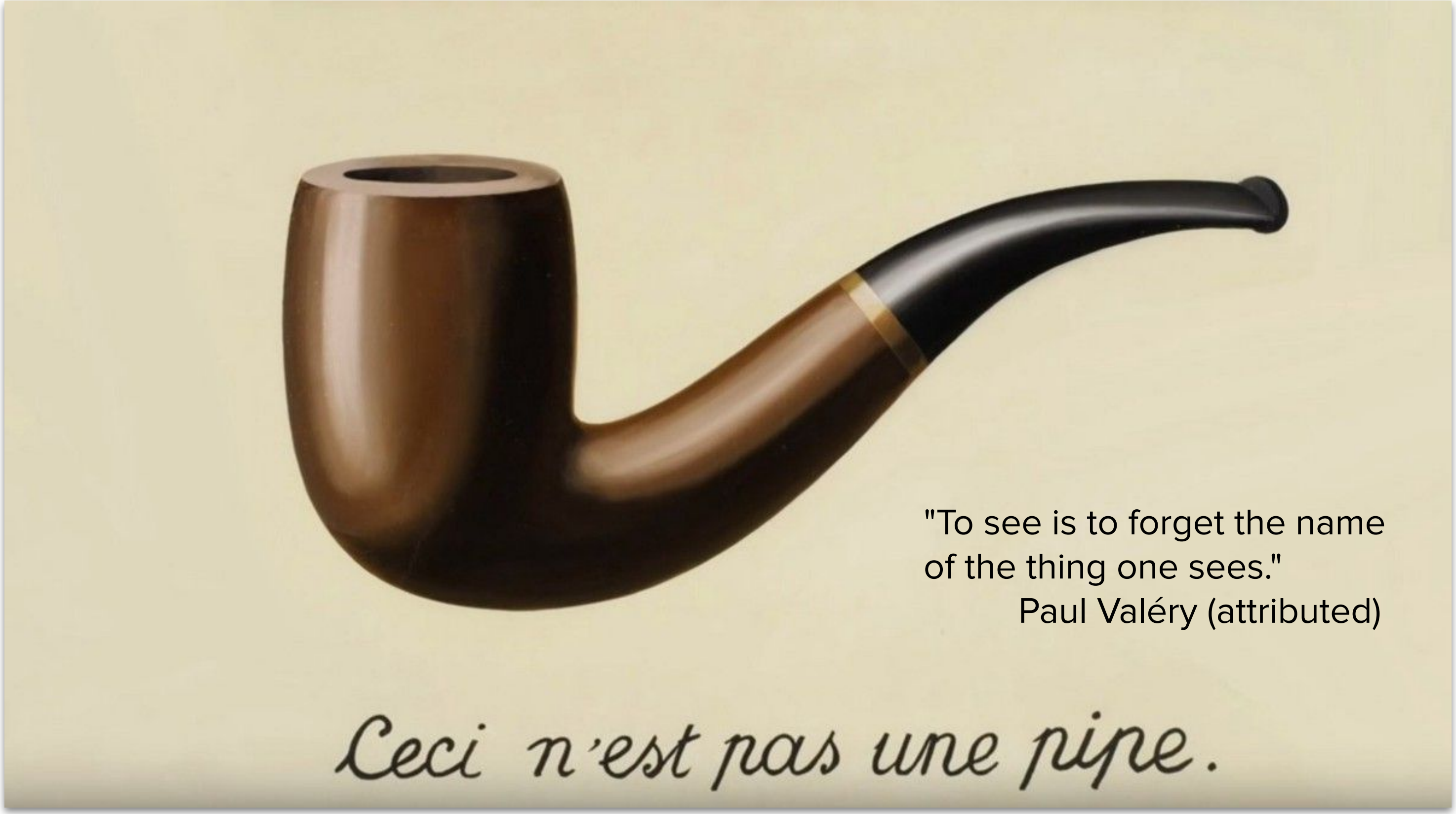
Physically Based Volume Rendering

Lecture, Tuesday 9:00-10:00

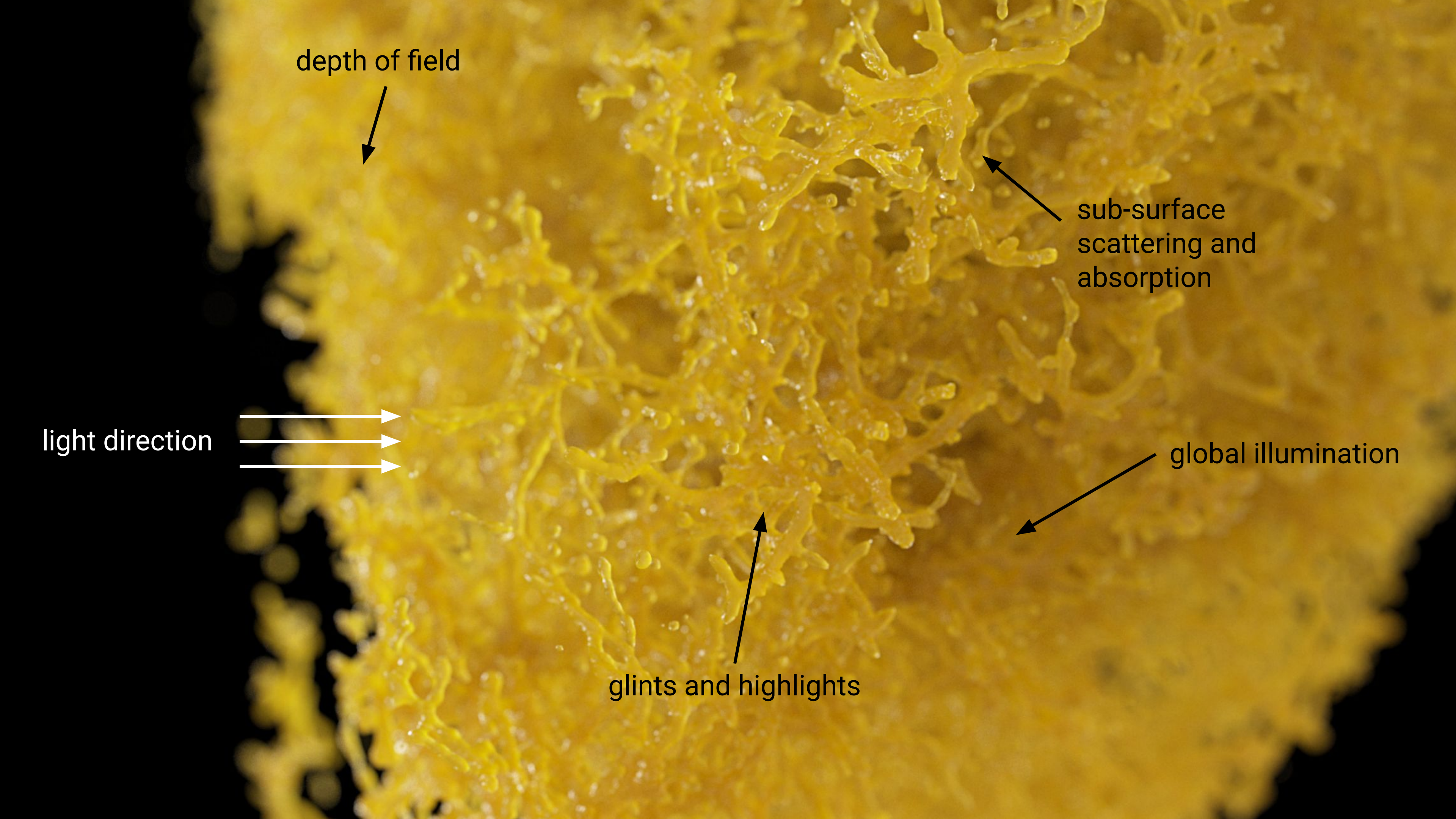
Dr.-Ing. Oskar Elek
University of California in Santa Cruz



What is this...?

Rene Magritte: **The Treachery of Images** (1929)
“can you stuff this pipe? no...it’s just a representation, n’est pas?”


easyJet.com


depth of field
sub-surface scattering and absorption
light direction
global illumination
glints and highlights

Physical intuition ‘thesis’

Everything we know about the world comes from (through) our senses (perception)

therefore

Our minds build a representation of the world based on perceived information

therefore

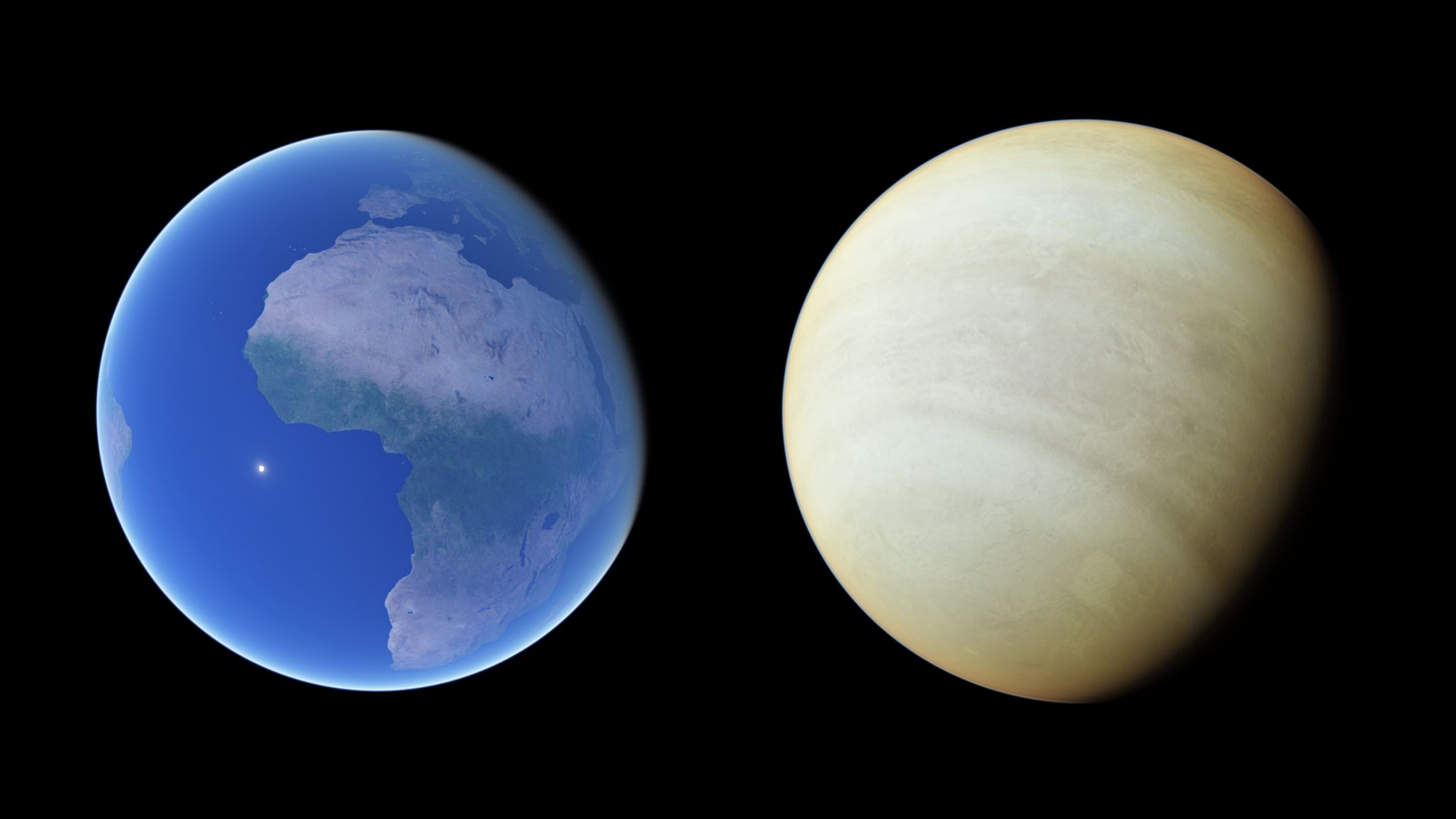
Our minds construct intuitive models of the world to process information efficiently

