VU Rendering SS 2012

Unit 6: Participating Media

Overview

1. Scattering process
2. Transport equation
3. Evaluation of the transport equation
4. Scattering Phenomena

Participating Media

- In vacuum, radiance is constant along the ray
- In real-world situations, light is scattered and attenuated (e.g. fog, smoke, ...)

- Two difficulties
  - Intersection phenomena takes place within any point of the medium
  - Spectral dependence of the medium characteristic parameters

Participating Media in Real Life - Fog

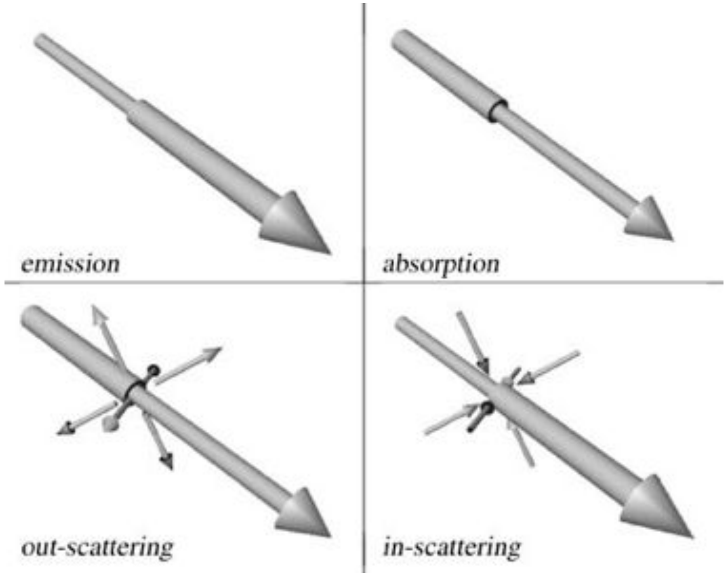
© Gordon Richardso

Participating Media in Real Life - Clouds

Participating Media in in CG - Milk

Process

- Radiation undergoes three different kinds of phenomena
  - Absorption
  - Emission
  - Scattering
    - In-scattering
    - Out-scattering



Absorption

- Energy is reduced (converted into other energy forms e.g. heat)
- Reduction is given by absorption coefficient κ_a
- Beer's law:

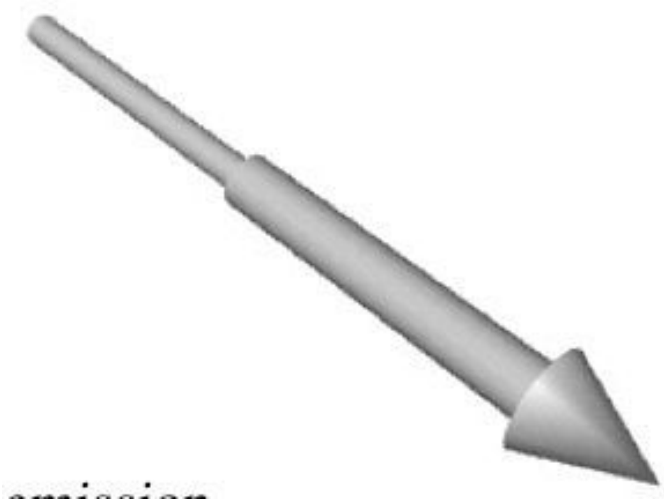
$$L(x) = L(x_0)\underbrace{e^{-\int_{x_0}^{x} \kappa_t(u)\,du}}_{\tau(x_0,x)} = L(x_0)\,\tau(x_0,x)$$

absorption

Real-life absorption: Smoke

Emission

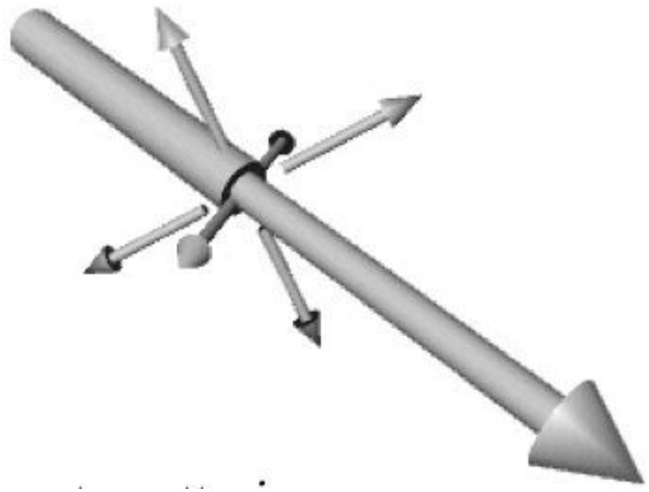
- Energy is added from luminous particles and converted to visible light
- Chemical, thermal or nuclear processes

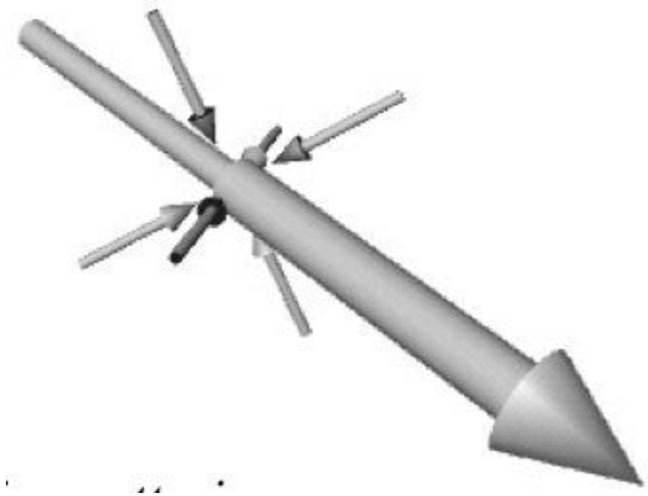


Real-life Emission: Fire

Scattering

- Change in propagation direction
  - Out-scattering: Light is scattered on particles, radiance is reduced along ray by the factor κ_s (scattering coefficient)
  - In-scattering: Radiance is increase from other directions





Real-life Out-Scattering: Clouds

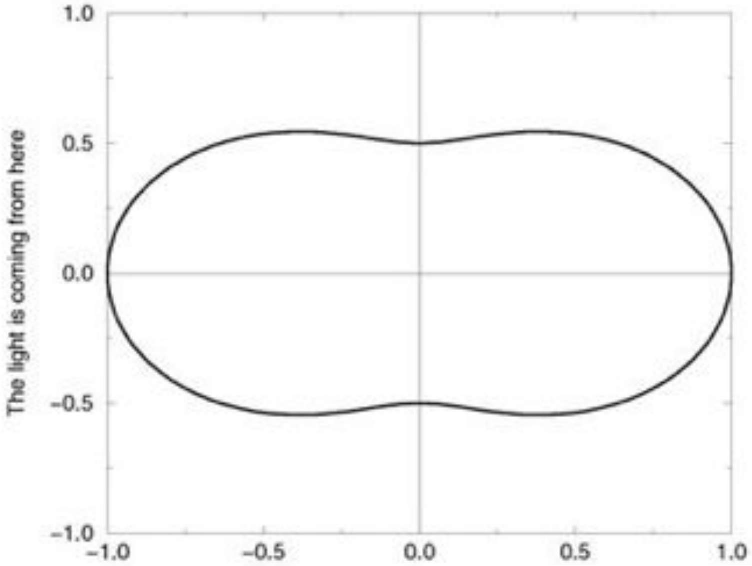
Real-Life In-Scattering: Mist

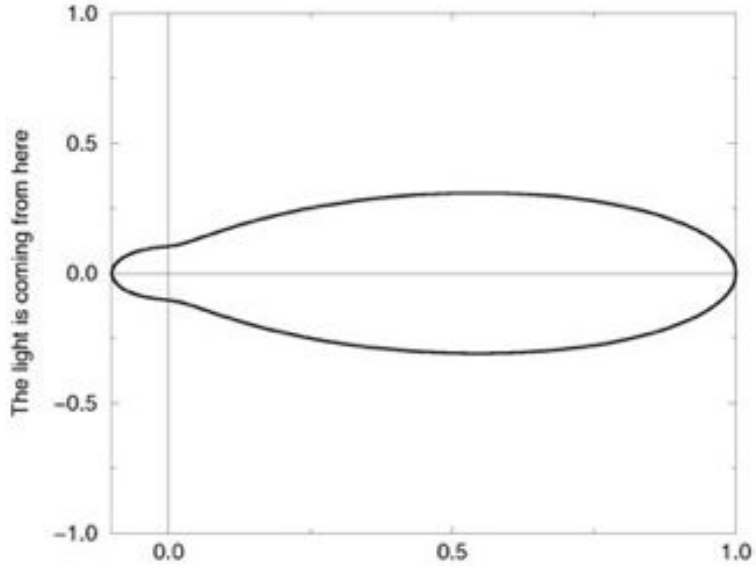
Phase Function

- Spatial distribution of the scattered light
- Intensity in direction ω_o divided by intensity that would be scattered in isotropic medium

- Different phase functions
  - Isotropic (counterpart of diffuse BRDF)
  - Rayleigh (small spherical particles, e.g. smoke)
  - Mie (particles have size of light, e.g. clouds)
  - Henyey-Greenstein (approximation of Mie)
  - ...

