VU Rendering SS 2015
186.101

Thomas Auzinger

Károly Zsolnai

Institute of Computer Graphics and Algorithms (E186)
Vienna University of Technology
http://www.cg.tuwien.ac.at/staff/ThomasAuzinger.html
http://www.cg.tuwien.ac.at/staff/KarolyZsolnai.html

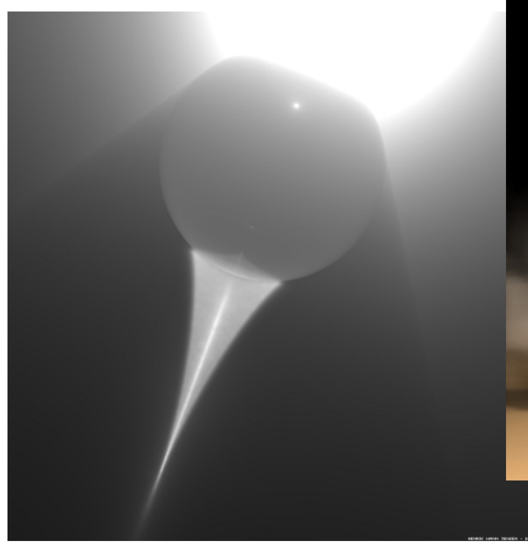
VU Rendering SS 2015

Unit 05 – Subsurface Scattering

So far...