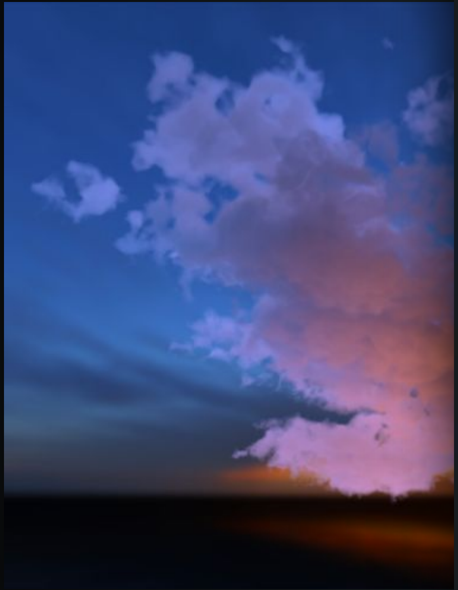
therefore

To gain understanding about something new (process, data, grandma’s chicken soup) we should take maximum advantage of those intuitive models

example

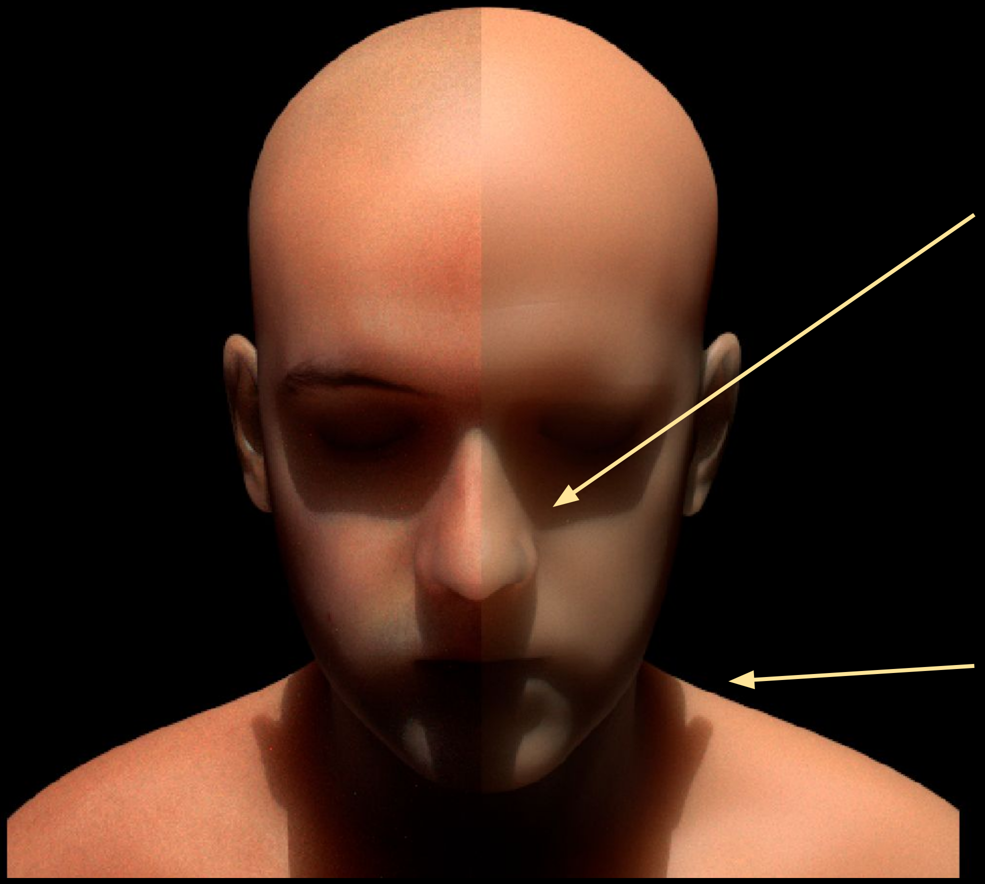
Volume Rendering



Principal ordinates (Ours)

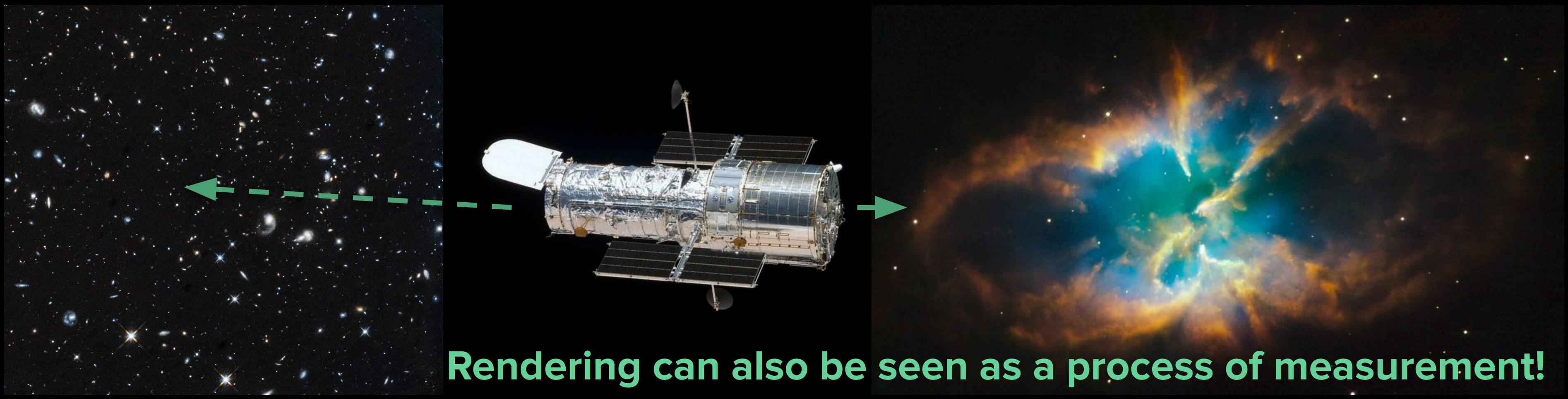
DOM (Previous work)



The rendering problem

“Rendering” = the process of **transforming** a **mathematical description** of a scene (‘world’) into an **observable result** ➔ in our case, an image

In the process of that transformation, information about reality is imperfectly copied, modified, shuffled… **Ultimately, reality is lost, only representation remains.**

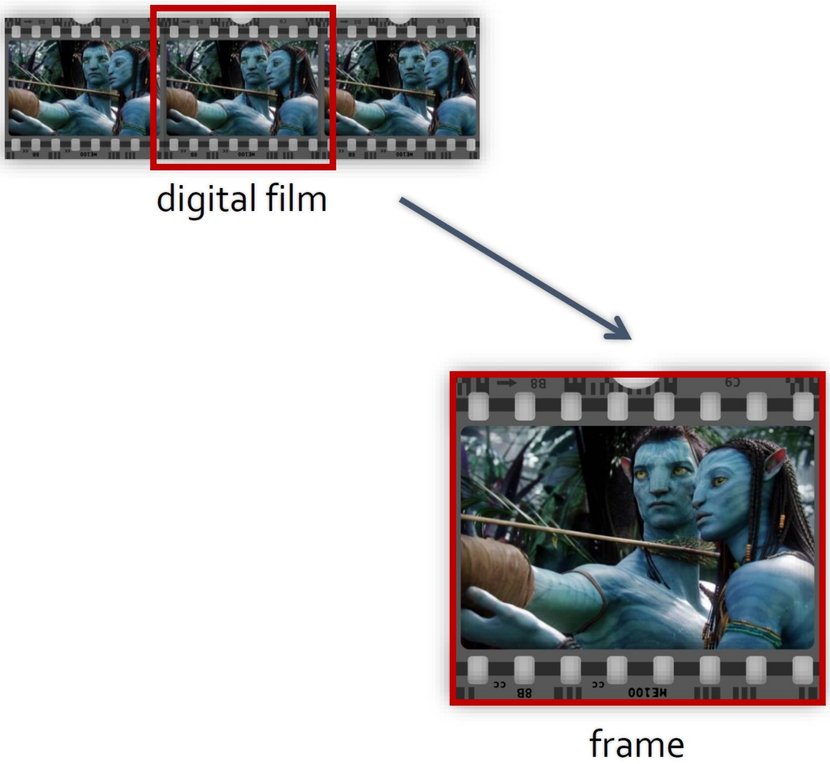


Rendering

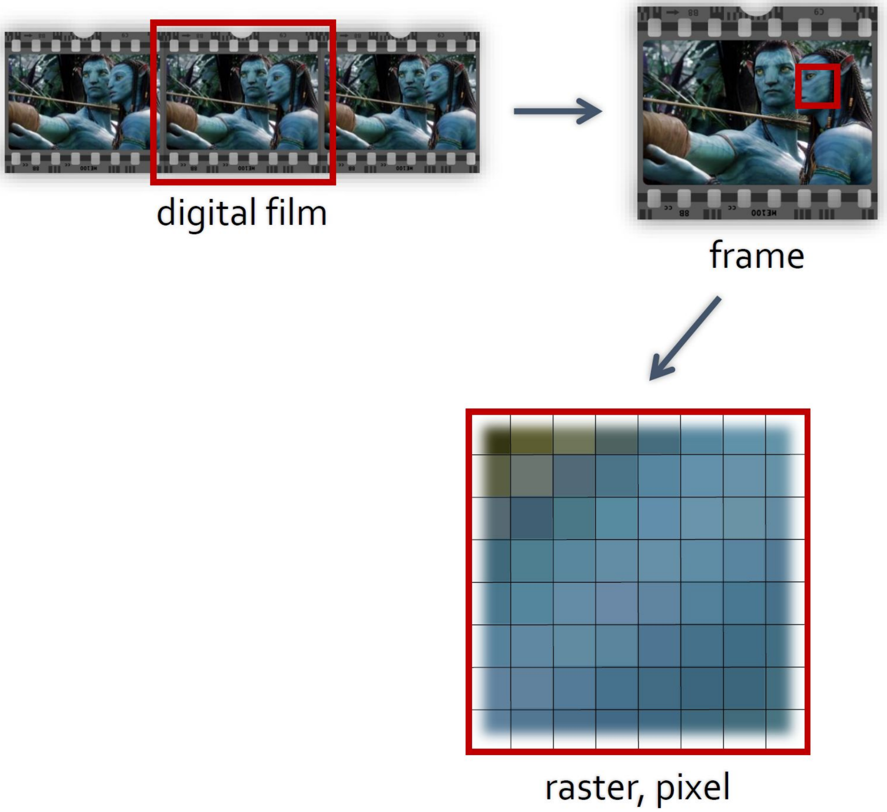
Let's illustrate this... **on Avatar!**

digital film

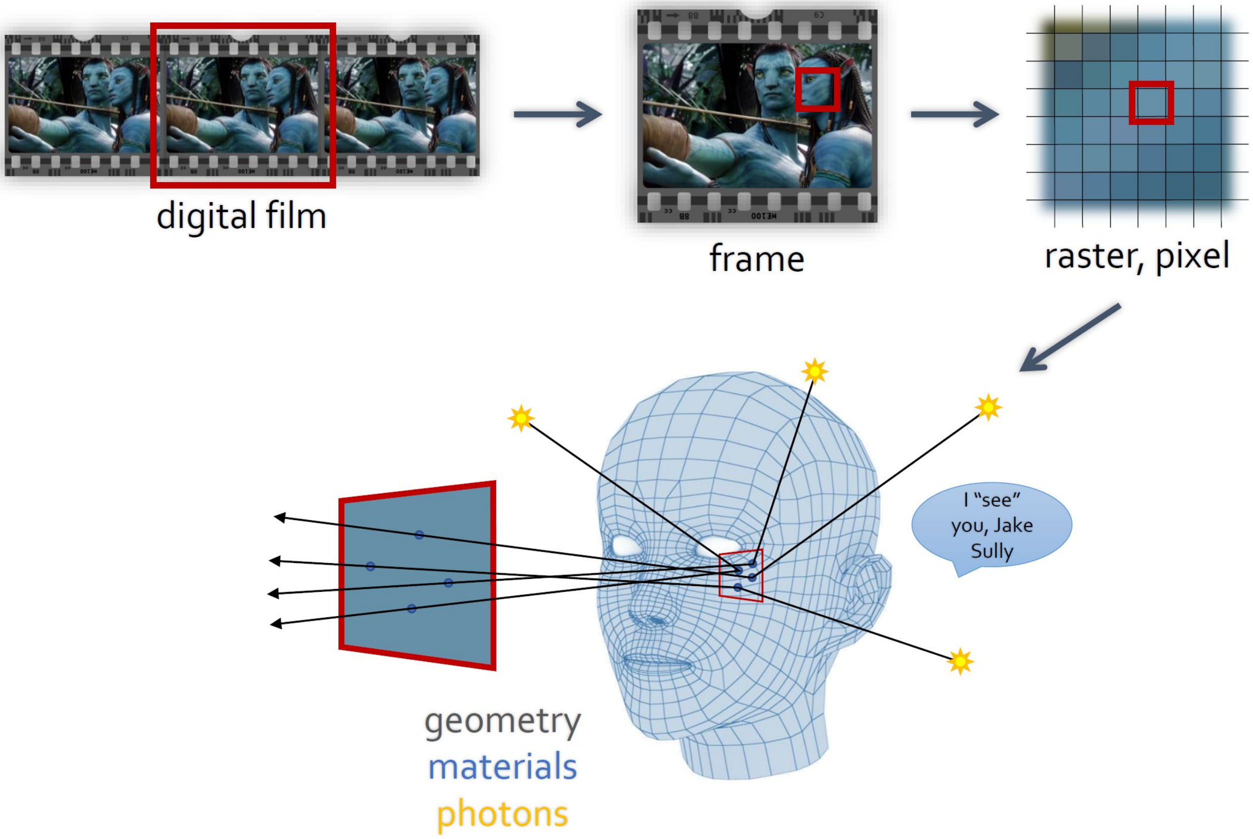
Rendering



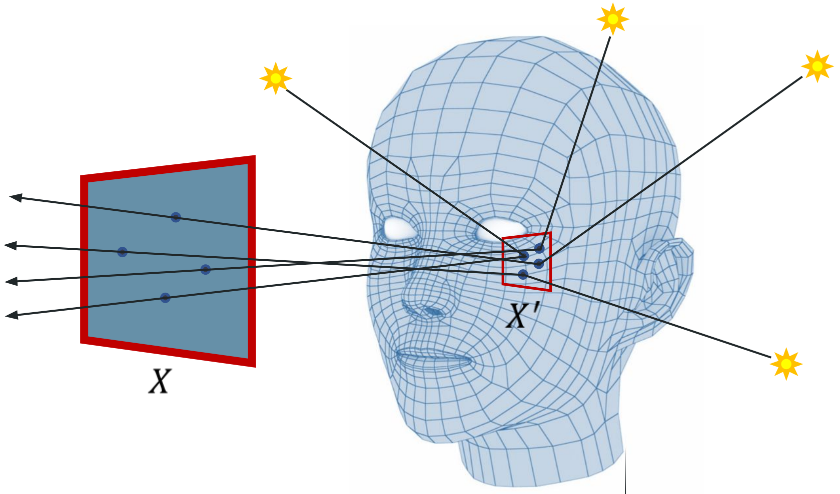
Rendering



Rendering


digital film
frame
raster, pixel
I "see" you, Jake Sully
geometry
materials
photons

