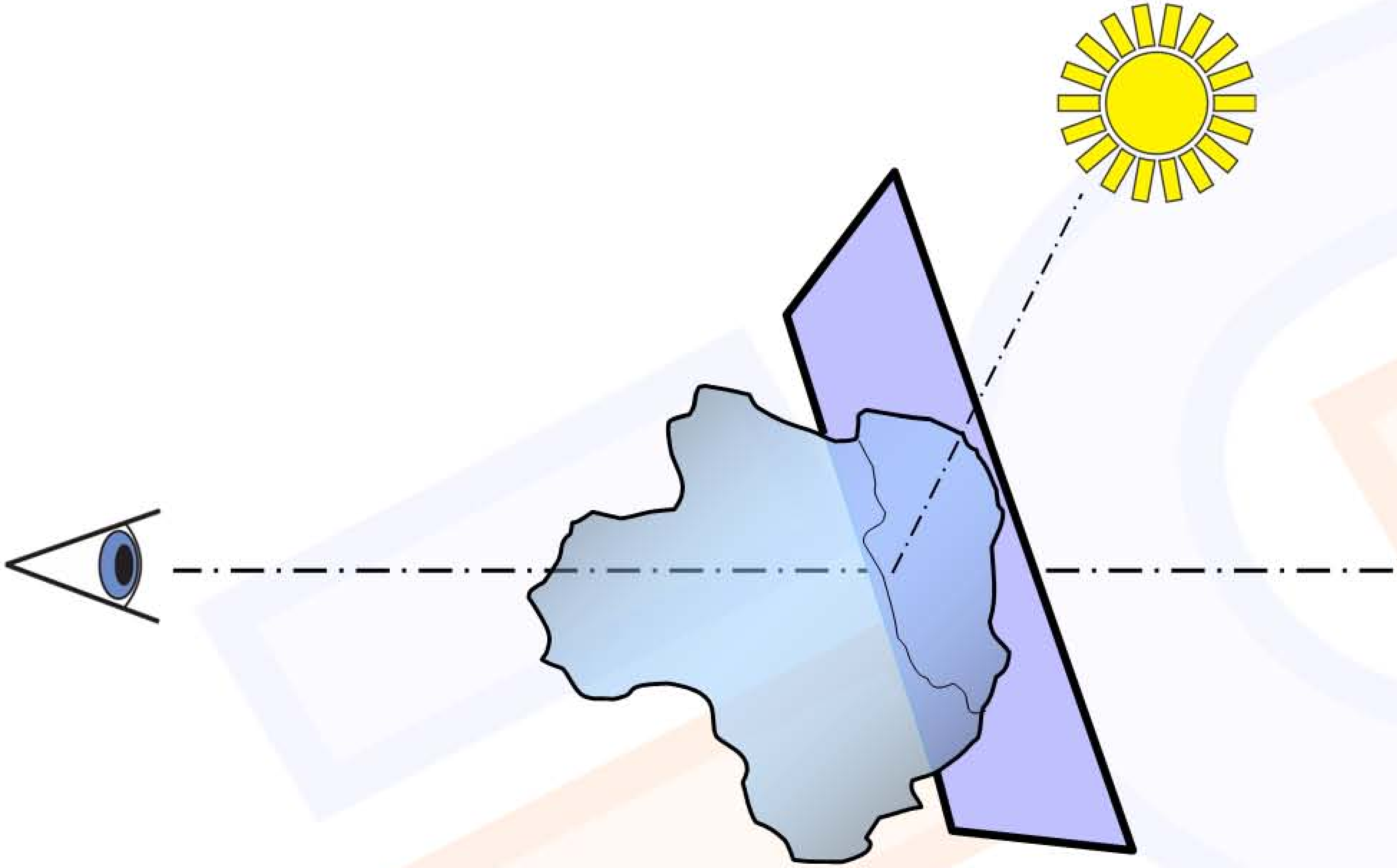
Shadow Maps

- For Volume Rendering:
  - Update image and shadow buffer slice-by-slice
  - Need proxy geometry, that can be rendered from two different views.



