CS 563 Advanced Topics in Computer Graphics
Skin and Participating Media

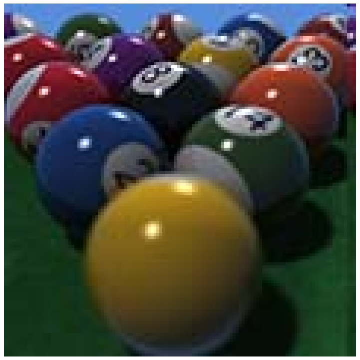
by Emmanuel Agu

Outline

- Nvidia
  - Optix Real Time Ray tracer
  - Shader library
- Skin
  - BSSRDF
  - Dipole Model (Donner and Jensen)
  - Multiple Dipole (Donner and Jensen)
- Participating Media
  - Examples
  - Model

Optix Real Time Raytracer

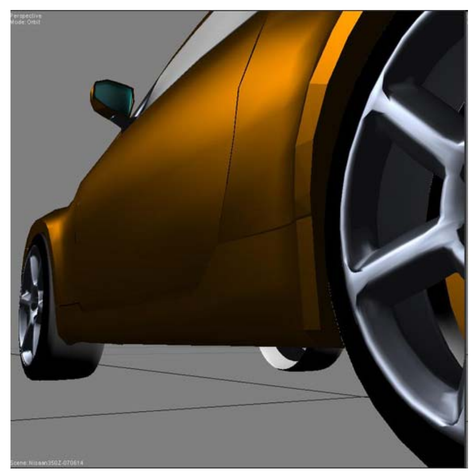
- Ray tracing on GPUs been hot research topic
- New games, applications incorporating ray tracing
- Nvidia written real time ray tracer
- Released SDK to developers
- Needs high end Nvidia graphics card

Nvidia Shader Library

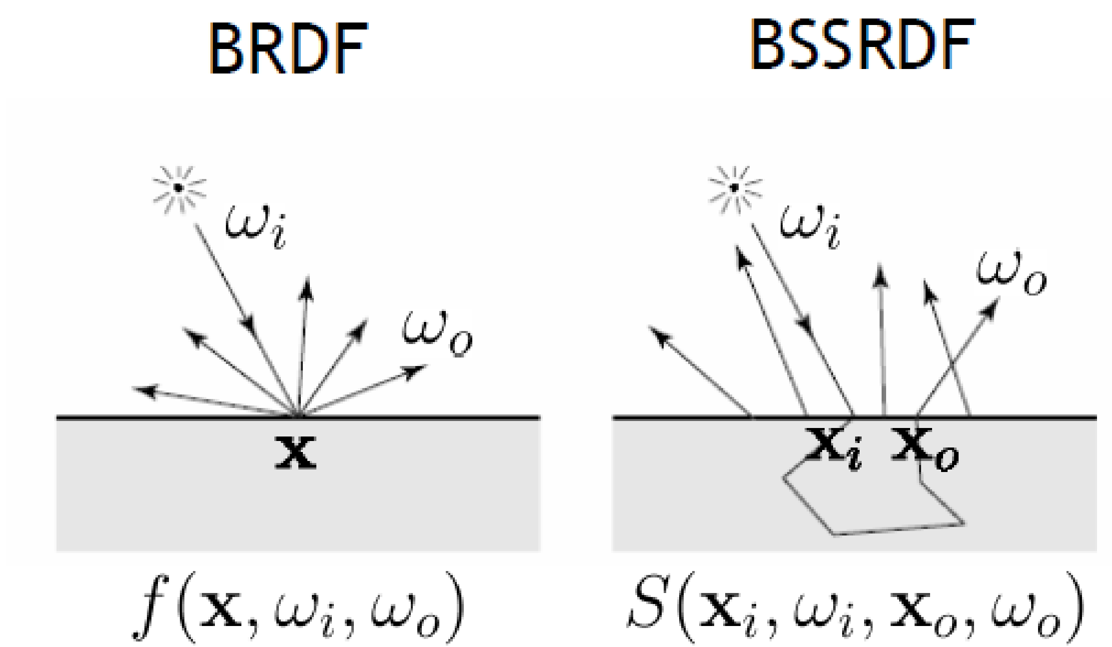
- Some useful examples: worth taking a look
- Drawback: Have to infer non-real time case
- Great implementation insights



Subsurface scattering

- BSSRDF: bidirectional scattering surface reflectance distribution function



Note: BSSRDF formulated by Nicodemus *et al*, accounts For light entering at one point/angle and leaving at another

Subsurface scattering

- BSSRDF has 8 degrees of freedom (2 positions, 2 orientations)
- Hard to capture in the general case
- Brute force Monte Carlo simulation very expensive

Subsurface scattering

Diffusion approximation

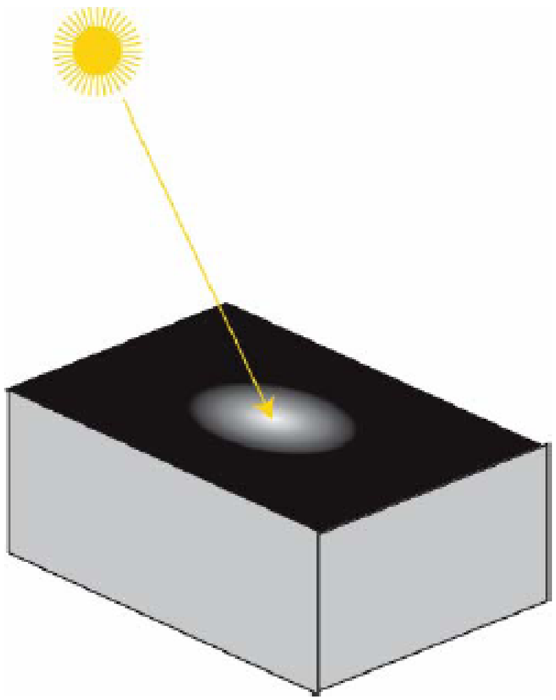
- Light distribution in highly scattering media tends to become isotropic
- We can a find a diffuse BSSRDF $R_d(r)$ where $r = \|\mathbf{x}_i - \mathbf{x}_o\|$
- 1D instead of 8D!
- Also known as “dipole model”