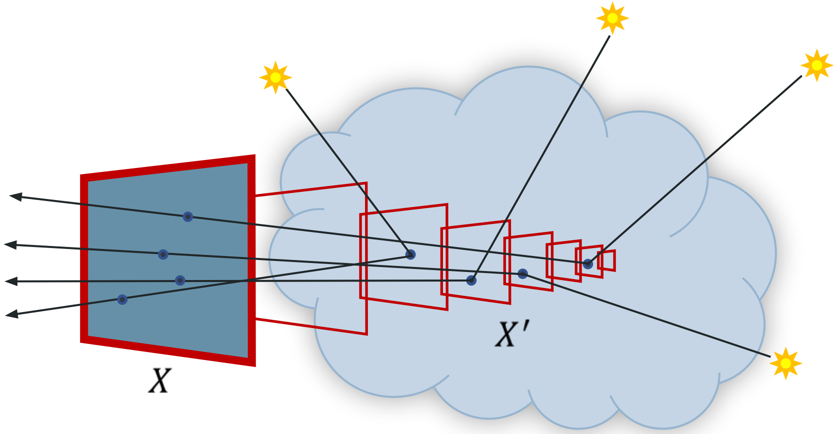
Rendering



$$\text{light}(X) \approx \int_{\square} \text{reflectance}(X') * \text{light}(X')$$

$$\text{light}(X) \approx \int \text{ref}(X') *$$

Volume rendering



$$\text{light}(X) \approx \int_{\text{(beam)}} \text{transmittance}(X,X') * \text{scattering}(X') * \text{light}(X')$$

$$\text{light}(X) \approx \int \text{tran}(X,X') * \text{scat}(X') * \left(\int \text{tran}(X',X'') * \text{scat}(X'') * \left(\int \text{tran}(X'',X''') * \text{scat}(X''') * \left(\int \ldots\right.\right.\right.$$

Case Study

Case study: Red Dead Redemption 2

volumetric fog

Case study: Red Dead Redemption 2

god rays (crepuscular rays)

Case study: Red Dead Redemption 2

weather and atmospheric effects

Case study: Red Dead Redemption 2

characters

Case study: Red Dead Redemption 2

fur and snow

Participating media ("volumes")

Volumetric media organized by particle density
(not the same as optical density)

Light ↔ Volume Interactions

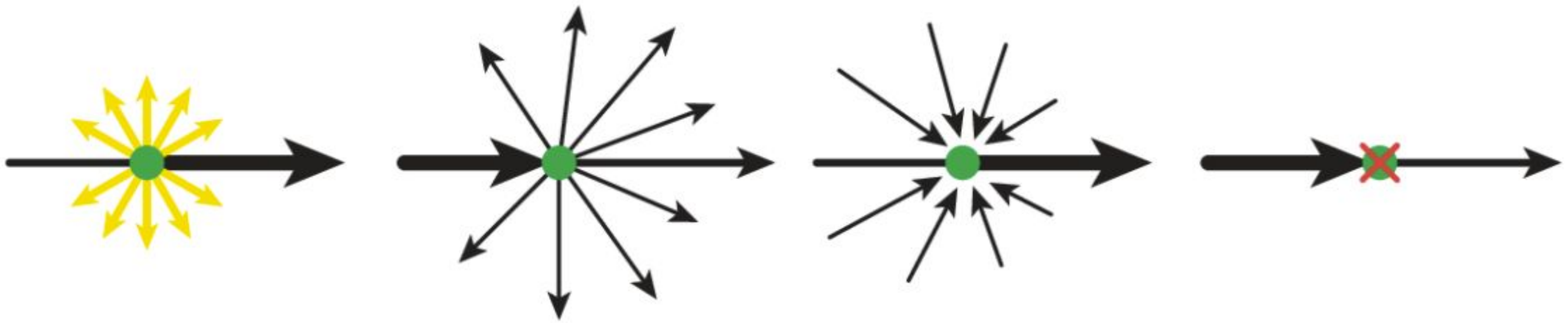
Volume interaction types

Photons interact with participating media particles in 3 possible ways:

emission ➔ photon is radiated (created)

scattering ➔ photon is redirected

absorption ➔ photon is lost (converted to heat)



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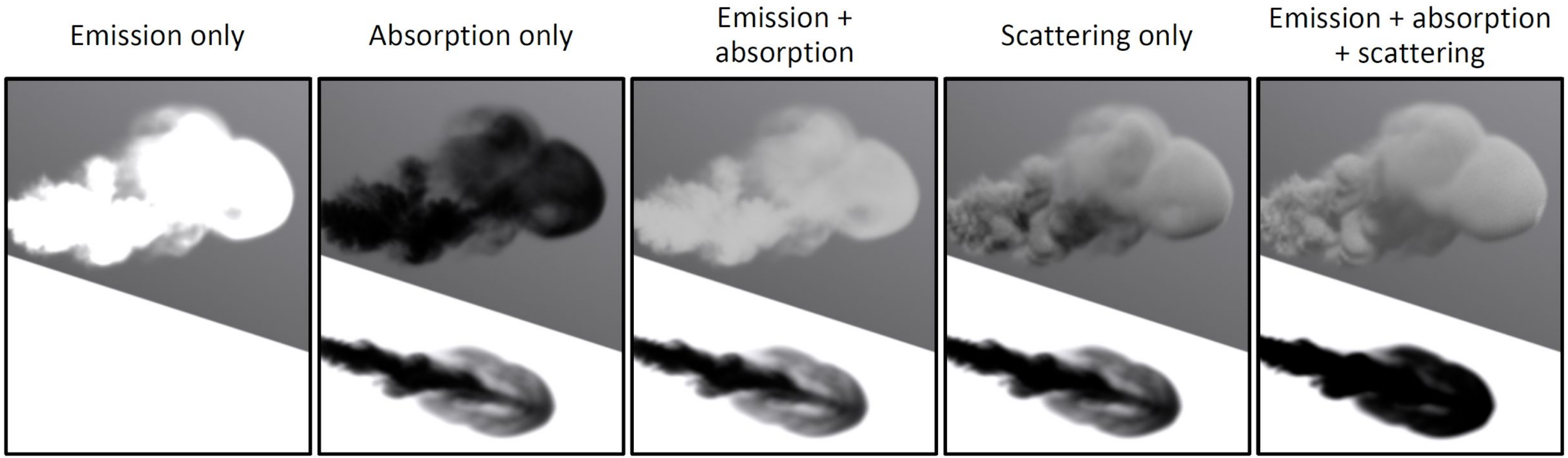
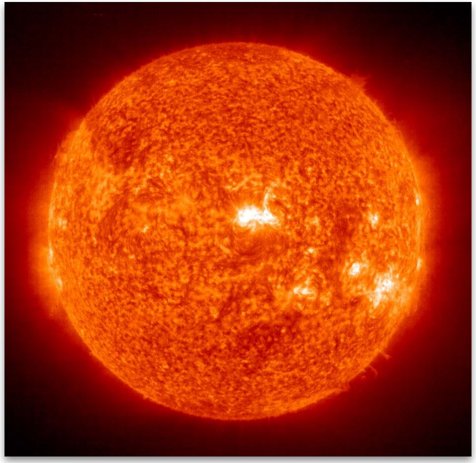


Volume interaction types



emission

absorption

scattering

Volume interaction types

absorption

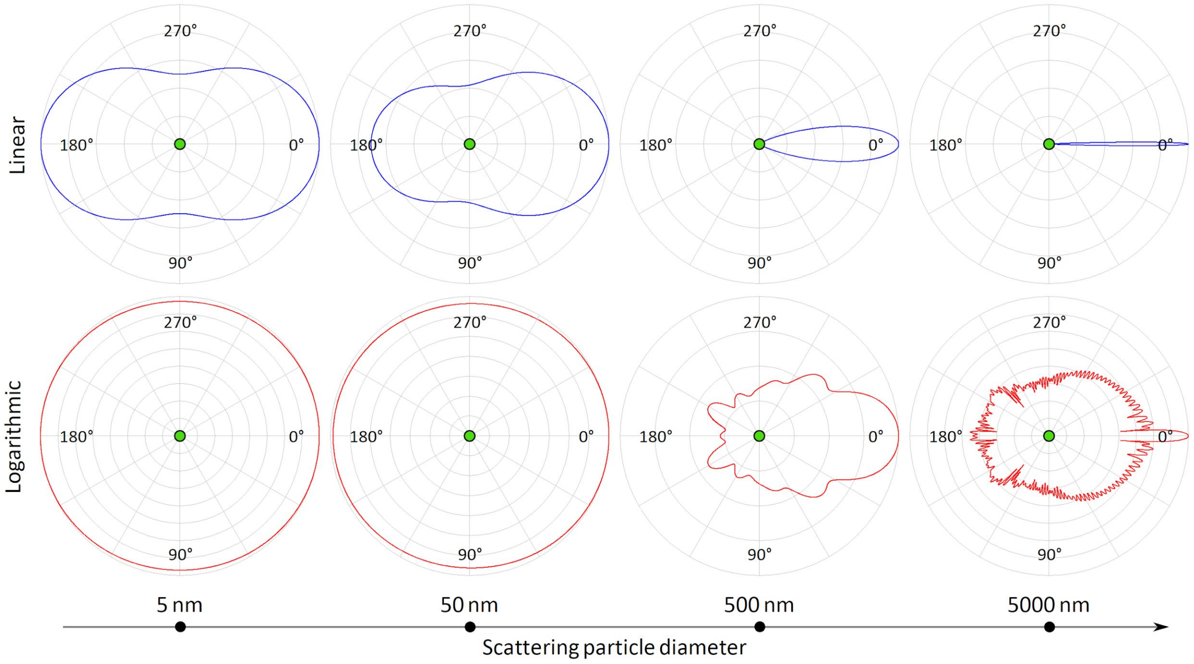
emission

scattering

Volume interaction types

Scattering is the most interesting phenomenon, creating actual **lighting features**

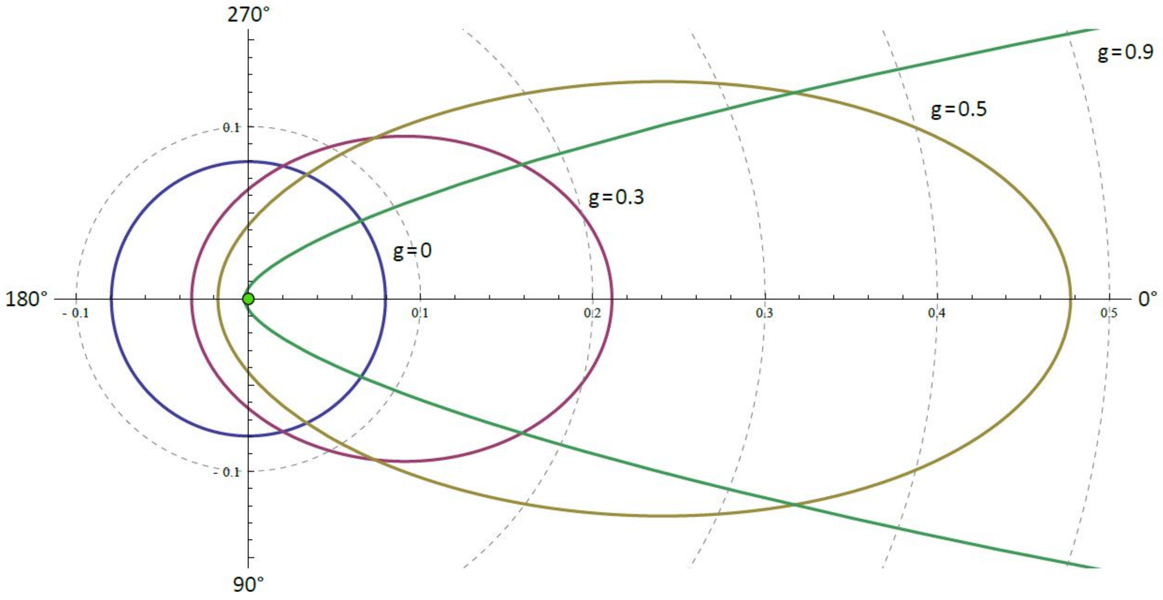
→ the directional distribution of light is called **phase function** (directional PDF)



