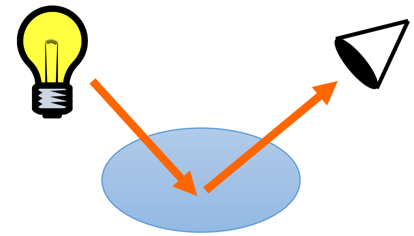
No.6
大域照明
Global illumination

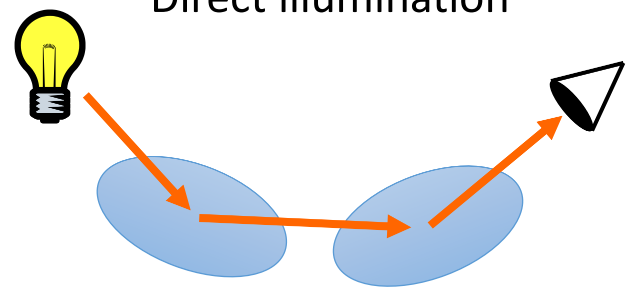
担当教員：向川康博・田中賢一郎

Direct and global illuminations

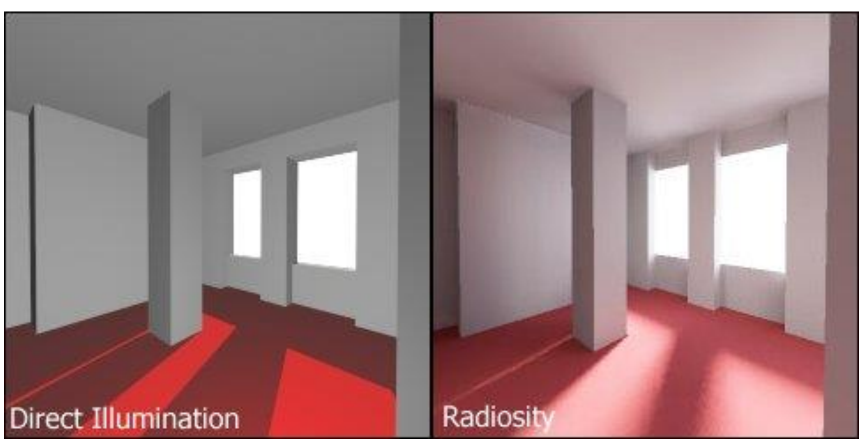
- Direct illumination
  - Light source→ Object surface →Observer
- Global (indirect) illumination
  - Light source→ Object surface → Object surface →…→Observer



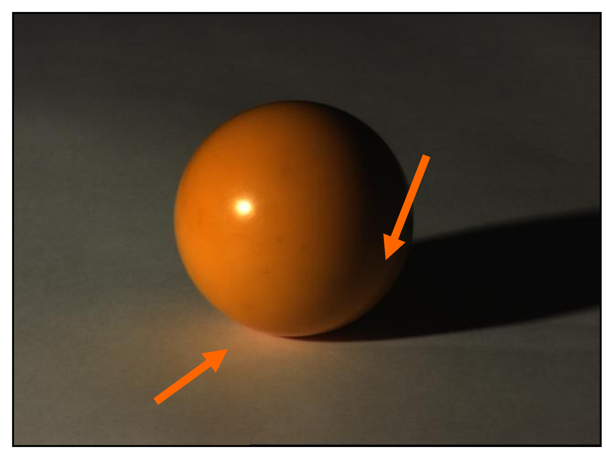
Direct illumination



Global illumination



Differences in CG（wikipedia）

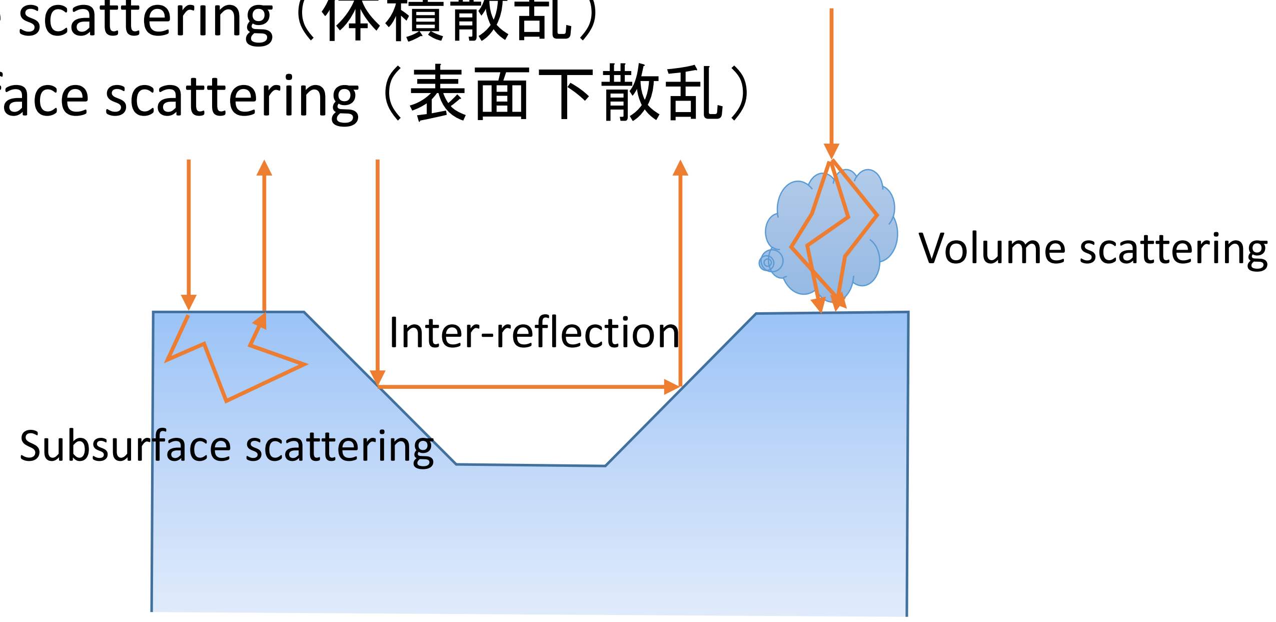


Real global illumination

What is global illumination?

- Rendering images considering global illumination
  - In CG, necessary to render realistic image
  - In CV, necessary to analyze real scene

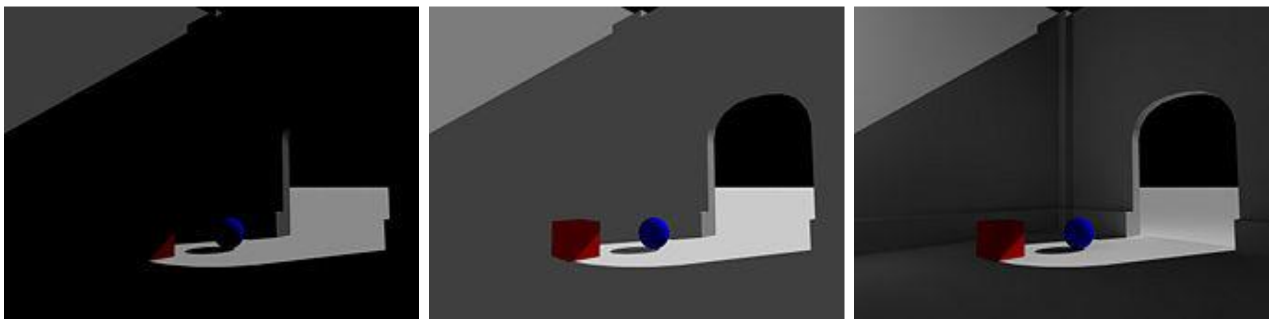
- Types of global illumination
  - Inter-reflection（相互反射）
  - Volume scattering（体積散乱）
  - Subsurface scattering（表面下散乱）



Inter-reflection
（相互反射）

Inter-reflection

- **Diffuse inter-reflection**
  - Radiosity
    - Describing light passing between object surfaces by finite element method

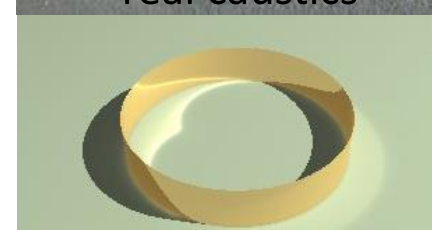


Only direct illumination | Direct illumination + ambient illumination | Radiosity

wiki.povray.org

- **Specular inter-reflection**
  - Expression of caustics（集光模様）
  - Monte Carlo ray tracing
    - Monte Carlo sampling from ray tracing
  - Photon mapping
    - Two-pass algorithm of distributing and counting photons

real caustics



Photon mapping by POV-Ray

Radiosity

- Compute diffuse inter-reflection components
- Developed for heat transfer at first
- Form factor between two patches

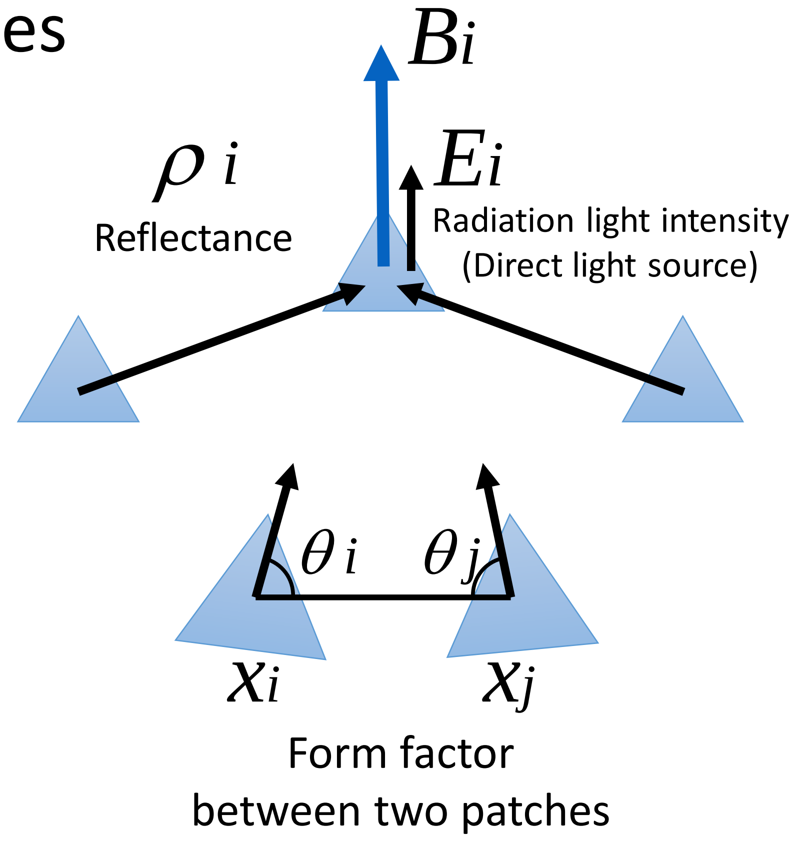
$$B_i = E_i + \rho_i \sum_j F_{ij} B_j$$

$$F_{ij} = V(x_i, x_j) G(x_i, x_j)$$

Visibility (Can see each other or not)

Geometric attenuation

$$G(x_i, x_j) = \frac{\cos\theta_i \cos\theta_j}{|x_i - x_j|}$$



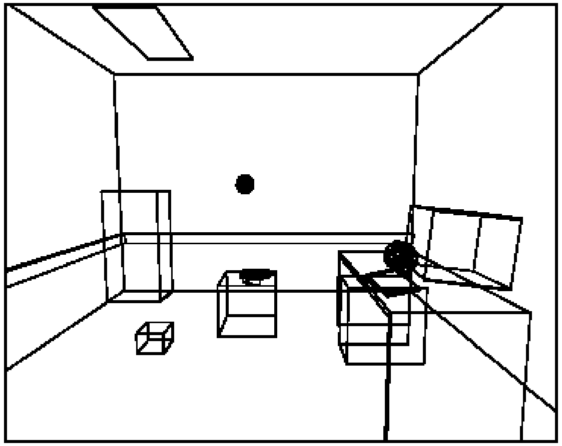
[Sillion94]