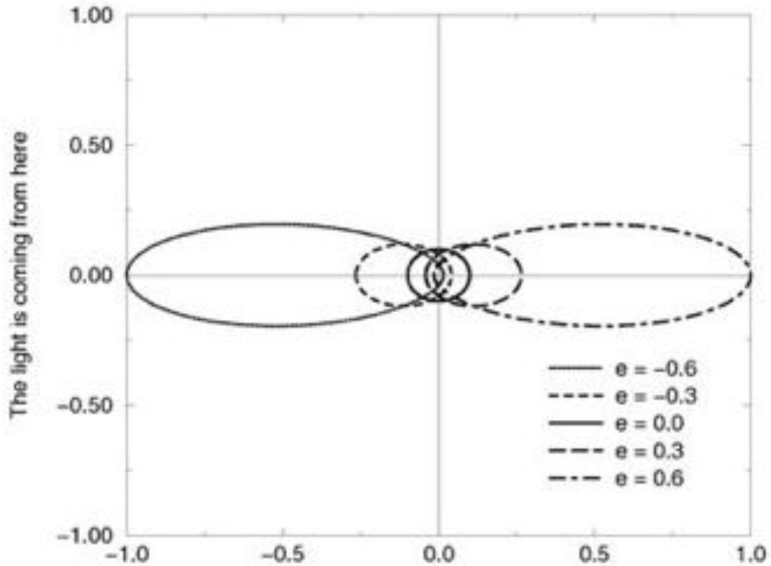
Different Phase Functions





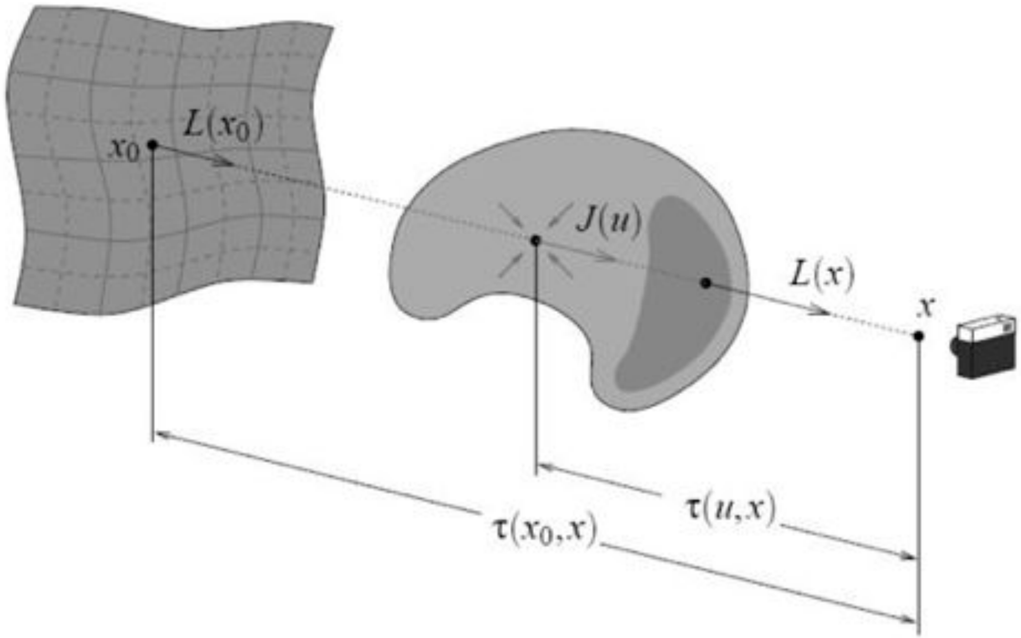
Rayleigh

Mie (haze)



Henyey-
Greenstein

Transport Equation Geometry



$$L(x) = \underbrace{\tau(x_0,x)\,L(x_0)}_{L_{\mathrm{ri}}(x)} + \underbrace{\int_{x_0}^{x} \tau(u,x)\,\kappa_t(u)\,J(u)\,du}_{L_{\mathrm{m}}(x)}$$

Radiance L(x) at point x in a given direction is the sum of the reduced incident radiance $\tau(x_0,x)L(x_0)$ and the contribution of the source radiance in the medium

Transport Equation

- Transport equation takes all these phenomena into account
- Describes variation of radiance

$$\frac{dL(x)}{dx} = \kappa_t(x)J(x) - \kappa_t(x)L(x)$$

$$= \underbrace{\kappa_a(x)L_e(x)}_{\text{emission}} + \underbrace{\frac{\kappa_s(x)}{4\pi}\int_S L(x,\omega_i)\,p(\omega_o,\omega_i)\,d\sigma_{\omega_i}}_{\text{in-scattering}}$$

$$- \underbrace{\kappa_a(x)L(x)}_{\text{absorption}} - \underbrace{\kappa_s(x)L(x)}_{\text{out-scattering}},$$

Solving the Problem

- Two challenges
  - Input data
    - Homogeneous (constant parameters)
    - Inhomogeneous (properties are varying in the medium)
  - Solving of the transport equation

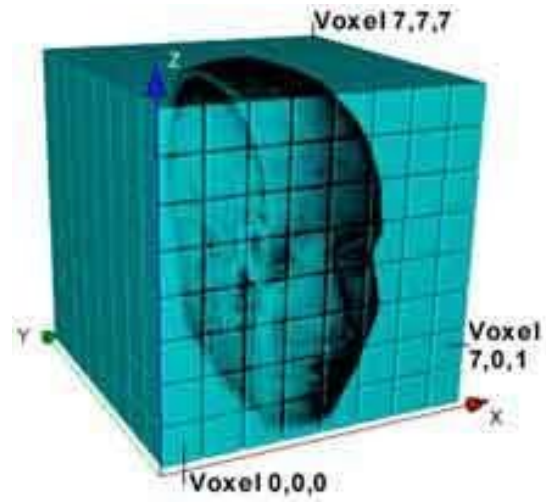
- Full solution is very expensive
- Rendering with simplified models

Step 1: Input Data

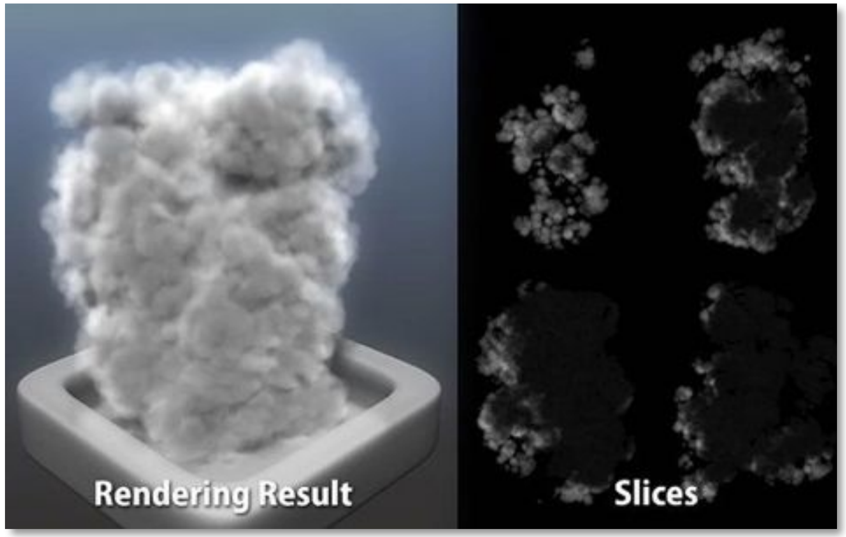
- Two fundamental approaches
  - Explicit storage of measured data
  - Numerical solutions
- (Similar to BRDFs)