Subsurface Scattering

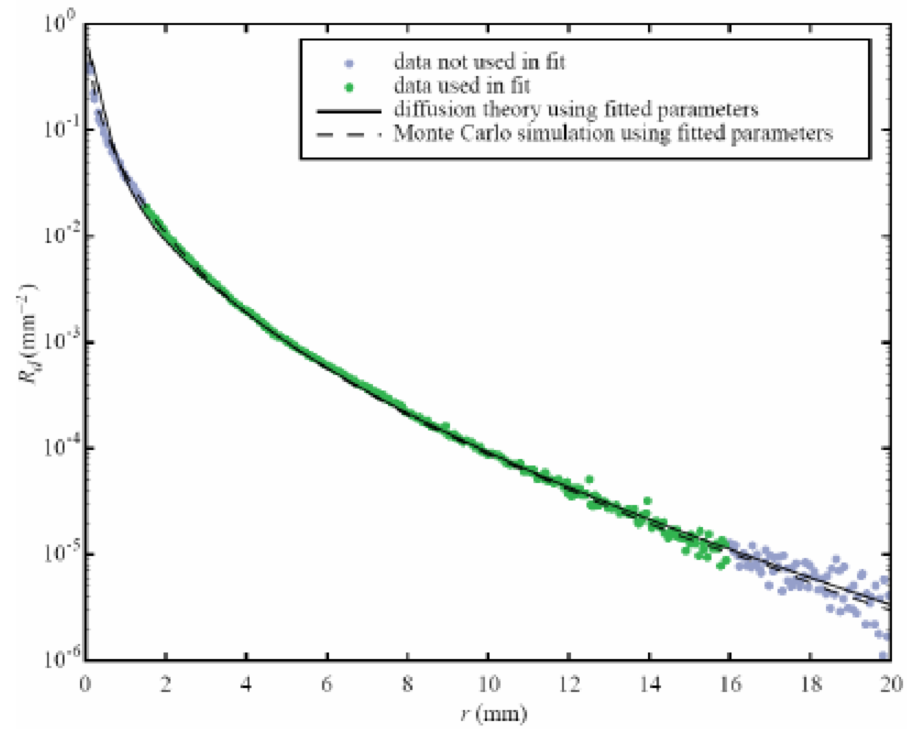
- Stam '95: first to model multiple scattering as a diffusion process
- Jensen *et al* SIGGRAPH '01*:* BSSRDF + Diffusion approximation of multiple scattering
- Single scattering + diffusion approximation
- Even highly scattering medium becomes blur since each scattering blurs light
- Simple solution for 1 isotropic source in infinite medium

Subsurface scattering

Diffusion approximation

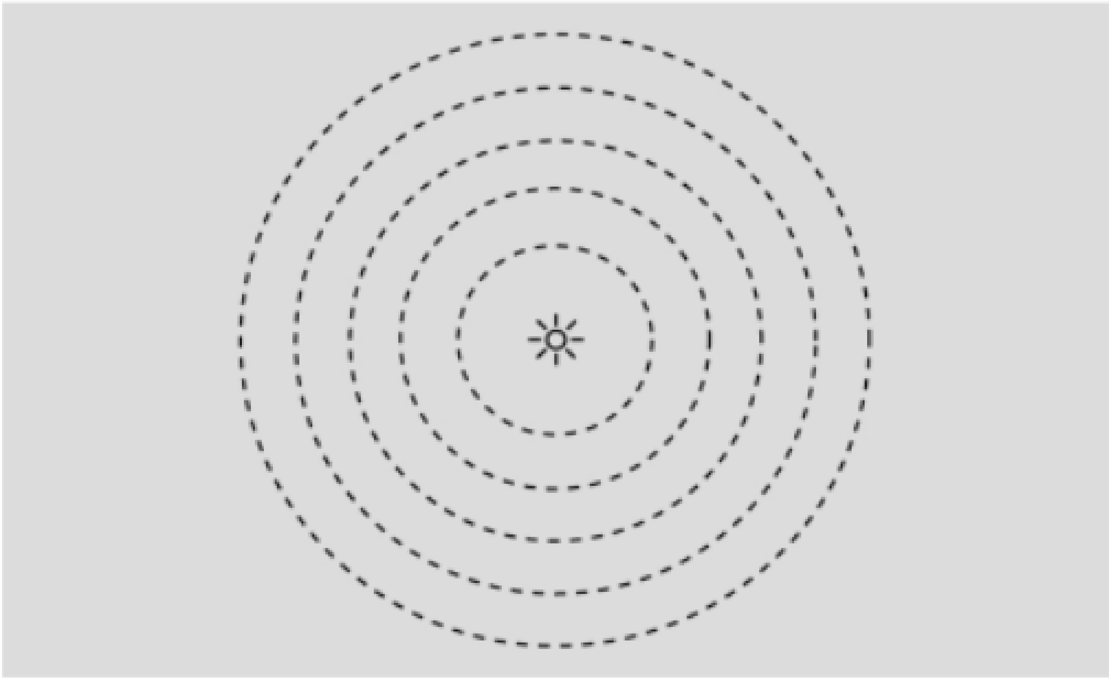


Diffusion profile



[Jensen et al.]