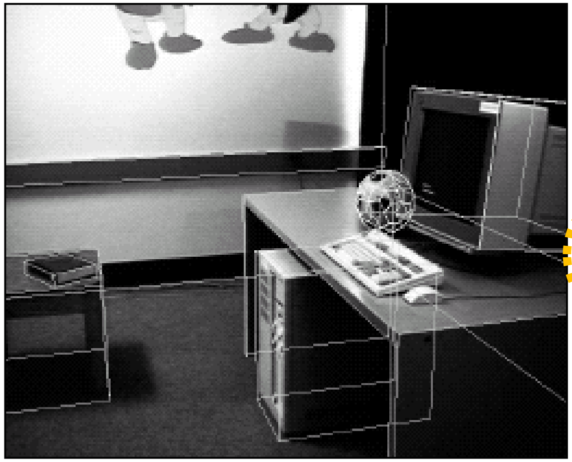
Scene analysis based on Radiosity

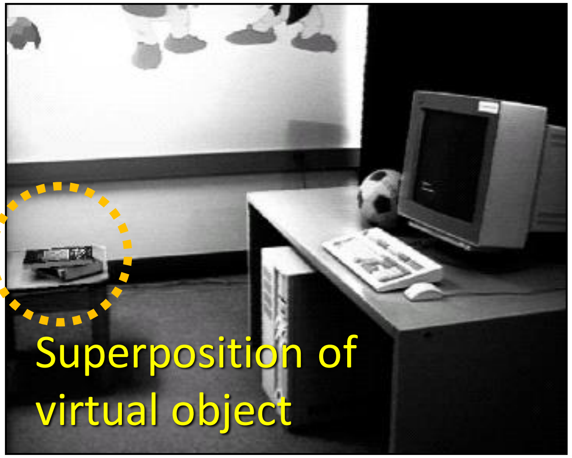
- Reflectance estimation considering diffuse inter-reflection
- Simple linear solution

$$B_i = E_i + \rho_i \sum_j F_{ij} B_j$$

$$\rho_i = (B_i - E_i) / \sum_j F_{ij} B_j$$



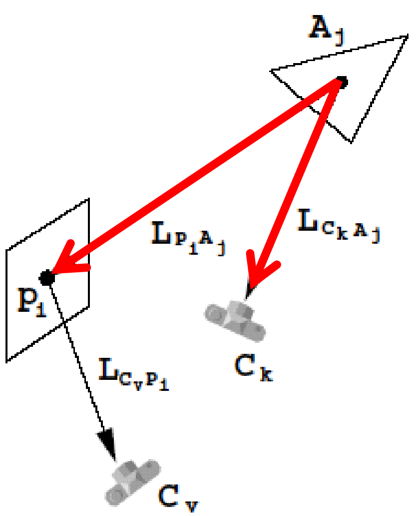


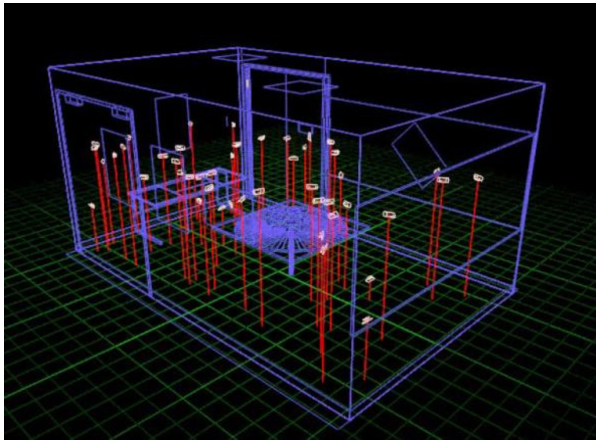


[Fournier93] [Drettakis97] [Loscos99] [Loscos00]

Specular inter-reflection

- Specular reflection depends on viewing direction
- The radiance of each patch can not be directly observed
- Iterative computation of
  - radiance of one-bounce specular reflection
  - specular reflectance





Room shape and
Camera position (40 places)

Yu et al., Inverse Global Illumination:
Recovering Reflectance Models of Real Scenes from Photographs, SIGGRAPH'99

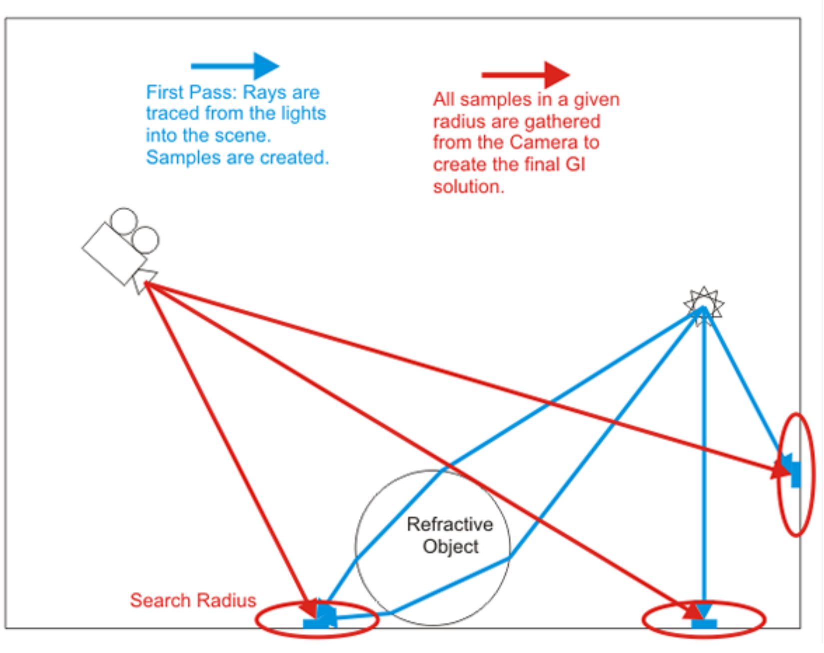
Specular reflectance

Resynthesis under original illumination

Superimposition of seven virtual objects

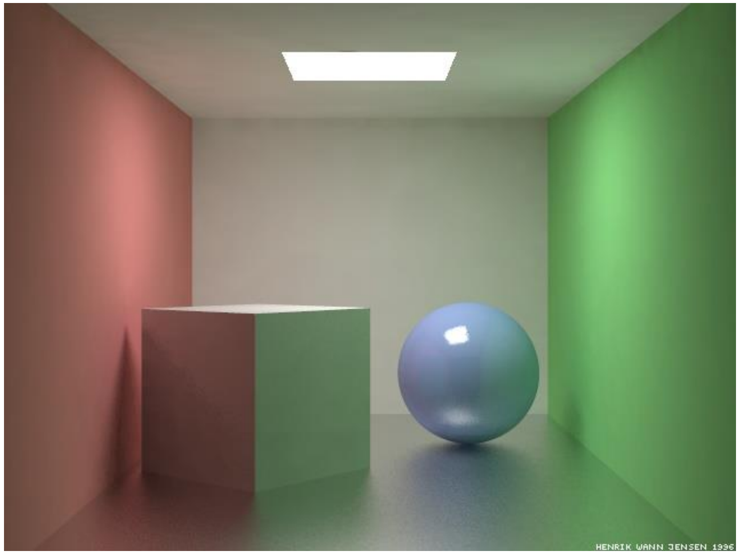
Photon mapping (Jensen 1996)

- Two-pass algorithm to express global illumination
  - **1st pass**: Construction of photon map
    - Distribute many photons from light
  - **2nd pass**: Rendering
    - Count photons by ray tracing from viewpoint

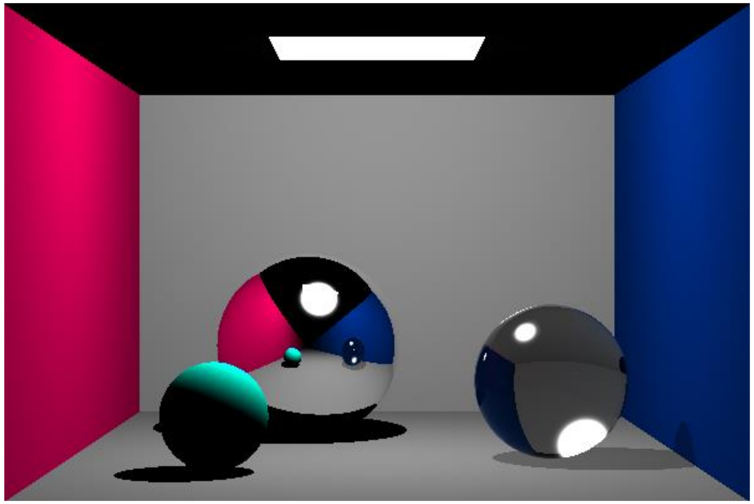


http://help.chaosgroup.com/vray/help/200R1/render_params_photonmap.htm

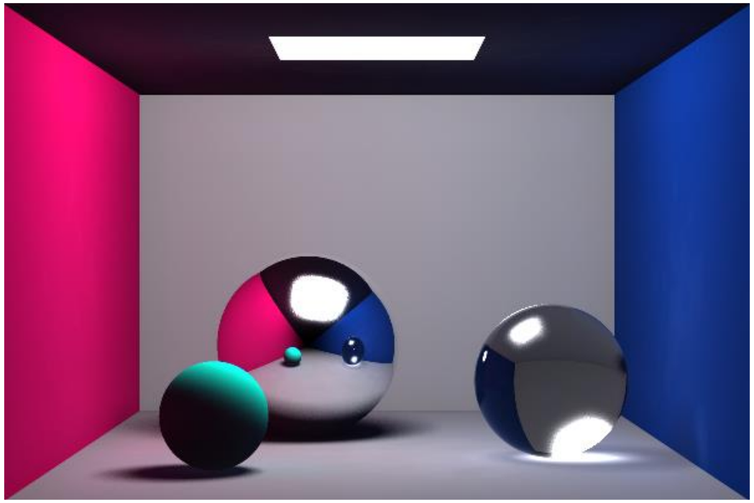
Examples of photon mapping



[Jensen, Global Illumination using Photon Maps, 1996]

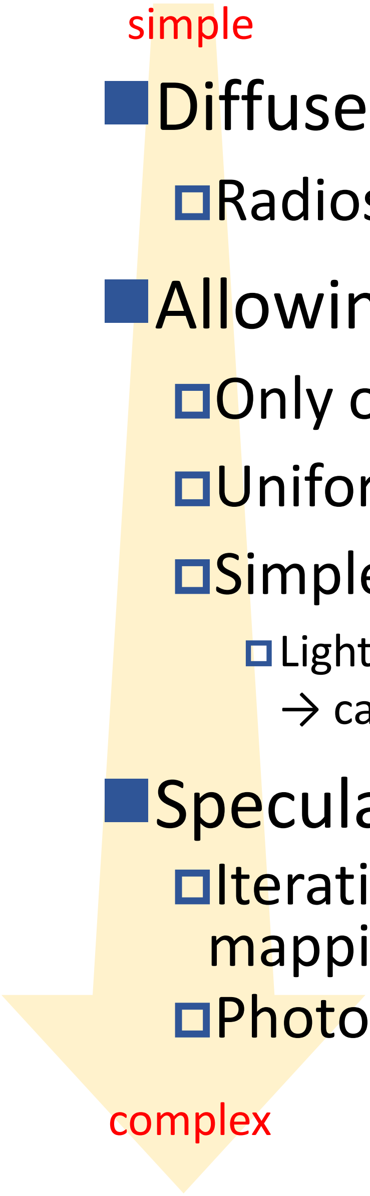


Simple ray tracing

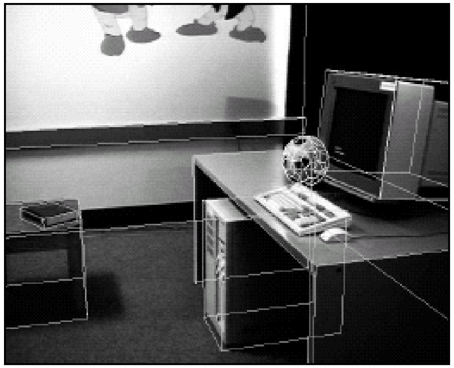


Photon mapping

Inter-reflection in complex scene



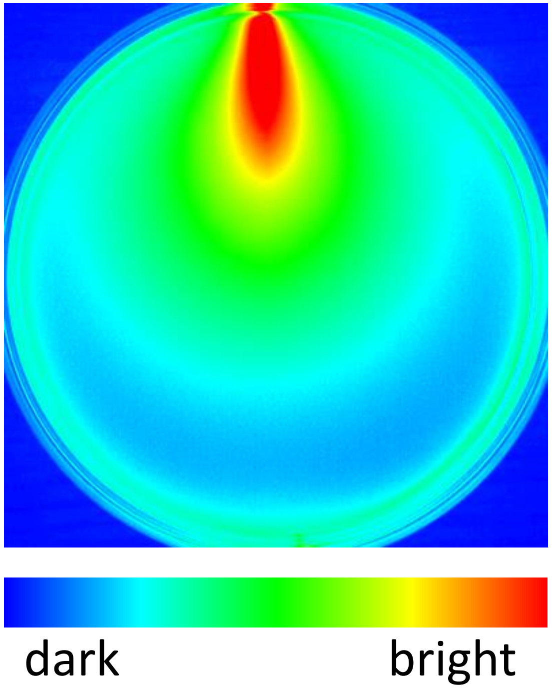
- Diffuse inter-reflection
  - Radiosity based on heat transfer
- Allowing specular reflection
  - Only one-bounce specular reflection
  - Uniform specular reflection
  - Simple path
    - Light source → Diffuse reflection → Specular reflection → camera
- Specular inter-reflection
  - Iterative computation to fit input Photon mapping method
  - Photon mapping



Volume Scattering
（体積散乱）

Scattering in translucent media

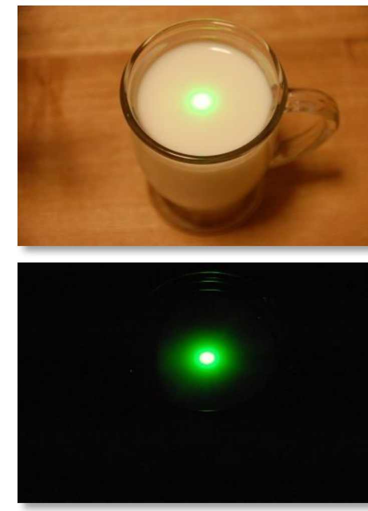
- How an incident ray repeats scattering and the light propagates in a translucent media?
  - Multiple bounces
  - Complex light field