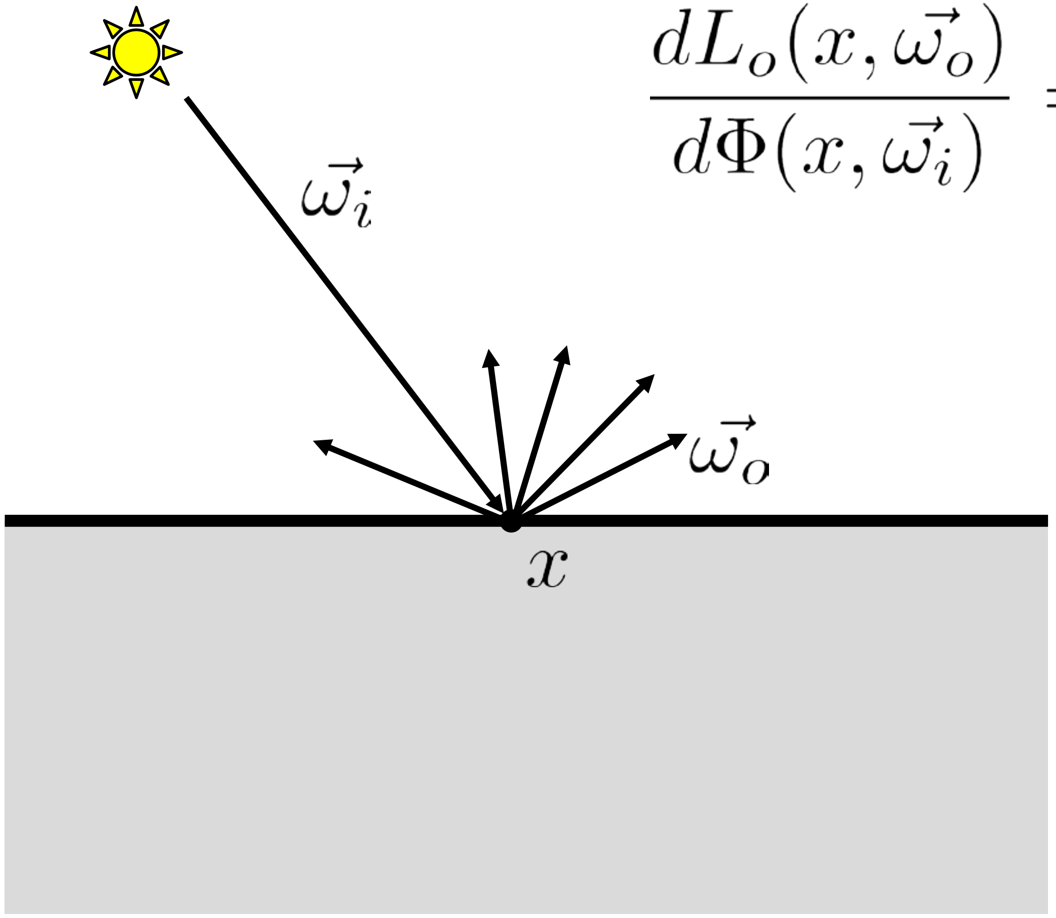
- Light interaction with surfaces

- Light interaction with volumes



Something in Between

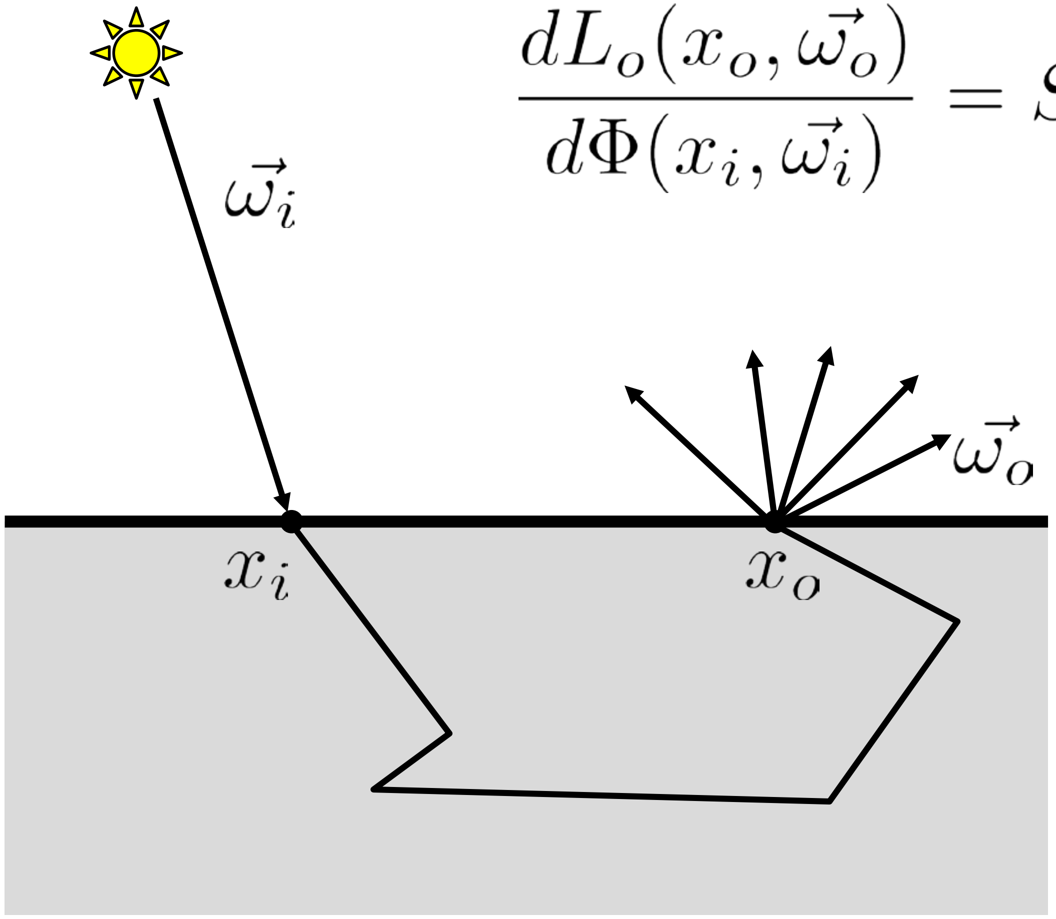
Surface Scattering (BRDF)



$$\frac{dL_o(x, \vec{\omega_o})}{d\Phi(x, \vec{\omega_i})} = f_r(x, \vec{\omega_i}, \vec{\omega_o})$$