Measured Data

- Commonly done in medicine, ocean and atmospheric science, …
- Data stored in voxel grids
  - Interpolation of data to give continuous volume
  - Often used in volume rendering



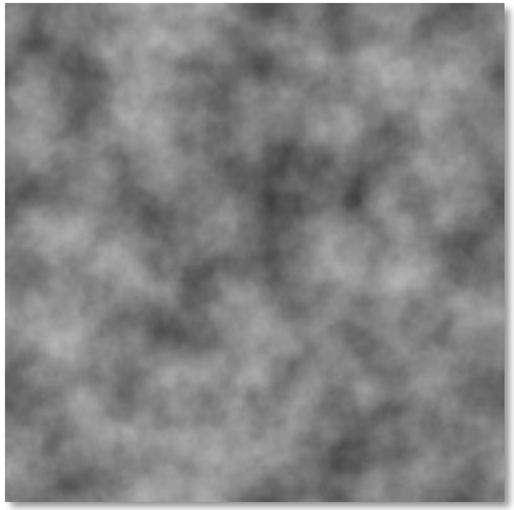
www.volumegraphics.cor



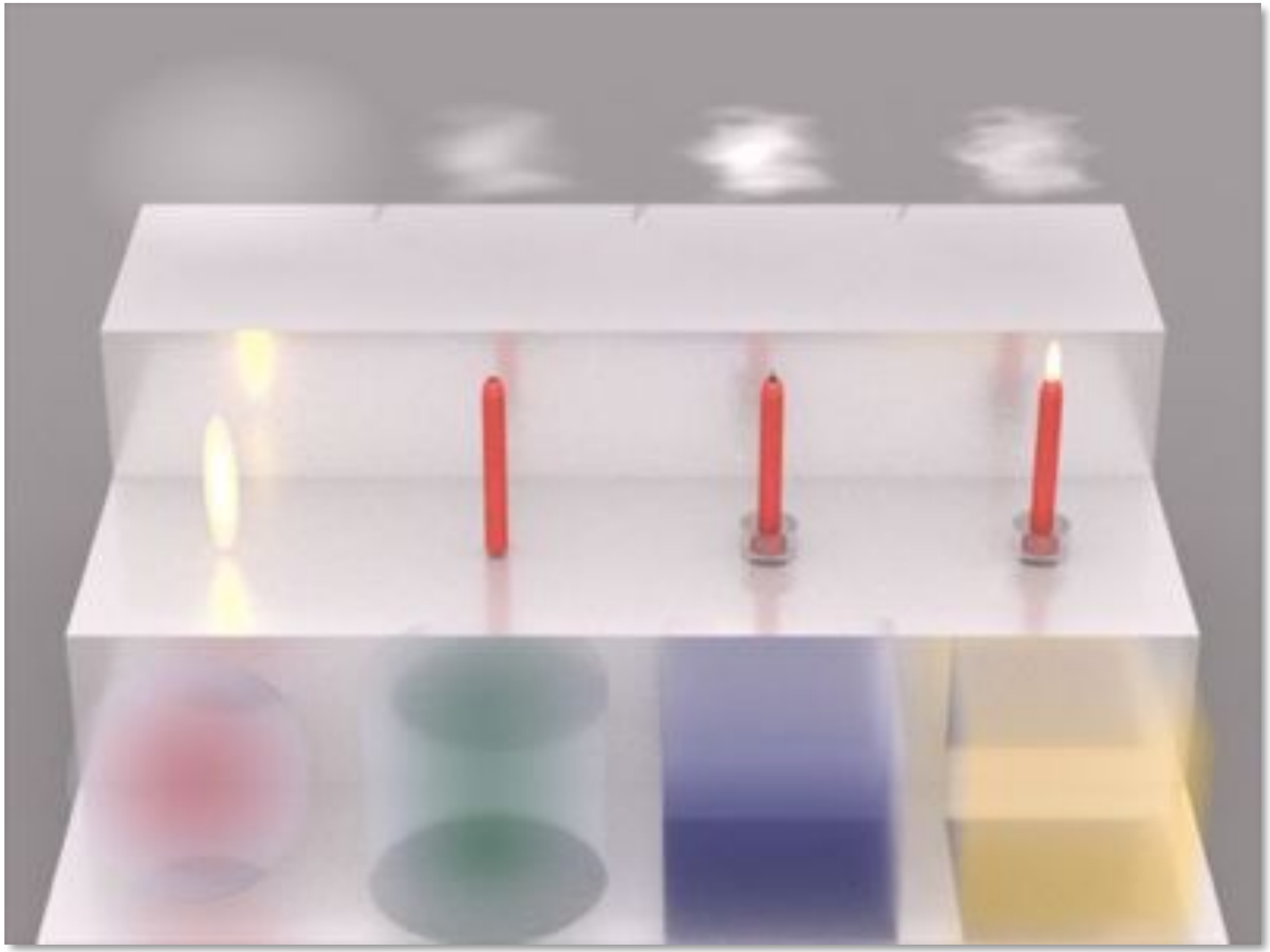
Acquisition of Time-Varying Media

Numerical Solutions

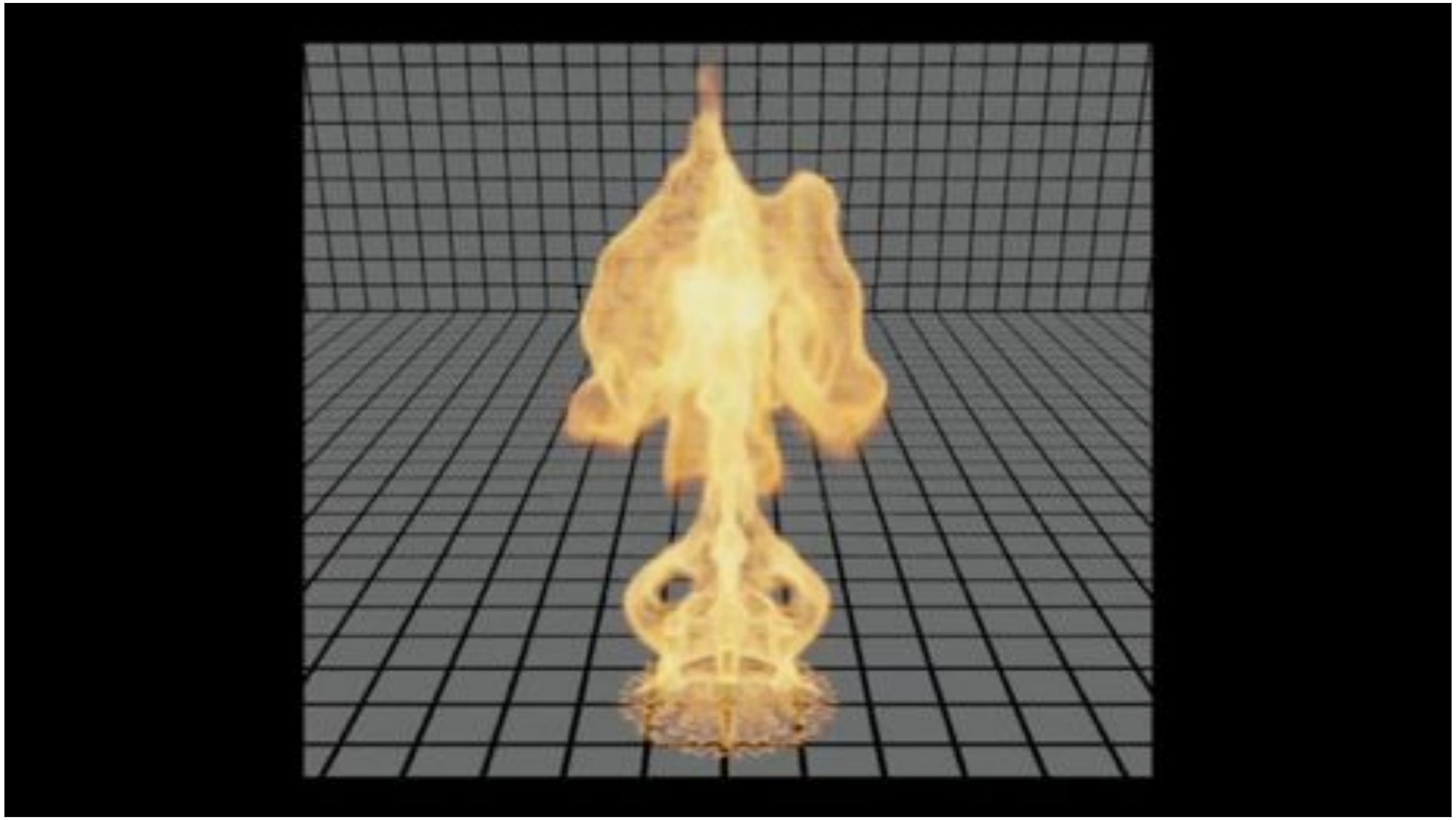
- Simple analytical functions
  - Perlin noise
  - Exponential function
  - ...
- Numerical
  - Fluid simulations
  - ...