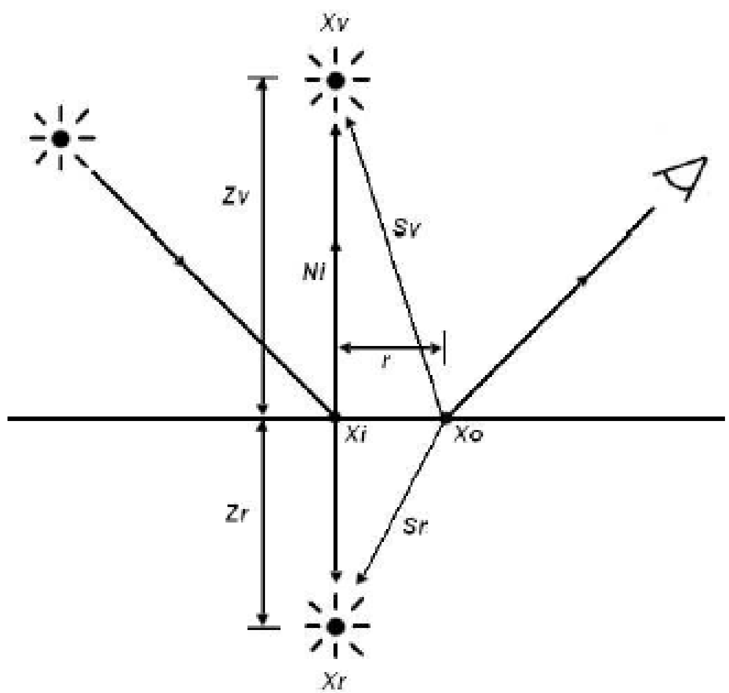
Diffusion Approximation



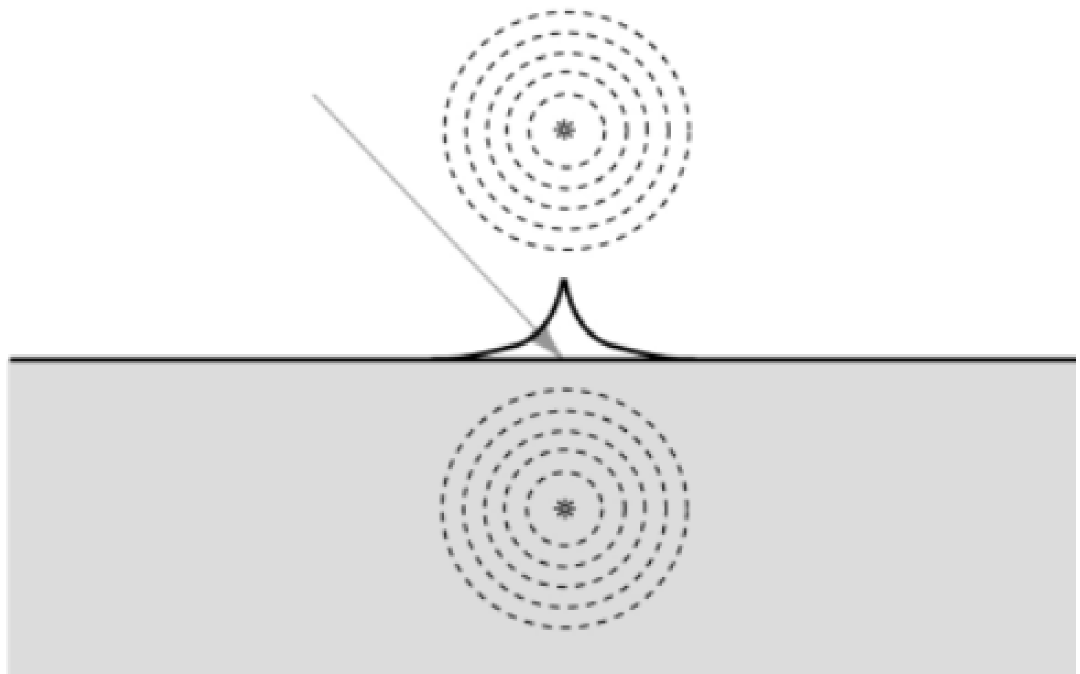
$$\phi(r) = \Phi \frac{e^{-kr}}{r}$$

Dipole Diffusion Approximation

- More accurate
- Replace volumetric light source with 2 point light sources (one above surface, one below)



Dipole Diffusion Approximation



$$R_d(r) = -\frac{\vec{\mathbf{N}} \bullet (\nabla \phi_1(r) - \nabla \phi_2(r))}{\Phi_i}$$

Subsurface scattering

BSSRDF

BRDF

[Jensen et al.]

Subsurface scattering

BRDF

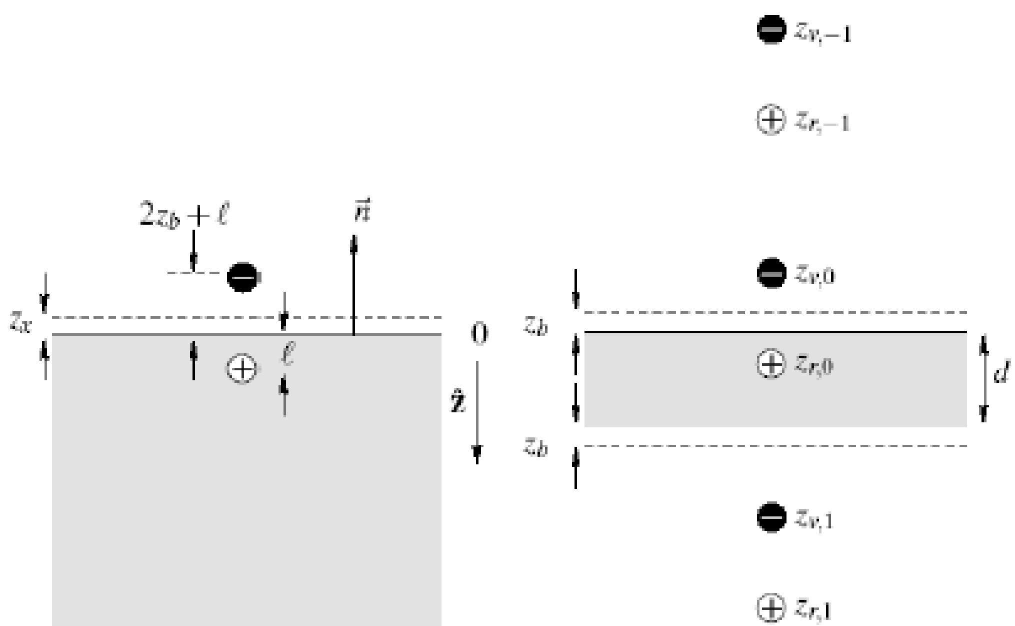
BSSRDF

Monte Carlo simulation

[Jensen et al.]