Subsurface Scattering (BSSRDF)

$$\frac{dL_o(x_o, \vec{\omega_o})}{d\Phi(x_i, \vec{\omega_i})} = S(x_i, \vec{\omega_i}; x_o, \vec{\omega_o})$$



Subsurface Scattering

Can be simulated with standard methods, e.g. volumetric path tracing

- General

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Many materials are highly-scattering, e.g. Milk albedo 0.9987 → 27% energy after 1000 scatterings

- General techniques very expensive

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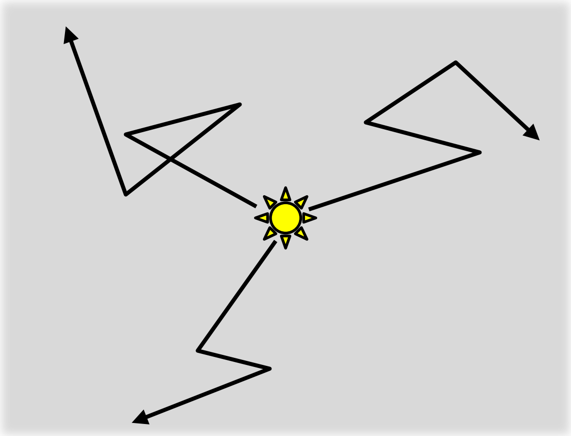
Many materials are highly-scattering, e.g. Milk albedo 0.9987 → 27% energy after 1000 scatterings

- General techniques very expensive

BUT: after many bounces the light distribution becomes isotropic (i.e. the same in all directions)

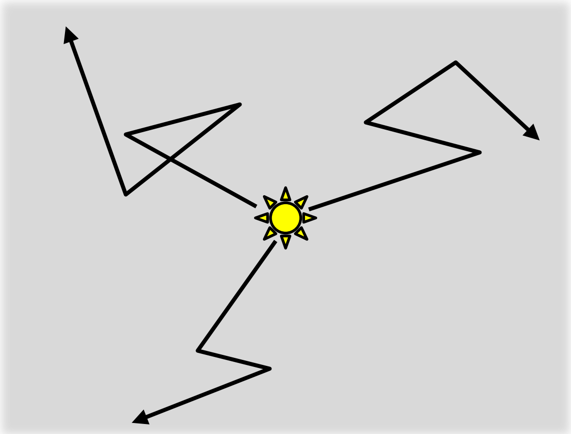
Diffusion Approximation

- Assume infinite medium



Diffusion Approximation

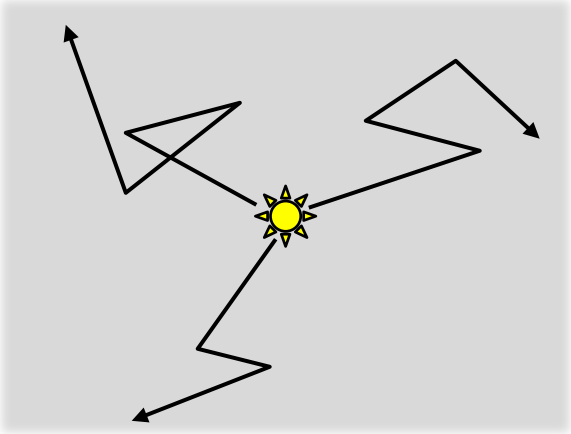
- Assume infinite medium



- Split radiance $L(r,\vec{\omega})$ into single scattering $L_s(r,\vec{\omega})$ and multiple scattering term $L_m(r,\vec{\omega})$

