VO Rendering
SS 2010

Unit 6: Participating Media

Sources:

Overview

- Scattering process
- Transport equation
- Evaluation of the transport equation
- 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

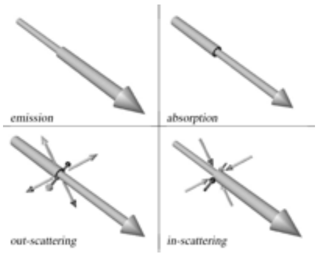
© Gordon Richards

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

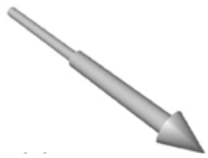
- Energy is reduced (converted into other energy forms e.g. heat)
- Reduction is given by absorption coefficient κ_a
- Beer‘s law:

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

Real-life absorption: Smoke

Emission

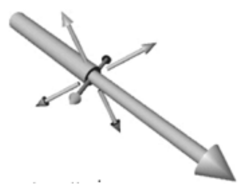
- Energy is added from luminous particles and converted to visible light
- Chemical, thermal or nuclear processes

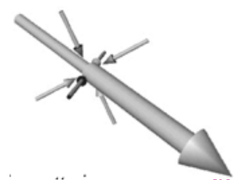


Real-life Emission: Fire

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





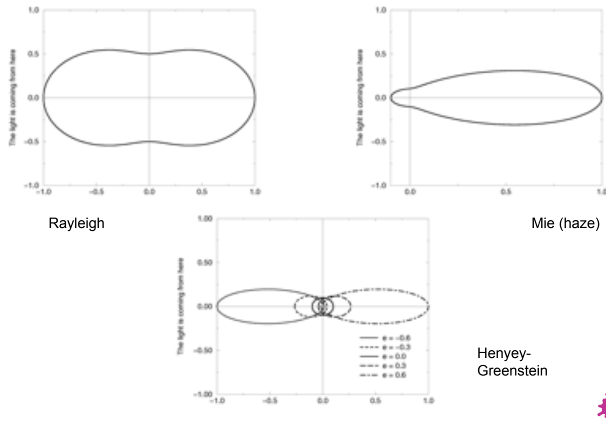
Real-life Out-Scattering: Clouds

Real-Life In-Scattering: Mist

Phase Function

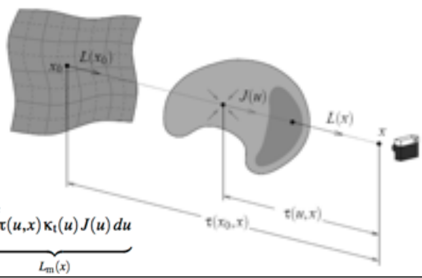
- Spatial distribution of the scattered light
- Intensity in direction ω_o divided by intensity that would be scattered in isotropic medium
- Different phase functions
  - Isotropic (counterpart of diffuse BRDF)
  - Rayleigh (small spherical particles, e.g. smoke)
  - Mie (particles have size of light, e.g. clouds)
  - Henyey-Greenstein (approximation of Mie)

Different Phase Functions



Transport Equation Geometry

- 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



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

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

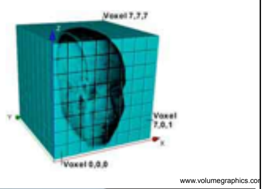
- Two challenges
  - Input data
    - Homogeneous (constant parameters)
    - Inhomogeneous (properties are varying in the medium)
  - Solving of the transport equation
- Full solution is very expensive
- Rendering with simplified models

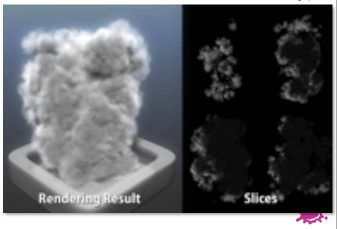
Step 1: Input Data

- Two fundamental approaches
  - Explicit storage of measured data
  - Numerical solutions