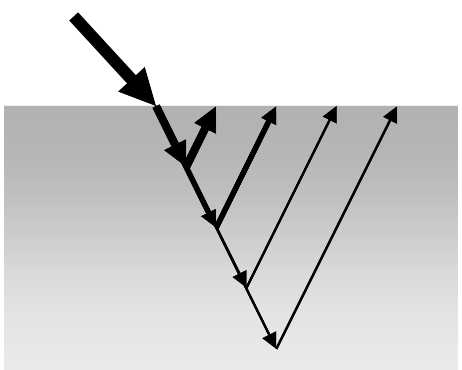
Different scattering due to optical density

Vitamin water

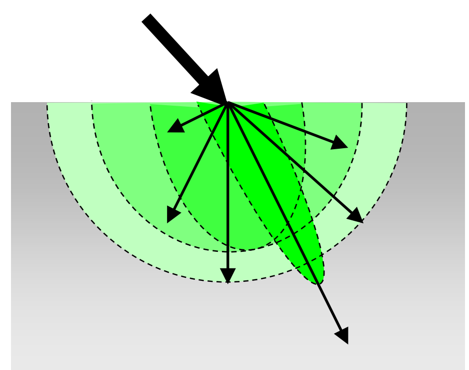
Orange juice



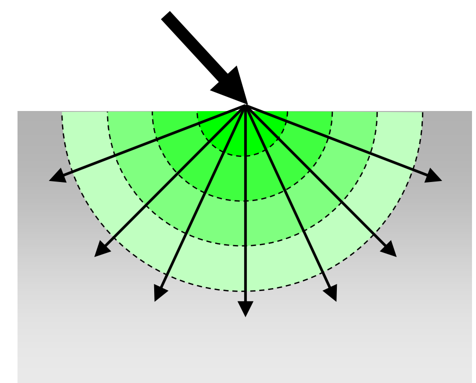
Milk



Single scattering



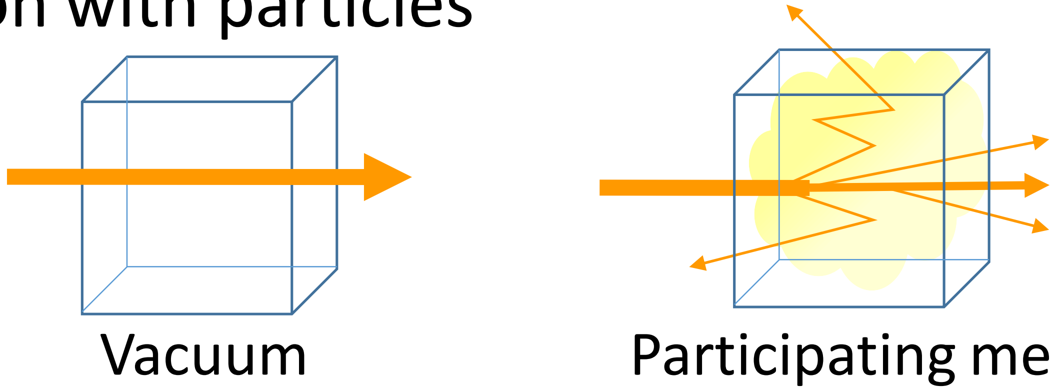
Low-order bounce scattering



Multiple scattering (diffusion)

Participating media（関与媒質）

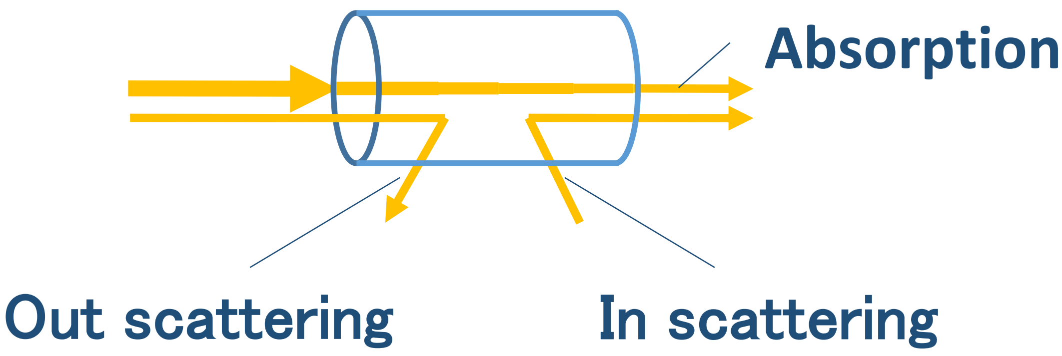
- Consist of small particles
- Collision with particles



SIGGRAPH ASIA 2008 Course Note

Light transport in participating media

- Absorption：
  - Collision with particles
  - Decrease in intensity
- Out scattering：
  - Scattered to outside
  - Decrease in intensity
- In scattering：
  - Ray from outside scatters and joins to traveling direction
  - Increase in intensity



Energy decrement

- Attenuation by absorption

$$dL(x,\omega) = -\sigma_a(x)L(x,\omega)ds \qquad \sigma_a(x)\text{ : Absorption coefficient } [\mathrm{m}^{-1}]$$

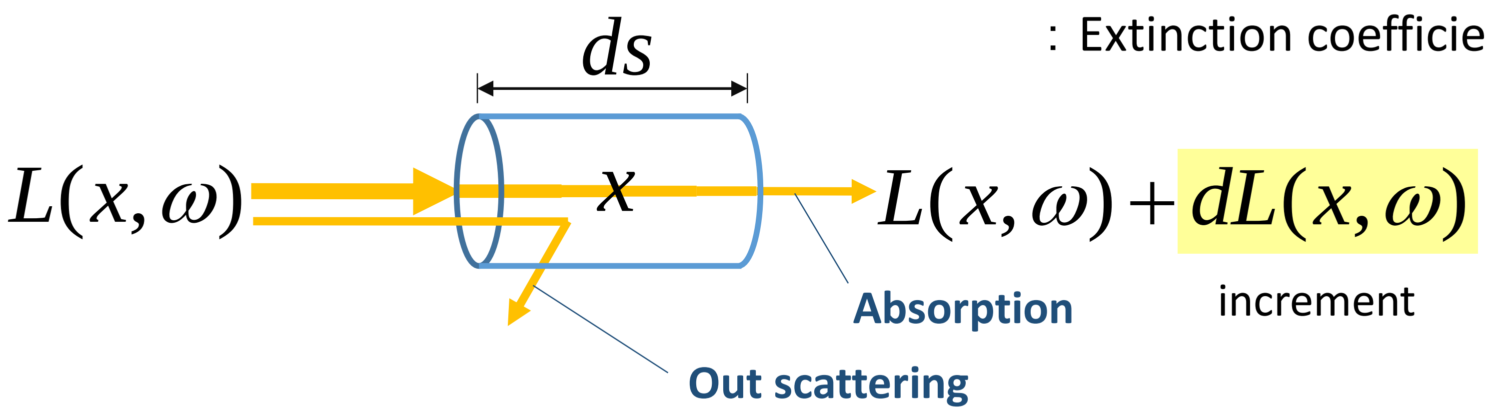
- Attenuation by out scattering

$$dL(x,\omega) = -\sigma_s(x)L(x,\omega)ds \qquad \sigma_s(x)\text{ : scattering coefficient } [\mathrm{m}^{-1}]$$

- Summing both attenuations by absorption + out scattering

$$dL(x,\omega) = -\sigma_t(x)L(x,\omega)ds \qquad \sigma_t(x) = \sigma_a(x) + \sigma_s(x)$$

: Extinction coefficient $[\mathrm{m}^{-1}]$

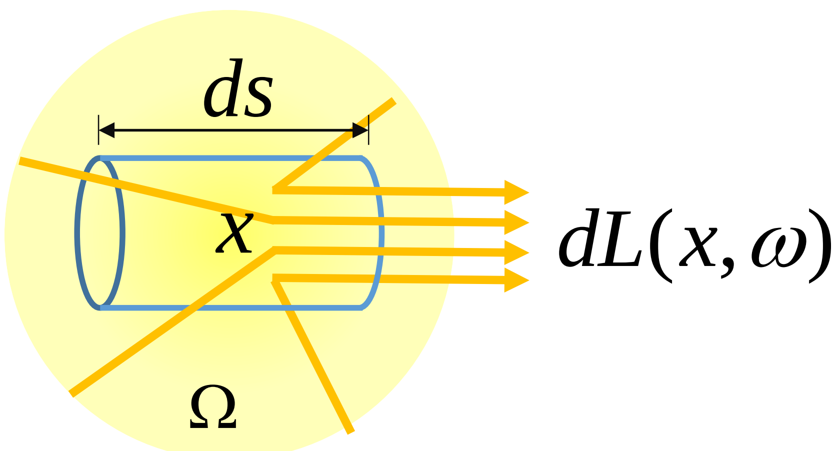


Energy increment

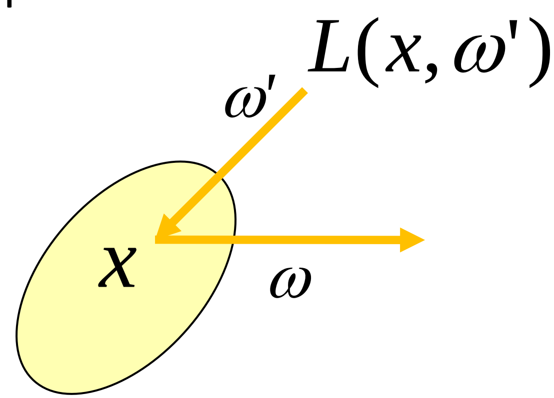
- **Increment by in scattering**
  - Integrating rays coming from each direction ω' of the spherical surface Ω surrounding point x

$$dL(x,\omega) = \sigma_s(x)\left(\int_\Omega p(x,\omega',\omega)L(x,\omega')d\omega'\right)ds$$

Phase function



In scattering

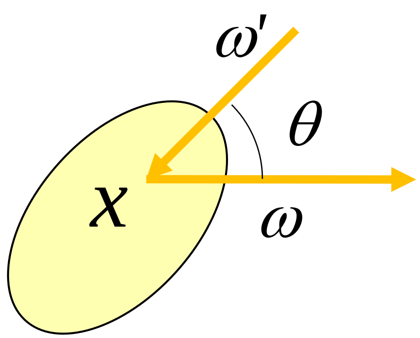


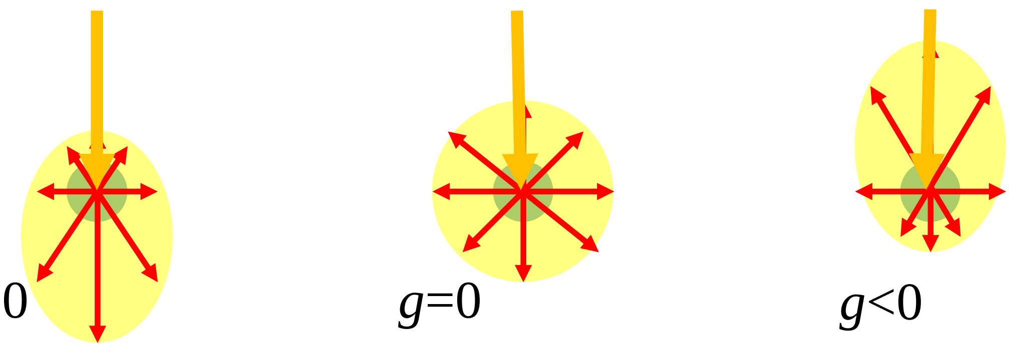
Phase function

Phase function

- Expression of scattering bias
  - depends only on the angle θ between ω and ω' for most media
  - Henyey-Greenstein function
    - g: scattering anisotropy