Volume interaction types

Scattering is the most interesting phenomenon, creating actual **lighting features**

→ key parameter: **scattering anisotropy “g”** (higher = more forward scattering)



Volume interaction types

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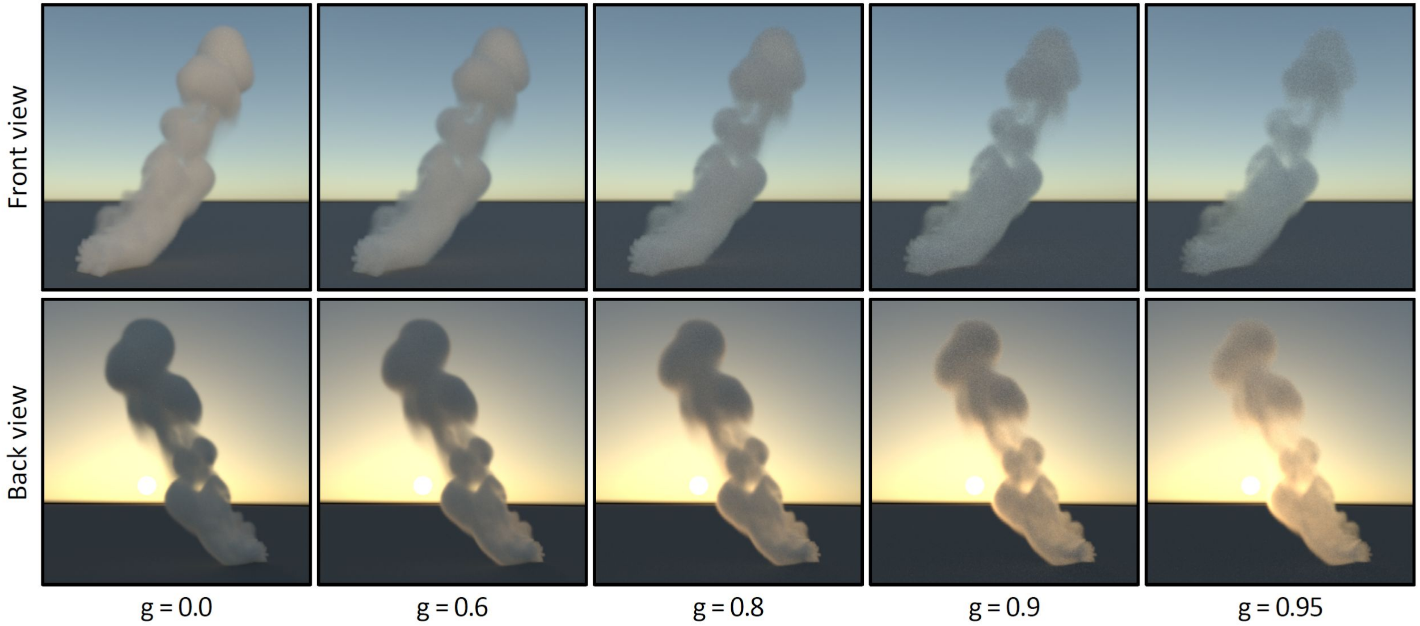
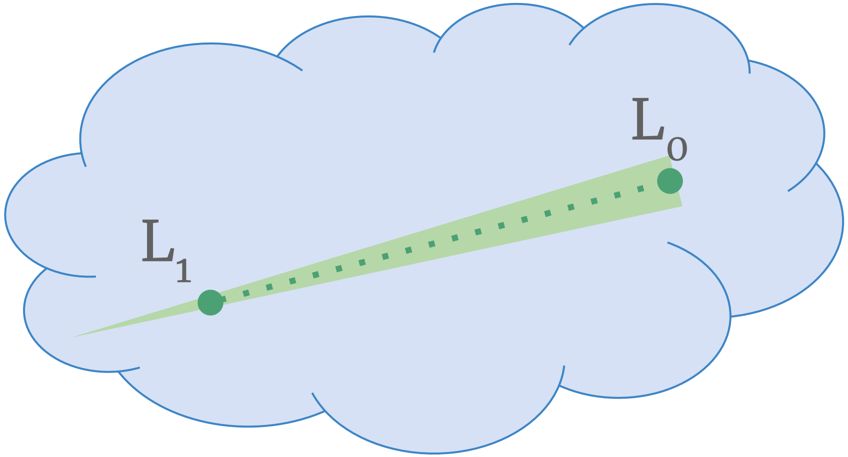


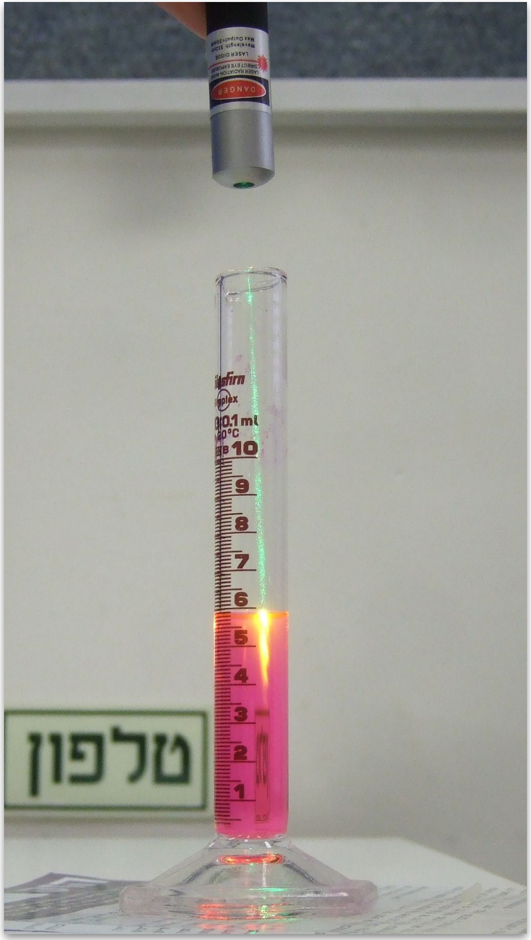
Transmittance in volumes

Defined by the Beer-Lambert law

$$L_1 = L_0 * e^{-\text{optical density} * \text{distance}}$$

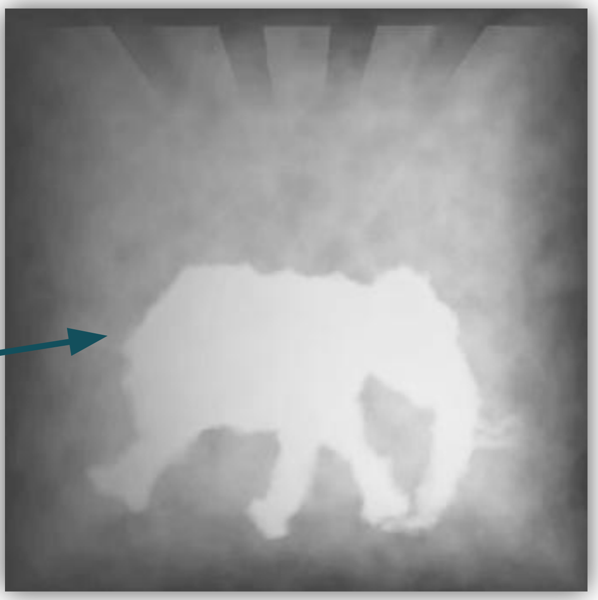
optical density = absorption + scattering