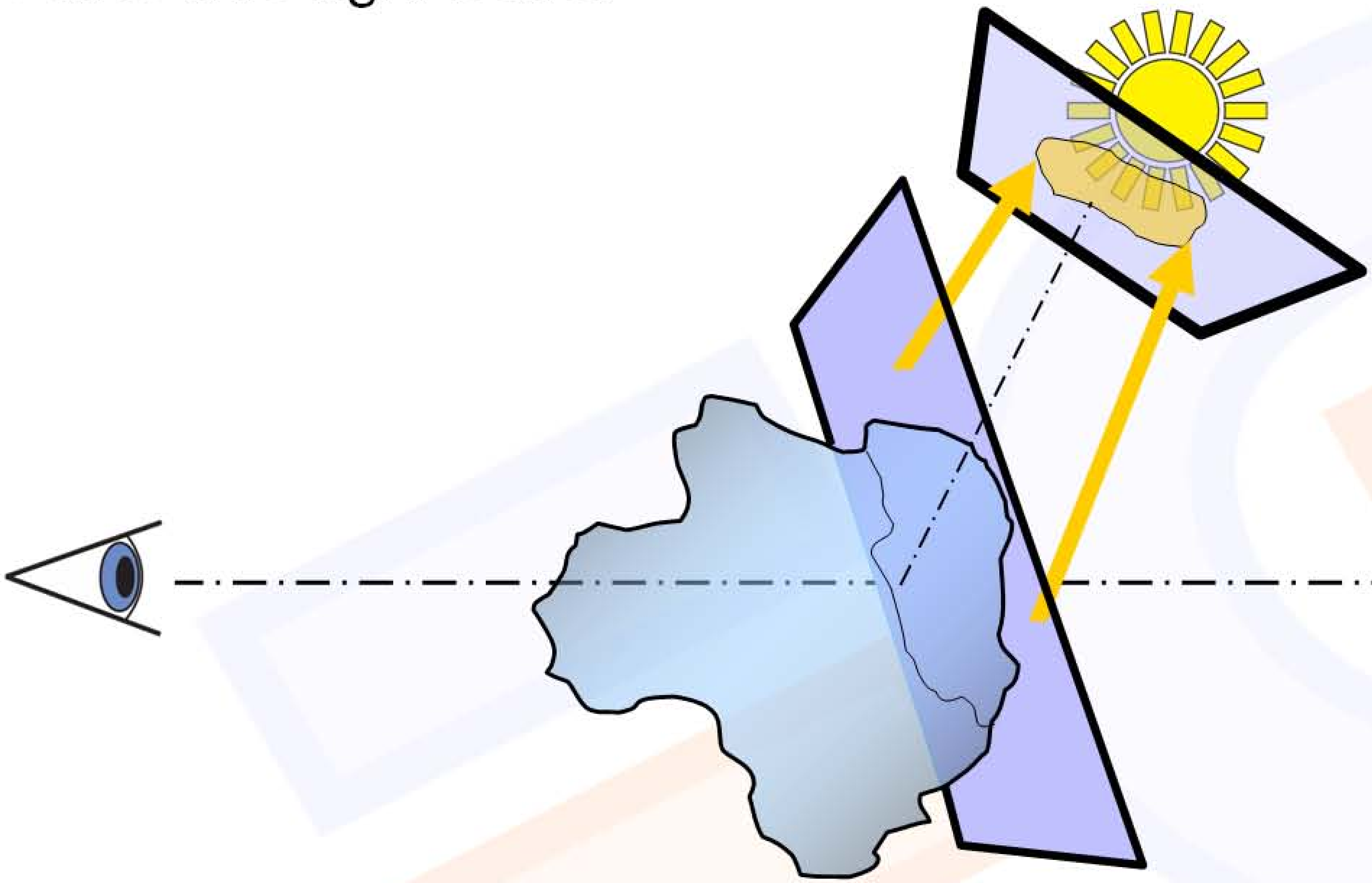
Half Angle Slicing

Light Source Attenuation



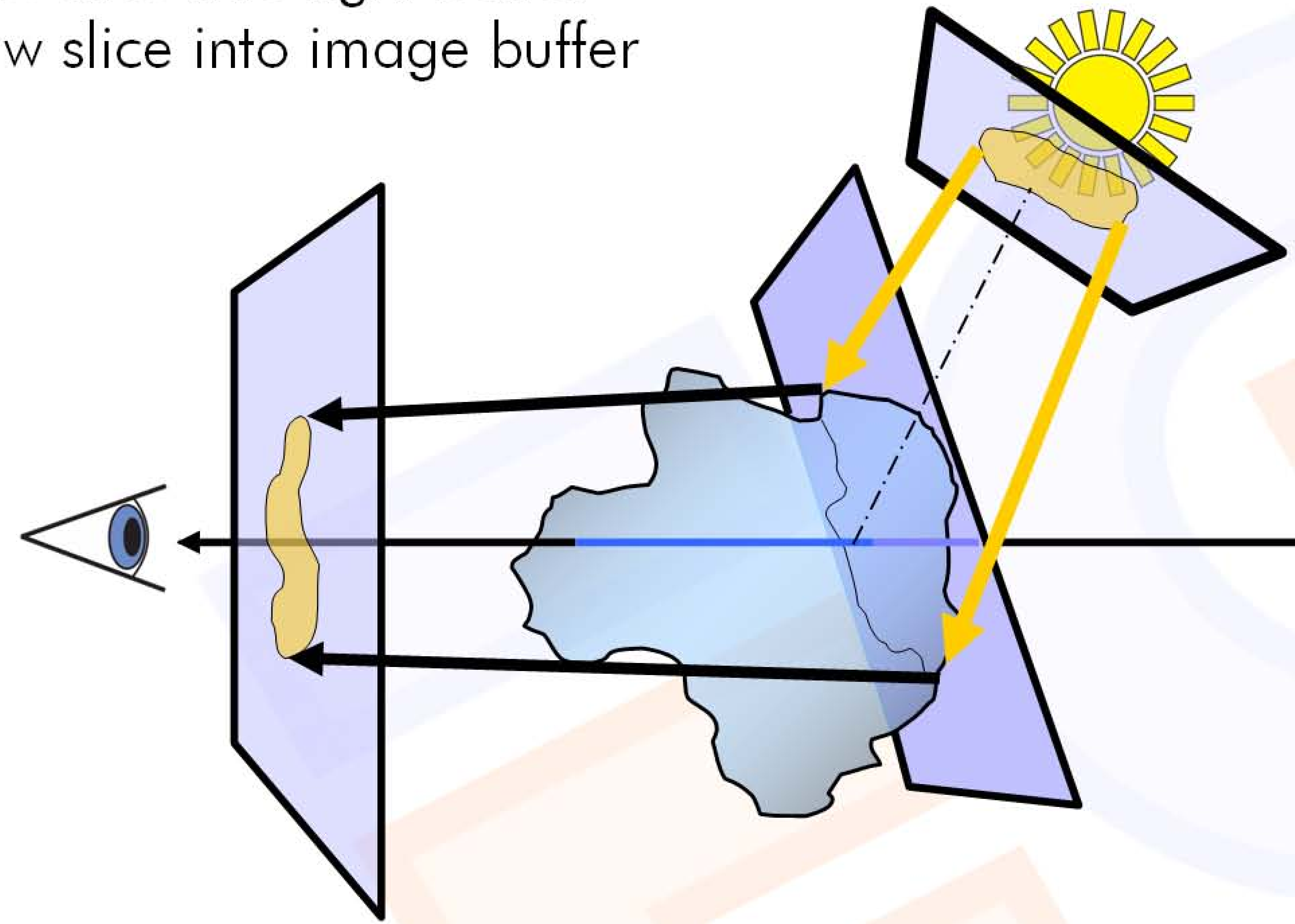
Light Source Attenuation

1. Draw slice into light buffer



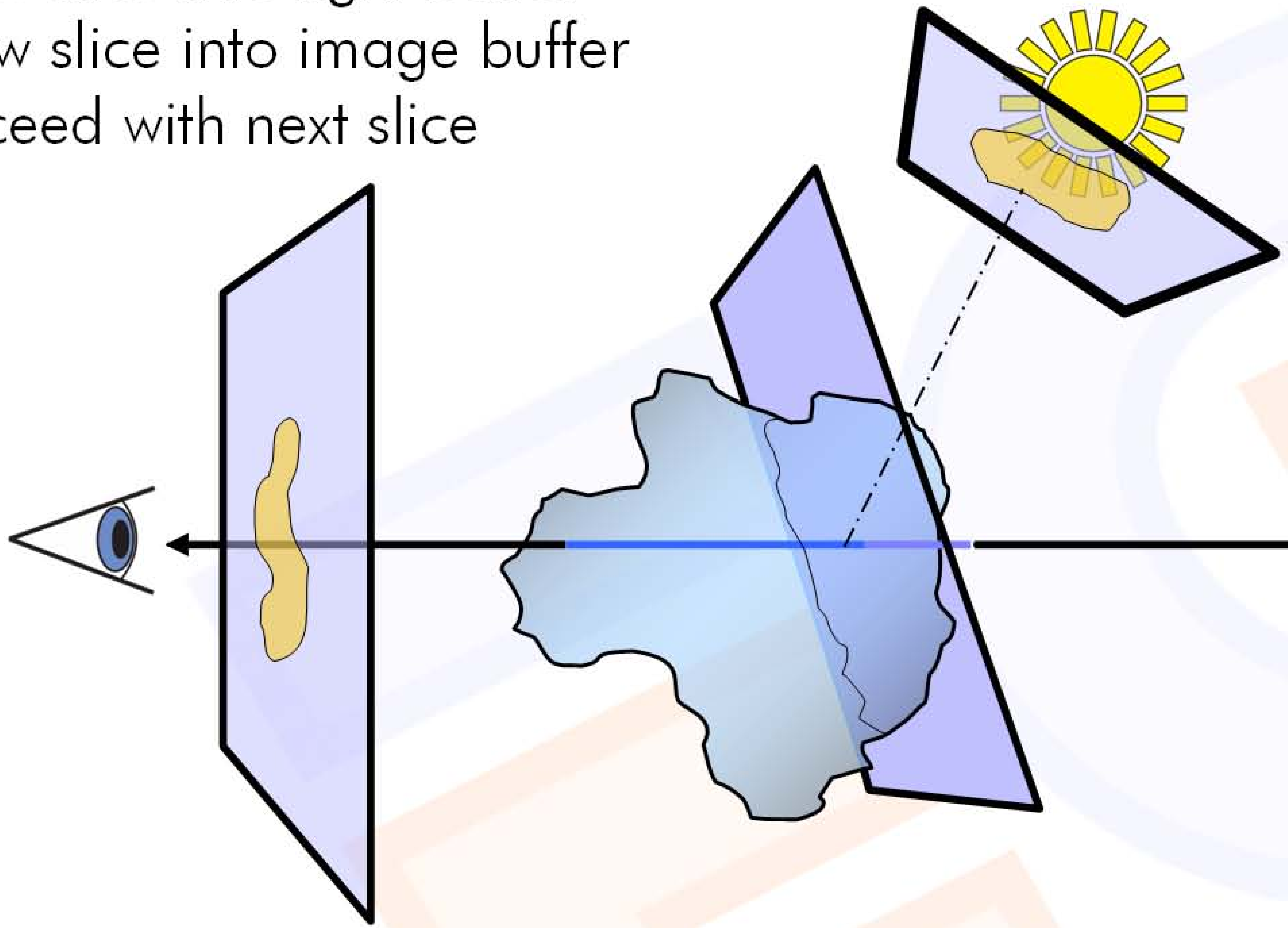
Light Source Attenuation

