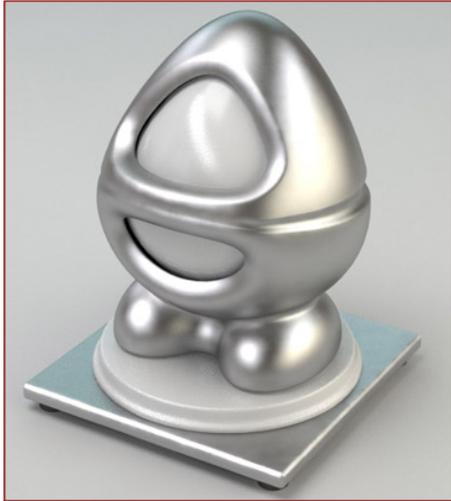


Materials and Appearance: An Introduction



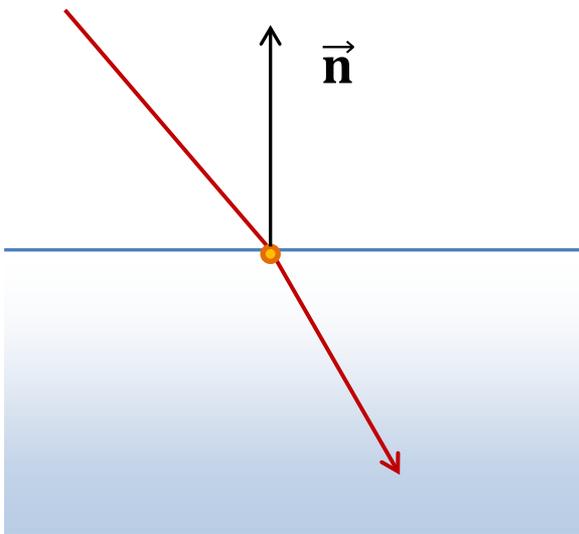
Visual Appearance



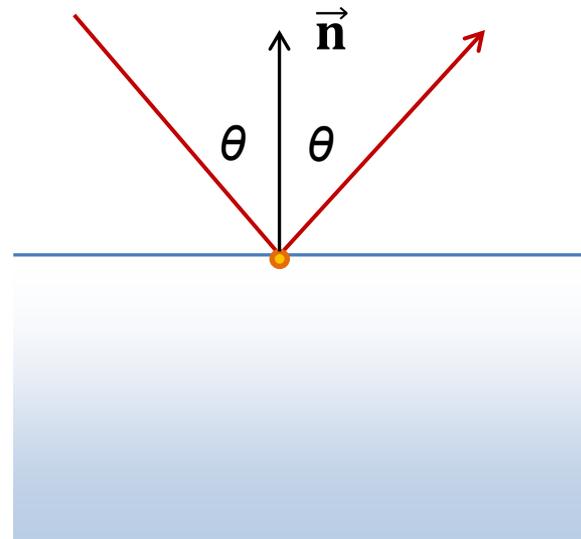
- What makes an object appear in a certain manner?
- Its ability to:
 - Reflect light on its surface (radiation in general)
 - Absorb light
 - Allow light to be transmitted inside it
- The phenomena that deflect the light inside its body (in/out-scattering)
- The spatio-temporal variation of the above (texture)

Basic Light Transport (1)

- When light encounters the interface of a surface, 2 things occur:
 - Light is reflected off the surface
 - Light is transmitted inside the volume of the object



Transmission



Reflection

Basic Light Transport (2)

- Light is an electromagnetic wave and the ratio of reflected vs transmitted energy is determined by
 - The angle of incidence (θ)
 - The index of refraction of the object (material property)
 - The mode of polarization of the incident light
- We will use particular properties for the above in the Shading Models slides

Reflected Light

- Materials reflect light differently
- Surface reflection is also called **specular reflection**
 - Non-metals in general do not change the wavelength of the reflected light



Reflected Light



- Metals allow particular wavelengths to be reflected and absorb the rest (depending also on the angle of incidence)

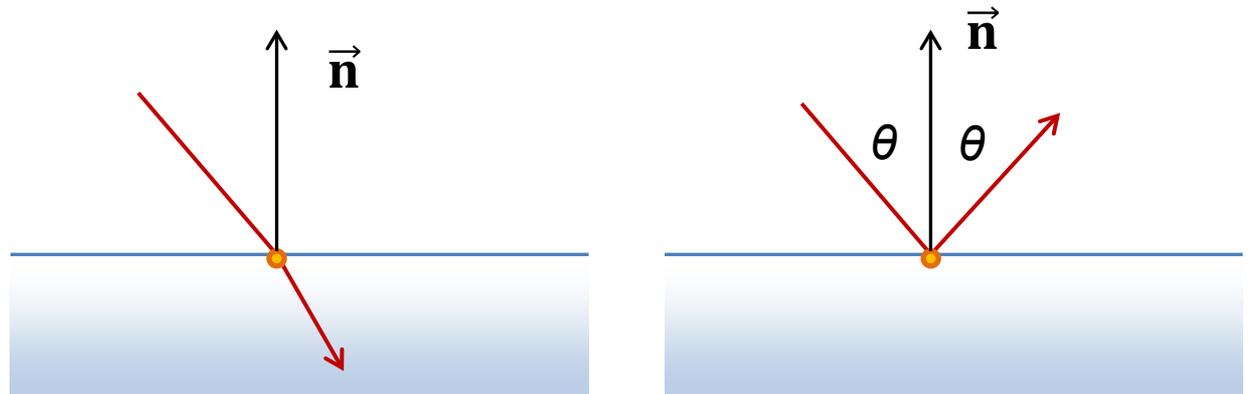
Transmitted Light

- Light that penetrates the surface of an object is **refracted** and transmitted through the object's body
- Transmitted light gets **scattered** and **absorbed** as it interacts with inhomogeneous matter (such as the body's particles)



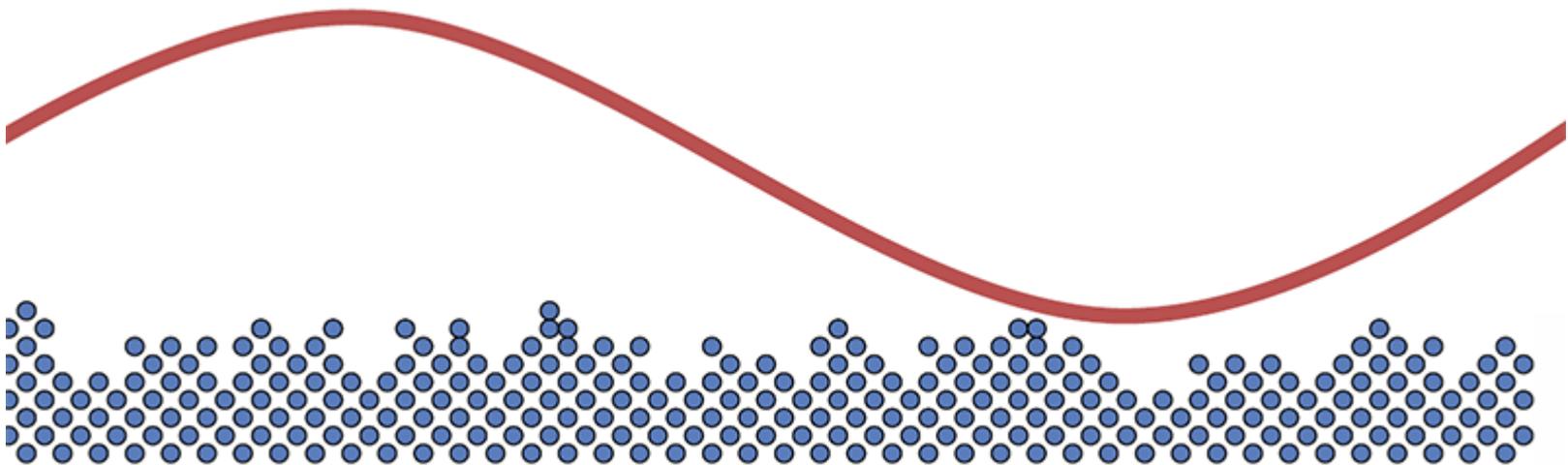
Ideal vs Non-Ideal Surfaces (1)