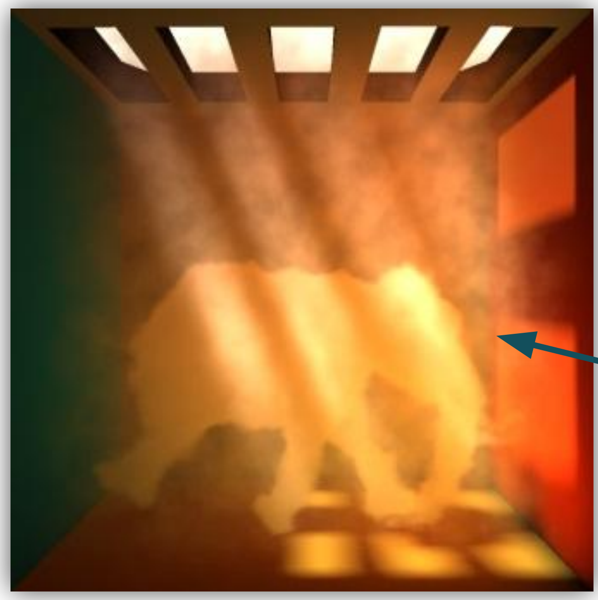


Representation of volumes

3D particle density function (scalar field) $d(x, y, z) \in [0, \infty]$



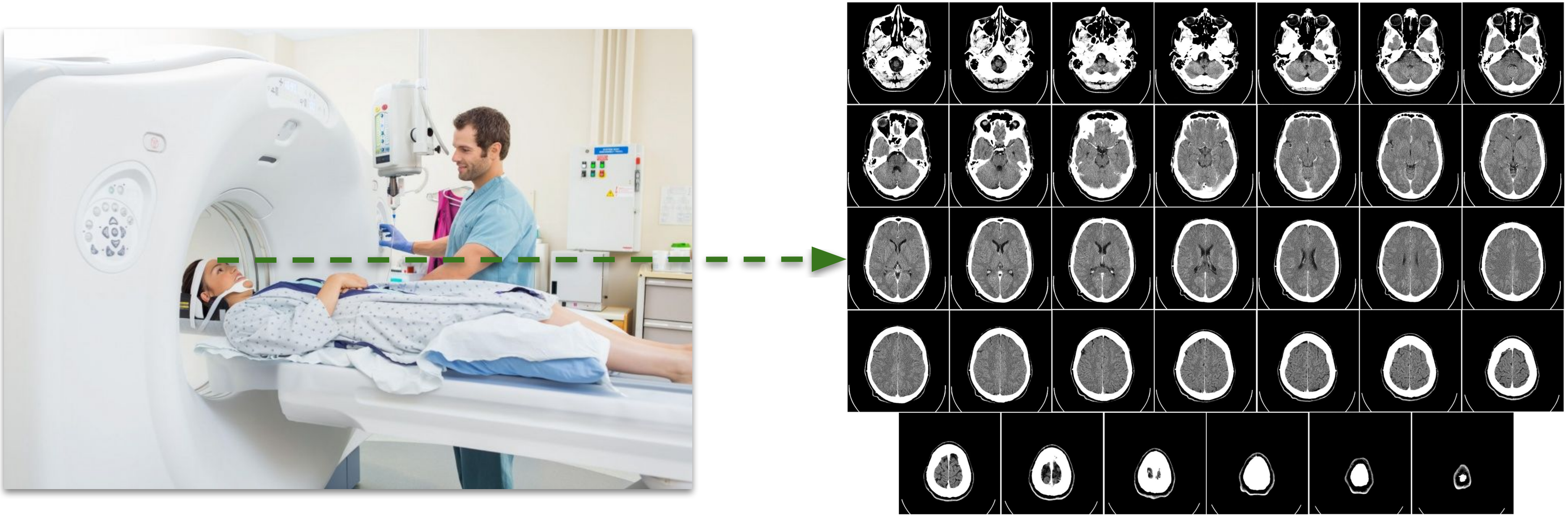
density field



actual render

Representation of volumes

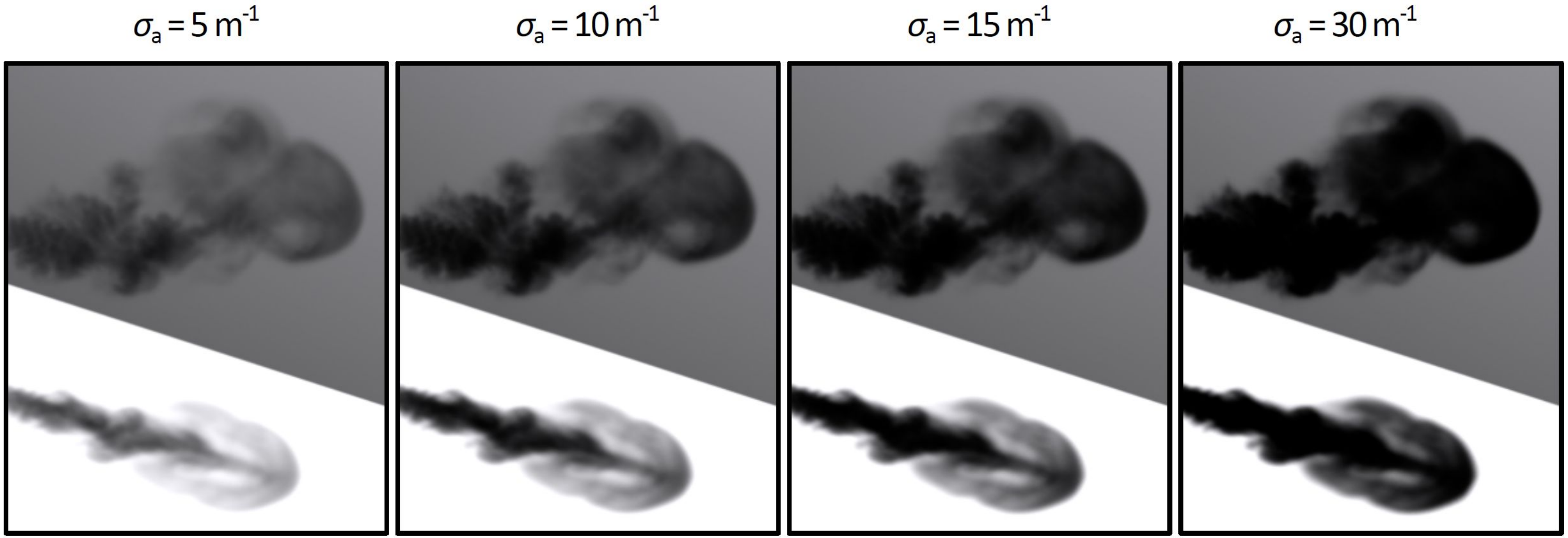
3D particle density function (scalar field) $d(x, y, z) \in [0, \infty]$



Example: **computer tomography** (3D X-ray)

Representation of volumes

3D particle density function (scalar field) $d(x, y, z) \in [0, \infty]$



Ray Marching

Ray marching

Generic algorithm template for numerical integration along a ray

“Generic template”

The function that’s being integrated is independent of the algorithm

The basic algorithm can be modified to many different conditions

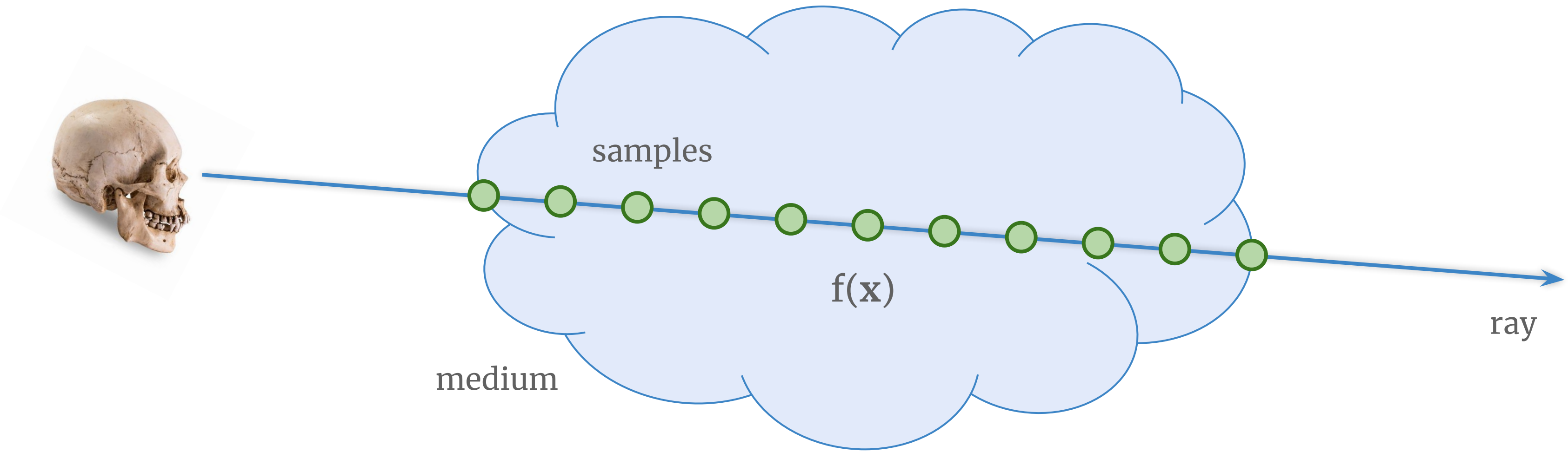
E.g. emission-only / emission + absorption / emission + absorption + scattering

You can think about ray marching as a **generalization of rasterization**: what is being projected is not just discrete 3D geometry, but an **entire 3D function** defined anywhere in space.

Ray marching

Generic algorithm template for numerical integration along a ray

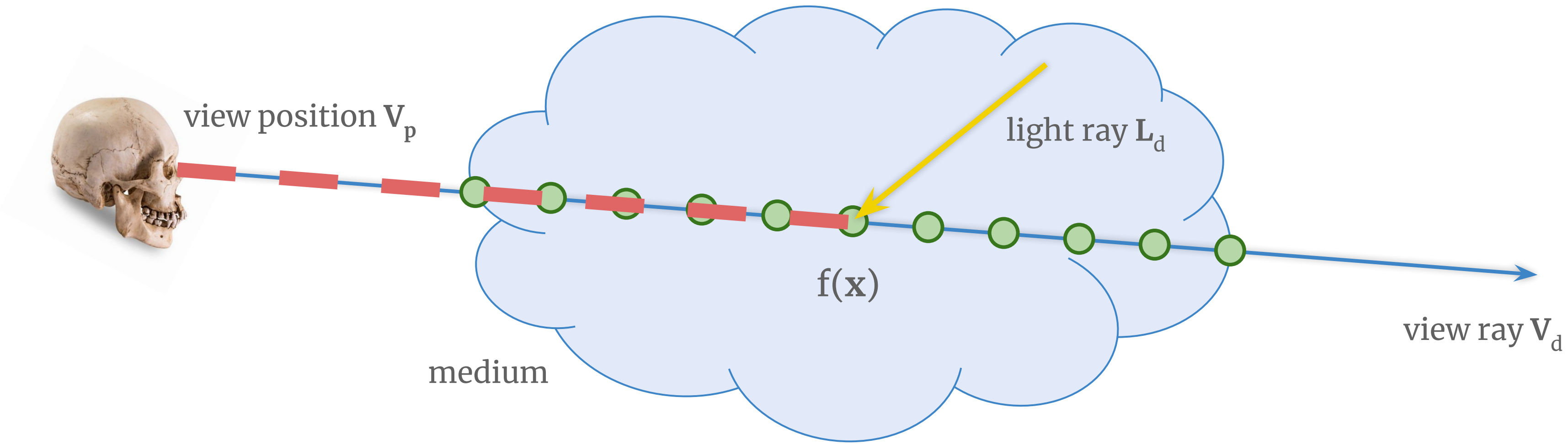
$$\mathrm{I}(\mathrm{ray}) = \int_{\mathrm{ray}} \mathrm{f}(\mathbf{x})\, d\mathbf{x}$$



Ray marching

Integral: direct volume rendering

$$f(\mathbf{x}) = \sigma_s(\mathbf{x}) * T(\mathbf{x},\mathbf{V}_p) * \left(E(\mathbf{x}) + L(\mathbf{x},\mathbf{L}_d) * \mathit{phase}(\mathbf{L}_d,\mathbf{V}_d)\right)$$



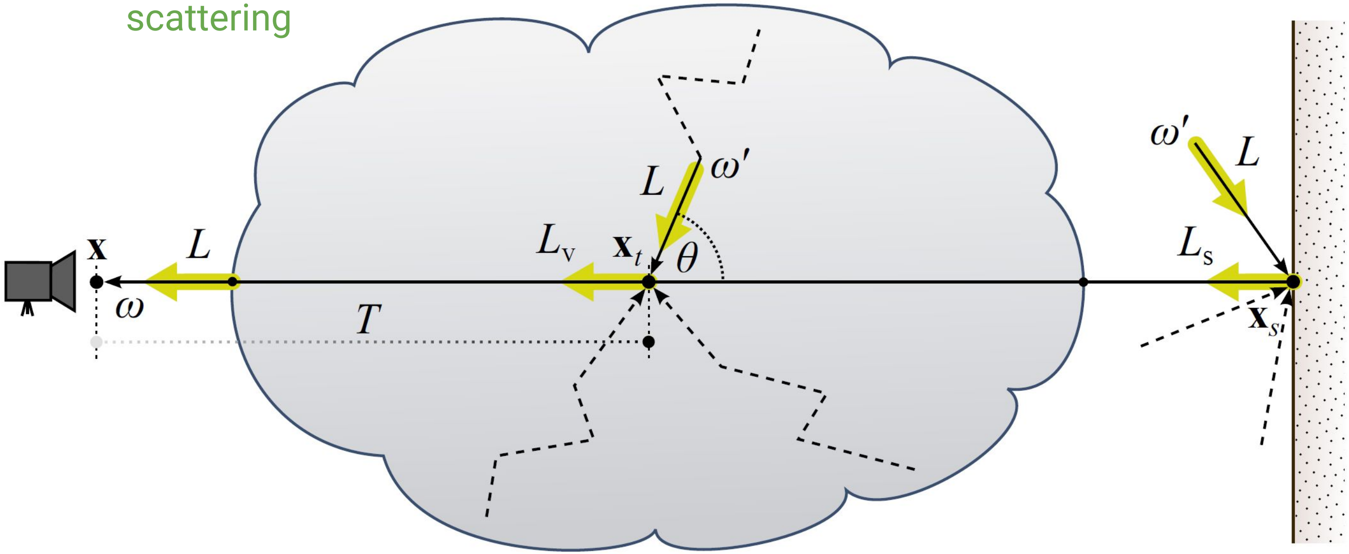
Global Illumination in Volumes

Radiative transport equation [Chandrasekhar 1960]

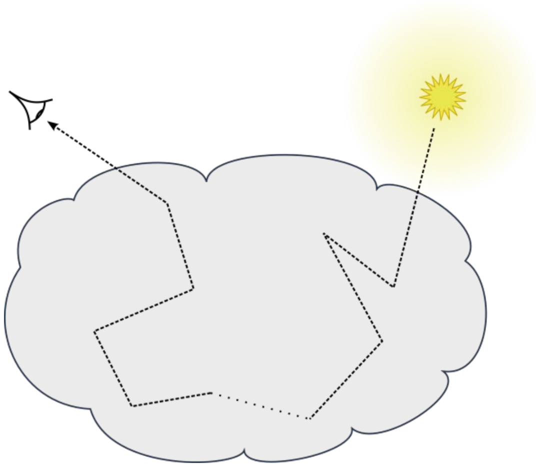
$$\frac{dL(\vec{x},\vec{\omega})}{d\vec{x}} = -\sigma_t L(\vec{x},\vec{\omega}) + \sigma_s \int_{\Omega_{4\pi}} f(\vec{x},\vec{\omega}',\vec{\omega}) L(\vec{x},\vec{\omega}')\, d\vec{\omega}'$$