Simple Density Functions



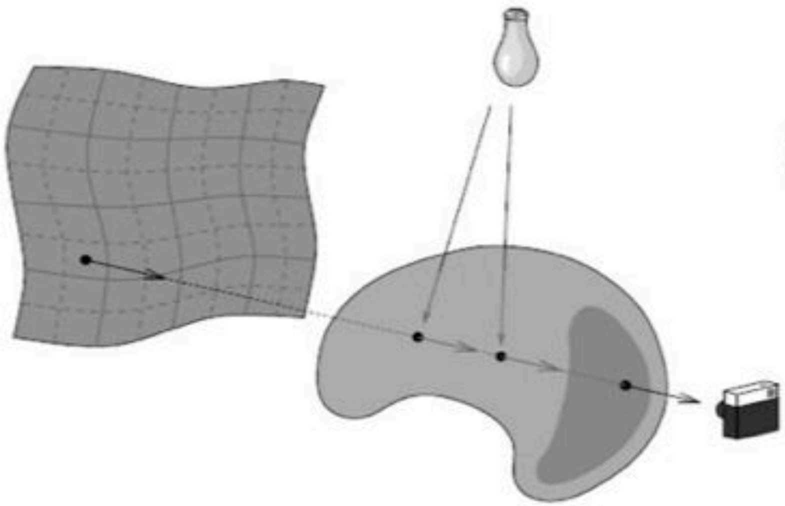
Fire Rendering



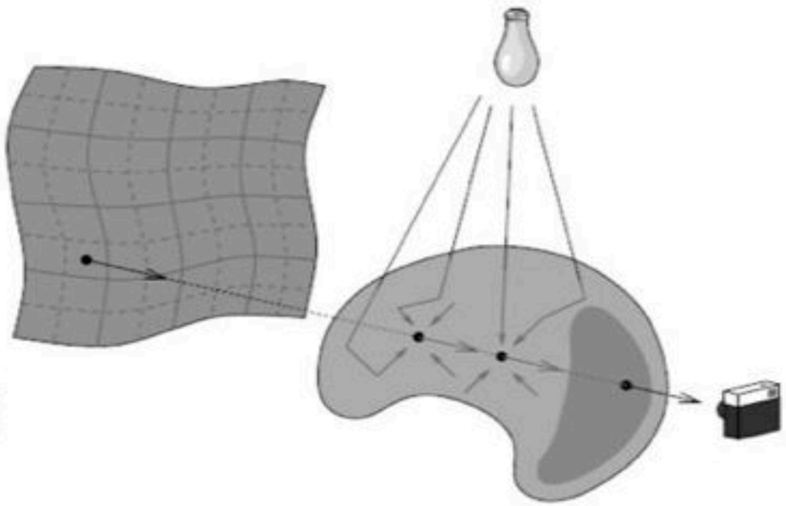
Step 2: Solving the Transport Equation

- Different simplifications of the transport equation
  - No scattering case (e.g. fire)
  - Single scattering case
    - In general not realistic
    - Strongly related to the specific medium
- Homogeneous vs. in-homogeneous

Single Scattering vs. Multiple Scattering



single scattering



multiple scattering

Absorption/Emission only

- No scattering

$$L(x) = \tau_a(x_0, x) L(x_0) + \int^{x} \tau_a(u, x) \kappa_a(u) L_e(u) \, du$$

$$\tau_a(x_0, x) \text{ being } \exp(-\int_{x_0}^{x} \kappa_a(u) \, du)$$

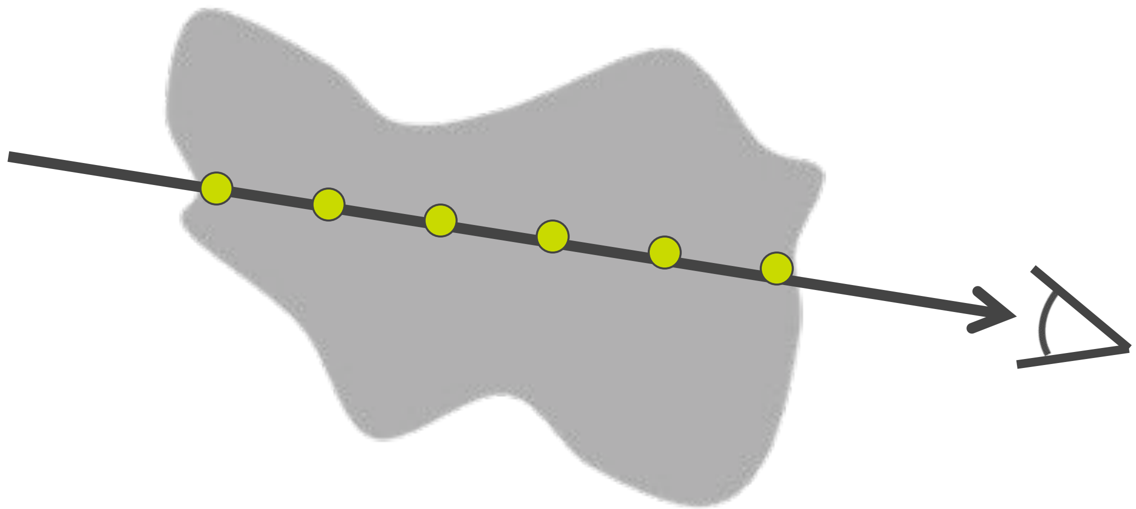
- For homogeneous non-emitting materials

$$L(x) = e^{-\kappa_a \|x_0 - x\|} L(x_0)$$

- For heterogeneous materials break up integral and compute it incrementally by ray marching

Ray Marching

- Computes the contribution from the medium by dividing the ray into smaller segments



Ray Sampling

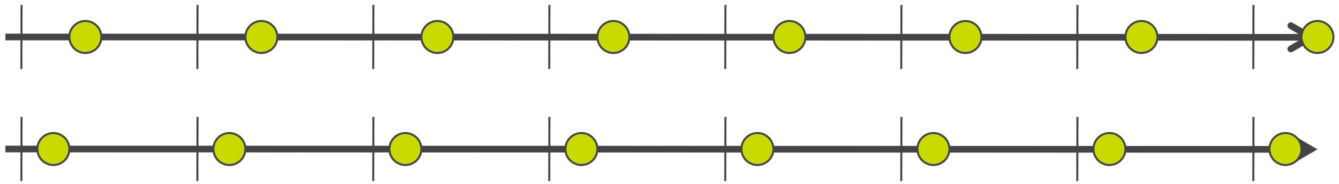
- Ray is divided into a number of segments
  - Random step size
  - Equal step size, first sample is placed randomly

- Deterministic sampling will produce aliasing artifacts!