- In a micro-scale level, all surfaces are considered ideal, i.e. “perfectly flat”
- As a consequence:
 - Light is reflected in a single “ideal” direction
 - Light is refracted in a single “ideal” direction (Snell’s law of optics)



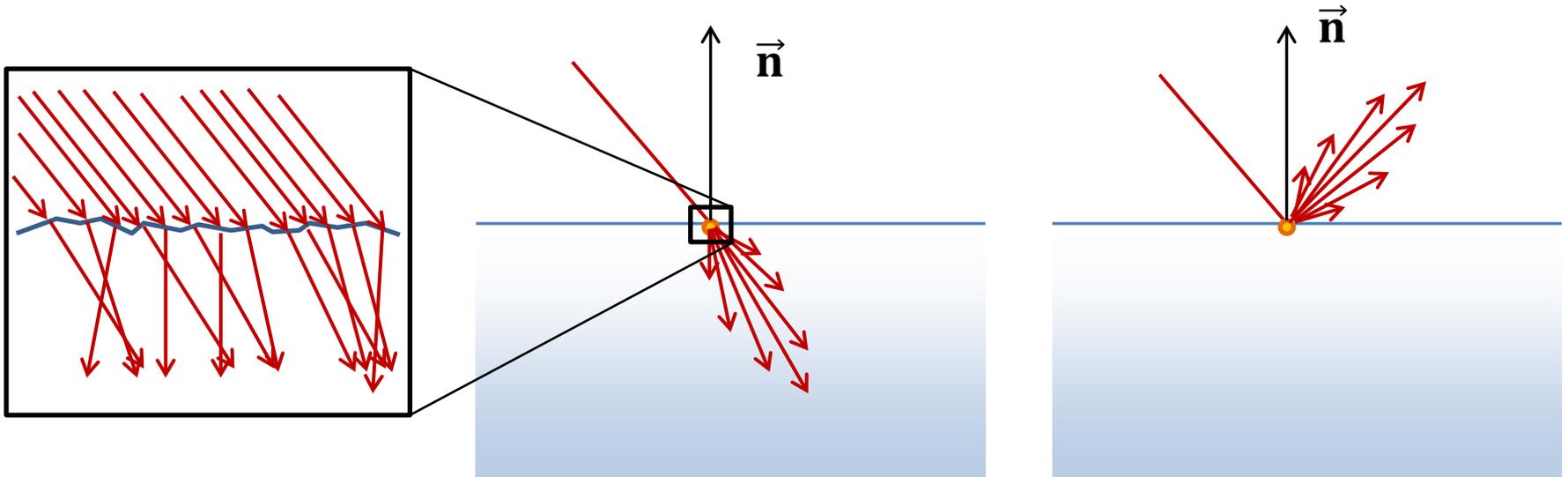
Ideal vs Non-Ideal Surfaces (2)

- Perfectly flat? What about atoms?
- We compare the scale relative to the wavelength of the light
 - For visible light, wavelength is considerably larger than the atomic scale level



Ideal vs Non-Ideal Surfaces (3)

- This however seldom happens in reality
- At a meso-/macro-scopic level most surfaces behave as imperfect ones and therefore reflect and refract the light in slightly different directions:



Ideal vs Non-Ideal Surfaces (4)

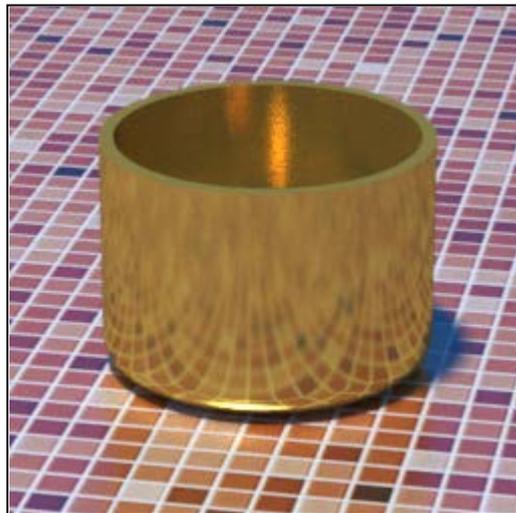
- Few surfaces (mostly high-quality optical mirrors and lenses) are *optically flat* (all irregularities are much smaller than visible light wavelengths)
- Most surfaces have irregularities, which are larger than light wavelengths but smaller than the *scale of observation* (e.g. subpixel size)

Ideal vs Non-Ideal Surfaces (5)

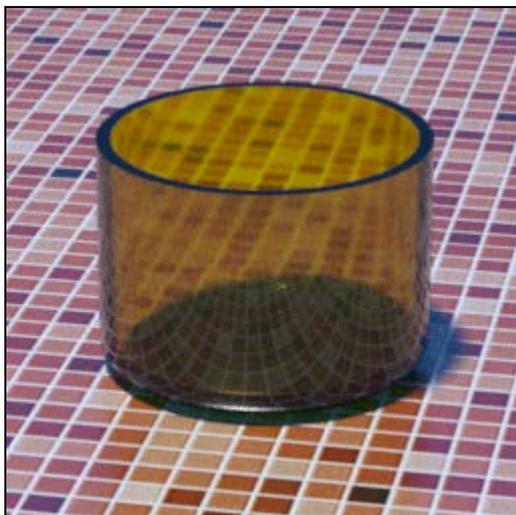
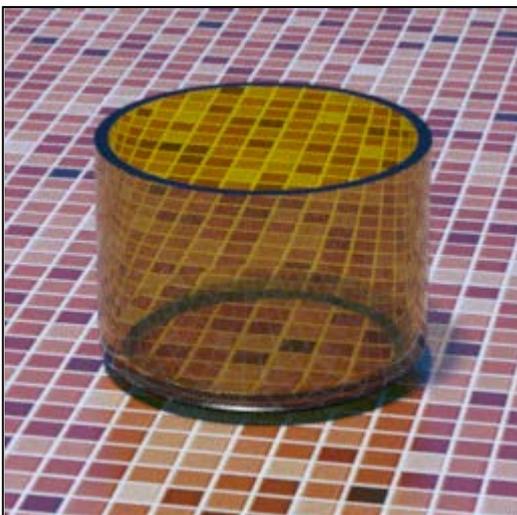
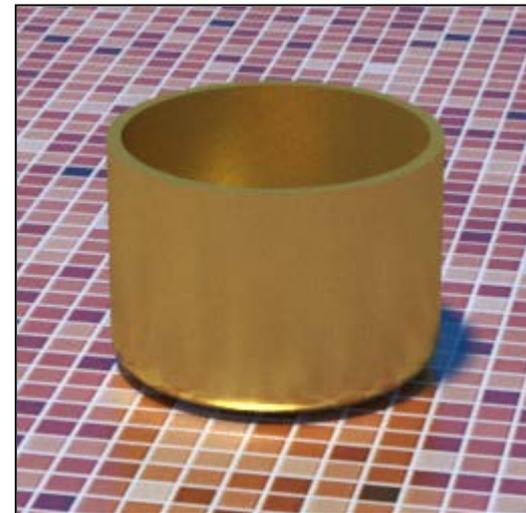
Ideal