Multiple Dipole Model
Donner and Jensen, SIGGRAPH '05

- Dipole approximation assumed homogeneous medium and semi-infinite thickness
- Multiple dipole model: Multiple layers, different optical properties, arbitrary thickness
- Apply Kubelka Munk theory in freq space



Spectral Rendering Model

Donner and Jensen, SIGGRAPH '06

- Accounts for both surface reflection and subsurface scattering
- Uses only 4 parameters, amount of oil, melanin and haemoglobin in skin
- generate spectral diffusion profiles by modelling skin as two-layer translucent material using the mutipole diffusion approximation

Spectral Rendering Model

Donner and Jensen, SIGGRAPH '06

- Two-layer translucent material
- Very accurate results

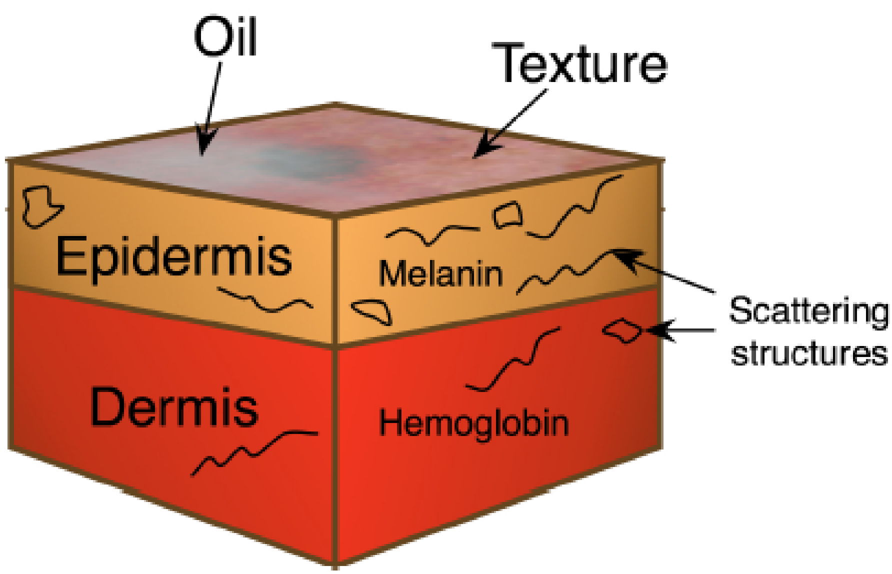
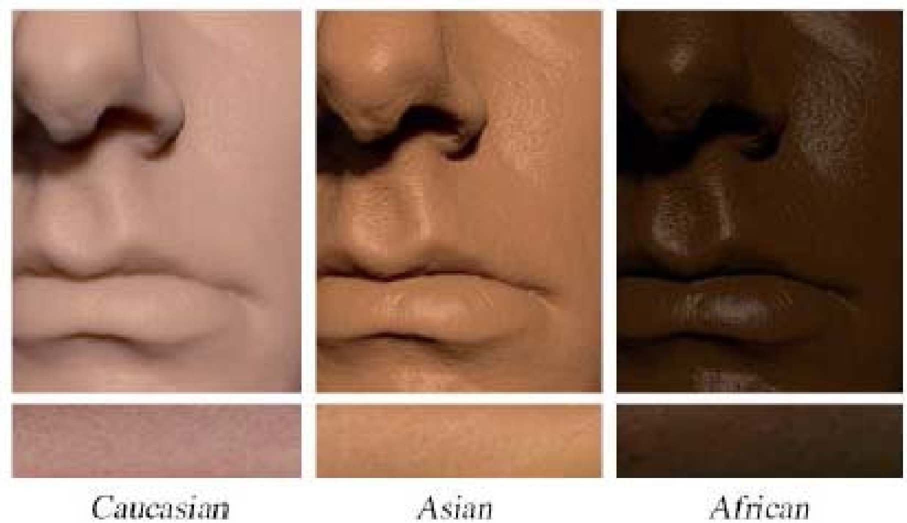


Figure 14: Two layer skin model

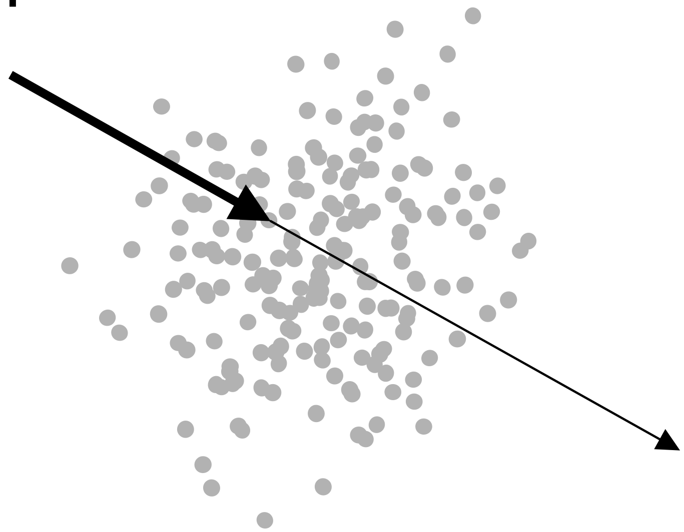


Participating Media

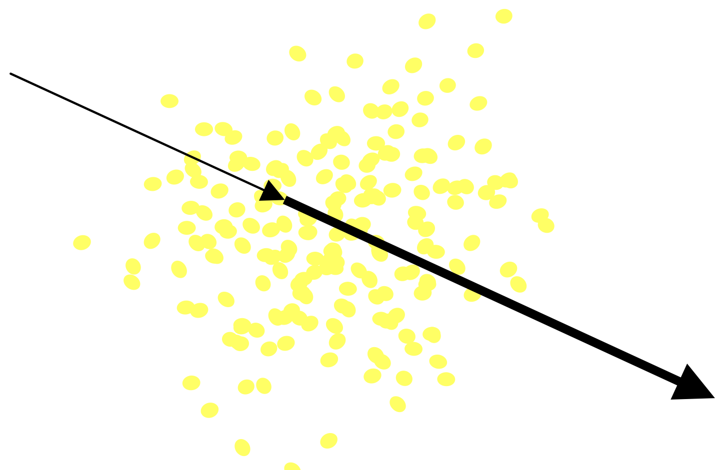
- So far assumed vacuum: radiance unchanged along ray
- Participating media affects radiance along ray
  - Absorption
  - Emission
  - Scattering
    - In-scattering
    - Out-scattering
- Examples of participating media (volume scattering)
  - Atmosphere
  - Smoke
  - Haze
  - Clouds
- Some media homogenous, some inhomogenous