Ray Sampling Strategies

- Deterministic

- Random start, equal step size



- Random step size

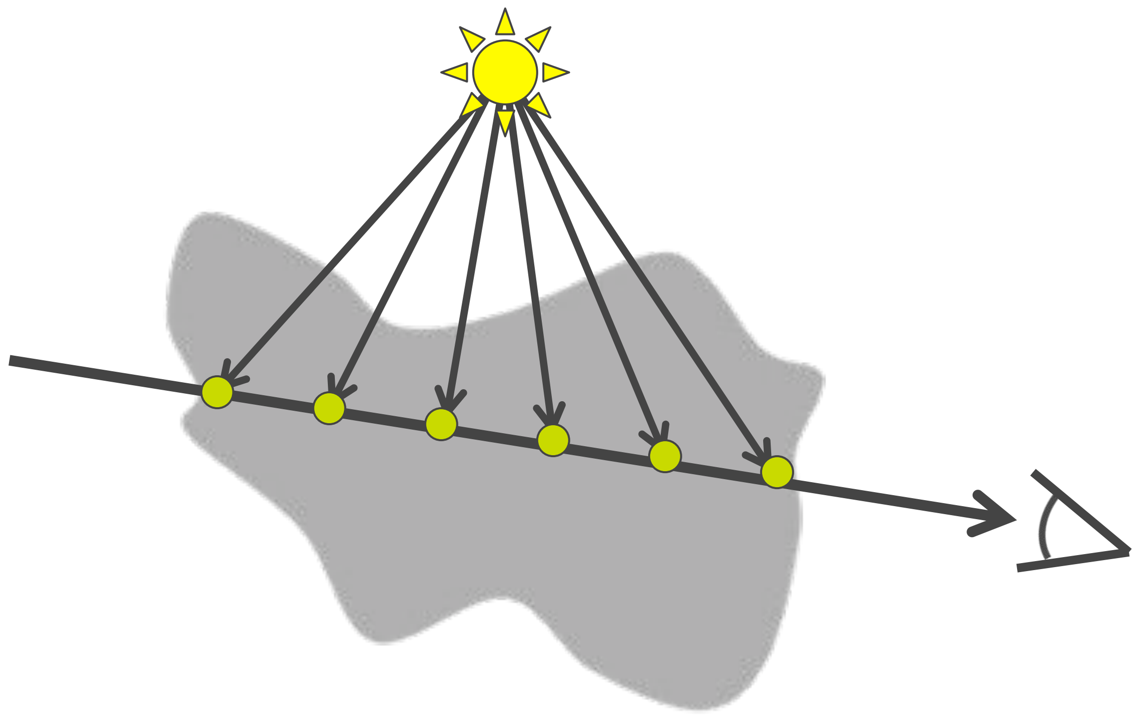
Single Scattering

- Scattering of light by a single particle
- Material is either
  - very thin
  - or very transparent

- Considers incidence radiance due to direct illumination

Single Scattering Integrator

- Compute the contribution from the medium by dividing the ray into smaller segments
- No refraction!



Single Scattering Implementation

- Evaluate direct illumination
- Use ray marching
- At each sample point
  - Shoot ray to light source
  - Radiance may be blocked by geometry
- Problem with refraction: New intersection point not knows

Single Scattering Integrator Example #1

www.pbrt.org/gallery

Single Scattering Integrator Example #2

www.pbrt.org/gallery

Multiple Scattering

- Scattering of light from multiple particles
- Two stages
  - Illumination pass (source radiance is computed, e.g. volume photon mapping)
  - Visualisation pass (transport equation is solved, e.g. ray marching)
- Similar to BSSRDF evaluation

Multiple Scattering to Single Scattering

Volume Photon Mapping

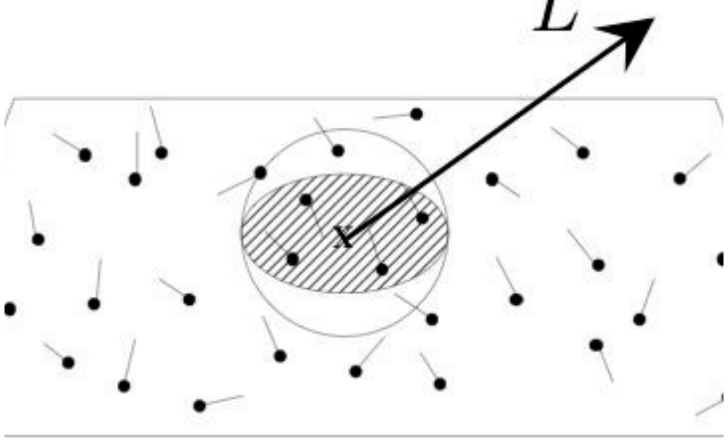
- Extend surface photon maps to volume photon maps
- Photons are stored in the volume
- Still two pass algorithm
  - Pass 1: Trace photons through volume
  - Pass 2: Evaluate photon maps using ray marching

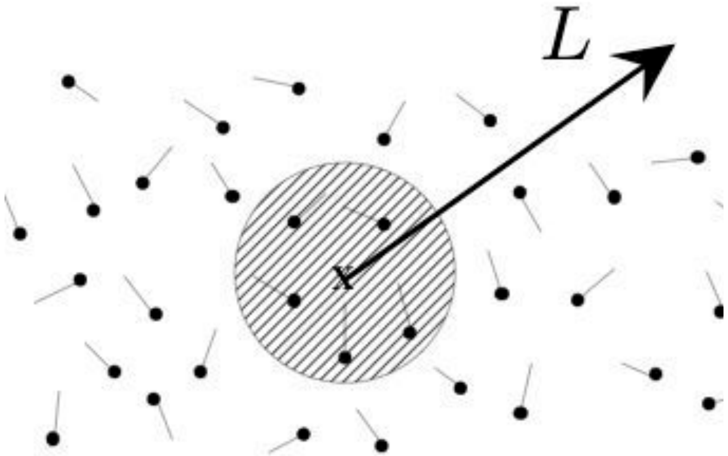
Volume Photon Tracing

- Photon can
  - Pass unaffected
  - Interact with medium (scattered or absorbed)
- Russian roulette decides whether the photon is scattered or absorbed
- Stored in the photon map, if it does not come directly form a light source and interacts
- Importance sampling of phase function to find new direction

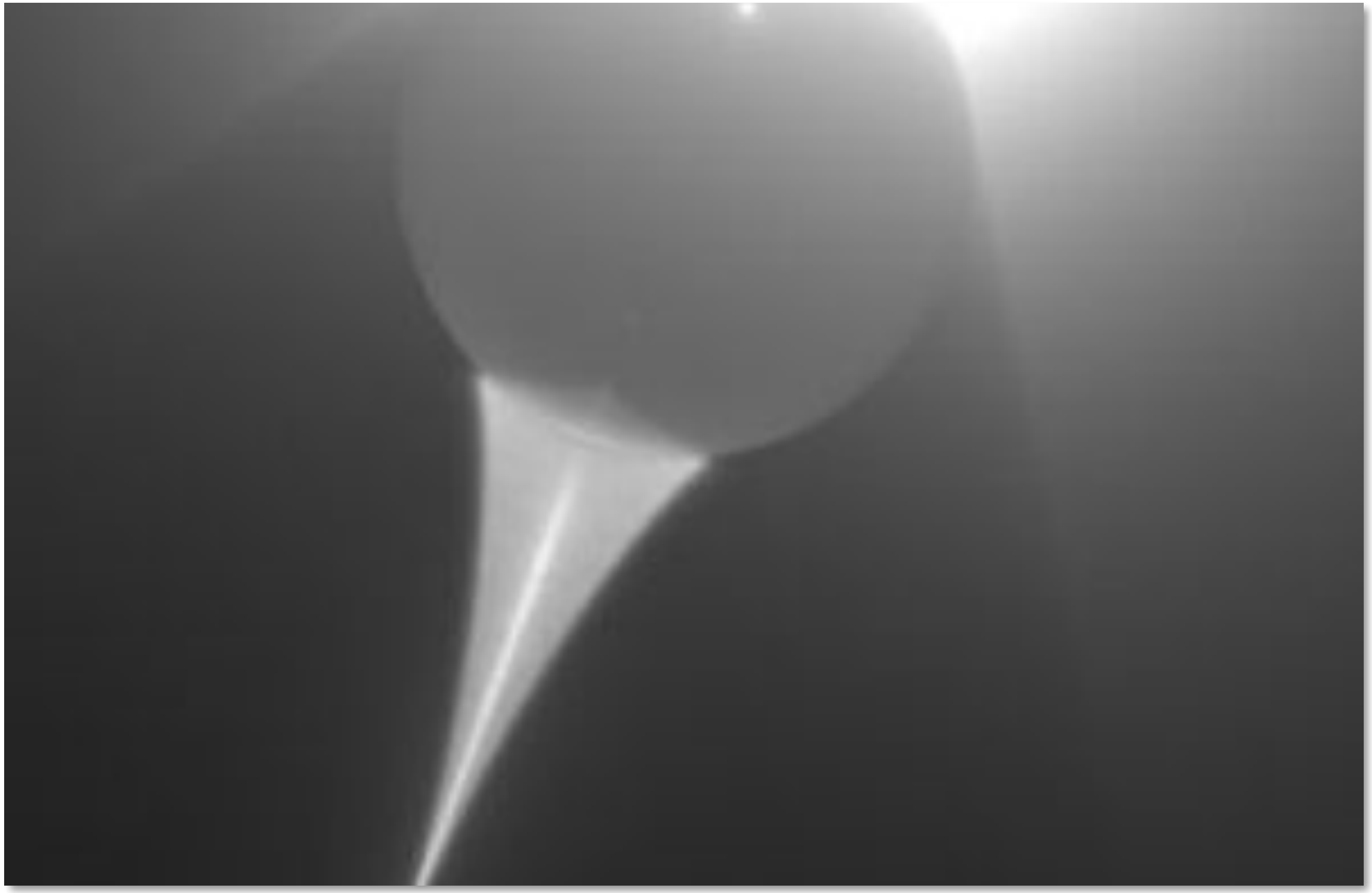
Estimating Radiance

- Different for surfaces and volumes
  - Surfaces: projected area
  - Volumes: full volume
- Direct Light by sampling of the light source using ray marching
- Indirect Light: volume radiance estimate