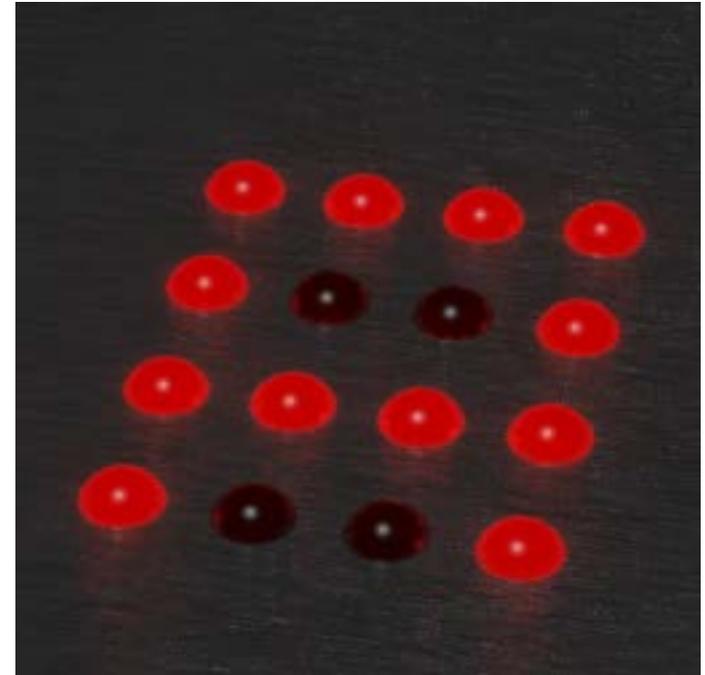
Low roughness



High roughness



- Bodies can emit light
- Intrinsic light emission is added to the reflected or scattered light of a surface or medium



Scattering & Absorption (1)

What happens **inside** the object?

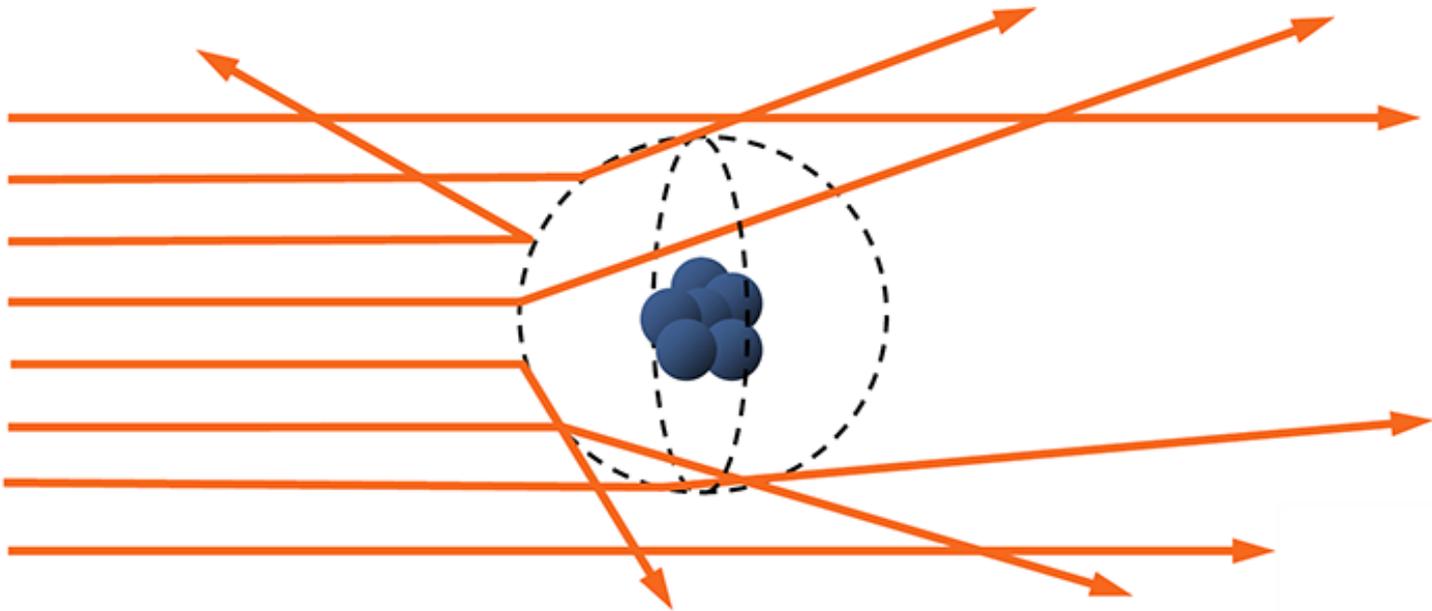
- Photons collide with particles and lose energy (converted to heat) → **absorption**
- Photons are deflected → **scattering**

Scattering & Absorption (2)

- Light propagating through a homogeneous medium is affected by medium's **refractive index**
 - Refractive index may vary with wavelength
- For inhomogeneous media, index of refraction changes:
 - If it changes slowly and continuously, light bends
 - If it changes abruptly, over a small distance (compared to the wavelength), then light **scatters**
 - Direction of light changes abruptly; amount of light stays the same

Scattering & Absorption (3)

- Collision with body particles results in potentially abrupt change of light transport direction



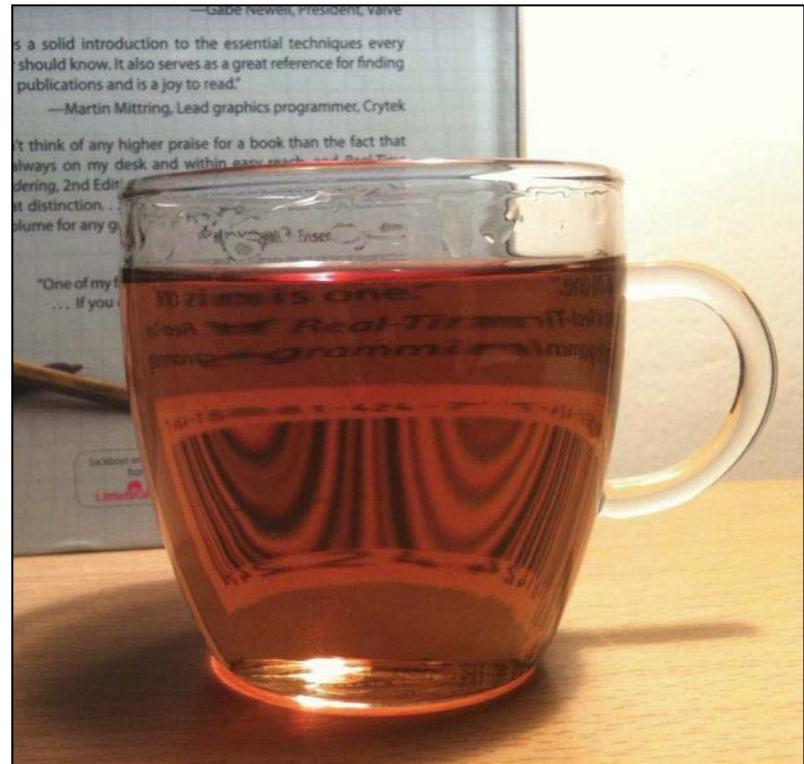
Scattering & Absorption (4)