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

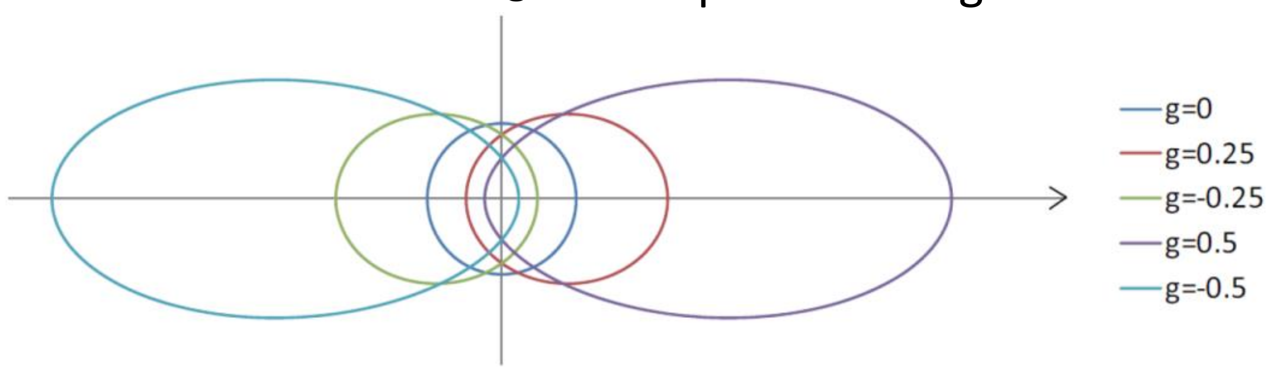




$g>0$ Forward scattering

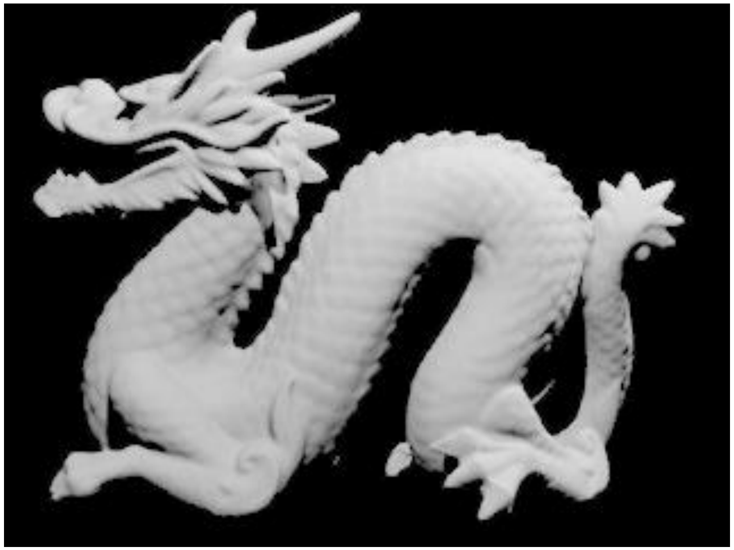
$g=0$ Isotropic scattering

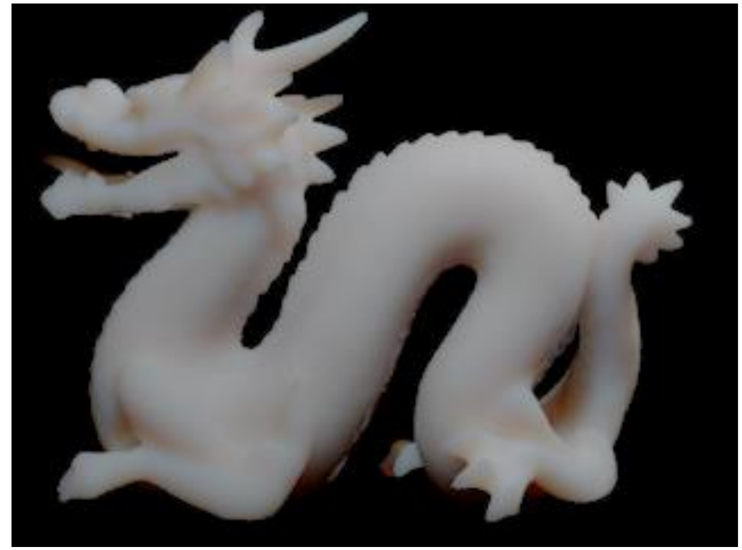
$g<0$ Back scattering

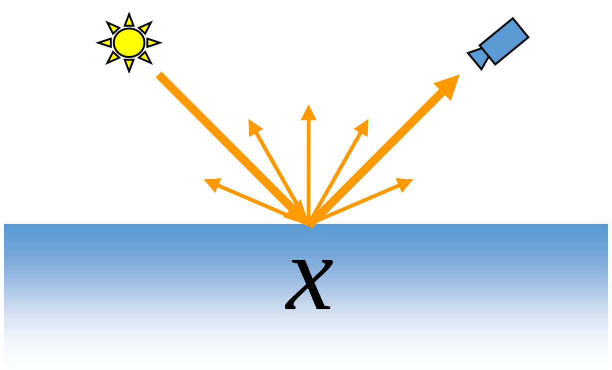


Subsurface Scattering
（表面下散乱）

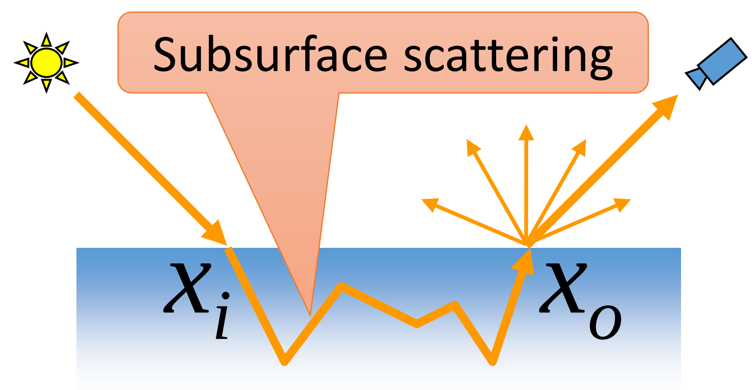
Subsurface scattering in translucent objects







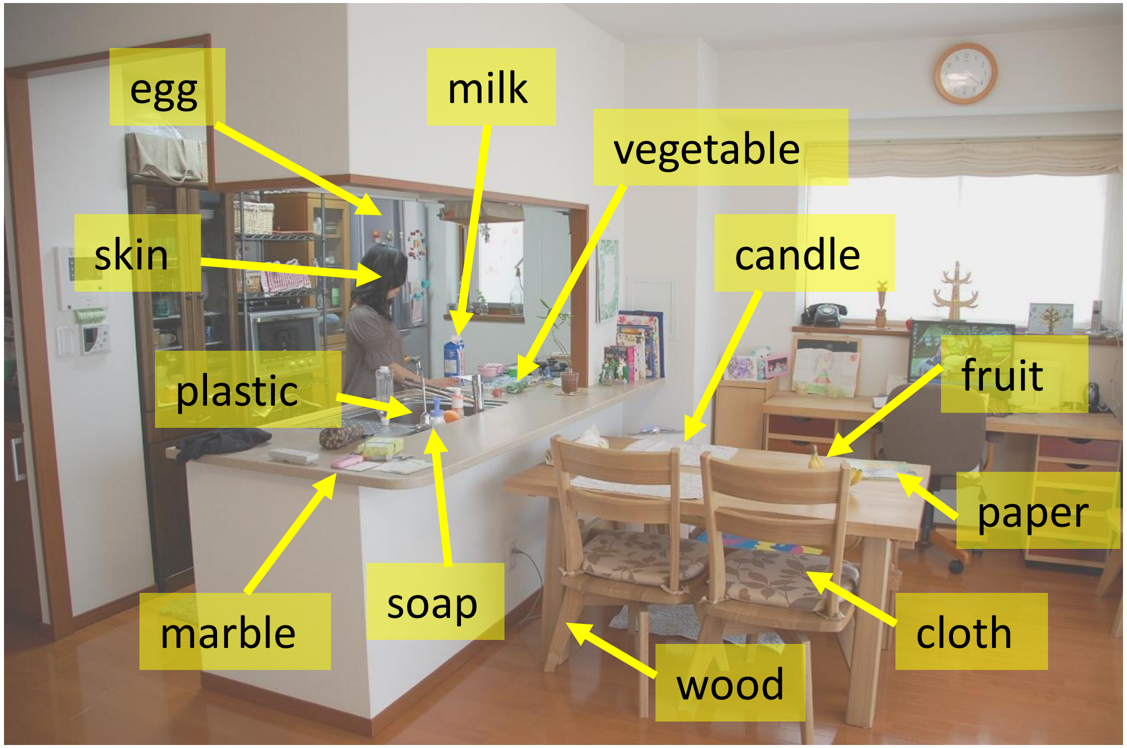
Opaque（不透明）



Translucent（半透明）

Translucent objects are not special

- Typical translucent objects:
  - marble, milk, and skin
- Most objects except for metal are translucent



Translucent objects in our daily environment

Importance of subsurface scattering in CG

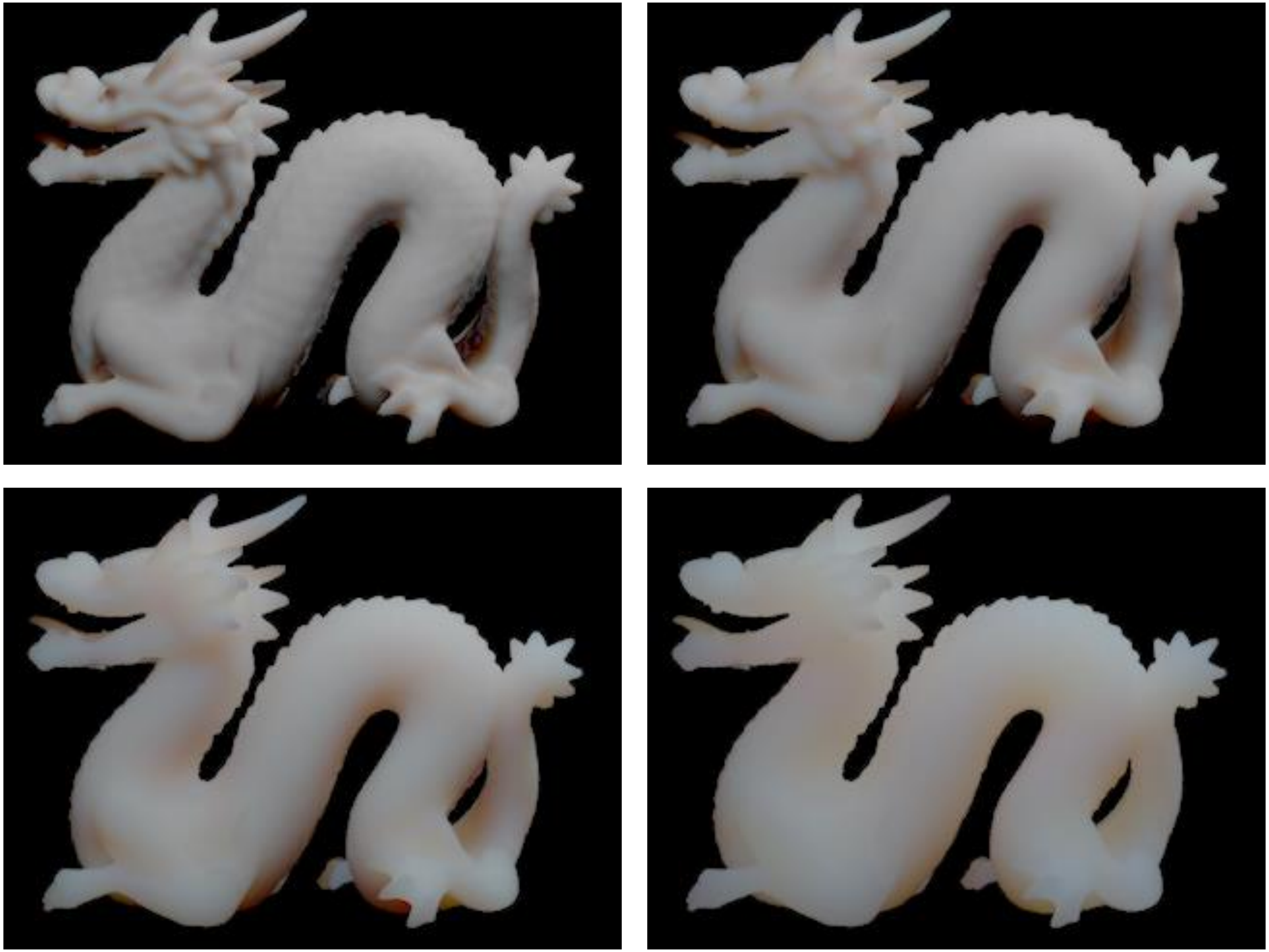
- Representation of realistic skin
- Especially necessary for rendering human image

Jurassic Park (1993)

Dobby of **" Harry Potter and the Chamber of Secrets "** (2002)
(The first movie that computed physically accurate subsurface scattering)

Gollum of
"Lord of the Rings"
(2002-2003)

Difference in scattering properties



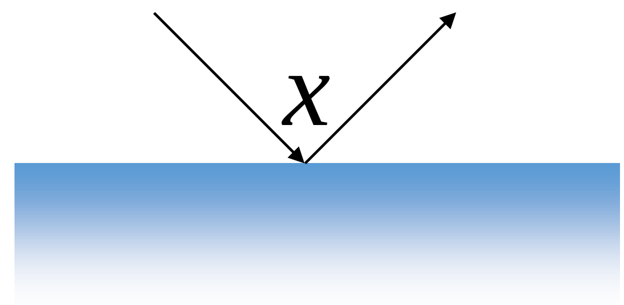
Different distribution

BSSRDF（双方向散乱表面反射分布関数）

(**B**idirectional **S**cattering **S**urface **R**eflectance **D**istribution **F**unction)