Volume Scattering Processes

- Absorption

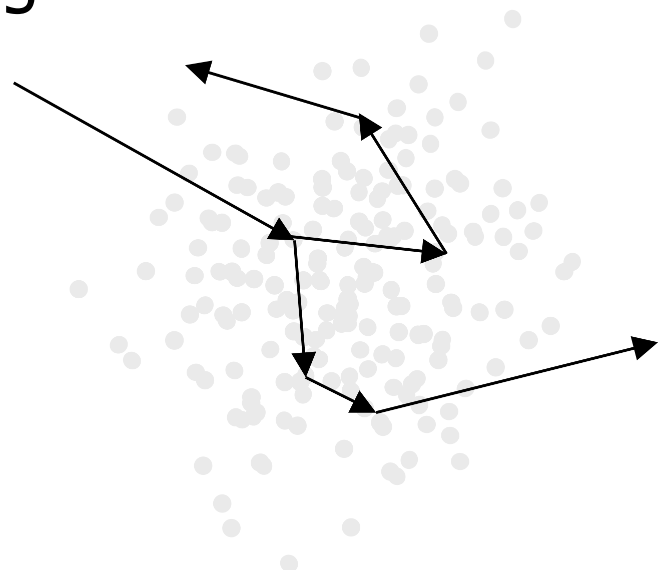


- Emission



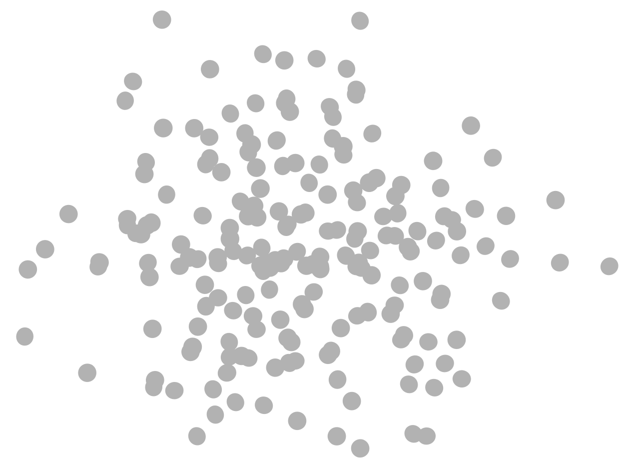
Volume Scattering Processes

- Scattering

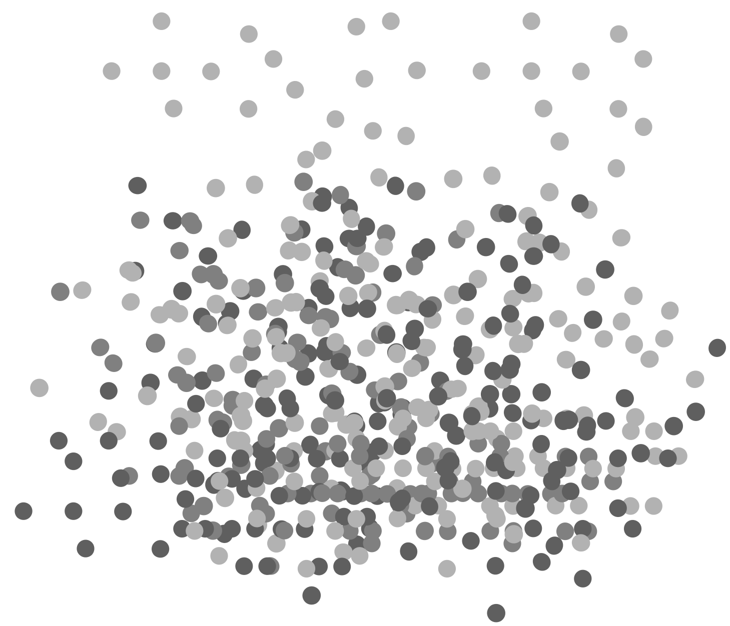


Volume Scattering Processes

- Homogeneous
  - Constant particle density
  - Uniform particle types distribution



- Inhomogeneous
  - Varying particle density
  - Varying particle distribution



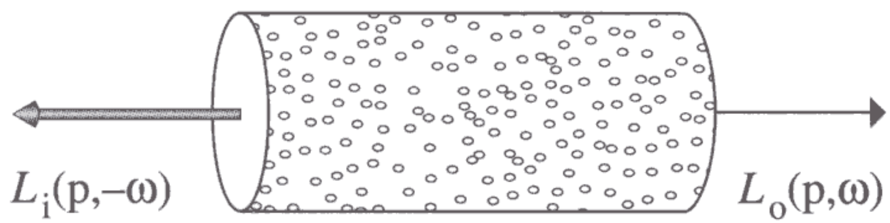
Volume Scattering Processes

- Absorption
  - Light is absorbed by medium
  - Ray radiance decreases through the medium
- Absorption crossed section σ_a
  - Light absorption probability density per unit distance traveled in medium
  - Units → m^{-1}
    - dt → through-medium-travel unit
    - Values may be larger than 1
  - Influence factors
    - Position (p)
    - Direction (ω)
    - Spectrum

Volume Scattering Processes

- Change in radiance per unit
  - Difference between incoming and outgoing radiance