- Absorption occurs over all or part of the visible spectrum

Clear medium – low absorption

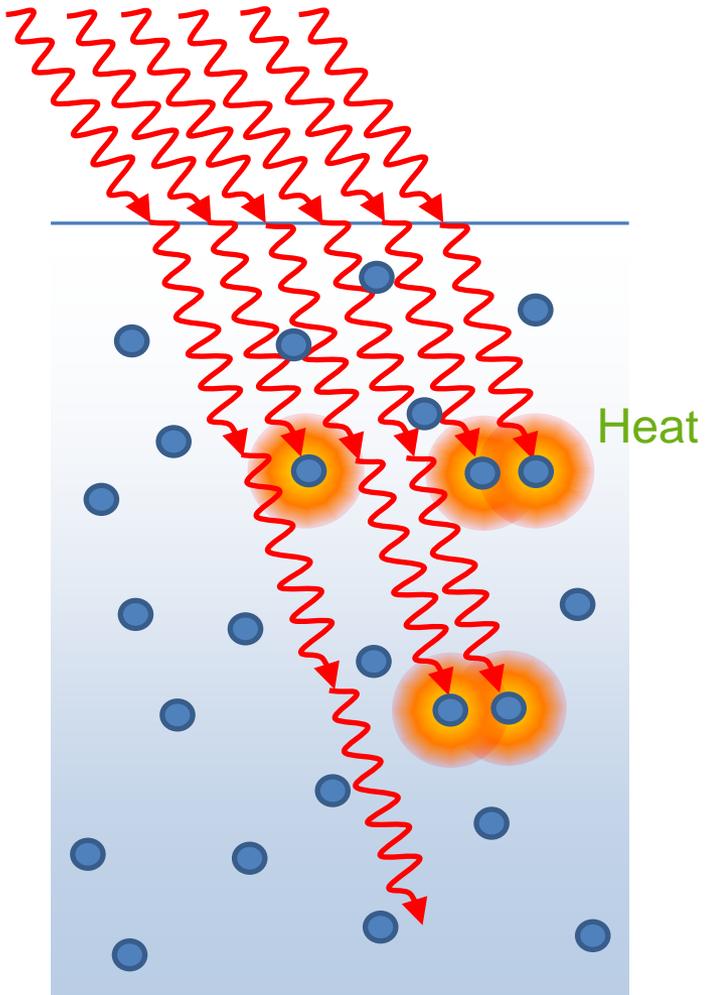


Denser medium – medium absorption

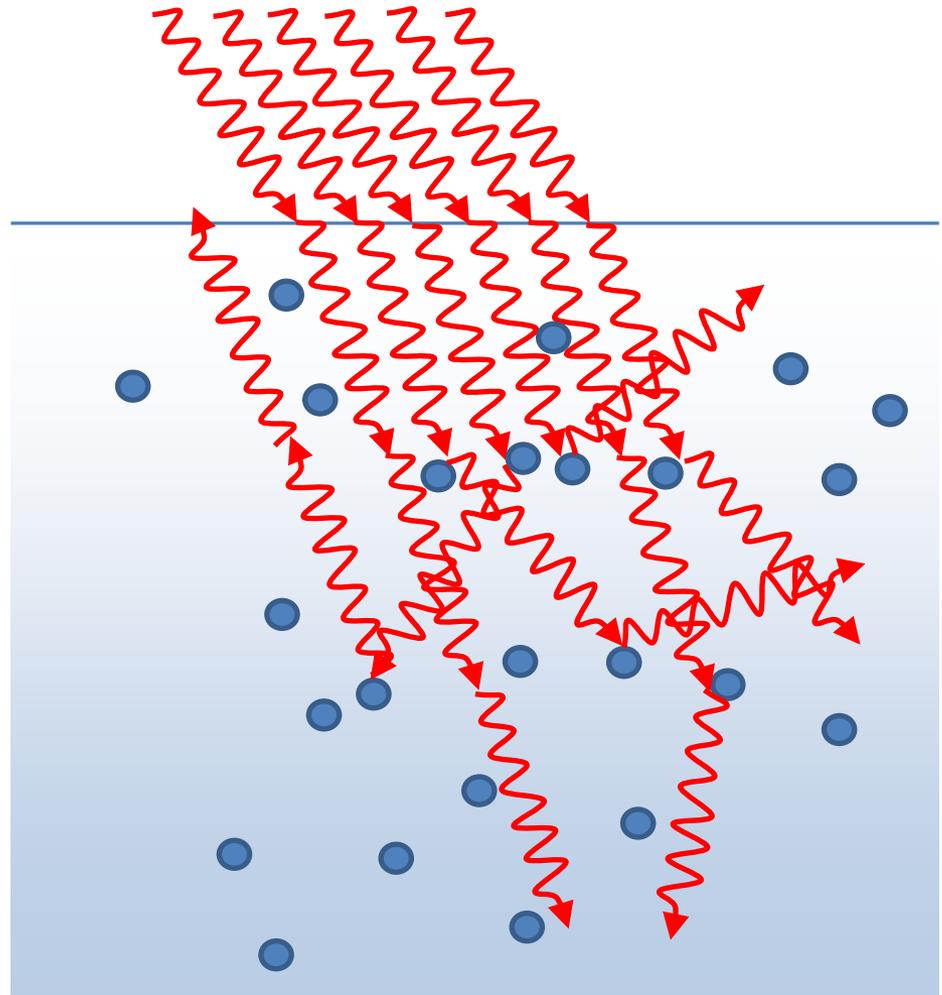


Scattering & Absorption (4)