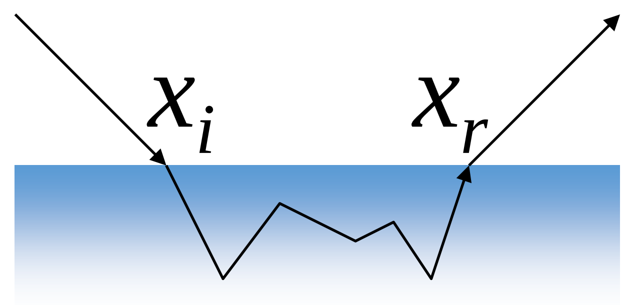
- How much the incident light at a point x_i from a direction (θ_i, ϕ_i) outgoes from a point x_r to a direction (θ_r, ϕ_r)
- The difference with BRDF is that the incident and outgoing exit points are different.
- **Opaque object**
  - locally defined

$$f_{BRDF}(x, \theta_i, \phi_i, \theta_r, \phi_r)$$



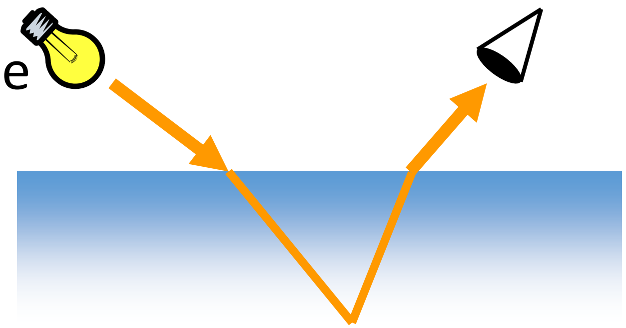
- **Translucent object**
  - globally defined

$$f_{BSSRDF}(x_i, \theta_i, \phi_i, x_r, \theta_r, \phi_r)$$

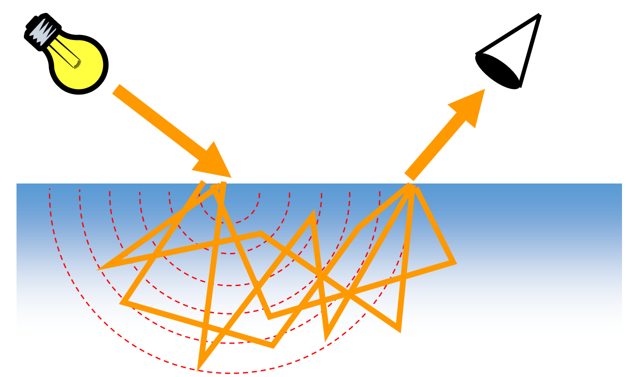


Single scattering and Multiple scattering

- **Single scattering** :
  - Collision with a particle **only once** inside the medium
  - Observed in optically thin medium
    - such as milky water, fog,...
  - High directivity and uniquely determined light path



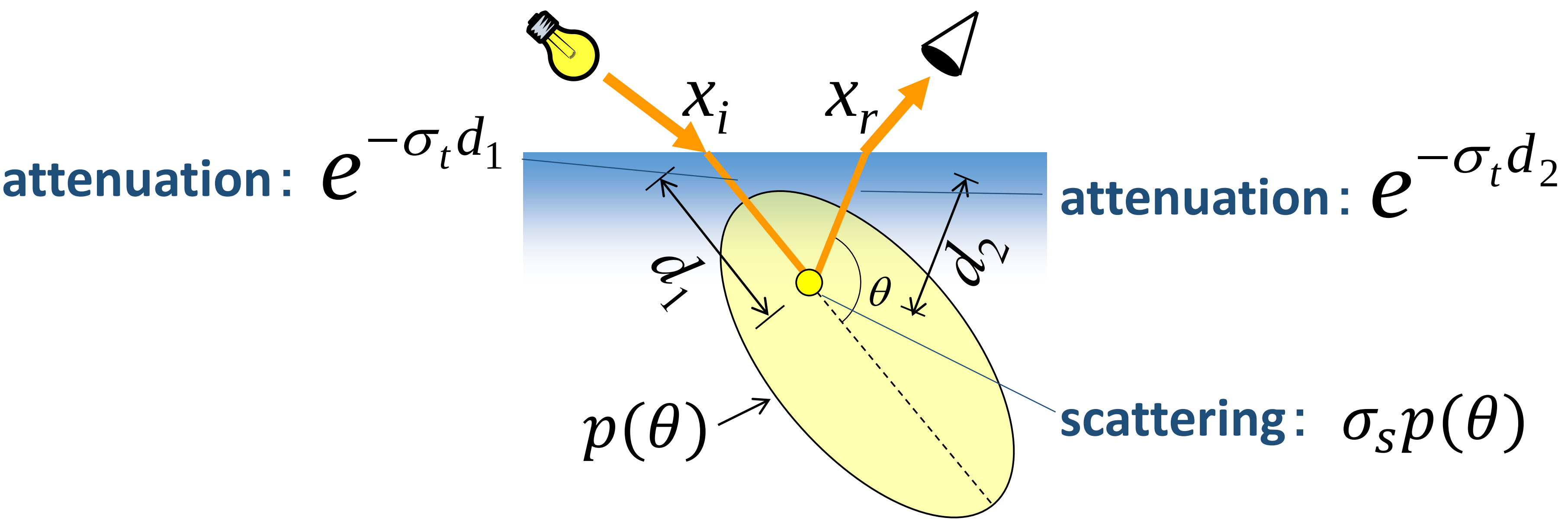
- **Multiple scattering** :
  - Repeat reflections **many times** inside the medium
  - Observed in optically dense medium
    - such as skin, marble, milk,...
  - **Diffusion approximation**



Model of single scattering

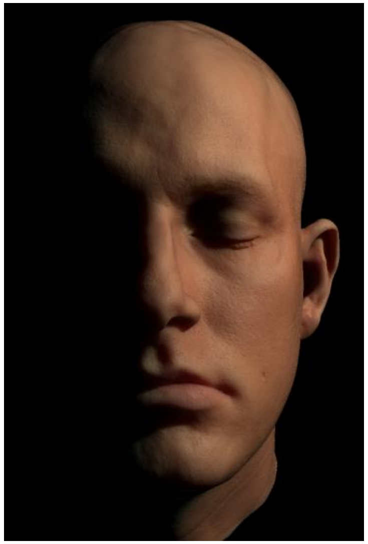
- Modeling the sequence of attenuation → scattering → attenuation

$$f_{BSSRDF}^{single}(x_i, \theta_i, \phi_i, x_r, \theta_r, \phi_r) = \sigma_s p(\theta) e^{-\sigma_t (d_1 + d_2)}$$

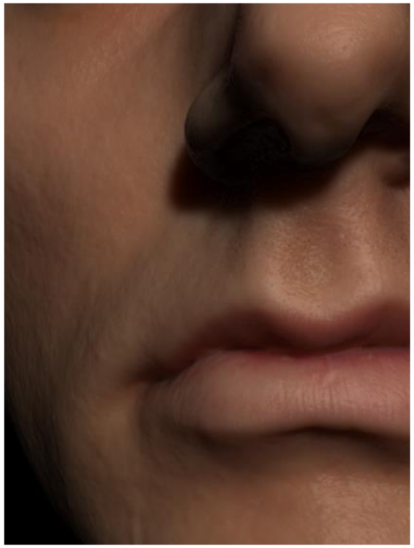


Model of multiple scattering

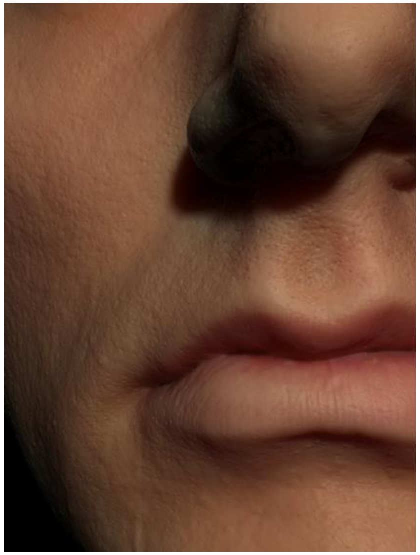
- Direst tracing
  - Monte Carlo ray tracing, photon mapping
  - High computational cost, since reflections are repeated.
- Approximated parametric function
  - Diffusion approximation
  - Dipole model (Jensen 2001) , multipole model (Donner 2005)



Multi-layered model



Dipole



Multi-layer

Dipole Model for BSSRDF (Jensen et al. SIGGRAPH2001)

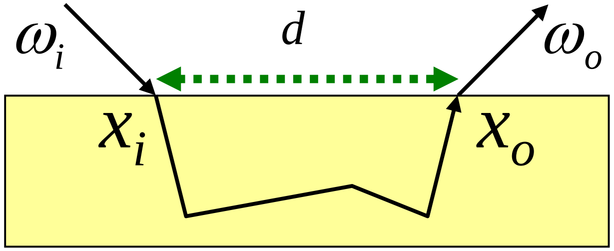
- Decomposition of the BSSRDF
  - Fresnel transmittance: $F_t(\eta, \omega)$
    - function of relative index of refraction η, incident and reflective angles ω_i and ω_o
  - Diffuse BSSRDF: $R(d)$
    - function of distance d between incident and outgoing points x_i and x_o
    - including two inherent parameters of the material
    - scattering coefficient: σs
    - absorption coefficient: σa

$$f_{BSSRDF}^{multiple}(x_i, \theta_i, \phi_i, x_r, \theta_r, \phi_r) = \frac{1}{\pi} F_t(\eta, \theta_i, \phi_i) R_d(\| x_i - x_r \|) F_t(\eta, \theta_r, \phi_r)$$

Diffuse BSSRDF

Fresnel transmittance at x_i

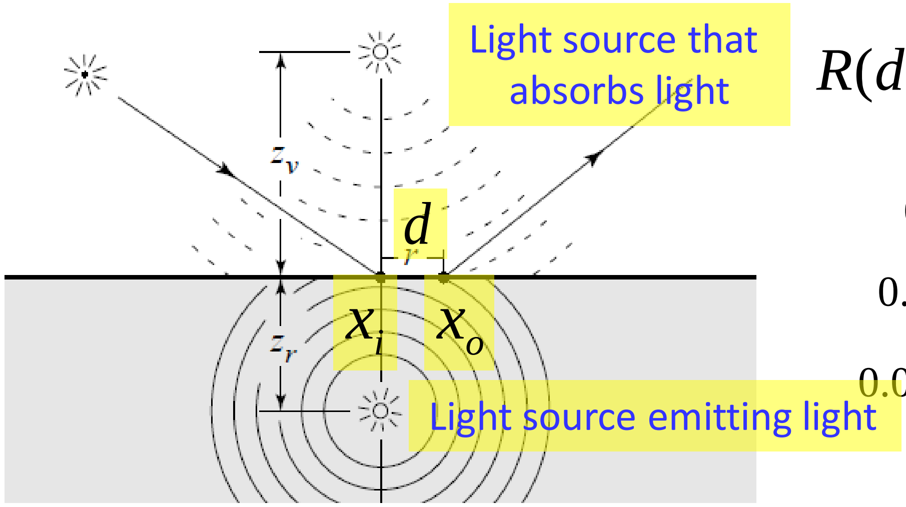
Fresnel transmittance at x_o



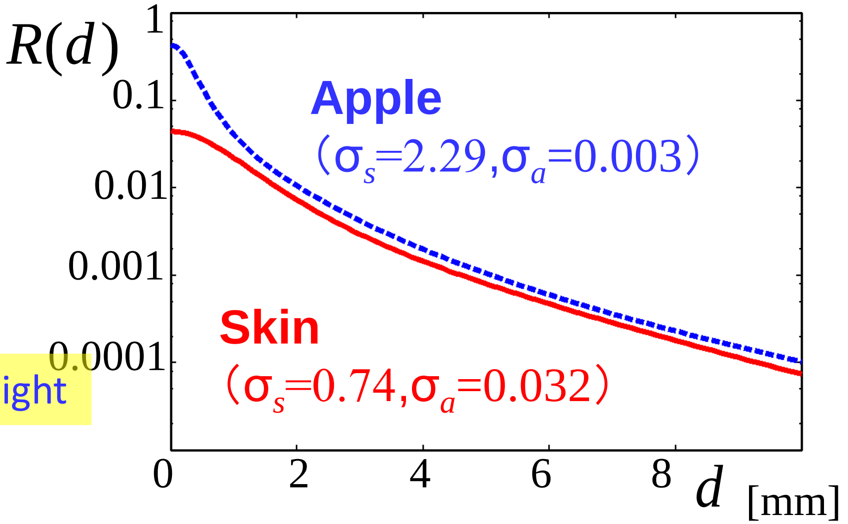
Diffuse BSSRDF in Dipole model

- Assumption of diffusion approximation
- A point light source in object
- In order to satisfy the boundary condition, a negative light source above the incident point

$$R(d) = \frac{\alpha'}{4\pi}\left[z_r(\sigma_{tr} d_r + 1)\frac{e^{-\sigma_{tr} d_r}}{\sigma'_t d_r^3} + z_v(\sigma_{tr} d_v + 1)\frac{e^{-\sigma_{tr} d_v}}{\sigma'_t d_v^3} \right]$$