Volume Caustics



http://
graphics.ucsd.edu/
~henrik/images/
parti.html

Participating Media in CG - Smoke

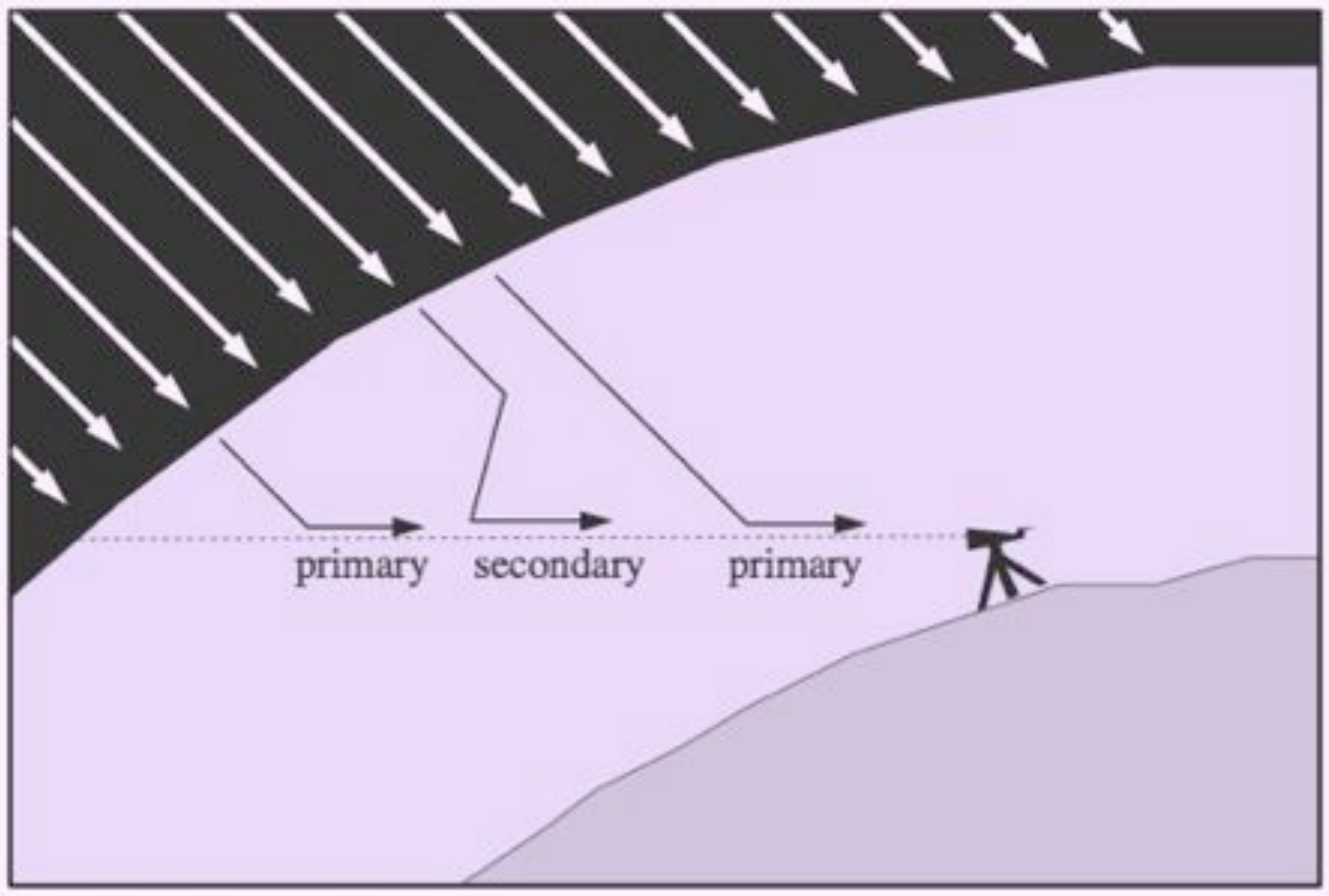
Other Multiple Scattering Algorithms…

- Deterministic
  - Discrete ordinates
  - Zonal methods
  - …
- Stochastic
  - Constant distance sampling
  - Random distance sampling

Participating Media in CG

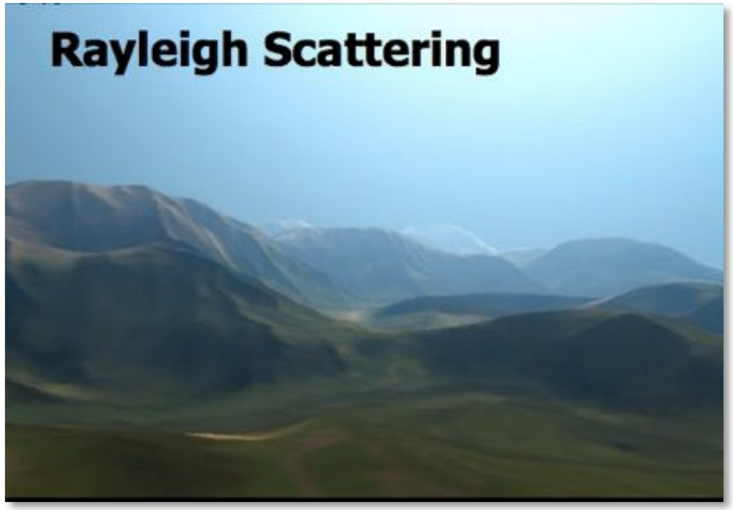
- Popular effects
  - Clouds
  - Sky
  - Fire
  - …
- Special models
- Opaque materials (e.g. milk, marble, jade …) are rendered with BSSRDFs

Atmospherical Scattering



Colour of the Sky

- Sunlight is scattered on particles
  - Blue → Rayleigh scattering on small particles
  - Orange → Mie scattering on aerosols
- Colour varies by
  - Time of Day
  - Weather
  - Pollution



Skydome Luminance

- Plain colour and simple colour gradient skies do not work
- HDR fisheye environment maps popular
  - Advantage: realistic cloud cover
- Alternative: analytical luminance models
  - Advantage: solar position & atmospheric parameters can be set
  - Disadvantage: clouds are separate

Hemispherical Samples

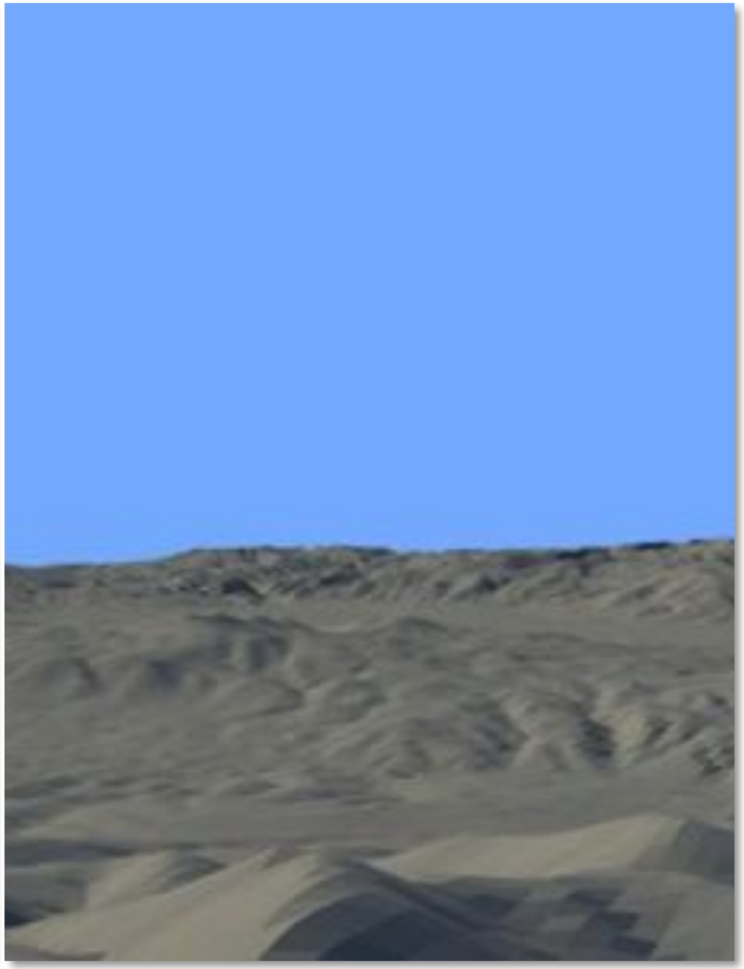
Analytical Models

- CIE
  - Monochrome (luminance only)
  - Validated to some degree
- Perez et al.
  - Improved CIE model
- Preetham et al.
  - Based on Perez model
  - Spectral colours for each solar elevation