Absorption

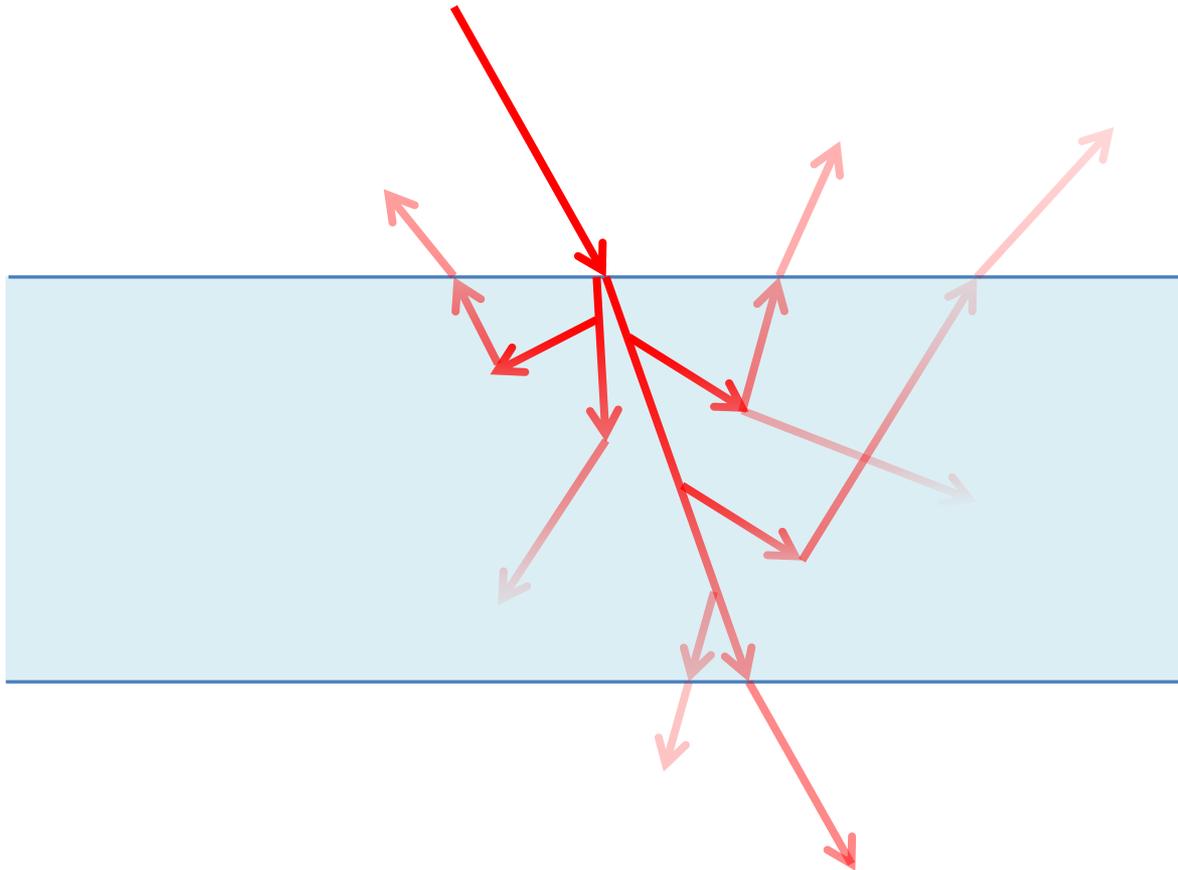


Scattering



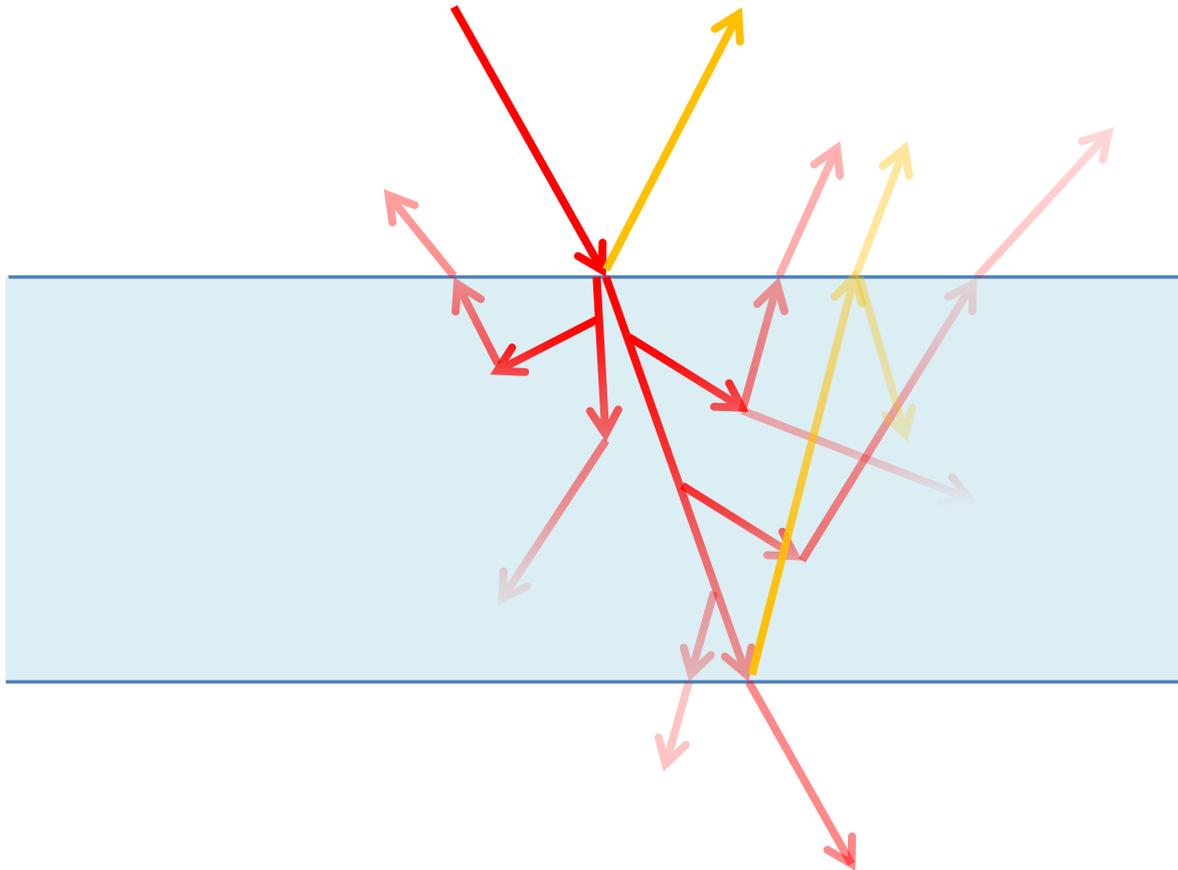
Scattering & Absorption (5)

The combined phenomena contribute to the appearance of the material



Scattering & Absorption (6)

... and are also combined with the reflected part of the energy



Scattering & Absorption (7)

Cloudy medium – medium scattering

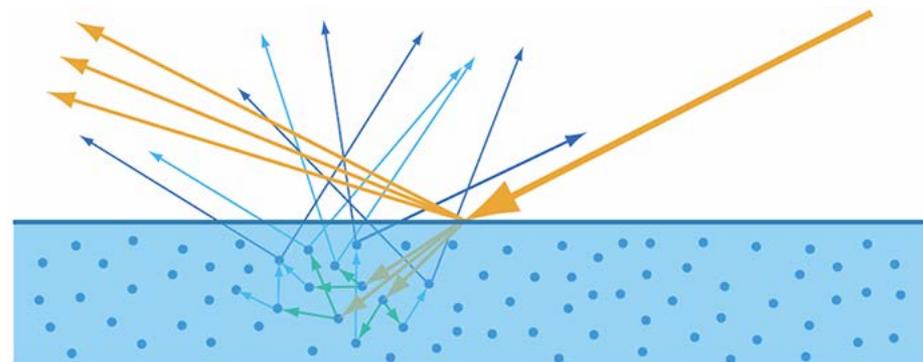
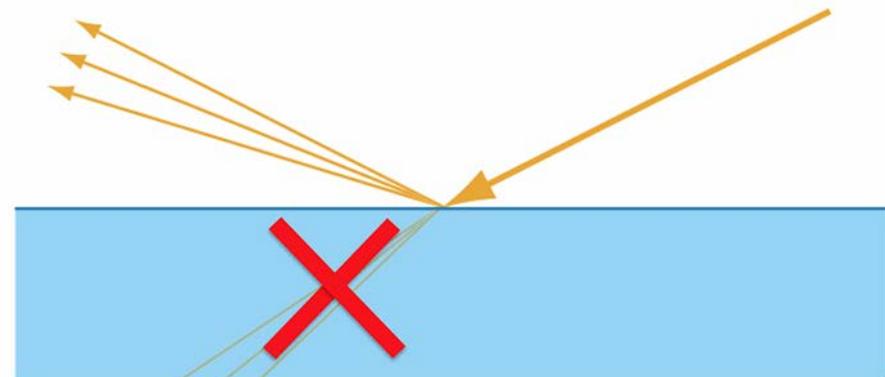