Concept of dipole model

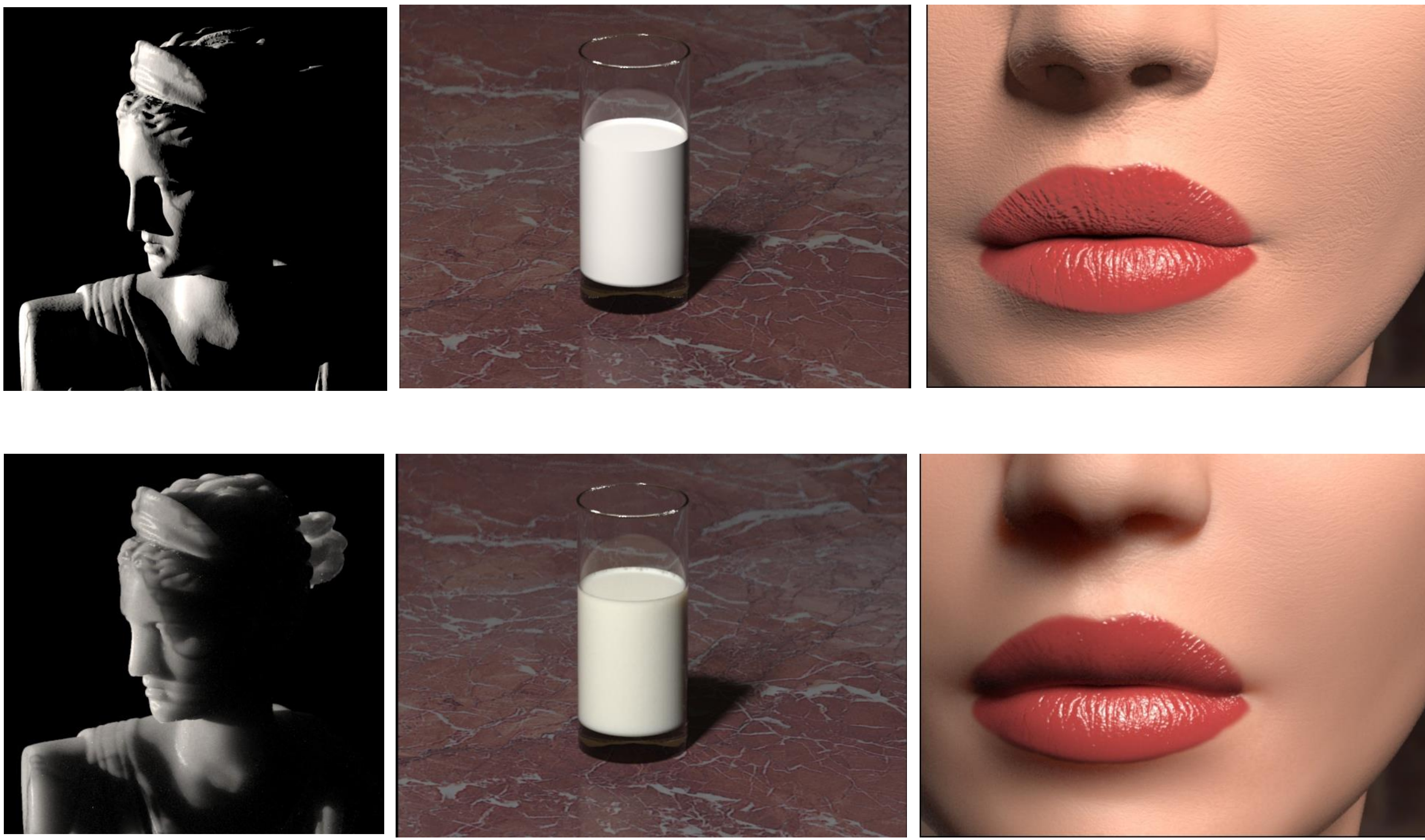


Examples of scattering terms

Rendering example with dipole model

BRDF

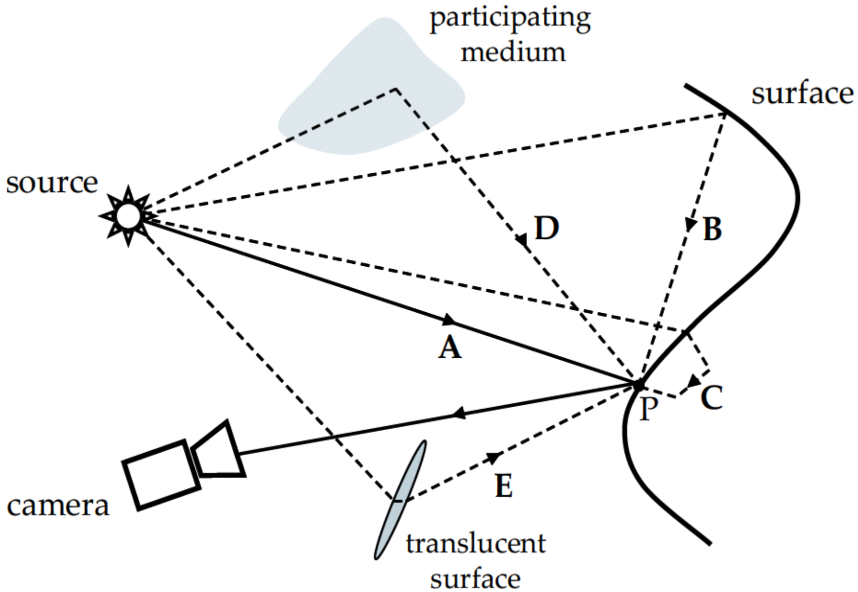
BSSRDF

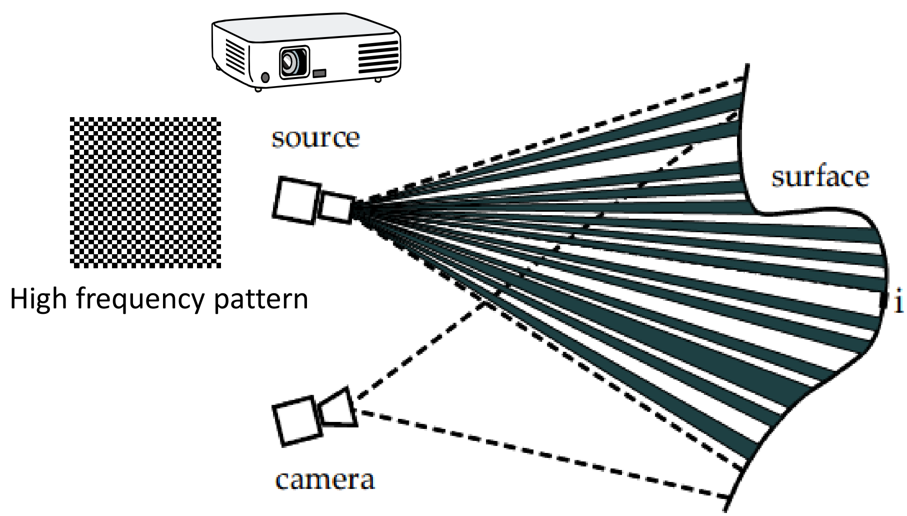


Decomposition using high-frequency illumination（高周波照明による成分分解）

Decomposition of Global Illumination(Nayar 2006)

- Separation of two components
  - Direct component (diffuse reflection / specular reflection)
  - Global components (inter-reflection, volume scattering, subsurface scattering ...)
- Using a projector as a light source
  - Projecting high frequency pattern (fine grid pattern)
  - Utilizing that the global illumination effect acts as a low-pass filter



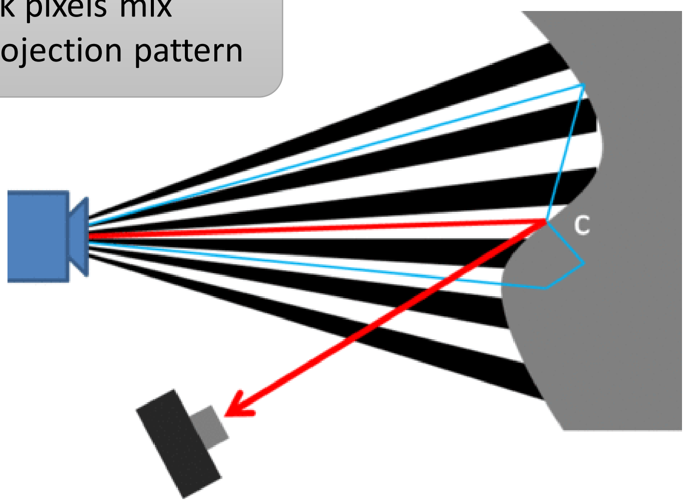


Principle of high frequency illumination

- When not illuminated：
  - Global component /2

> - White pixels and black pixels mix
> - Half is white in the projection pattern

- When illuminated：
  - Direct component ＋ Global component /2
- Separation of two components

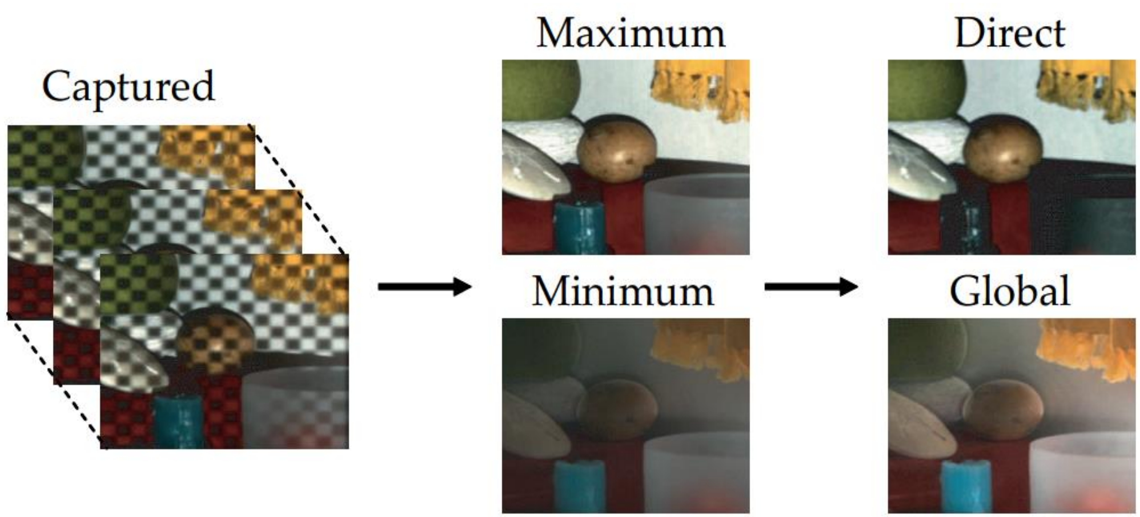


$$\max = \color{red}{direct} + \frac{1}{2}\color{green}{global}$$

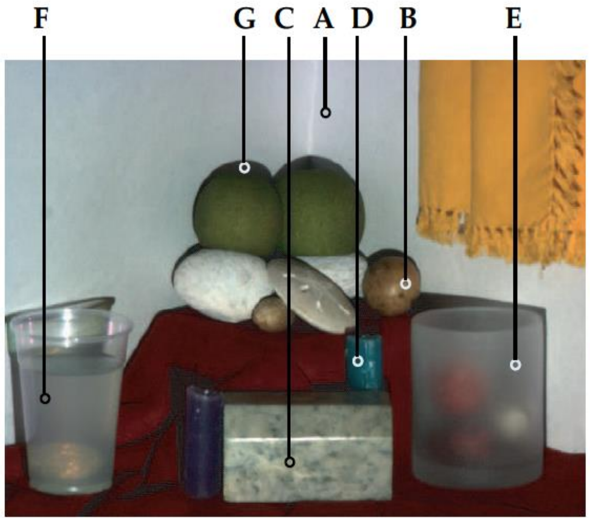
$$\min = \frac{1}{2}\color{green}{global}$$

$$\color{red}{direct} = \max - \min$$

$$\color{green}{global} = 2\min$$



Decomposition of direct and global components



A: Diffuse Interreflection (Board)

B: Specular Interreflection (Nut)

C: Subsurface Scattering (Marble)

D: Subsurface Scattering (Wax)

E: Translucency (Frosted Glass)