absorption

scattering

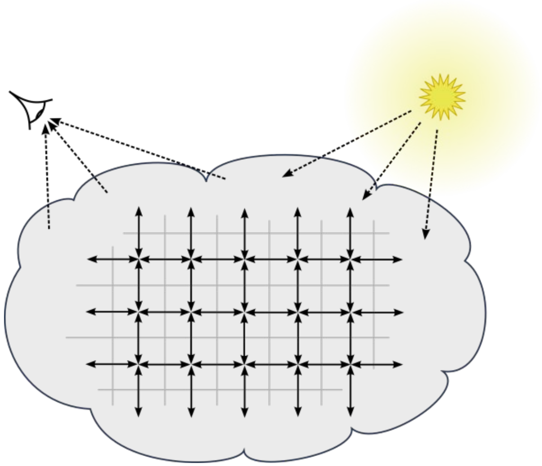


Radiative transport equation: Solvers



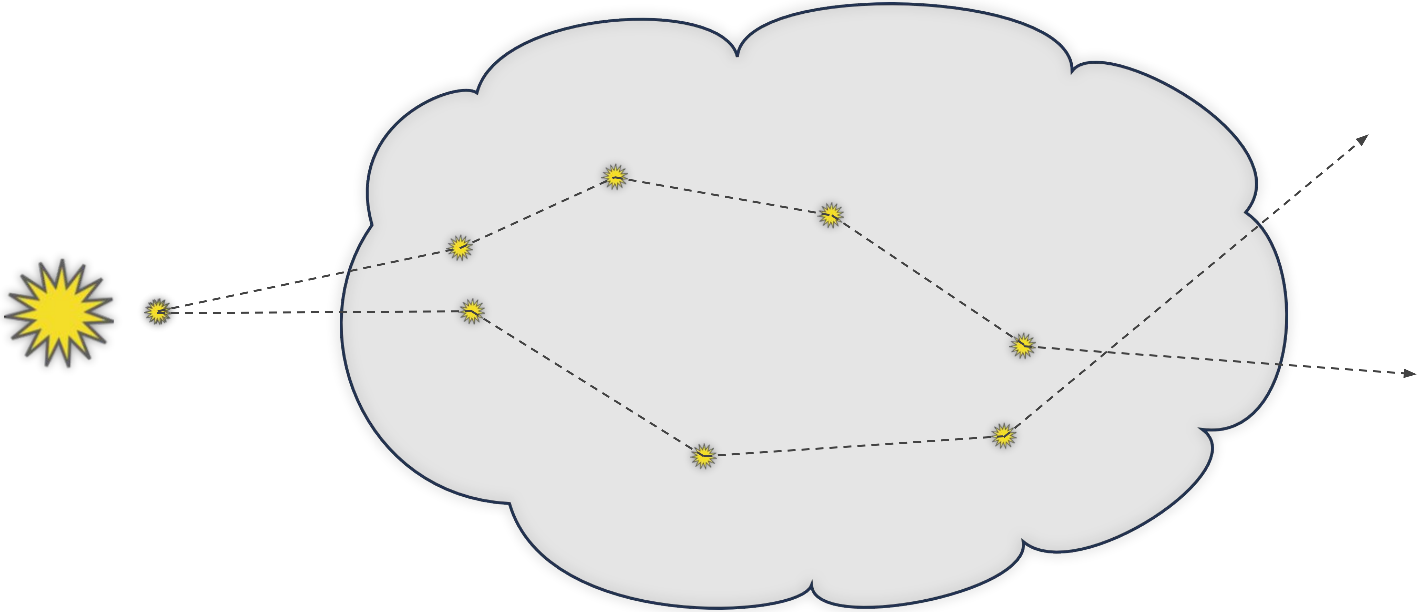
Probabilistic: Monte Carlo

(Path Tracing, Photon Mapping, …)

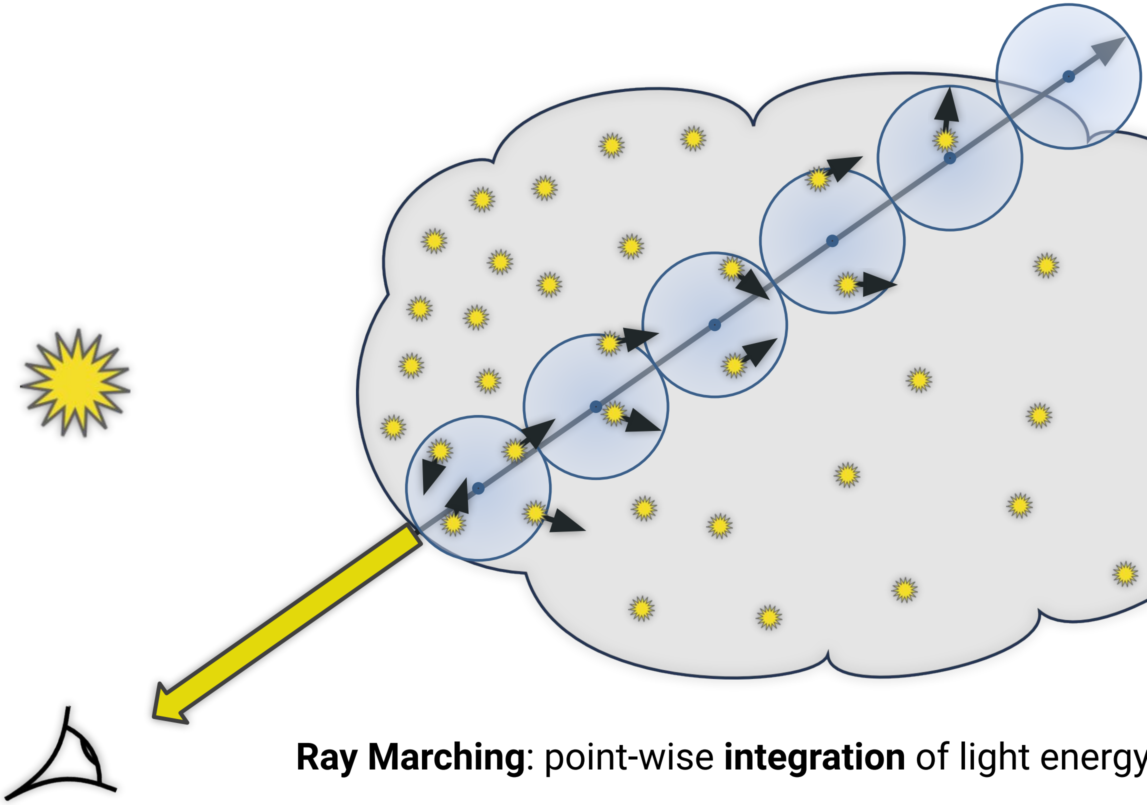


Deterministic: Finite Elements

(Diffusion, Discrete Ordinates, …)