Translucent medium – heavy scattering



Metals and Dielectrics

- Metals: All refracted light is immediately absorbed
- Dielectrics: Refracted light undergoes scattering and/or absorption, often re-emerging from the surface



The Appearance of Scattering (1)

- Scattering is in general responsible for the intrinsic color of a body
- What light energy is not absorbed, is returned back to the environment
 - Each wavelength is scattered and absorbed differently, resulting to a perceived “color”

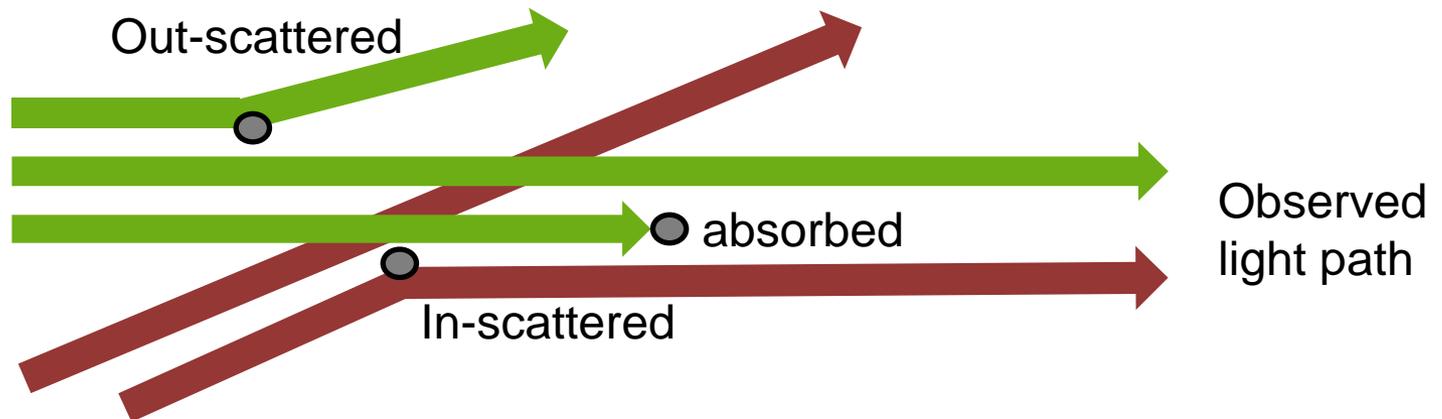
The Appearance of Scattering (2)

- For dense objects, light **scattered back** through the surface of incidence **near** the point of entry is namely **diffusely reflected** or **diffused**
 - The scattered color is the **albedo** of the surface (objective color)



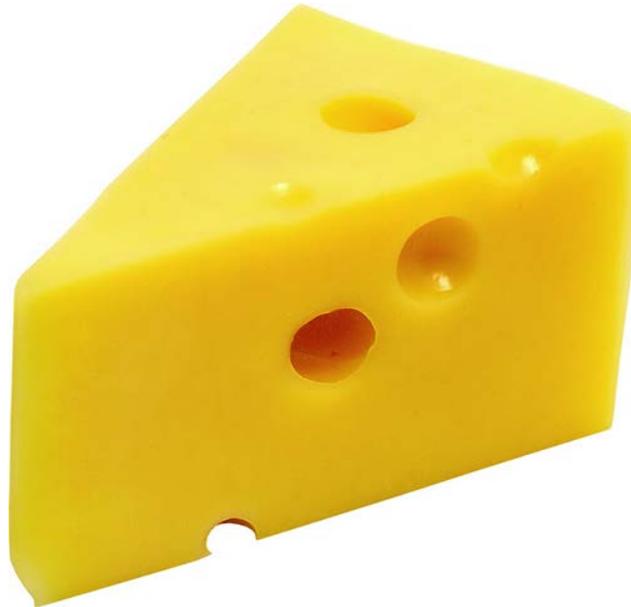
In-Scattering vs Out-Scattering

- The contribution of light on a single direction, consists of:
 - Light traveling on this path that is deflected off it or absorbed (out-scattering)
 - Light traveling on different paths that is deflected towards this direction (in-scattering)

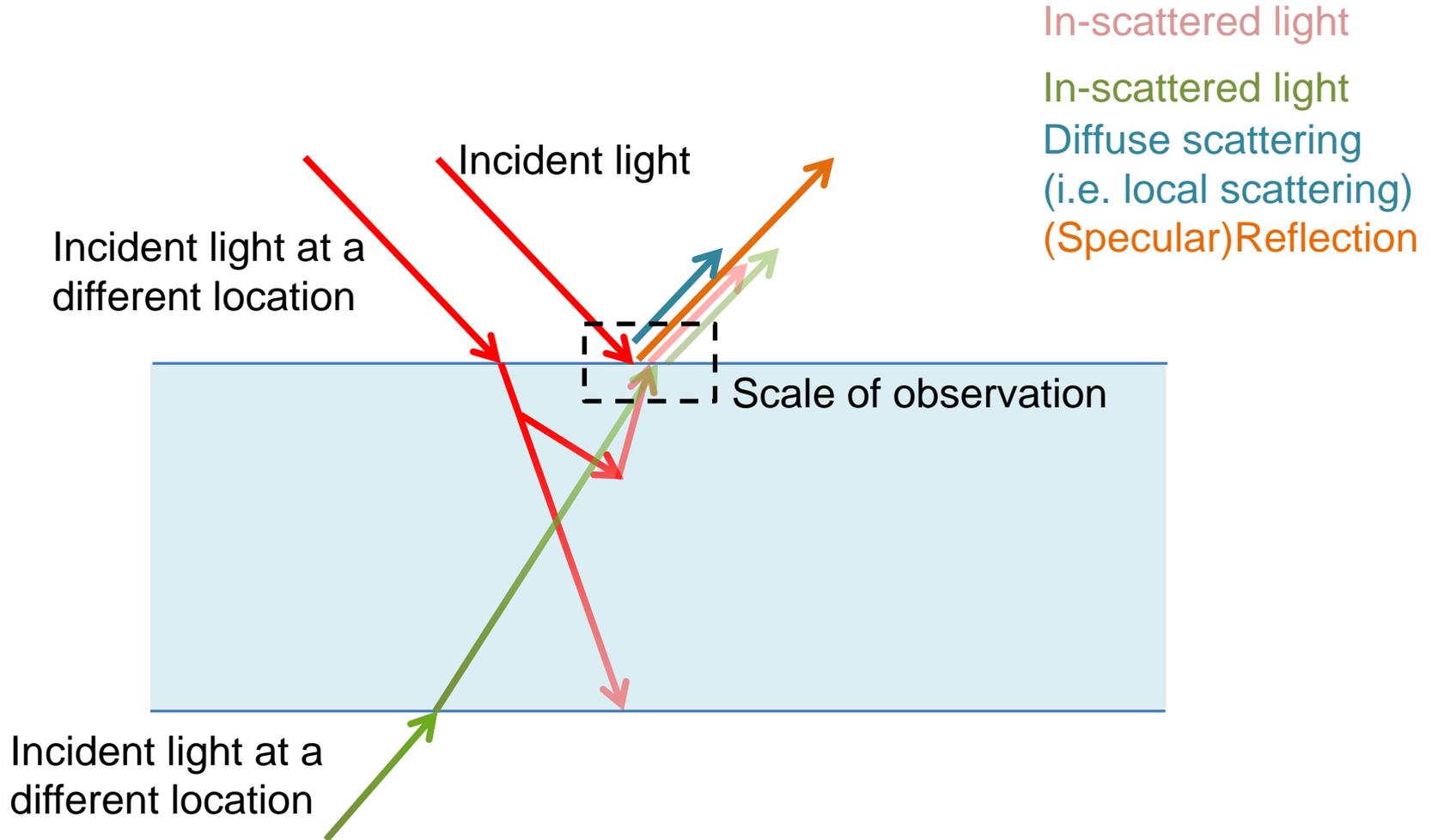


Subsurface Scattering (1)