1. Draw slice into light buffer
2. Draw slice into image buffer

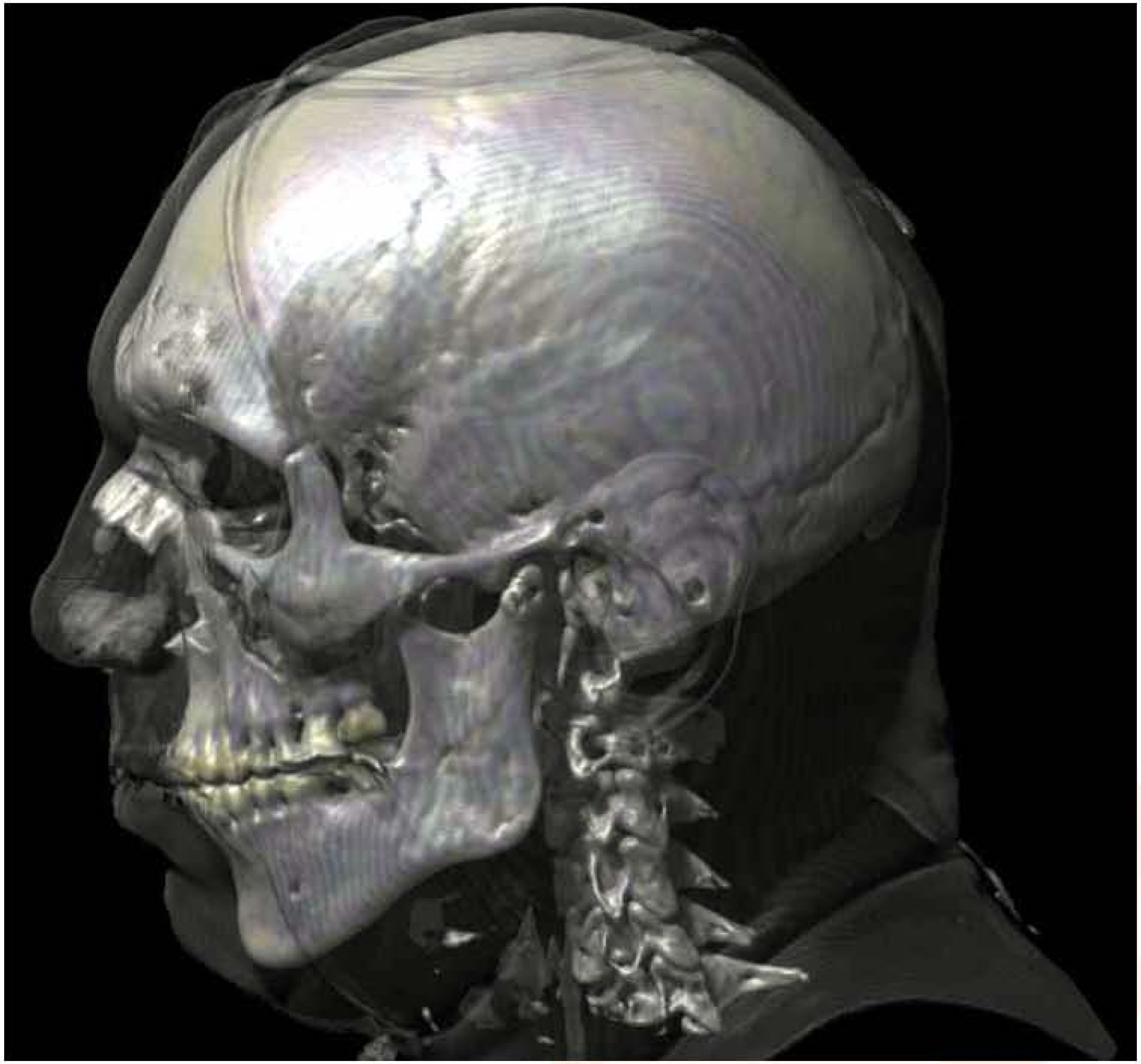


Light Source Attenuation

1. Draw slice into light buffer
2. Draw slice into image buffer
3. Proceed with next slice



Light Source Attenuation



Example:

Visible Human CT Head

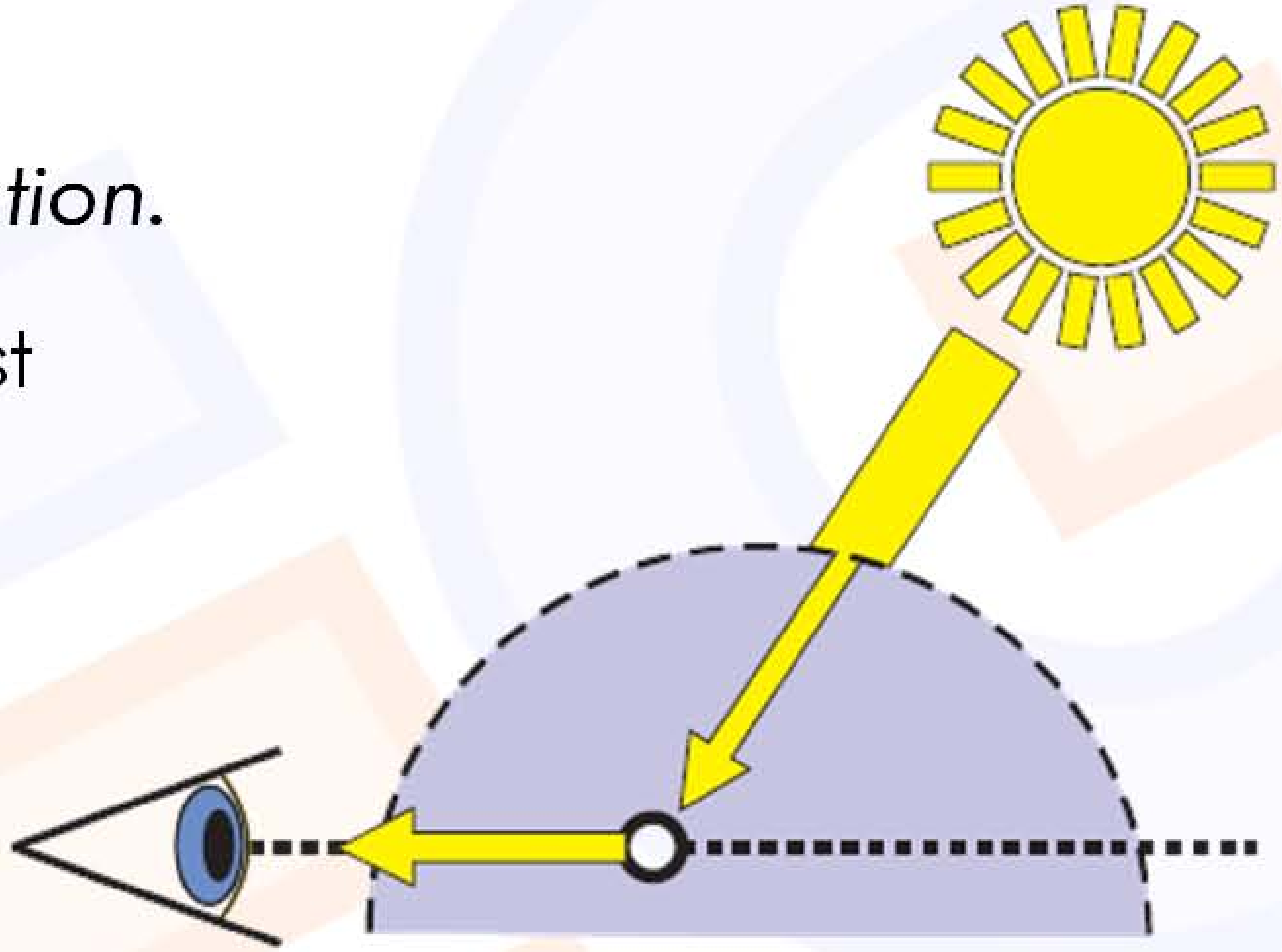
Direct Light + Attenuation

Volume Illumination

- *Up until now:* External light is attenuated by volume

Single scattering with attenuation.

- Light is attenuated along ist way through the volume *(Volumetric shadows)*
- Light is scattered once before it reaches the eye

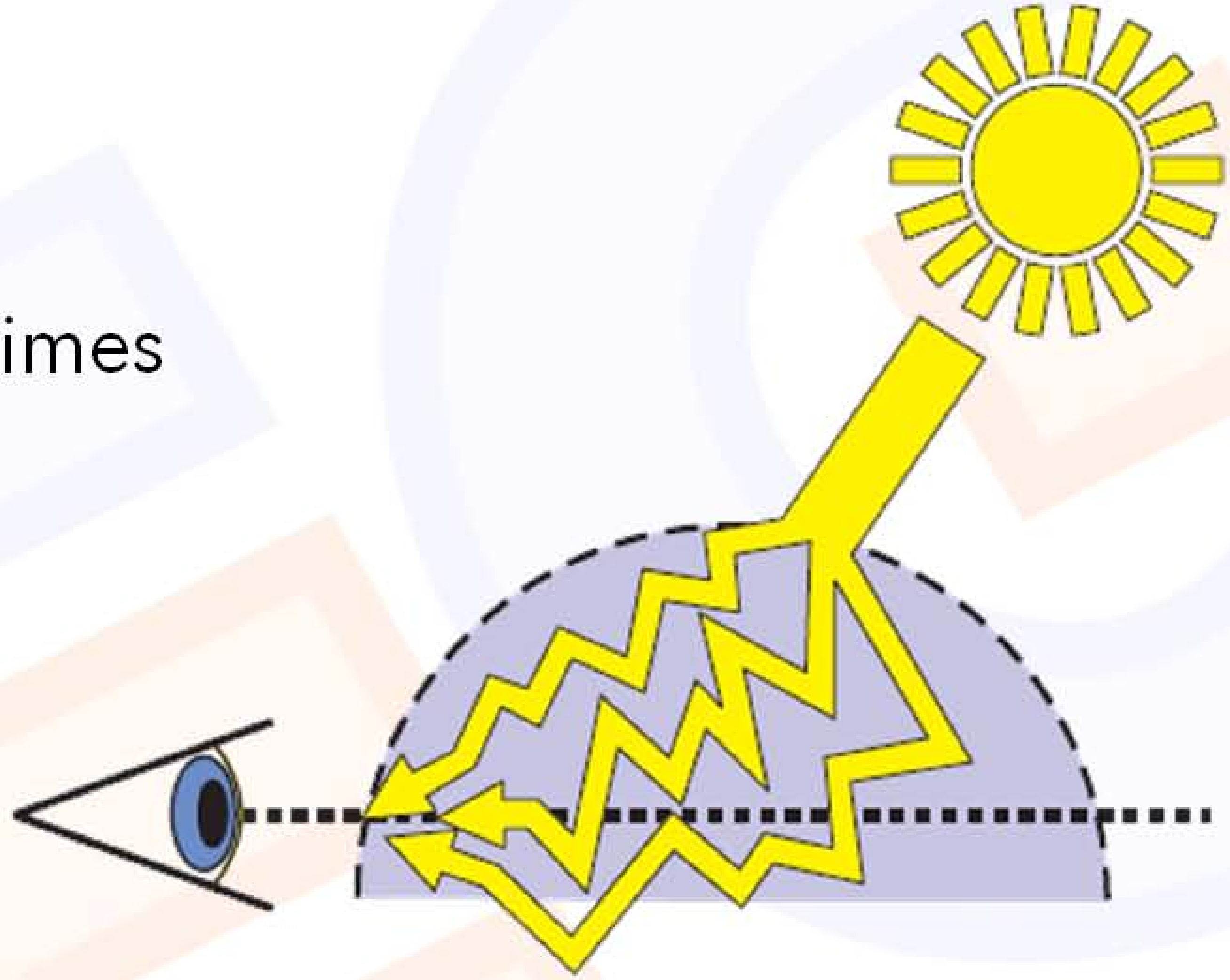


Volume Illumination

- *Up until now:* External light is attenuated by volume
- *Now:* Light is scattered inside the volume