$$dL_o(p,\omega) = L_o(p,\omega) - L_i(p,\omega)$$

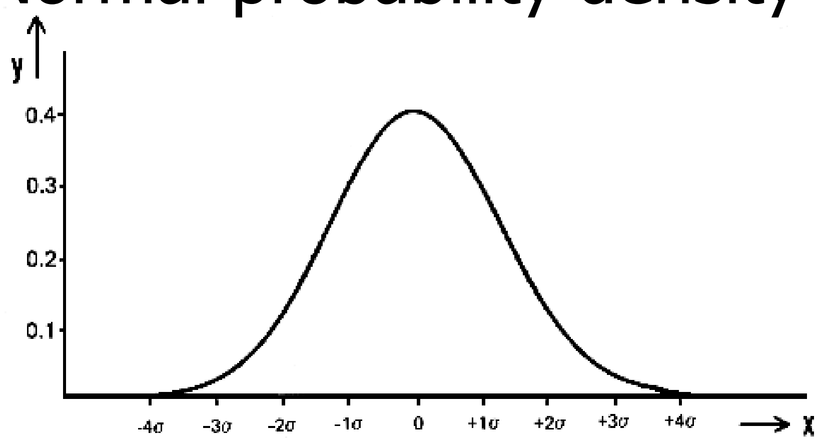


Volume Scattering Processes

- Absorbed radiance
  - Traveled a distance *d* through medium

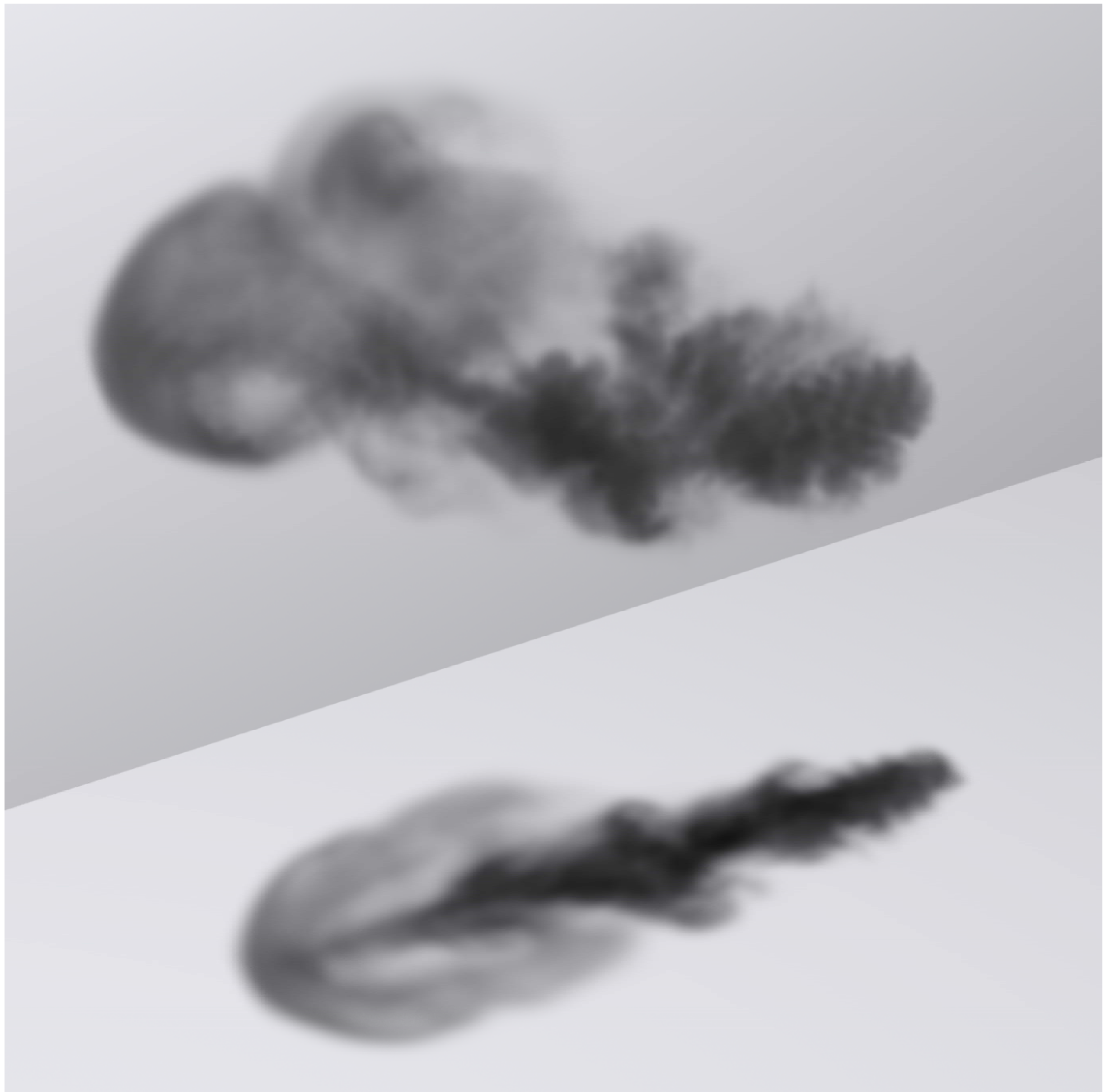
$$\underbrace{L(\mathbf{p}+\omega d,\omega)}_{L_o}=\underbrace{L(\mathbf{p},\omega)}_{L_i}\underbrace{e^{-\overbrace{\int_0^d \sigma_a(\mathbf{p}+\omega t,\omega)\,dt}^{\sigma_a \text{ integrated in } d}}}_{\text{Probability density function}}$$

- Normal probability density function (Gaussian)



$$\phi(x)=\frac{1}{\sqrt{2\pi}}e^{-\frac{x^2}{2}}$$

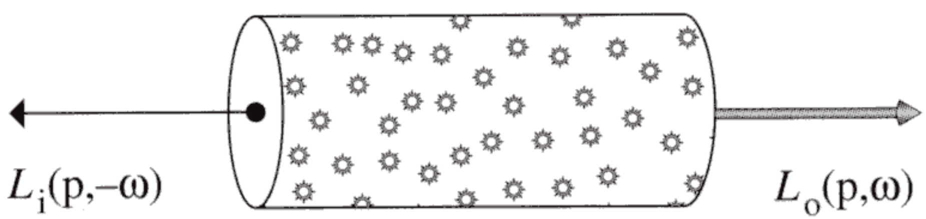
Absorption



Emission

- Emission
  - Light is emitted by the medium
- Emitted radiance: $L_{ve}(p,\omega)$
  - Independent of incoming light
- Change in radiance per unit

$$dL_o(p,\omega) = L_{ve}(p,\omega)dt$$

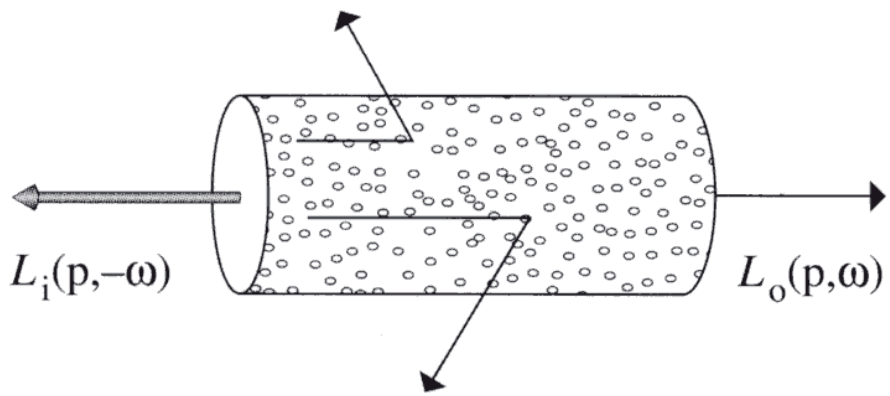


Emission

Out-Scattering

- Out-scattering
  - Light is scattered out of the path of the ray
  - Probability density for scattering: σ_s
  - Reduction in radiance is given by