- Scattered light that exits at a “relatively” different point than the point of entry to the surface creates the **subsurface scattering effect** → **translucency**



Subsurface Scattering (2)



Yes, Size Does Matter! (1)

- The scale of observation makes a lot of difference
 - It alters the appearance of surfaces (perceived through each pixel)
 - So, it dictates the use of different algorithms to handle the light transport



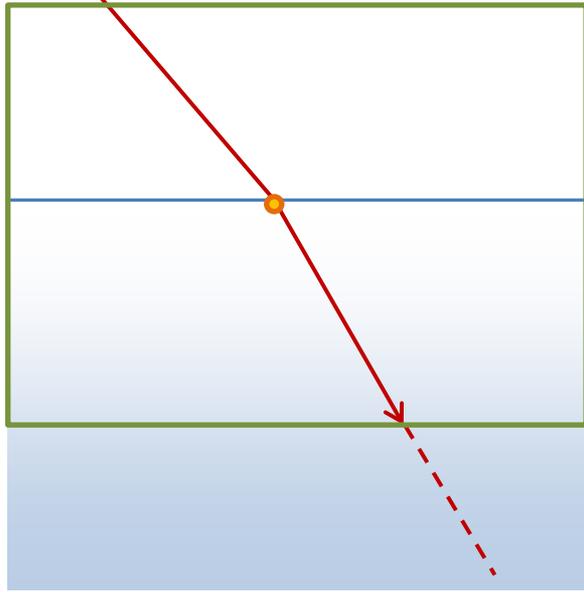
Glossy, translucent, directional lighting



Highly uniform in/out-scattering

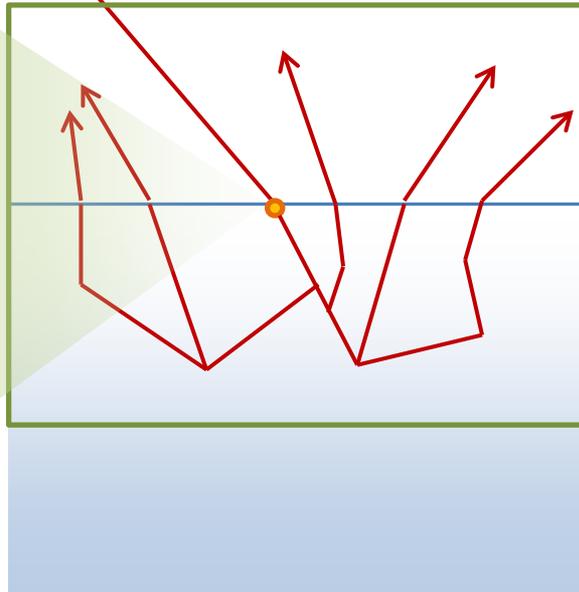
Yes, Size Does Matter! (2)

Zoom: 1000 X
(Micro-scale)



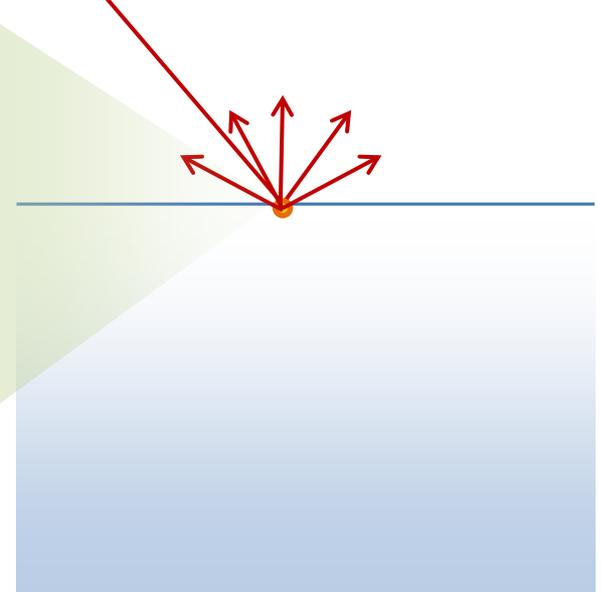
Refraction (transmission)

Zoom: 1 X
(Meso-scale)



Sub-surface scattering

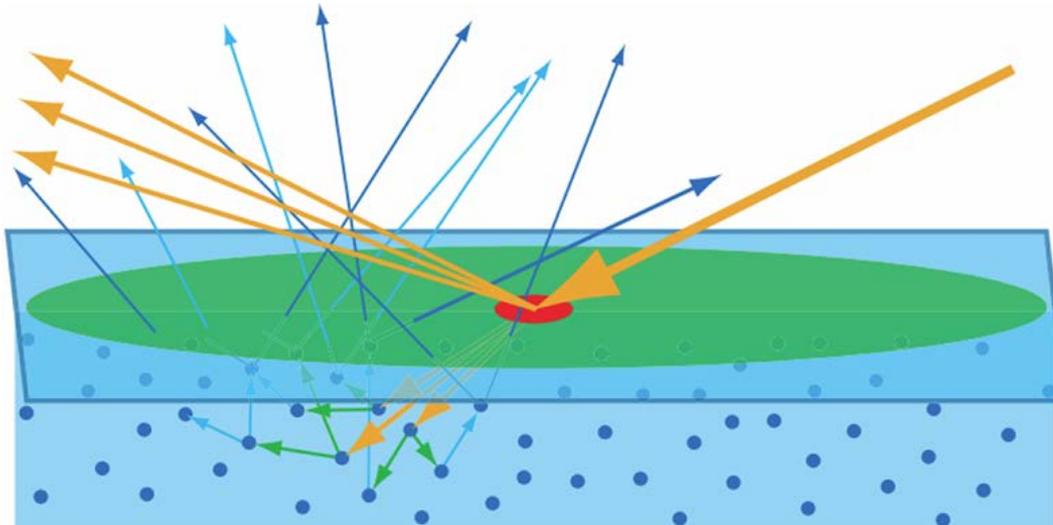
Zoom: 0.01 X
(Macro-scale)



Diffuse "reflection"