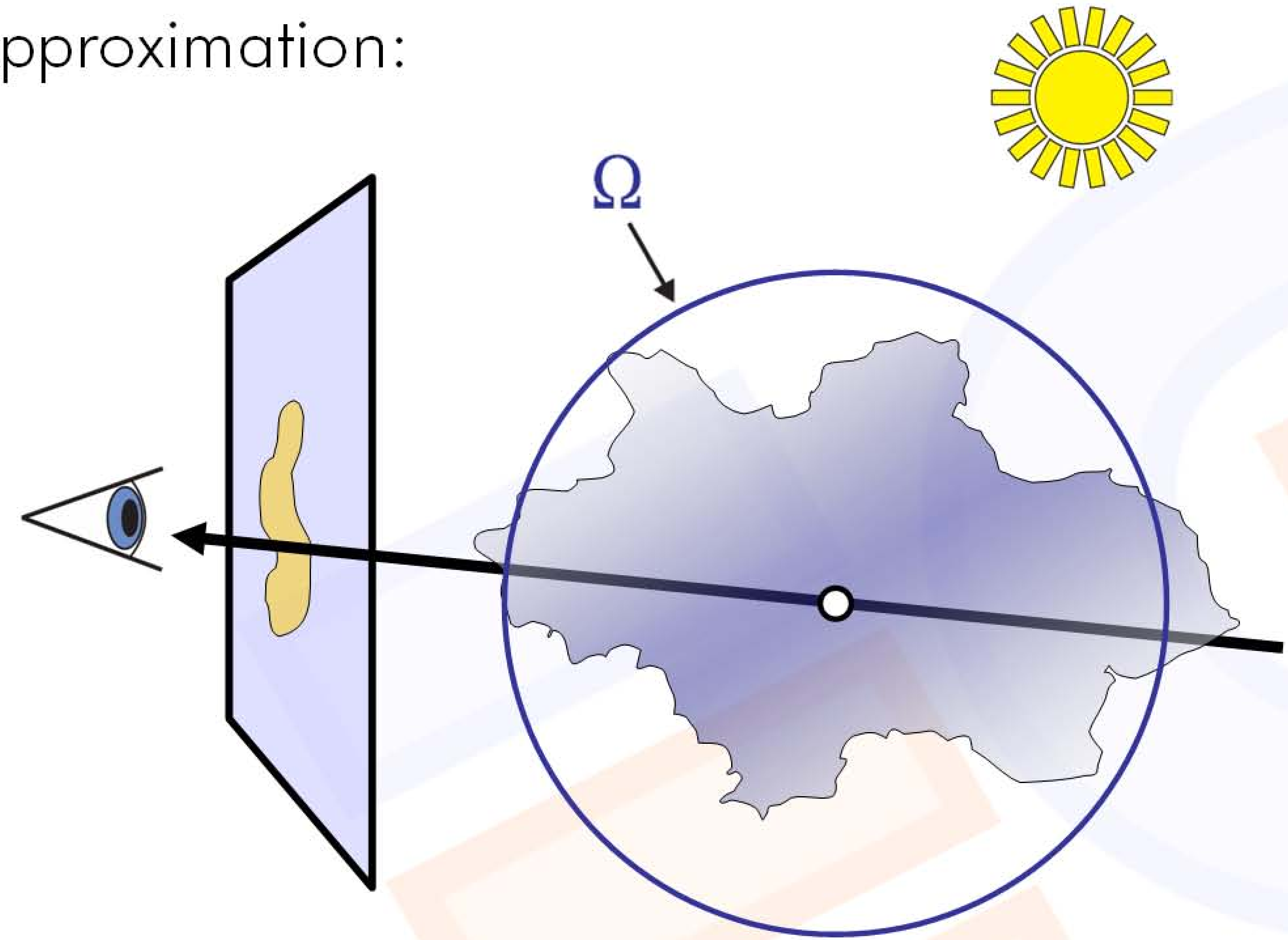
Multiple scattering

- Light is scattered multiple times before it reaches the eye *(Global illumination)*



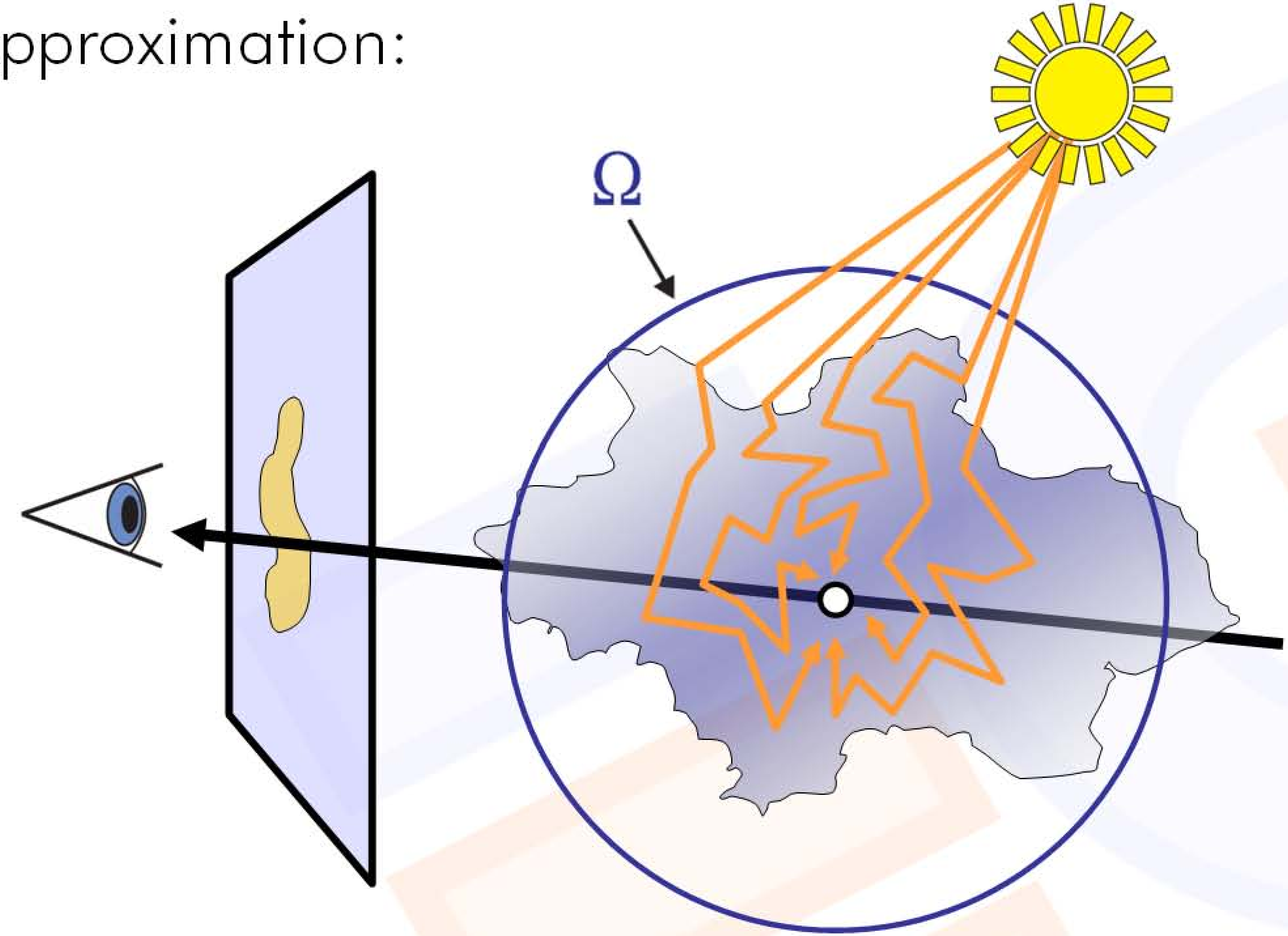
Scattering

- Approximation:



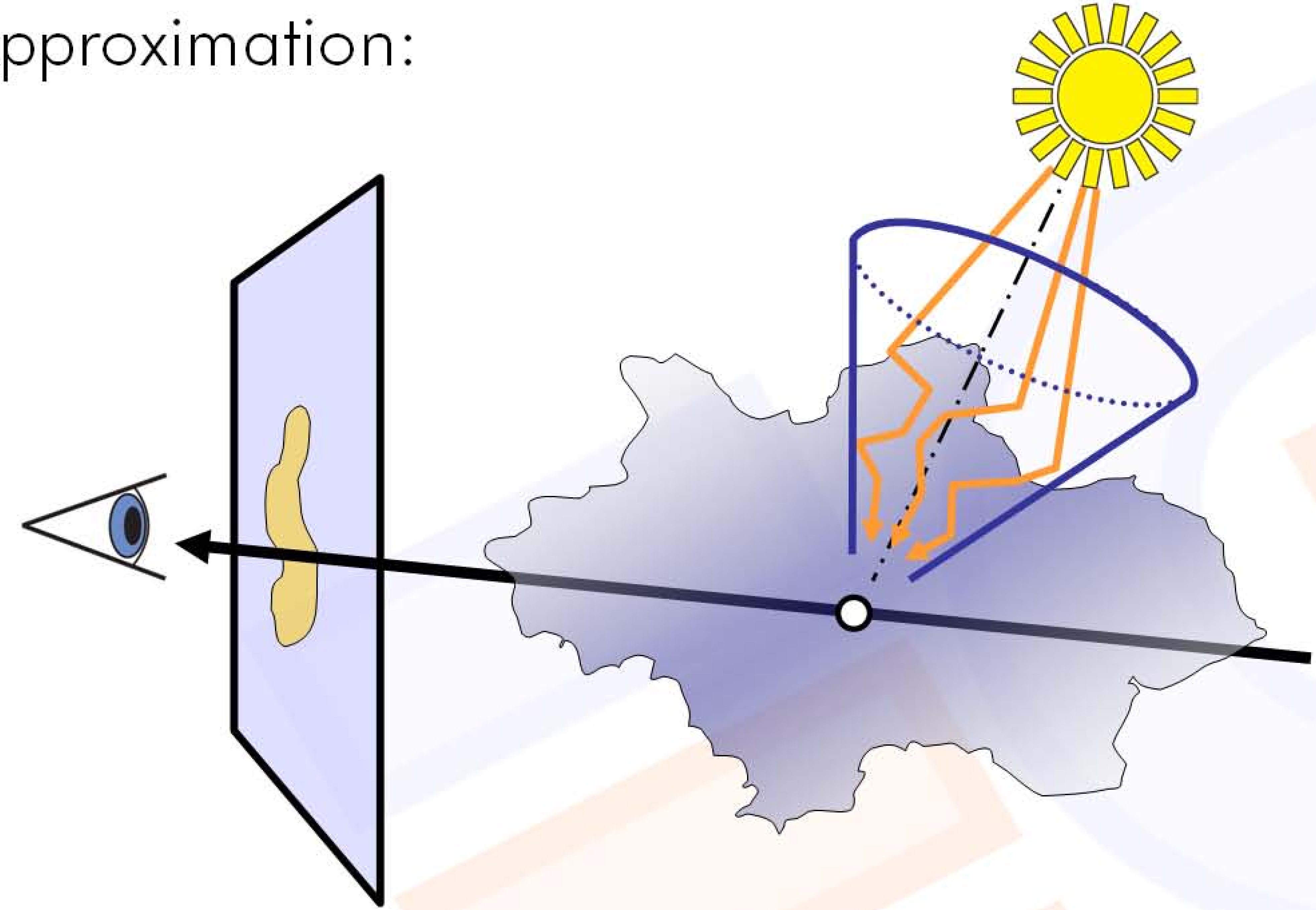
Scattering

- Approximation:



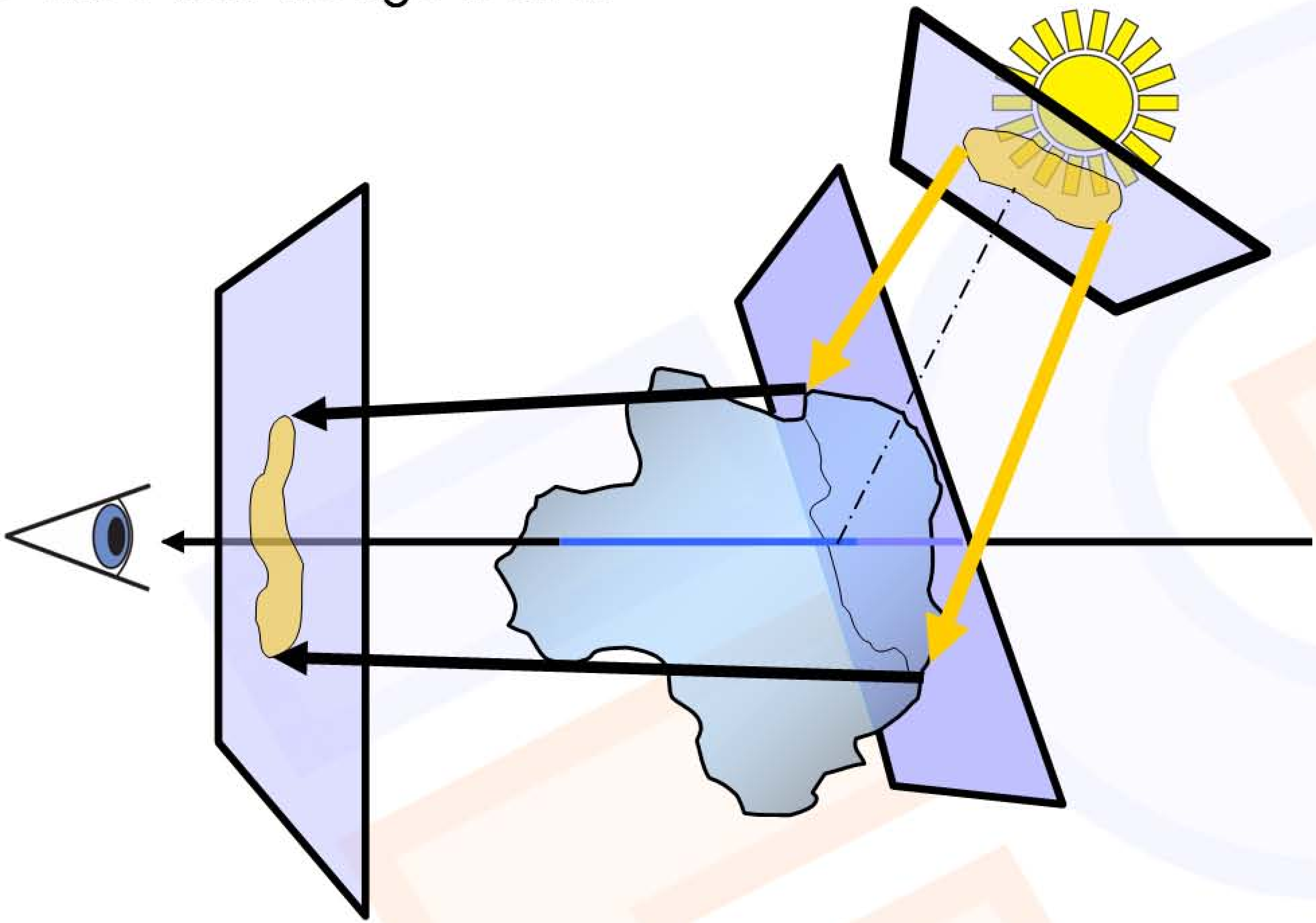
Scattering

- Approximation:



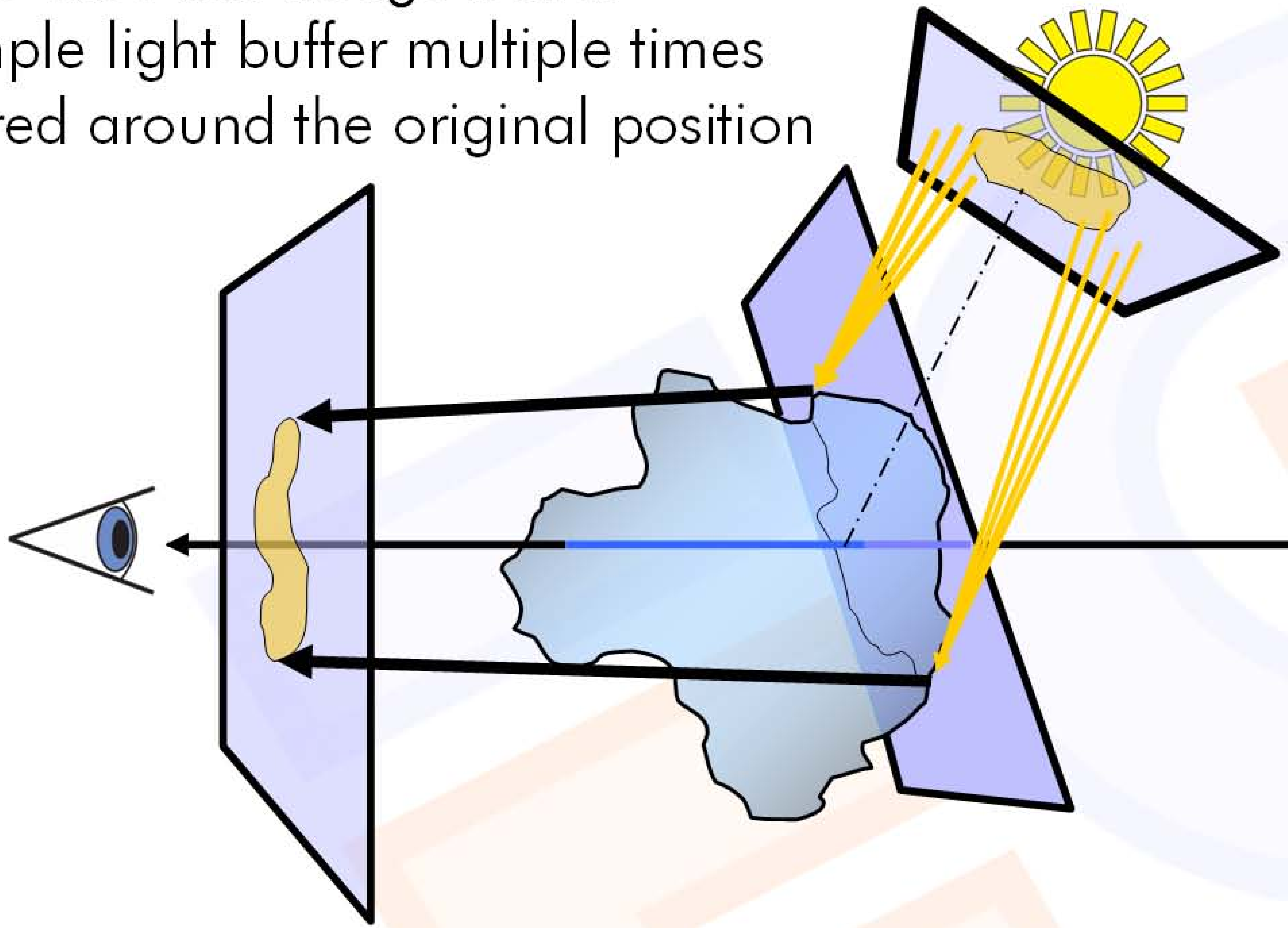
Volumetric Scattering

2. Draw slice into image buffer



Volumetric Scattering

2. *Draw slice into image buffer*
   Sample light buffer multiple times jittered around the original position

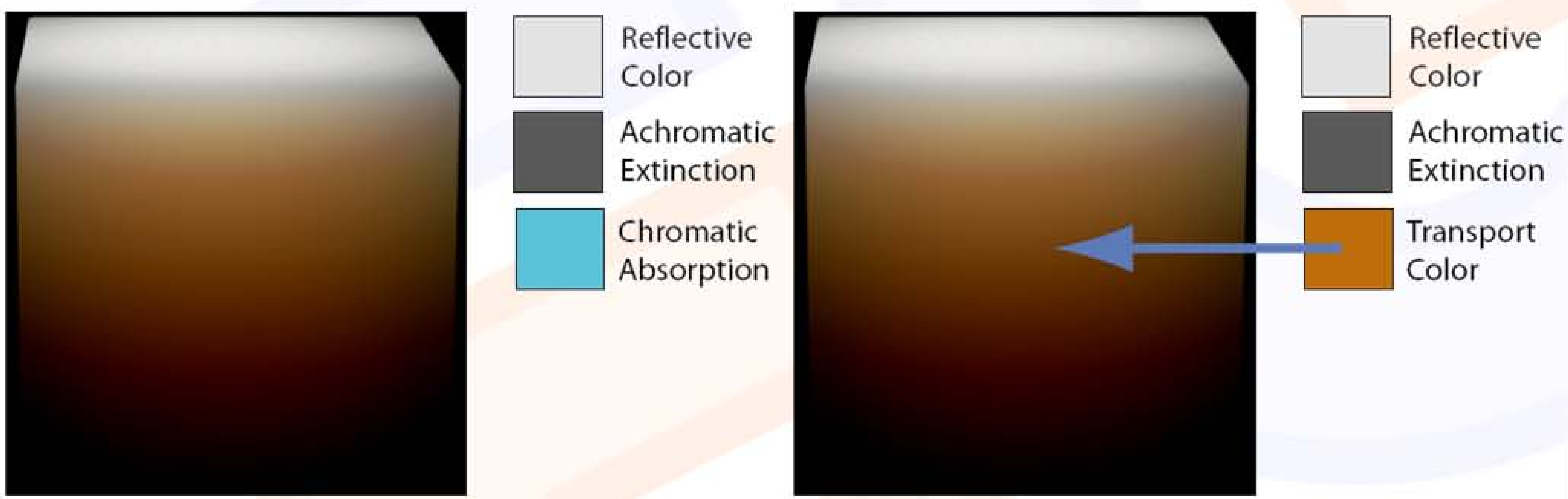


Volumetric Scattering

- Scattering part:

$$j(\mathbf{x},\omega) = \frac{1}{4\pi}\int_{\text{sphere}} \sigma(\mathbf{x},\omega')p(\mathbf{x},\omega',\omega)I(\mathbf{x},\omega')\mathrm{d}\omega'$$