Preetham Skylight

- Five parameters
  - A: darkening or brightening of the horizon
  - B: luminance gradient near the horizon
  - C: relative intensity of the circum-solar region
  - D: width of the circum-solar region
  - E: relative backscattered light

Preetham vs. Constant



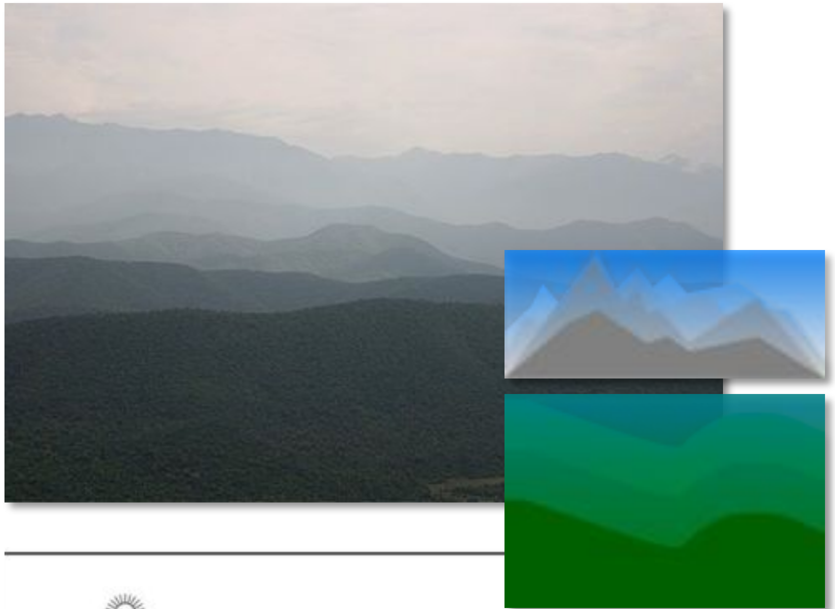
Preetham vs. CIE

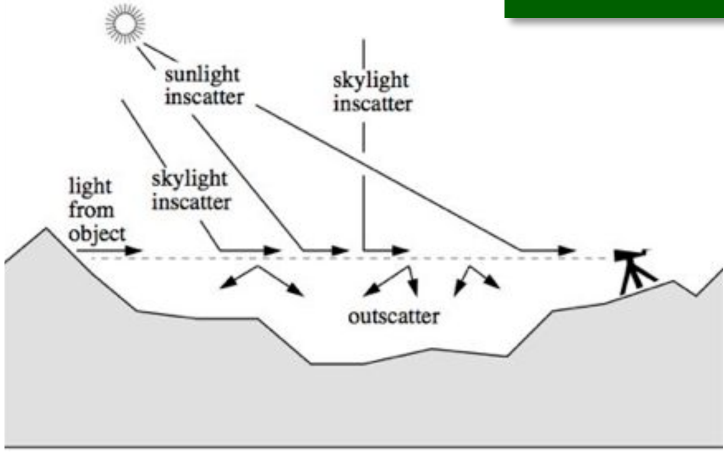
Aerial Perspective

- Haze
- Light is changed when it passes through the atmosphere

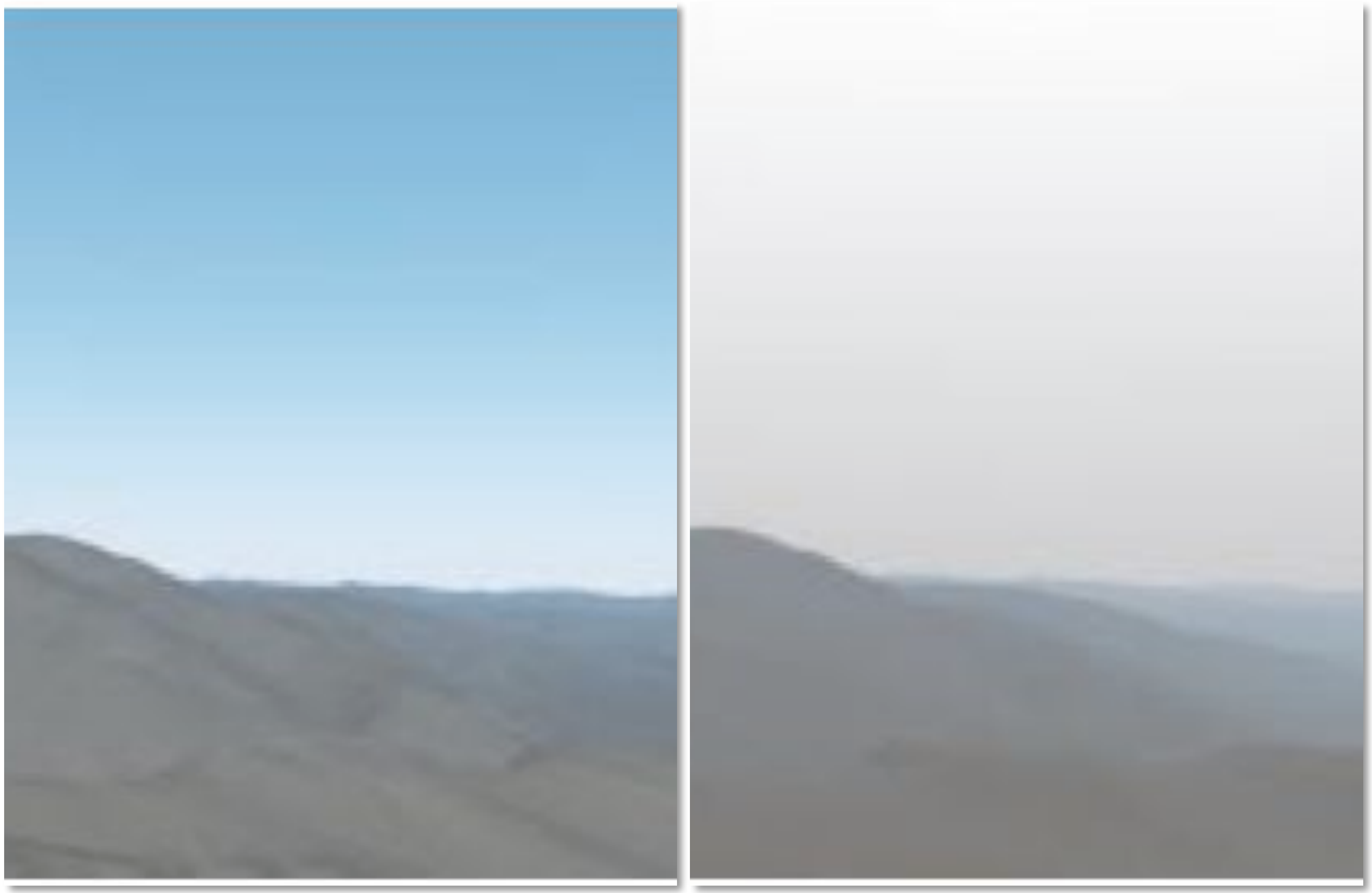
- Integral has to be evaluated numerically