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

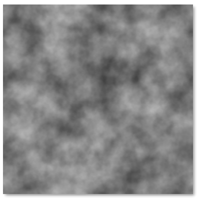




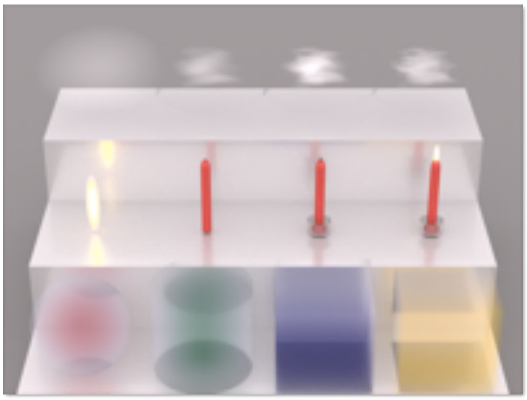
Acquisition of Time-Varying Media

Numerical Solutions

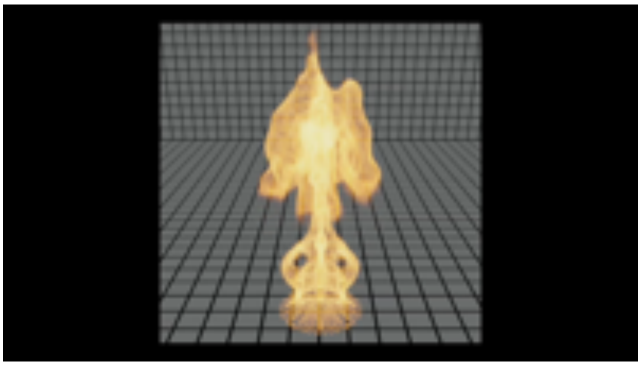
- Simple analytical functions
  - Perlin noise
  - Exponential function
  - ...
- Numerical
  - Fluid simulations
  - ...



Simple Density Functions



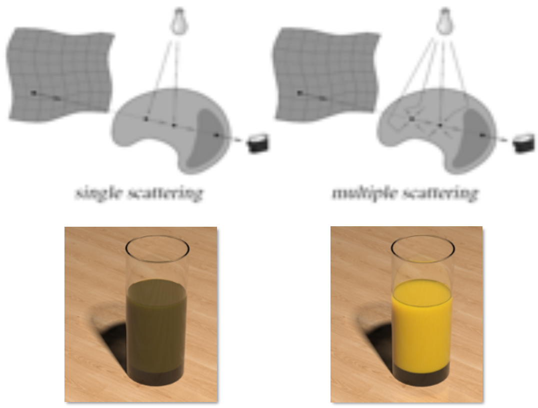
Fire Rendering



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



Absorption/Emission only

- No scattering

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

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

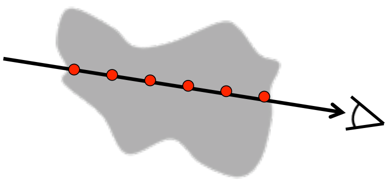
- For homogeneous non-emitting materials

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

- 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

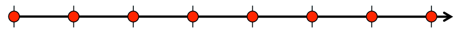


Ray Sampling

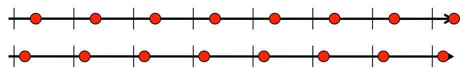
- Ray is divided into a number of segments
  - Random step size
  - Equal step size, first sample is placed randomly
- Deterministic sampling will produce aliasing artifacts!

Ray Sampling Strategies

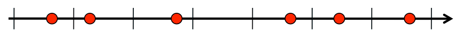
- Deterministic



- Random start, equal step size



- Random step size

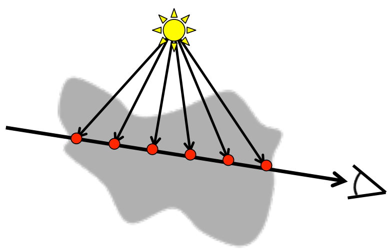


Single Scattering

- 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

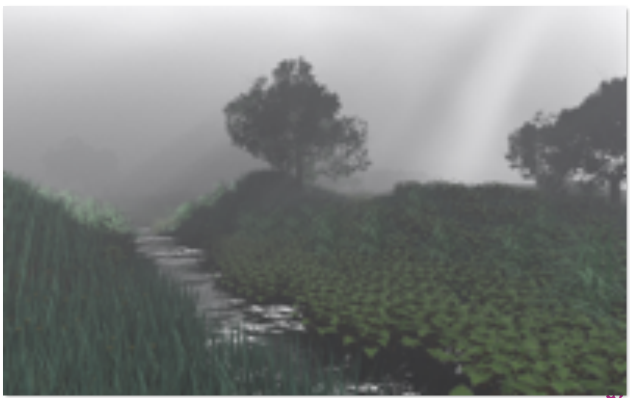
- Compute the contribution from the medium by dividing the ray into smaller segments
- No refraction!