- Chromatic out-scattering term $\sigma(\mathbf{x},\omega')$ can be used to change color of light as it travels throught the volume



Volumetric Scattering

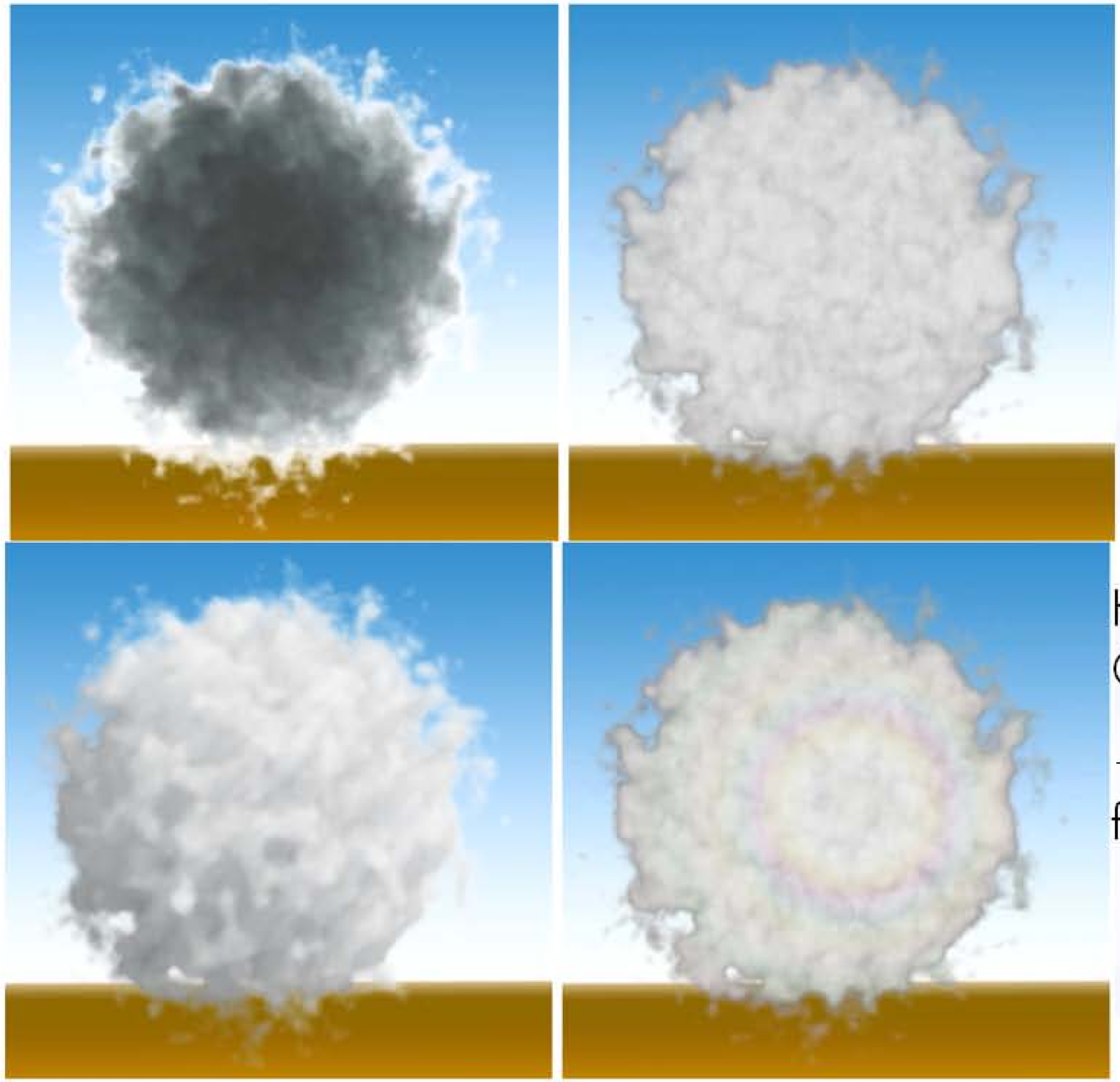
Photograph of real wax block

Volumetric Scattering + Chromatic Attenuation

Bright blue reflective color

Direct attenuation only

Examples Phase Function



Henyey-Greenstein

Lit from behind

Henyey-Greenstein

Lit from front

Henyey-Greenstein

Lit 45° degrees from above

Henyey-Greenstein

+ Mie Phase function

Examples

Examples

Direct light only

Achromatic indirect light

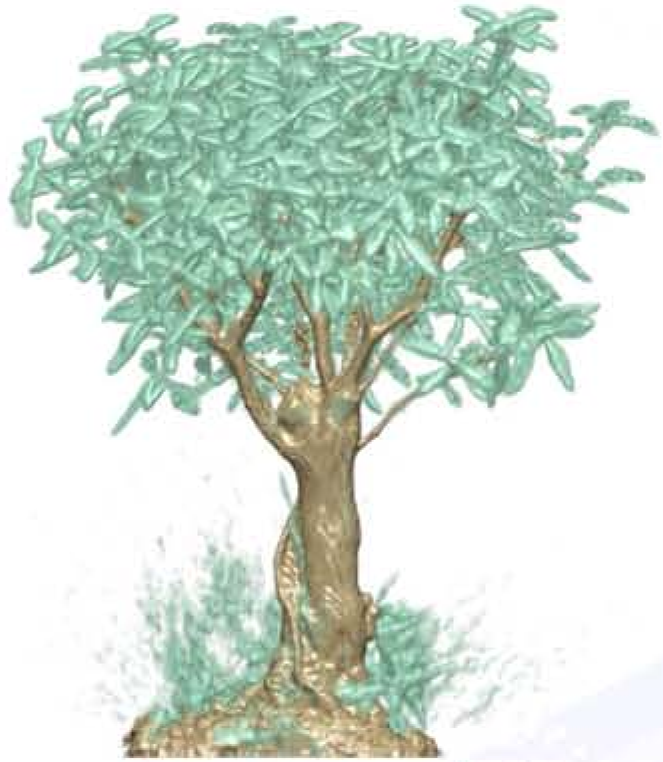
Chromatic indirect light

Examples

- Approximation of opalescent materials (lit from above)

Examples

Surface Shading



Direct Light + Shadows

Direct Light+ Indirect Light

Direct Light+ Indirect Light

Surface shading on the leaves only