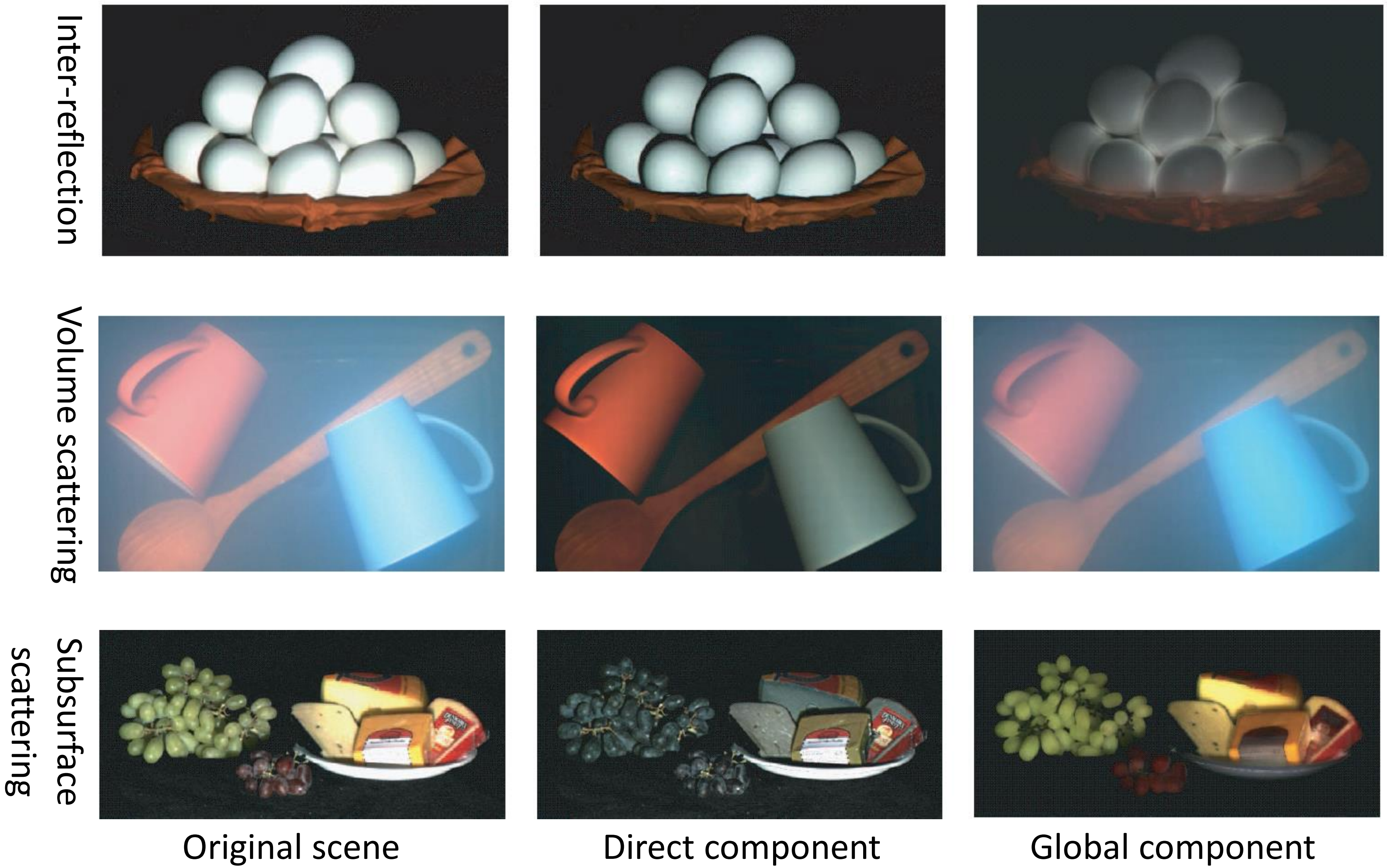
F: Volumetric Scattering (Dil. Milk)

G: Shadow (Fruit on Board)

Direct component

Global component

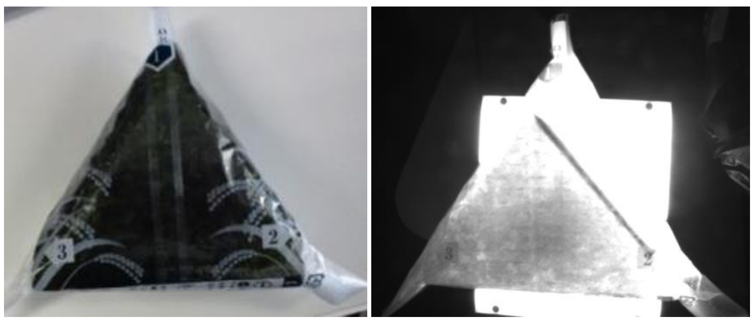
Decomposition of direct and global components



Decomposition of transmissive lights （透過光の分解）

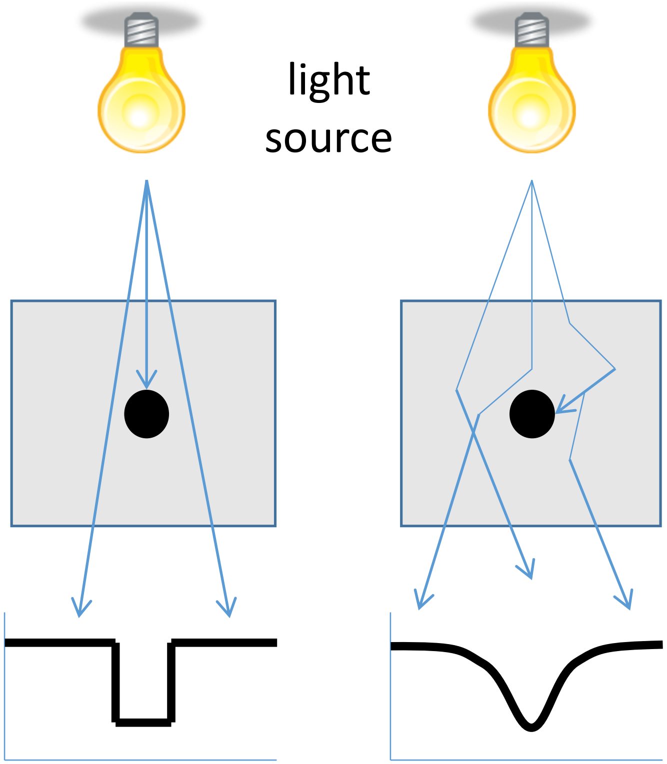
Visualization using IR light

- Transmissive image using IR light.
- Unclear image due to ***scattering.***



Metal object in food

Vein pattern



Transmissive high frequency illumination

(ICCP2013)

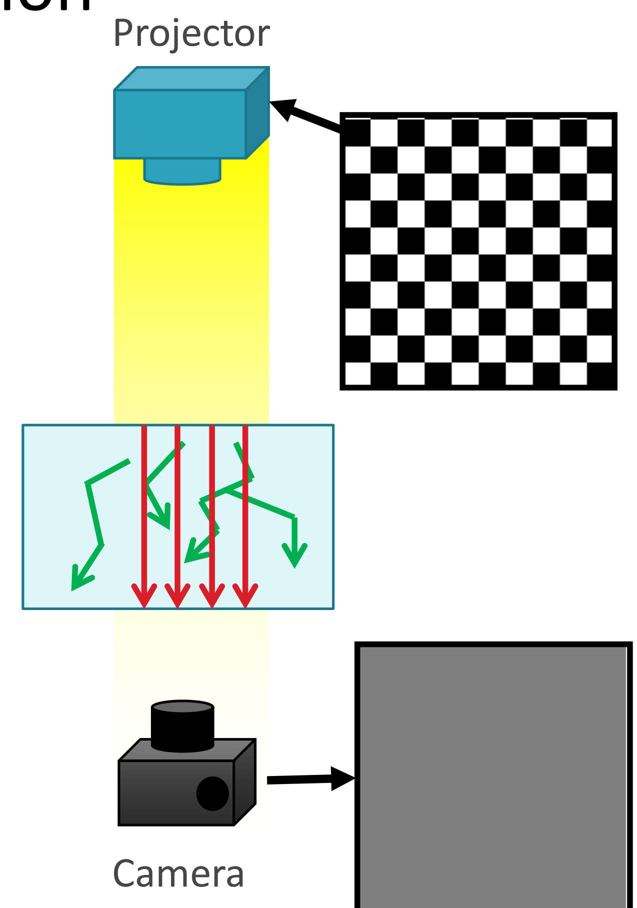
- Decomposition of transmissive and scattered rays.
- Parallel high frequency illumination
  - When phase change,
    - transmissive : change
    - scattered : no change
- Decomposition