$$L(s) = L_0\tau + L_{in}$$





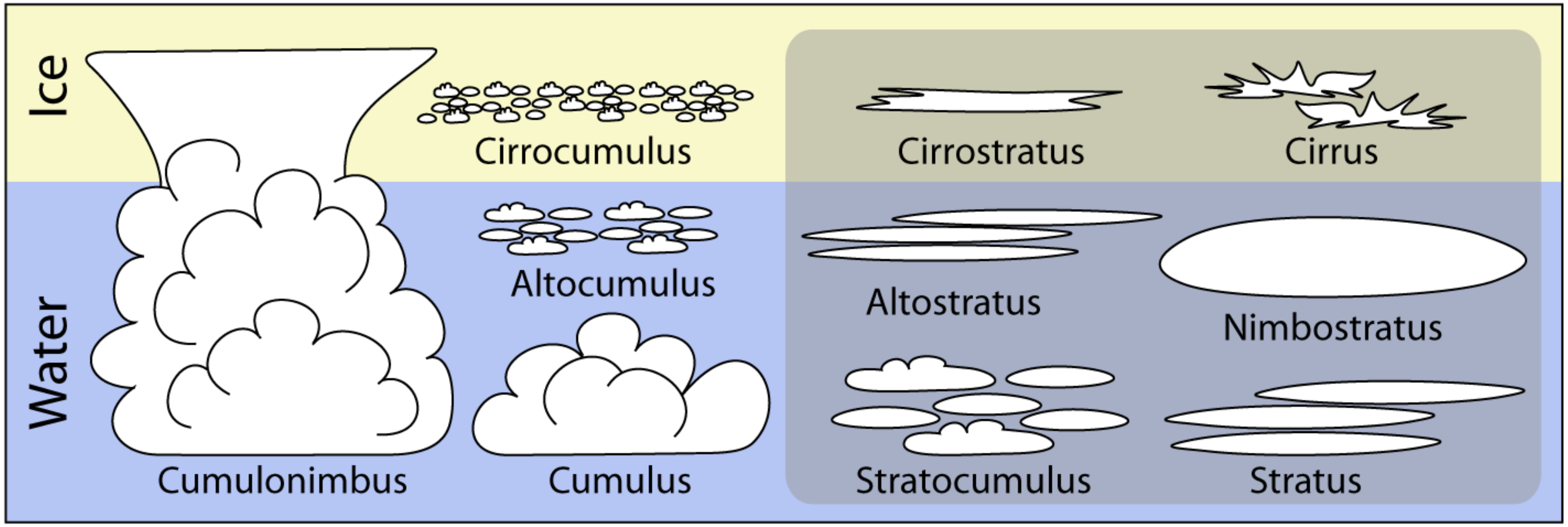
Low vs. High Turbidity



Clouds

- Either „quick and dirty“ (environment map) or „tedious“ (simulation)
- 2 different problems:
  - Shape
    - Dependent on meteorological conditions, location, etc.
  - Light interaction
    - Properly solvable through path tracing
    - Not feasible, accelerations are used

Cloud Types



Ice
Water
Cirrocumulus
Cirrostratus
Cirrus
Altocumulus
Altostratus
Nimbostratus
Cumulonimbus
Cumulus
Stratocumulus
Stratus

Real Cloud Shapes #1

Real Cloud Shapes #2

Cloud Shape

- In reality: direct function of process which generates them, many different shapes
  - High-reaching ice clouds usually textures
  - Low „puffball“ clouds are more likely to exhibit parallax errors ➔ 3D models
- Plasma fractals
  - Inaccurate, but convincing
- Full simulation usually not feasible, but needed for animations

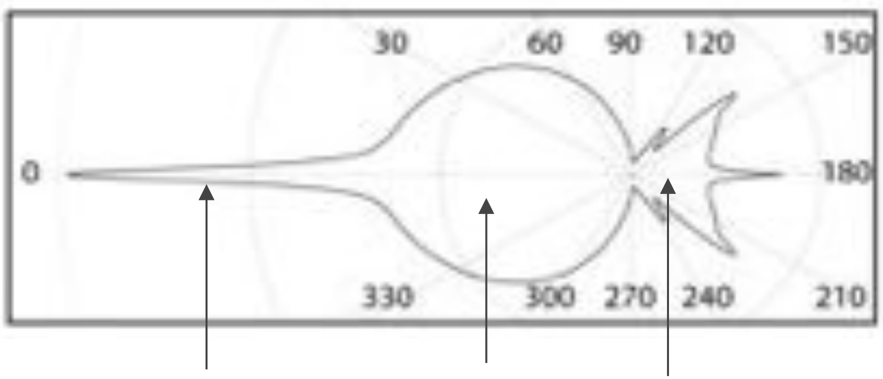
Shape Models (Simulations)

Fractal Clouds (MojoWorld)

Cloud Illumination

- Full volumetric lighting required
  - Mie scattering (anisotropic)
  - Self-shadowing
    important aspect of cloud appearance
  - No absorption!
- Path tracing theoretically possible
  - Much too slow, reference solutions only
- Scattering processes usually simplified

log plot



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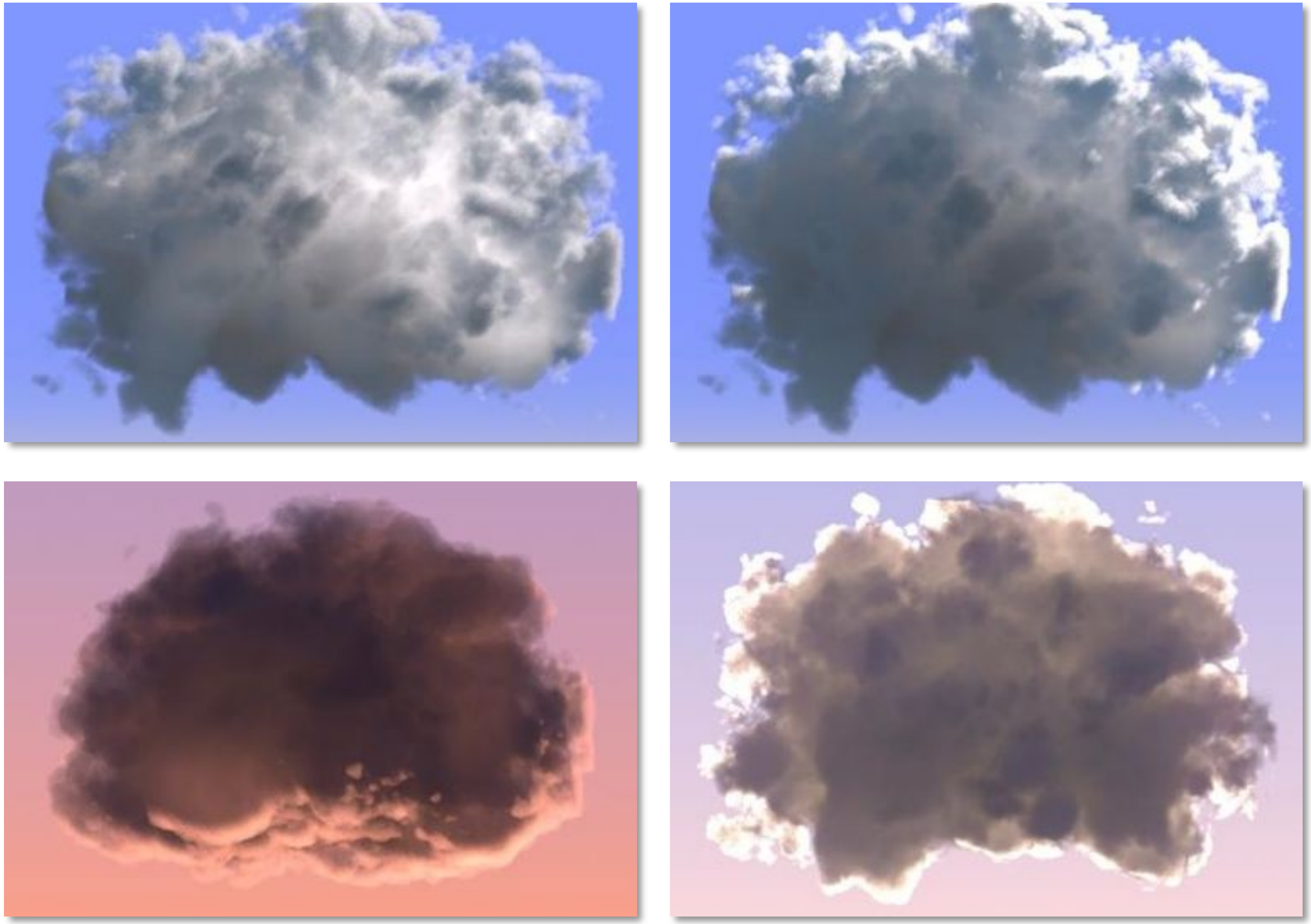
Strato Example (Real-time)

Cloud Examples



More Clouds... :)




The End
Thank you for your attention!