Single Scattering Implementation

- Evaluate direct illumination
- Use ray marching
- At each sample point
  - Shoot ray to light source
  - Radiance may be blocked by geometry

Single Scattering Integrator Example #1



Single Scattering Integrator Example #2

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)

Multiple Scattering to Single Scattering

Volume Photon Mapping

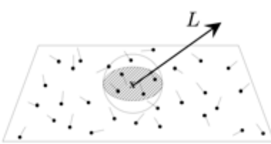
- Extend surface photon maps to volume photon maps
- Photons are stored in the volume
- Still two pass algorithm
  - **Pass 1:** Trace photons through volume
  - **Pass 2:** Evaluate photon maps using ray marching

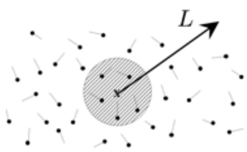
Volume Photon Tracing

- 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

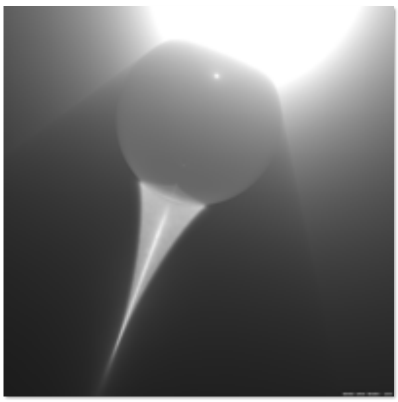
Estimating Radiance

- 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



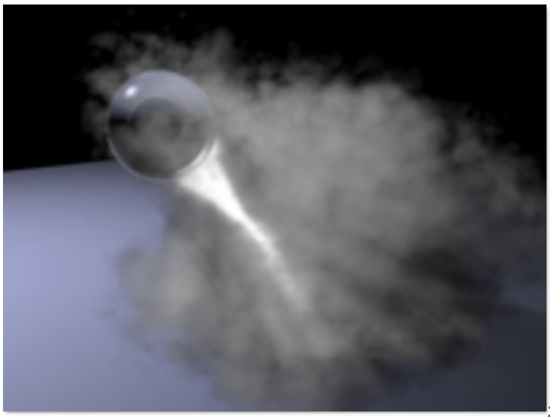


Volume Caustics



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

Participating Media in CG - Smoke



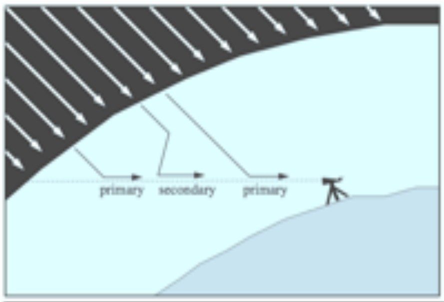
Other Multiple Scattering Algorithms...

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

Participating Media in CG

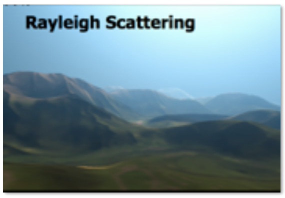
- Popular effects
  - Clouds
  - Sky
  - Fire
  - …
- Special models
- Opaque materials (e.g. milk, marble, jade …) are rendered with BSSRDFs

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 increasingly popular
  - Advantage: realistic cloud cover
- Alternative: analytical luminance models
  - Advantage: solar position & atmospheric parameters can be set
  - Disadvantage: clouds are separate