Diffusion Approximation

- Assume infinite medium



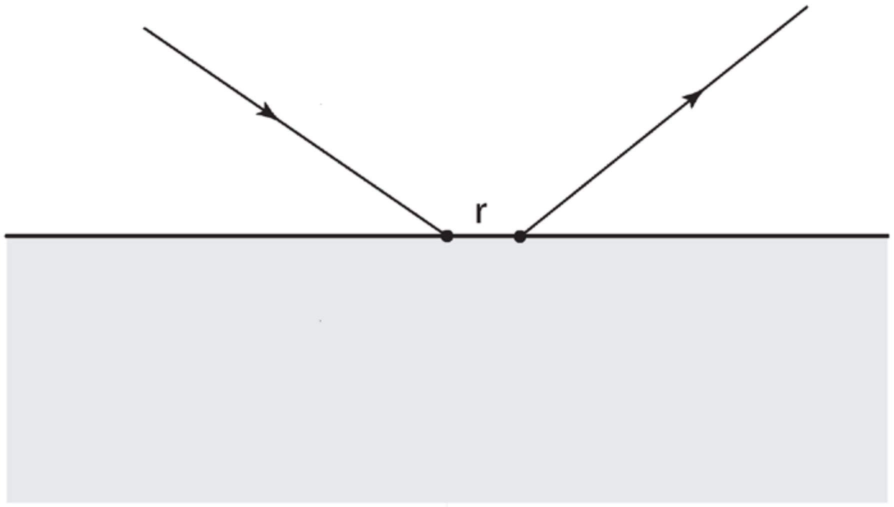
- Split radiance $L(r, \vec{\omega})$ into single scattering $L_s(r, \vec{\omega})$ and multiple scattering term $L_m(r, \vec{\omega})$
- Average over multiple directions of multiple scattering term

$$L_m(r, \vec{\omega}) \rightarrow \phi(r) = \int_{4\pi} L_m(r, \vec{\omega}) d\vec{\omega}$$

Diffusion Approximation

- Radiative Transfer Equation becomes diffusion equation
  $$\nabla^2\phi(r) - 3\,c\,\phi(r) = 0, \qquad c = \text{const.}$$

- Solve for semi-infinite slab
  $$R(r) = ?$$



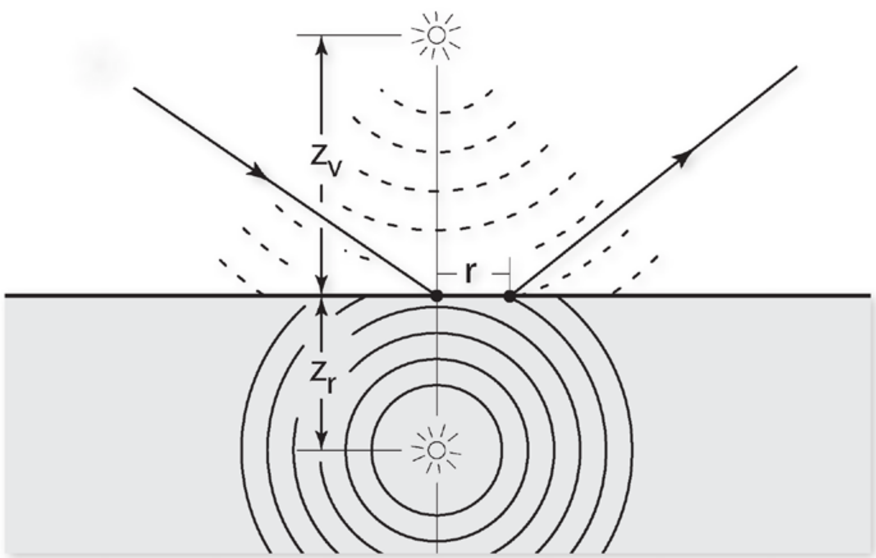
Diffusion Approximation

- Radiative Transfer Equation becomes diffusion equation

$$\nabla^2 \phi(r) - 3\,c\,\phi(r) = 0, \qquad c = \text{const.}$$

- Solve for semi-infinite slab

$$R(r) \propto z_r R_r(r) + z_v R_v(r)$$



Diffusion Dipole BSSRDF

Multiple-scattering approximated

$$S(x_i, \vec{\omega_i}; x_o, \vec{\omega_o}) = S_s(x_i, \vec{\omega_i}; x_o, \vec{\omega_o}) + S_m(x_i, \vec{\omega_i}; x_o, \vec{\omega_o})$$

$$S_m(x_i, \vec{\omega_i}; x_o, \vec{\omega_o}) \propto F(\vec{\omega}_i) R(\|x_i - x_o\|) F(\vec{\omega}_o)$$

$S_m(.) \ldots$ diffuse part of the BSSRDF

$F(.) \ldots$ Frensel terms on entry and exit

$R(.) \ldots$ dipole approximation of diffuse transport

Add single scattering as in volumetric ray marching.