$$dL_o(p,\omega) = -\sigma_s(p,\omega)L_i(p,-\omega)dt$$



Extinction

- Total radiance reduction
  - Absorption
  - Scattering
- Attenuation or extinction
  - Coefficient: σ_t

$$\sigma_t(p,\omega) = \sigma_a(p,\omega) + \sigma_s(p,\omega)$$

- Change in radiance per unit

$$dL_o(p,\omega) = -\sigma_t(p,\omega) L_i(p,-\omega) dt$$

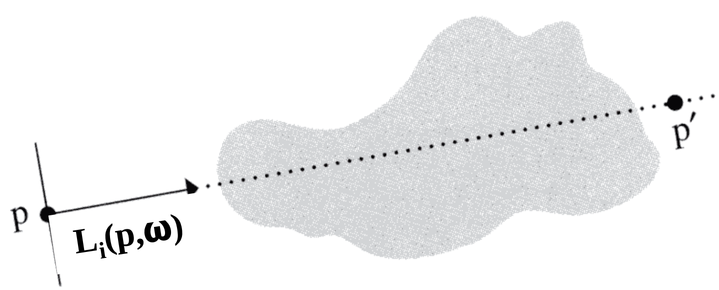
Beam Transmittance

- Beam transmittance T_r

σ$_t$ integrated along *d (p to p′)*

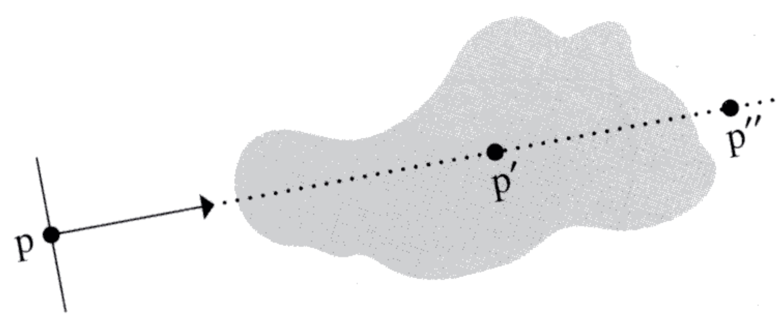
$$T_r(\mathbf{p} \rightarrow \mathbf{p}') = e^{-\overbrace{\int_0^d \sigma_t(\mathbf{p}+\omega t, \omega)\,dt}}$$

$$\underbrace{L(\mathbf{p}')}_{L_o} = \underbrace{T_r(\mathbf{p} \rightarrow \mathbf{p}')}_{\text{Probability density function}} \underbrace{L(\mathbf{p}, \omega)}_{L_i}$$



Transmittance

- Transmittance
  - Fraction of light that is transmitted between two points
  - Values between 0 and 1
  - Properties
    - $Tr(p \rightarrow p) = 1$
    - In vacuum: $Tr(p \rightarrow p') = 1$, for all p'
    - **Multiplicative:** $Tr(p \rightarrow p'') = Tr(p \rightarrow p')\, Tr(p' \rightarrow p'')$



Beer's Law

$$T_r(\mathbf{p} \to \mathbf{p}') = e^{-\int_0^d \sigma_t(\mathbf{p}+\omega t, \omega)\, dt}$$

- Optical thickness

$$\tau(\mathbf{p} \to \mathbf{p}') = \int_0^d \sigma_t(\mathbf{p} + \omega t, \omega)\, dt$$

- Homogeneous medium
  - σ_t is position independent
  - Transmittance reduced to Beer's Law

$$T_r(\mathbf{p} \to \mathbf{p}') = e^{-\sigma_t d}$$

Beer's Law

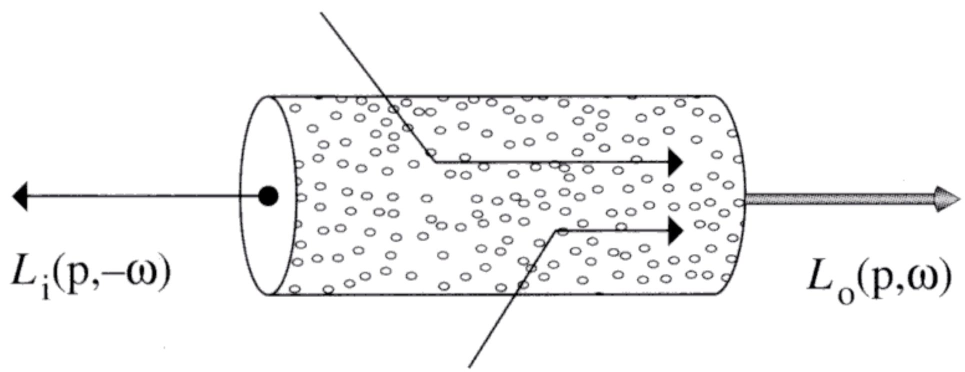
- Beer's Law

$$A = \alpha l c$$

- A = amount of light absorbed
- α = Absorption coefficient or molar absorptivity of medium
- l = distance light travels through medium
- c = Concentration or particle density

In-Scattering

- In-scattering
  - Outside light scatters converging to ray path
  - Phase functions to represent scattered radiation in a point