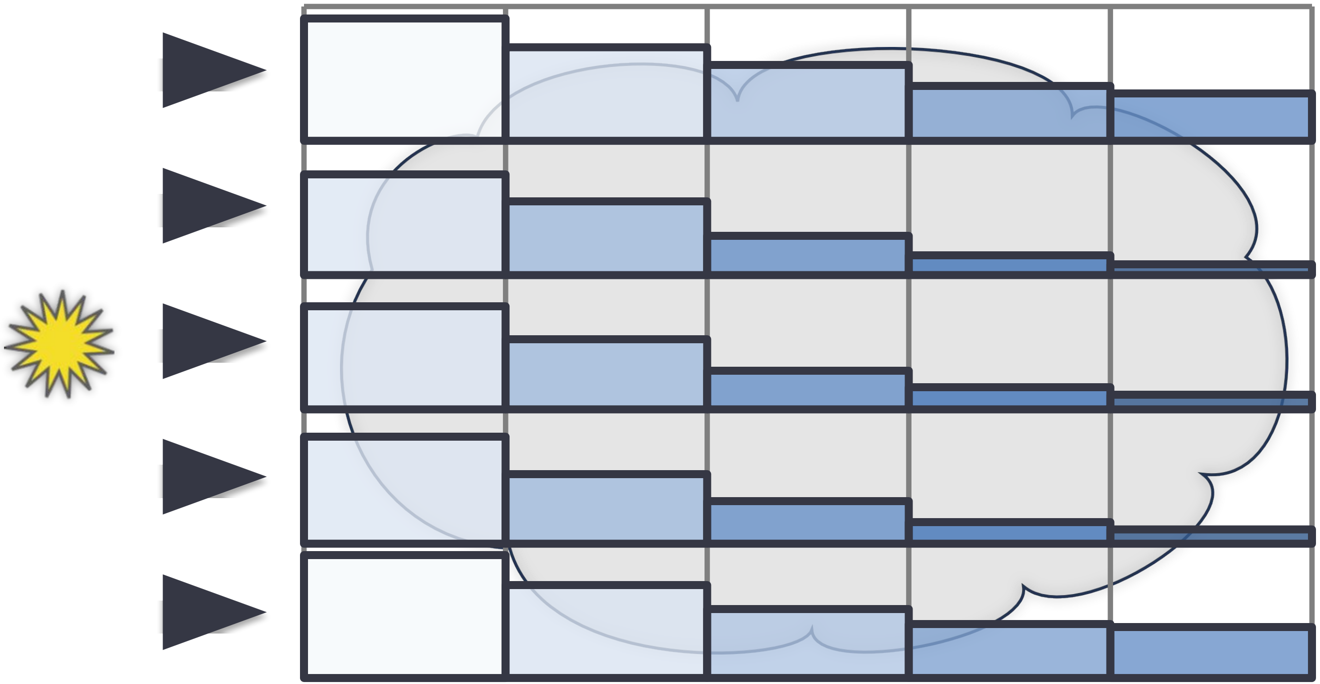


Photon Mapping

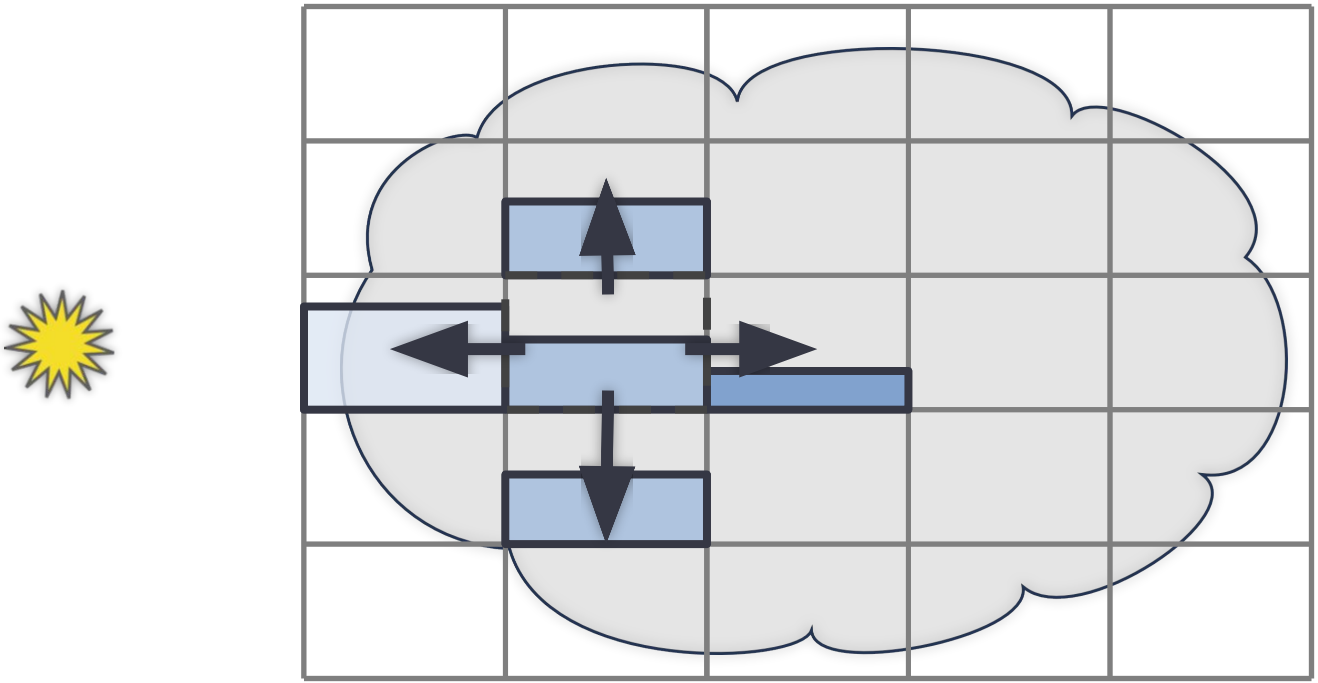


Ray Marching: point-wise **integration** of light energy along a ray

Photon Mapping



Light Diffusion



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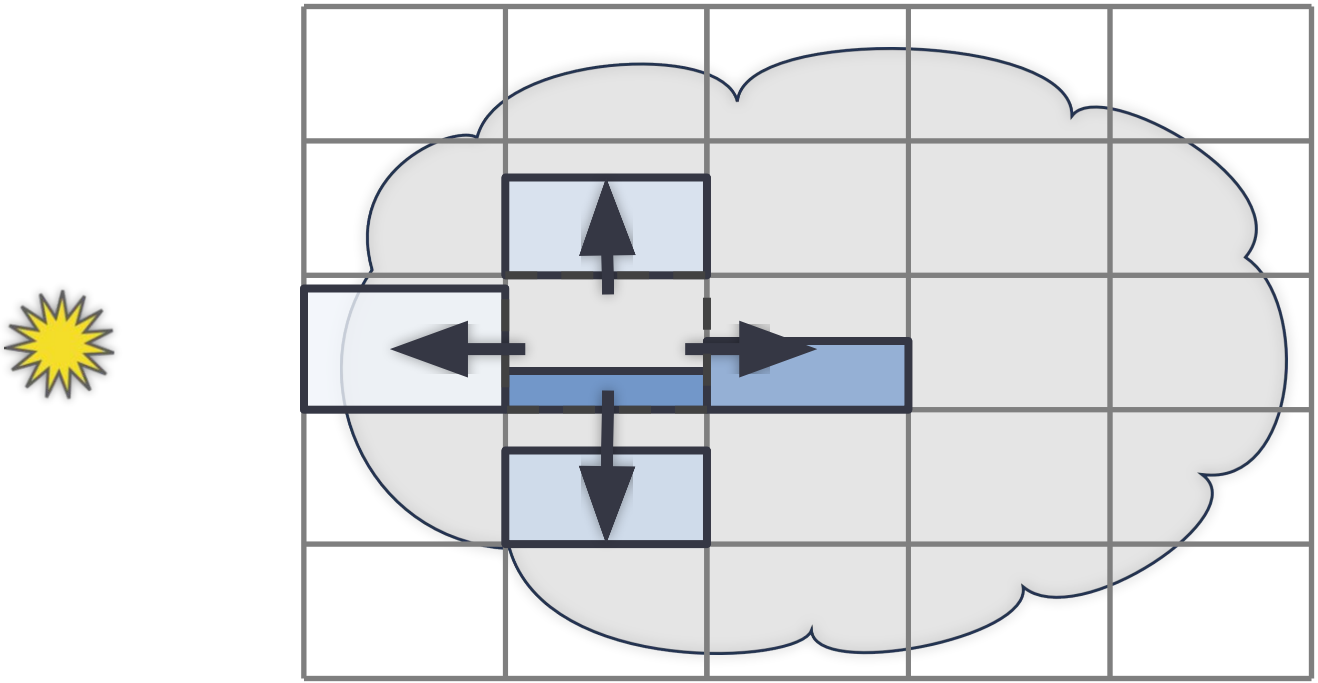
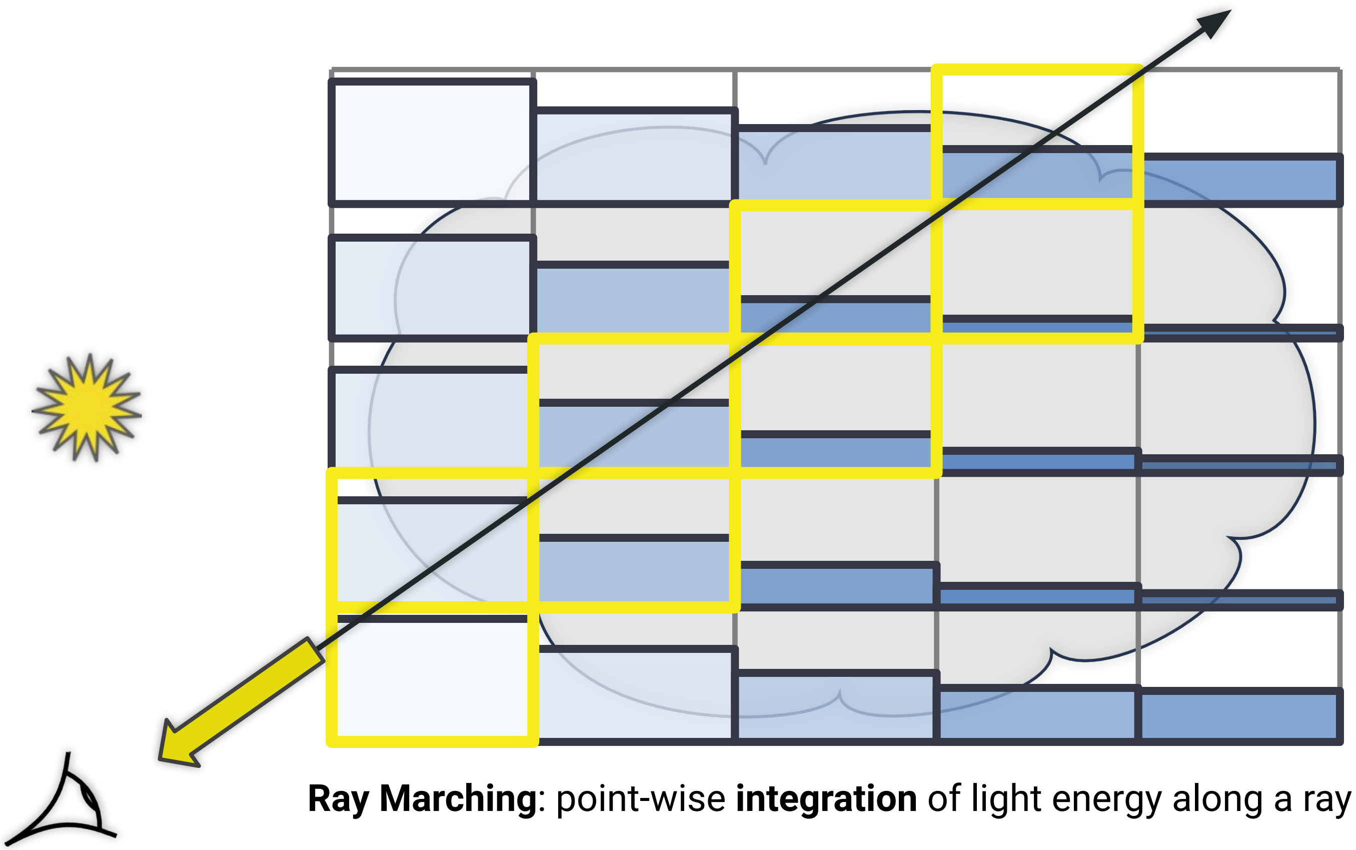


Light Diffusion



Ray Marching: point-wise **integration** of light energy along a ray

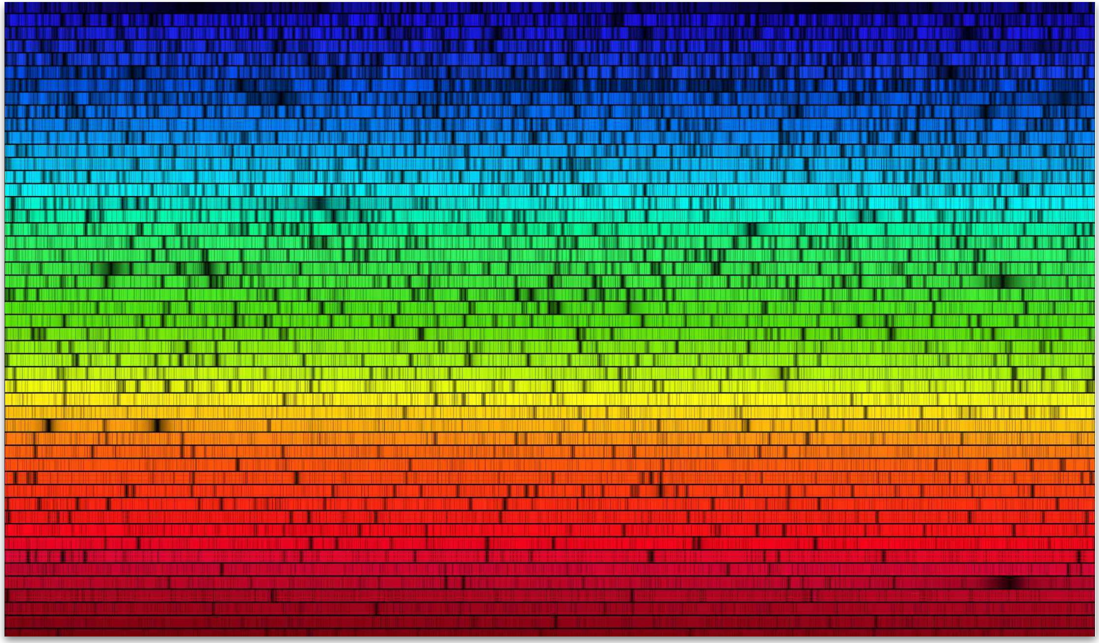
Light Diffusion

Color

Color

The **objective** (light) meets the **subjective** (color)

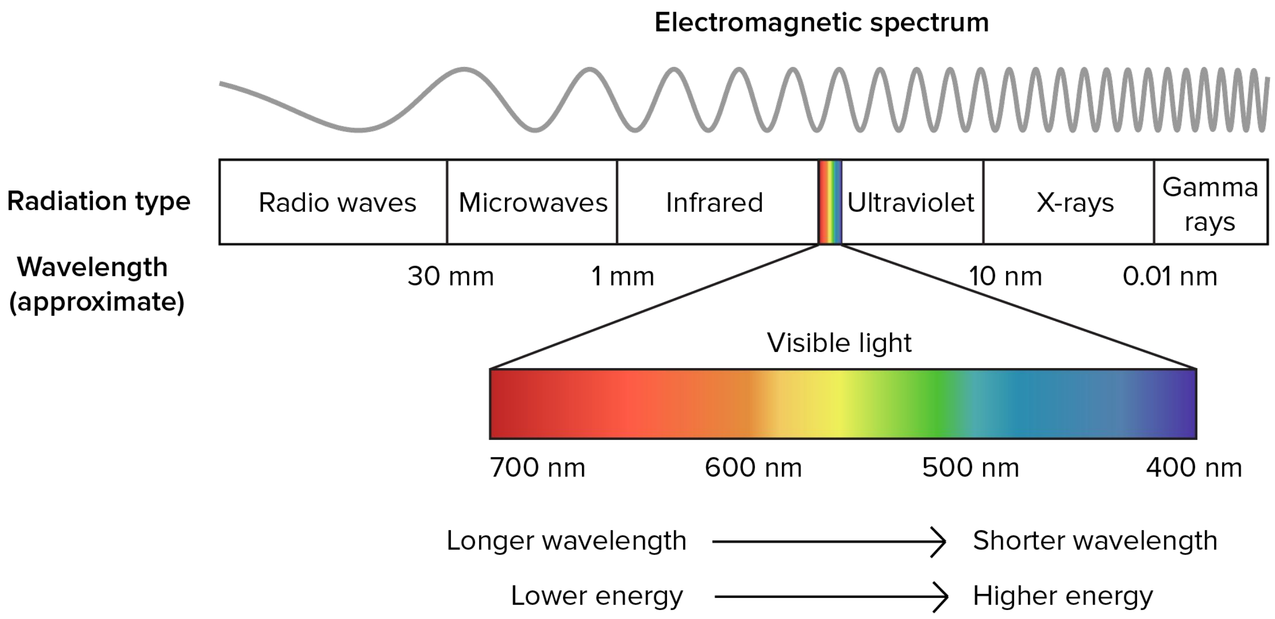
Sun…



…and its spectral 'fingerprint' (1000s of specific absorption lines)

Color

The **objective** (light) meets the **subjective** (color)

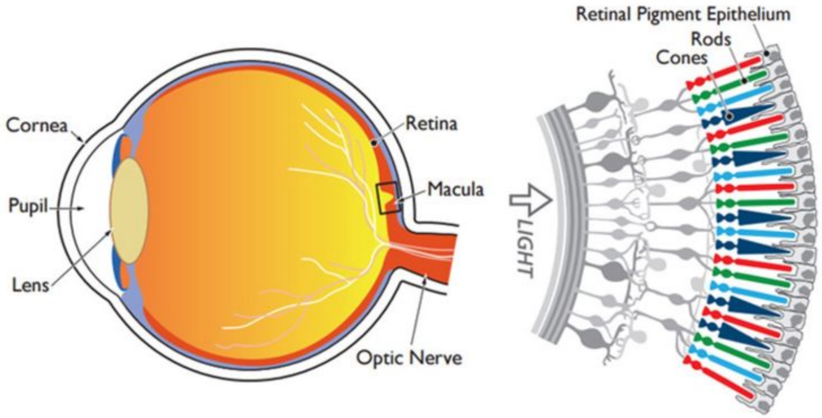


The **visible light** (to us humans anyway) is only a tiny fraction of the whole **EM spectrum**!