BSSRDF Rendering

- BRDF

$$L_o(x,\vec{\omega}_o) = \int_\Omega L_i(x,\vec{\omega}_i) f_r(x,\vec{\omega}_i,\vec{\omega}_o) \cos\theta \; d\vec{\omega}_i$$

- BSSRDF

$$L_o(x_o,\vec{\omega}_o) = \int_A \int_\Omega L_i(x_i,\vec{\omega}_i) S(x_i,\vec{\omega}_i; x_o,\vec{\omega}_o) \cos\theta \; d\vec{\omega}_i \; dA(x_i)$$

  - Integrate over both hemisphere and area
  - Single-scattering by ray marching
  - Multiple scattering by sampling x_i around x_o with exponential density.

Example

Fresnel term

Example

Single scattering

Example

Multiple scattering (diffusion)

Example

Full BSSRDF

Example

BRDF

Examples

Realtime Example

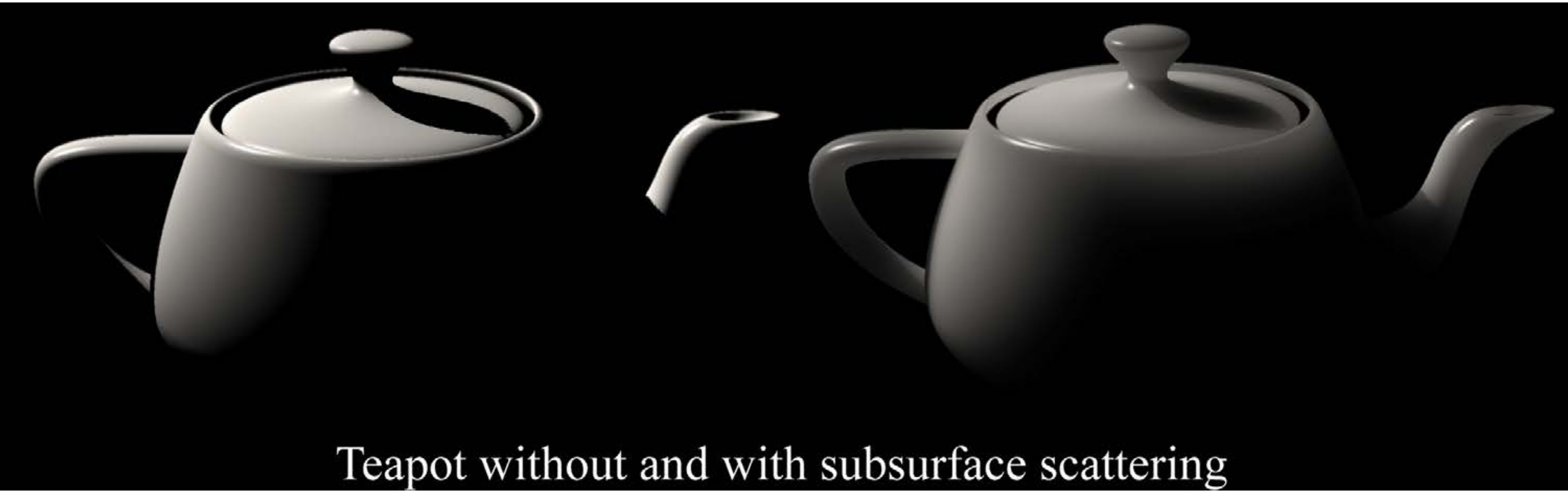
Extensions

Dipol approximation not valid for materials that are

- thin
- layered
- heterogeneous

Use multipol expansion (i.e. more terms in the initial approximation

Questions?



(from **Lehtinen et al. 2011**)