Volume Scattering Processes

- Phase function (PF)
  - Volumetric analog of BSDF
  - Normalization constraints
    - PF defines a direction's scattering probability distribution

$$\int_{S^2} p(\omega \to \omega')\, d\omega' = 1$$

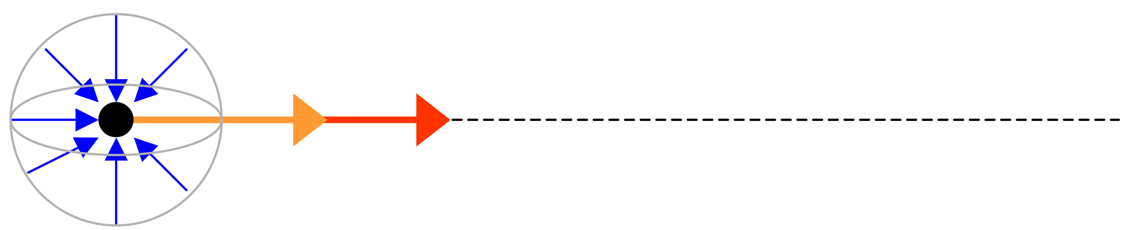
- Change in radiance per unit

$$dL_o(p, \omega) = S(p, \omega)\, dt$$

Volume Scattering Processes

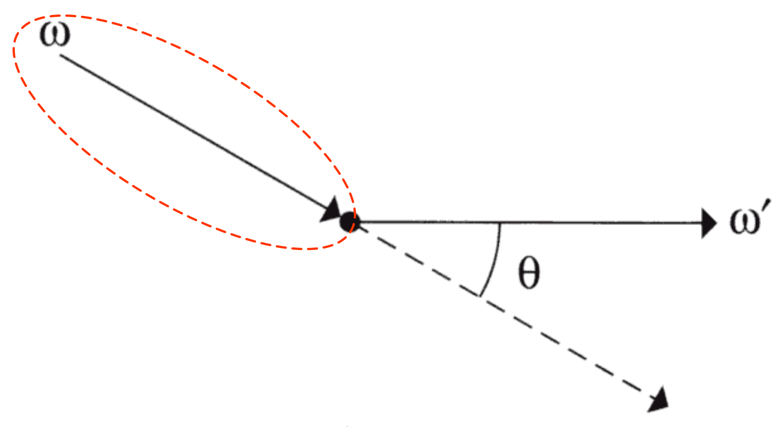
- S(p,w) includes volume emission

$$S(\mathbf{p},\omega) = \underbrace{L_{ve}(\mathbf{p},\omega)}_{\text{Emission}} + \underbrace{\overbrace{\sigma_s(\mathbf{p},\omega)}^{\text{In-scattering Probability}} \overbrace{\int_{S^2} \overbrace{p(\mathbf{p},-\omega' \rightarrow \omega)}^{\text{Phase function (range: } 0 \rightarrow 1\text{)}} \overbrace{L_i(\mathbf{p},\omega')}^{\text{Incident radiance}} d\omega'}^{\text{Amount of added radiance}}}_{\text{In-scattering}}$$



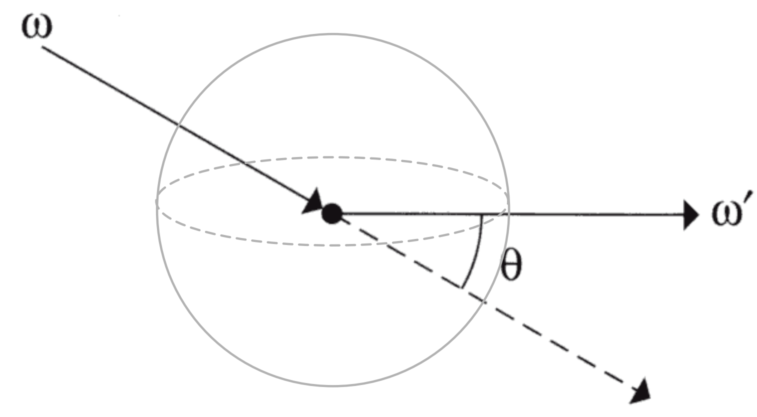
Phase Functions

- BSDFs for volume scattering
- Vary complexity according to medium
  - Isotropic
  - Anisotropic
- Properties
  - Direction reciprocity
  - May also be classified as
    - Isotropic – uniform scattering
    - Anisotropic – variable scattering



Phase Functions

- Isotropic
  - Basic PFs
  - PFs is constant
  - Since
    - Area of sphere = 4л*r2
    - pfS are normalized (r =1)



$$p_{isotropic}(\omega \rightarrow \omega') = \frac{1}{4\pi}$$

Phase Functions

- Rayleigh
  - Very small particles
  - Acurately describes light scattering when
    - Particle radii < light wavelength
  - Good for atmospheric simulation
- Mie
  - Based on Maxwell's equations
  - Broader range of particle sizes
  - Good for fog and water droplets simulation

Phase Functions

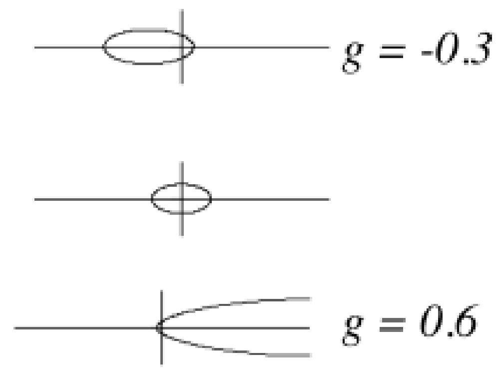
- Henyey and Greenstein
  - Easy to fit
  - Single control parameter
    - Controls relative proportion of forward backward scattering
    - $g \in (-1, 1)$
    - $g < 0$: back scattering

$$p_{HG}(\cos\theta : g) = \frac{1}{4\pi} \frac{1 - g^2}{\left(1 + g^2 - 2g(\cos\theta)\right)^{3/2}}$$

Henyey-Greenstein Phase Function

Empirical phase function

$$p(\cos\theta) = \frac{1}{4\pi}\frac{1-g^2}{\left(1+g^2-2g\cos\theta\right)^{3/2}}$$



$$2\pi\int_0^{\pi} p(\cos\theta)\cos\theta\, d\theta = g$$

g: **average phase angle**

Phase Functions

- Increase complexity by combination

$$p(\cos\theta) = \sum_{i=1}^{n} w_i p_{HG}(\cos\theta : g_i)$$

- More efficient version
  - Avoids 3/2 power computation
  - $k \sim 1.55g - 0.55g^3$

$$p_{Schlick}(\cos\theta) = \frac{1}{4\pi} \frac{1-k^2}{(1-k\cos\theta)^2}$$

References

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