$$max = transmissive + \frac{1}{2} scattered$$

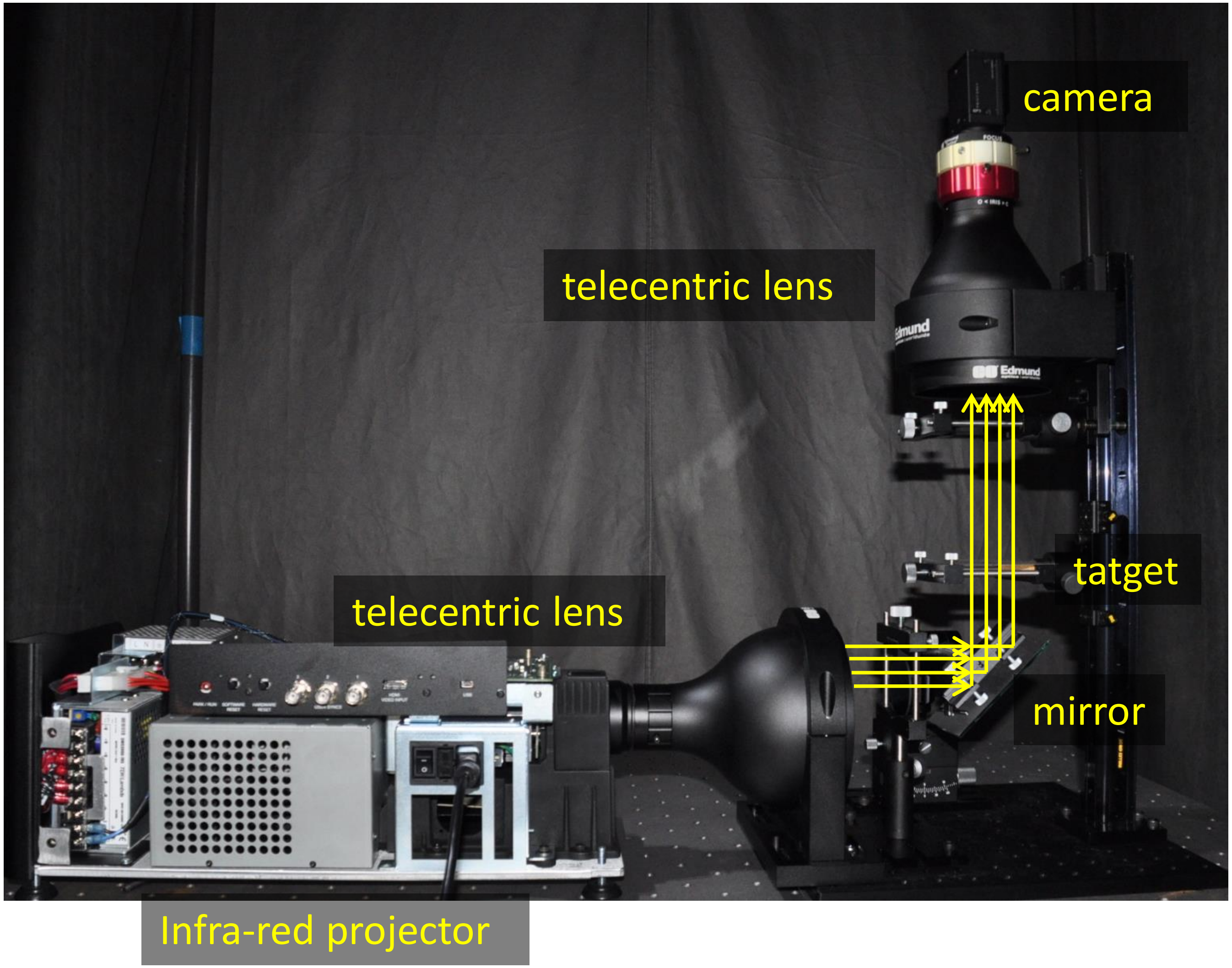
$$min = \frac{1}{2} scattered$$

$$transmissive = max - min$$

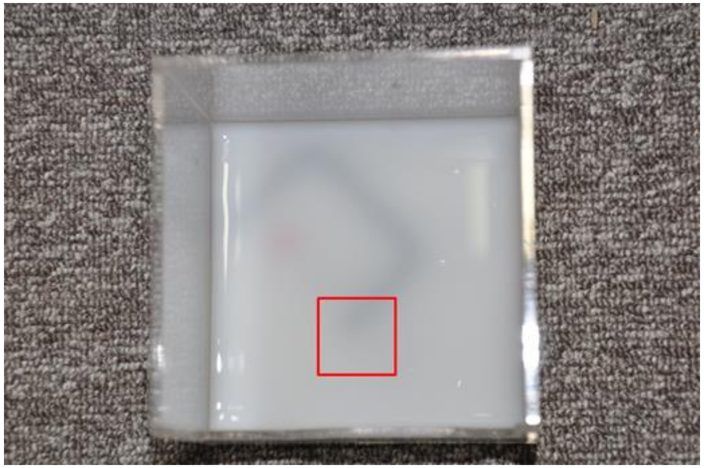
$$scattered = 2\times mix$$



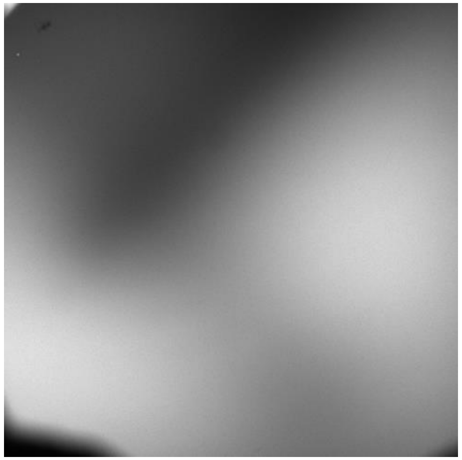
Overview


camera
telecentric lens
tatget
telecentric lens
mirror
Infra-red projector

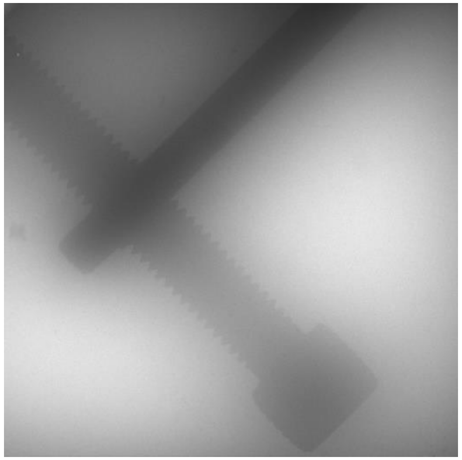
Transmissive images



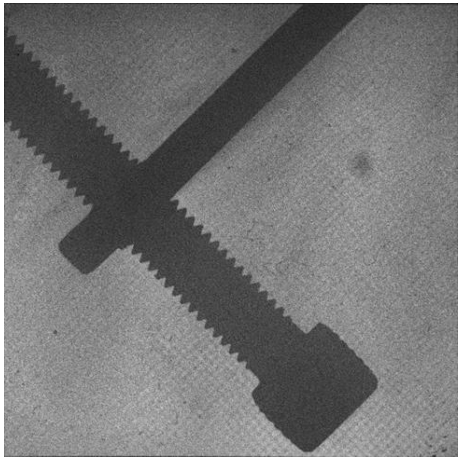
Metal object in murky water



Normal image
with visible light

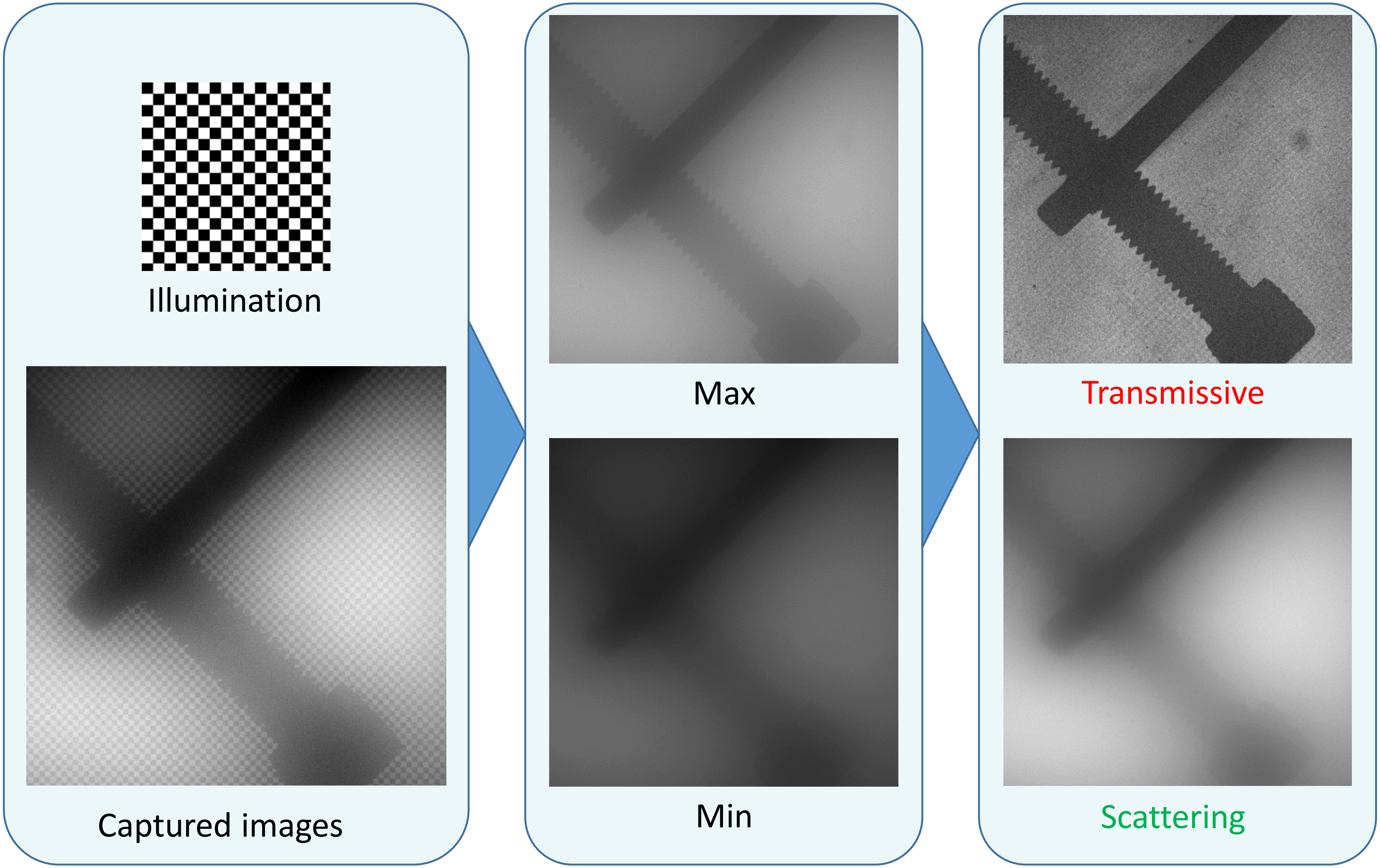


Infra-red image



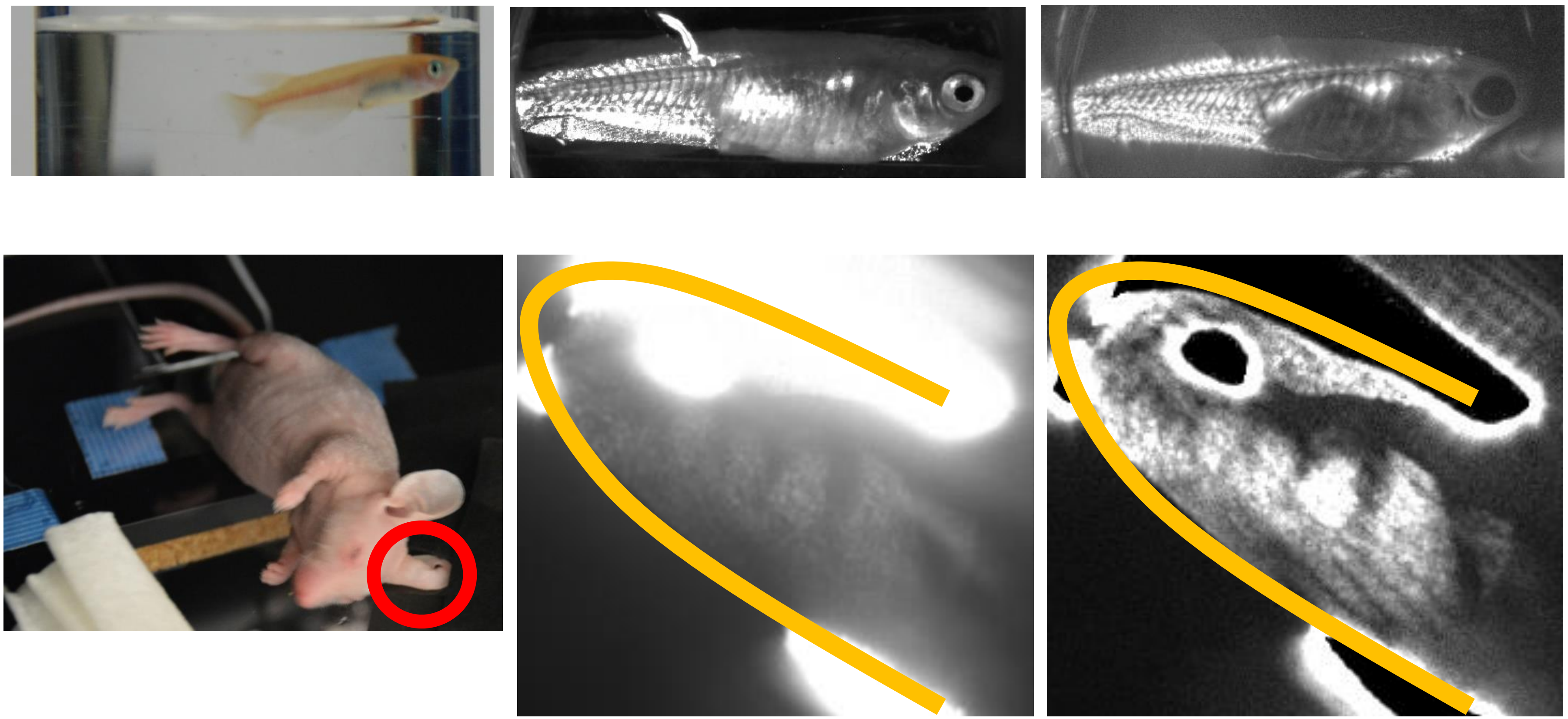
Descattered image

Process of the descattering



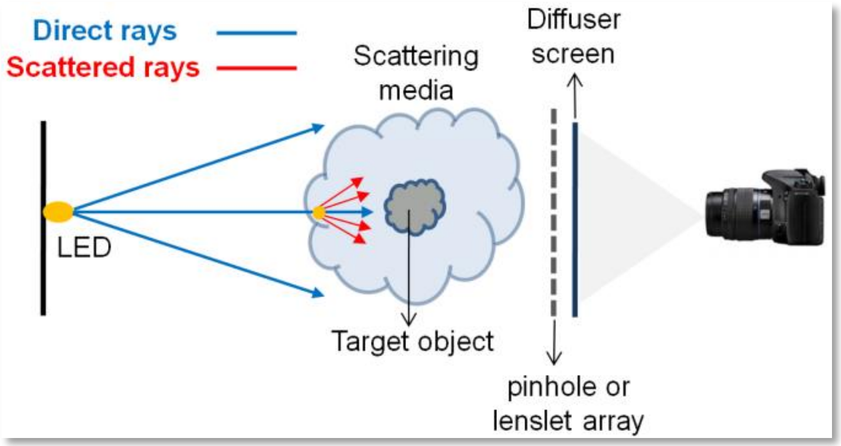
Application for Bioimaging

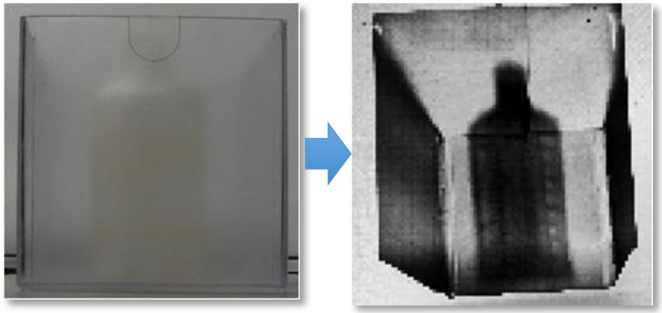
- Fish and mouse

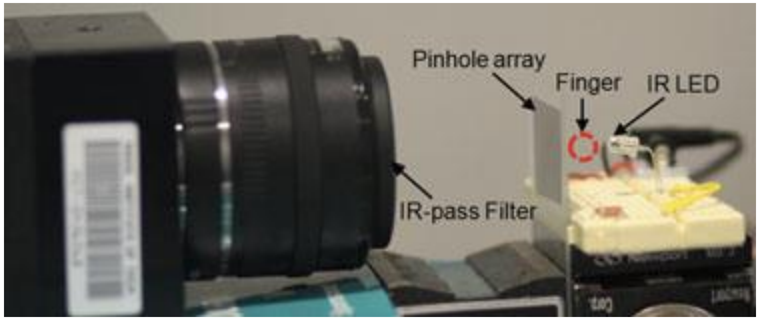


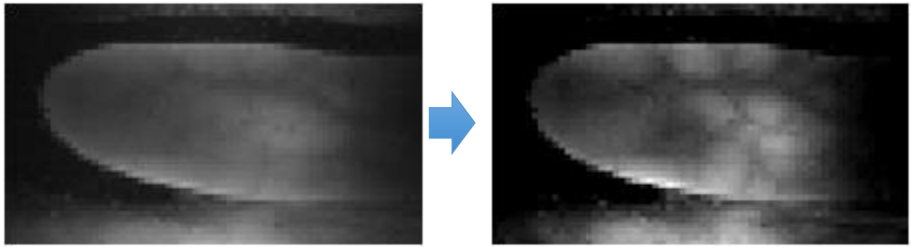
Light field camera for descattering (ECCV2010)

- Light field camera to record spatial (x, y) and angular (θ, ϕ) information of rays









Clear vein pattern using NIR light

Summary of global Illumination

- In our daily environment, there are a lot of volume scattering and subsurface scattering
- In particular, it is difficult to analyze scattering on inhomogeneous materials
- Perfect photometric modeling of real scene is extremely difficult

candle

marble

Report

- What is the difference of direct and global components? Explain from the following viewpoints.
  - Optical phenomena（光学現象）
  - Spatial frequency（空間的な周波数）
  - Simplicity for modeling（モデル化の容易さ）

Direct component

Global component

Report

- What is the difference of direct and global illuminations? Explain from the following viewpoints.
  - Optical phenomena（光学現象）
    - It depends on the settings. Generally,
    - **Direct**: locally defined -> diffuse and specular reflections
    - **Global**: globally defined -> inter-reflection, volume scattering, subsurface scattering.
  - Spatial frequency（空間的な周波数）
    - Generally, direct illumination keeps incident frequency.
    - Global illumination acts as a low pass filter.
  - Simplicity for modeling（モデル化の容易さ）
    - Direct illumination is easy to model because locally defined.
    - Global illumination is difficult to model because the intensity cannot be defined at the point. All effect from surrounding environments should be considered.