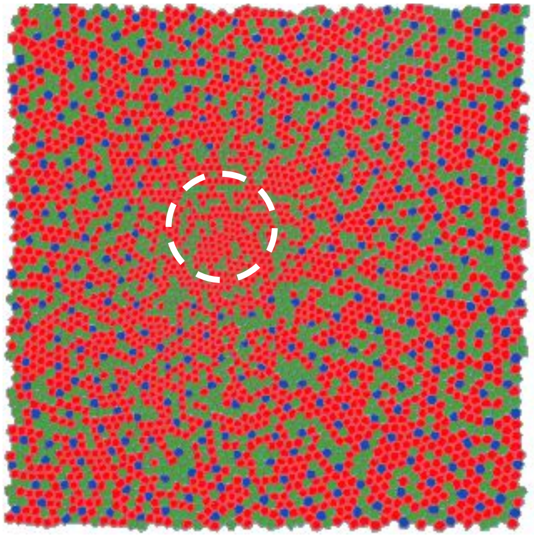
Color

Human retina contains **3 types of photoreceptors**: ‘long’ / ’medium’ / ’short’-wave

In other words: **red** / **green** / **blue** (RGB)



Longer wavelength ⟶ Shorter wavelength

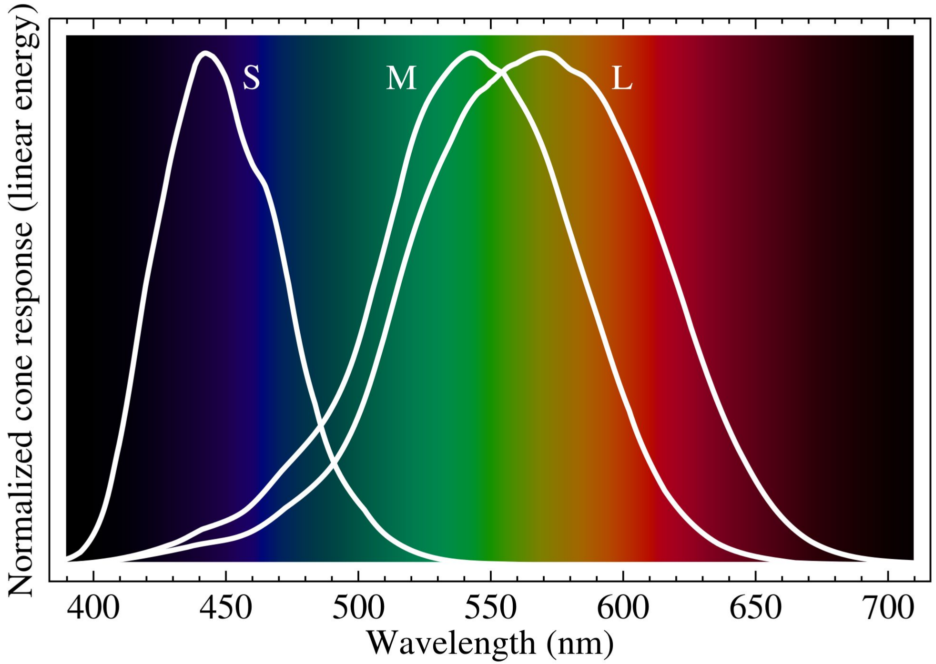


Distribution of receptors is different for each channel ➔ **our vision is not constant!**

Color perception

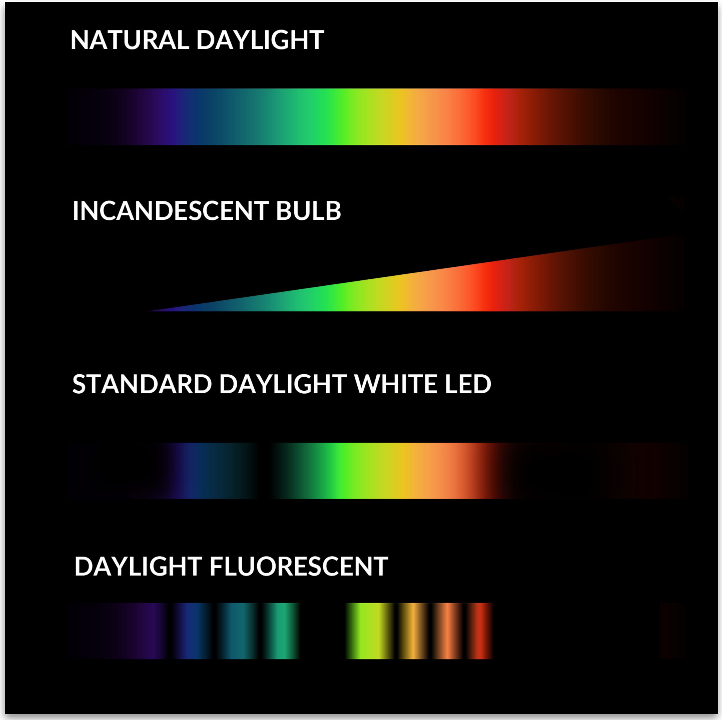
In humans, we compute color using **3 color response curves $S_{R,G,B}(\lambda)$**

These **encode the sensitivity** of each color channel to particular wavelengths

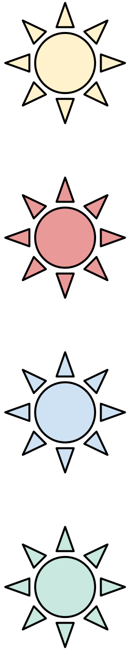


Color perception

Light comes in different varieties: every light source has a different spectral composition ("profile") **L(λ):**

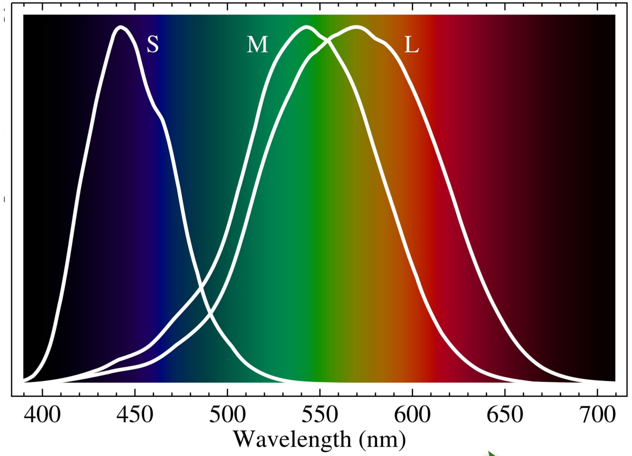


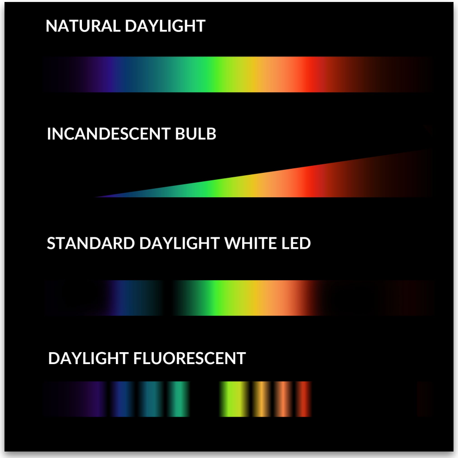
Color:



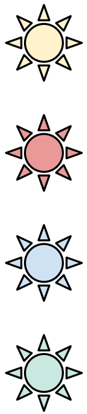
Color perception

Resulting RGB color $\mathbf{C}_{R,G,B}$ is a wavelength-wise product $\otimes$ of the respective spectral sensitivity curve $\mathbf{S}_{R,G,B}(\lambda)$ and the incoming light spectrum $\mathbf{L}(\lambda)$





$\mathbf{C}_{R,G,B}$

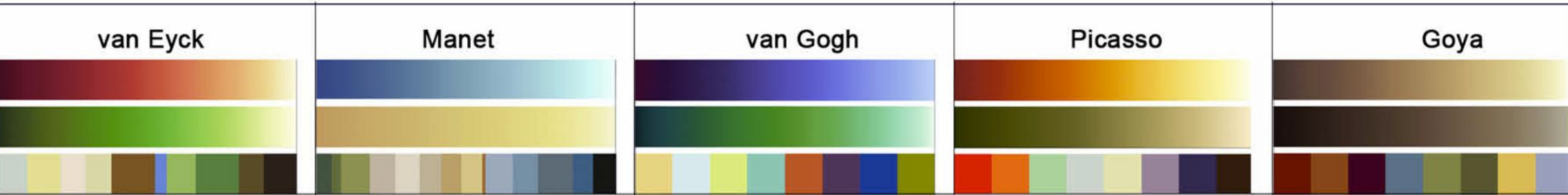


$$\mathbf{C}_{R,G,B} = \mathbf{S}_{R,G,B} \otimes \mathbf{L} = \int_\lambda \mathbf{S}_{R,G,B}(\lambda) * \mathbf{L}(\lambda)$$

Volume transfer function

Mapping between the underlying **scalar density field** $d(x, y, z) \in [0, \infty]$ and attribute **color profiles:**

- emission color (RGB)
- absorption intensity (usually single channel)
- scattering (usually single channel)



Next: Praktikum at 10:30

Bring:

- laptop
- pen & paper
- lateral thinking

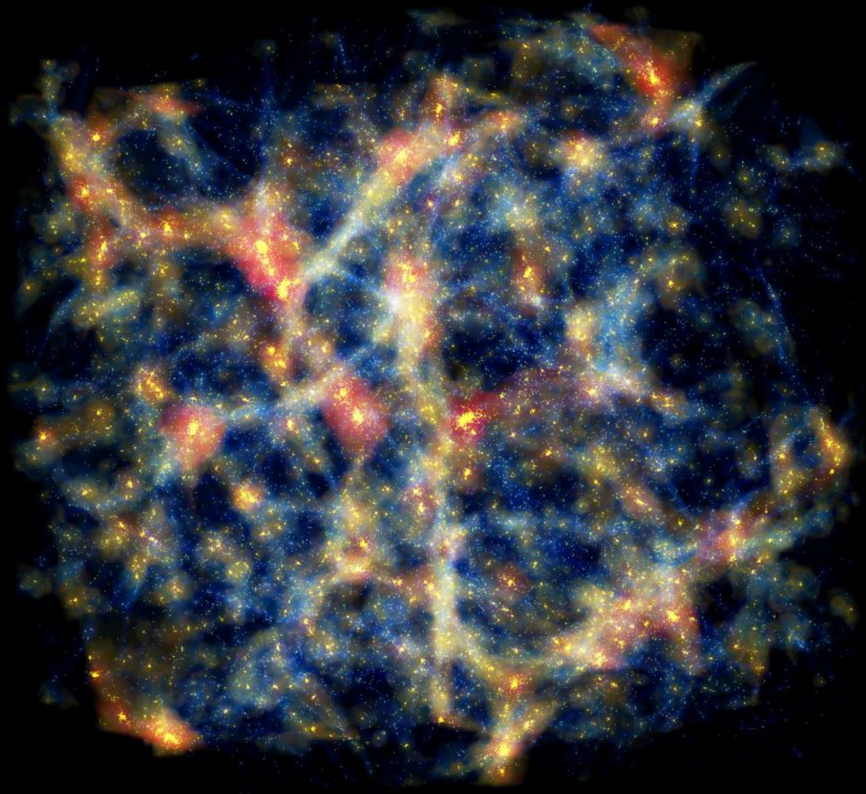
Physically Based Volume Rendering

Praktikum, Tuesday 10:30-12:00

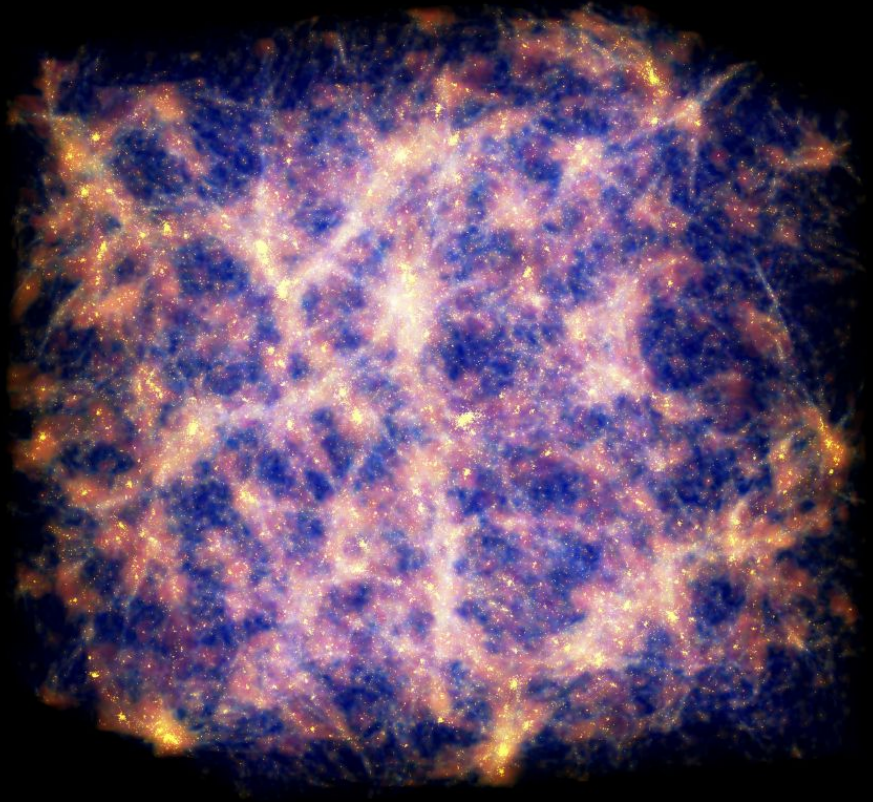
Dr.-Ing. Oskar Elek
University of California in Santa Cruz


Polyphorm

temperature



metallicity



CosmoVis

Eagle data rendered with CosmoVis (https://github.com/CreativeCodingLab/CosmoVis)
by David Abramov, Joe Burchett, Oskar Elek, and Faranul Hasan [Abramov+2022]

Exercises

1. Storyboarding

Using tools available in CosmoVis, create a 3-panel figure highlighting an interesting feature in the dataset of your choice. Work with transfer functions, different modalities, different perspective (parallax, slicing, zooming).

https://github.com/CreativeCodingLab/CosmoVis

2) Sketching

Using pen and paper, brainstorm with a colleague about how you can use volume visualization to better understand your own data. Think about the choice of color, occlusion, perspective, required level of detail, auxiliary tools.