Hemispherical Samples

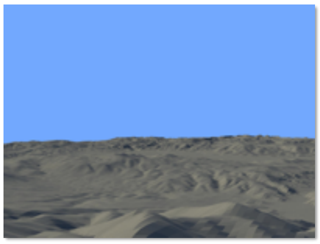
Analytical Models

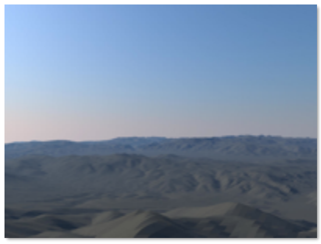
- CIE
  - Monochrome (luminance only)
  - Validated to some degree
- Perez et al.
  - Improved CIE model
- Preetham et al.
  - Based on Perez model
  - Spectral colours for each solar elevation

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

Constant vs. Preetham





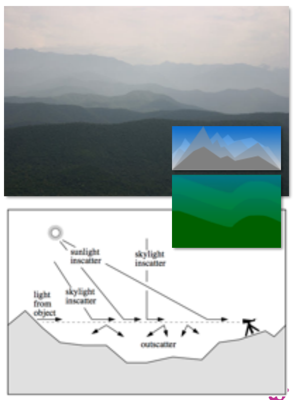
CIE vs. Preetham

Aerial Perspective

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

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

- Integral has to be evaluated numerically

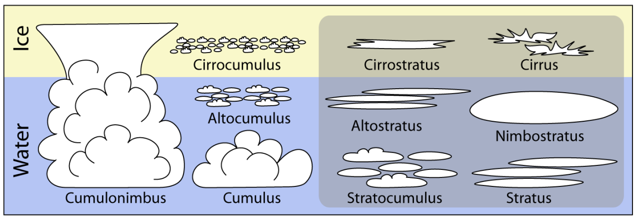


Low vs. High Turbidity

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



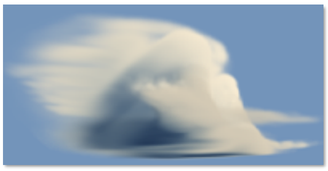
Real Cloud Shapes #1

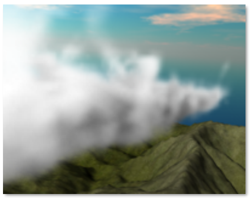
Real Cloud Shapes #2

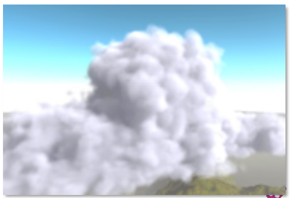
Cloud Shape

- 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)



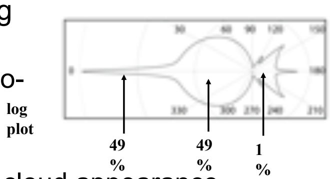




Fractal Clouds (MojoWorld)

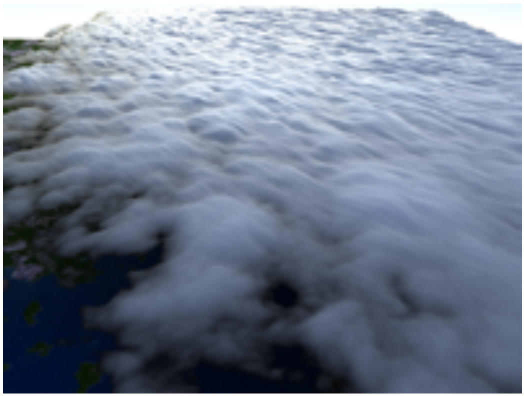
Cloud Illumination

- Full volumetric lighting required
  - Mie scattering (aniso-tropic)
  - Self-shadowing important aspect of cloud appearance
  - No absorption!

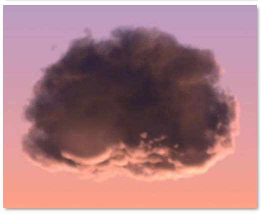


- Path tracing theoretically possible
  - Much too slow, reference solutions only
- Scattering processes usually simplified

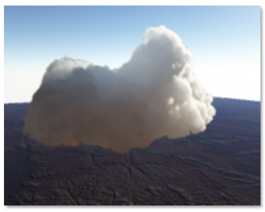
Strato Example (Real-time)



Cloud Examples



More Clouds… :)



The End

Thank you for your attention!