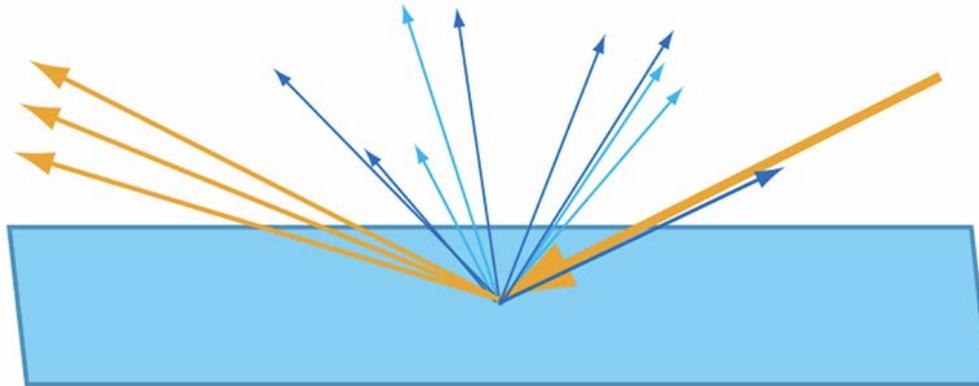
Scale and Subsurface Scattering (1)

- Distribution of entry-exit distances depends on density and properties of scattering particles
- If pixel is large (green circle) compared to entry-exit distances, can assume distances are zero



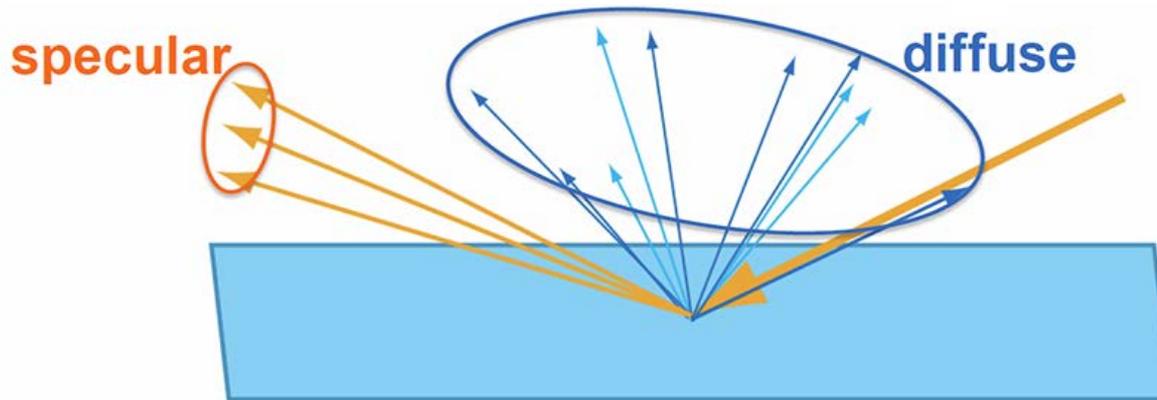
Scale and Subsurface Scattering (2)

- By ignoring entry-exit distance, all shading can be computed locally, at a single point



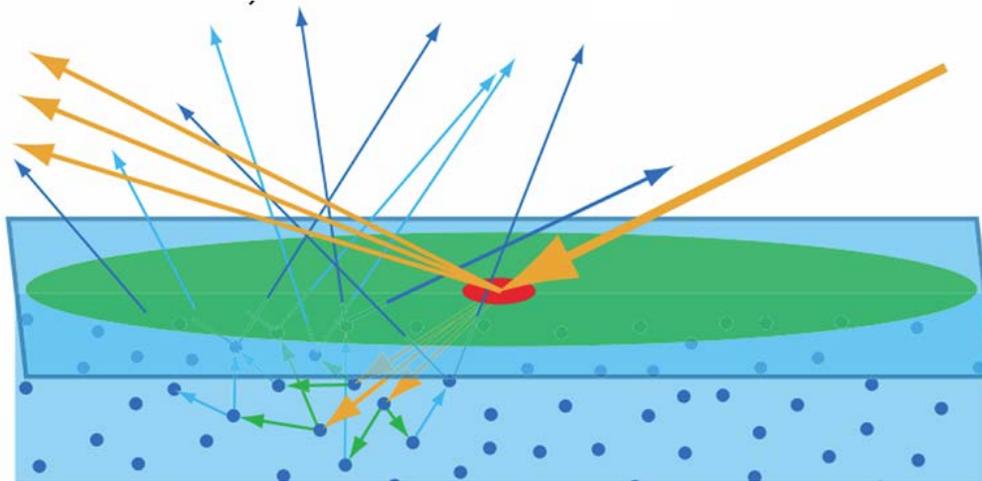
Scale and Subsurface Scattering (3)

- Surface reflection is typically modeled as **specular** and refraction with subsurface scattering as **diffuse**



Scale and Subsurface Scattering (4)

- If pixel is small (red circle) compared to entry-exit distances, local shading does not suffice and scattering must be computed otherwise



Reflection and Scattering Combined



+



+



=



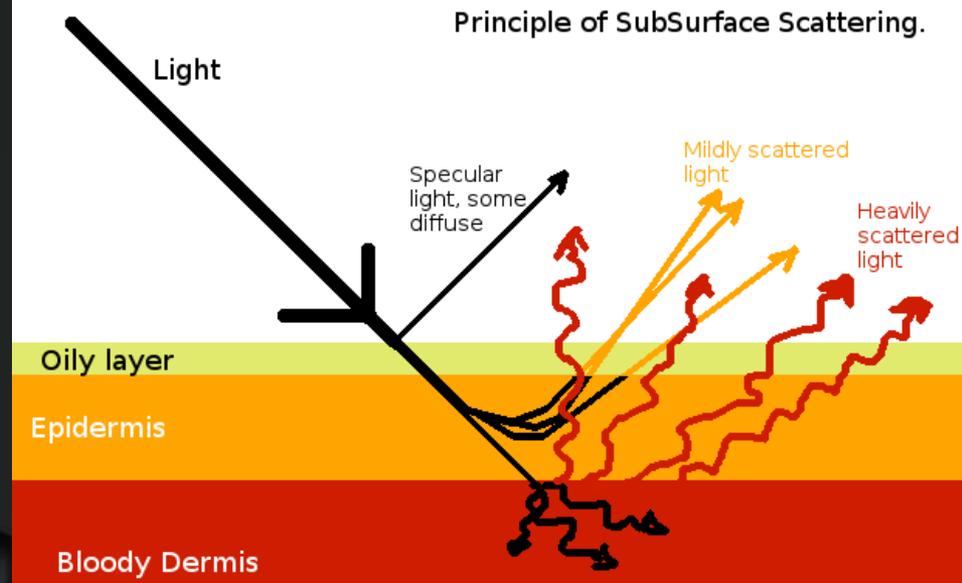
Scattering in Thin Media

- Smoke, clouds, haze etc. consist of small particles that deflect the light in various directions
- We call these bodies, whose surface cannot be defined or is not involved in the lighting estimation, **participating media**



Layered Materials

- Many real world materials consist of multiple layers with different properties each
- Typical examples:
 - Skin
 - Paint
 - Leaves



Spatial Material Variation (1)

- Spatial material attribute variations are determined by a process called **texturing** (more on the respective chapter)



Spatial Material Variation (2)

- Texture patterns (procedural, bitmaps), called **textures**, are mapped to the 3D coordinates of surfaces and volumes
 - They determine any attribute of the material (e.g. albedo, index of refraction, reflectivity etc.) as a function of position and direction

- An “event” is a state change to light as it travels through a medium or intercepts a surface
- In CG algorithms, typically used events on surfaces are:
 - Specular reflection (ideal/non-ideal)
 - Specular transmission (ideal/non-ideal)
 - Diffuse reflection
 - Diffuse transmission
 - Absorption (due to extinction near the surface)

- Georgios Papaioannou
- Sources:
 - [PBSM] SIGGRAPH 2010 Course: Physically Based Shading Models in Film and Game Production