EG 2020 STAR presentation

Eurographics
EUROPEAN ASSOCIATION FOR COMPUTER GRAPHICS

Overview of Graphics Models and Categorization

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BxDiff
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EMPIR EURAMET

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EG 2020: Overview of graphics models for acquiring the optical properties of translucent materials

Marker taxonomy (with associated markers in parentheses):

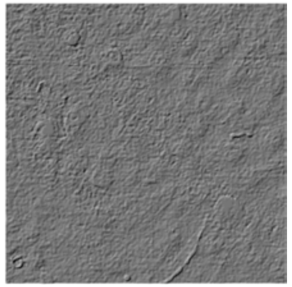
- Formal model based on theory(t).
- Experimental(x) measurements with fibres(1), flat or spherical or cylindrical surfaces(2), or arbitrary 3D surfaces(3).
- Colour/density(c) or wavelength(λ).
- Isotropic(i) or anisotropic(a) surface reflectance.
- Homogeneous($\cdot$) or heterogeneous($\star$) material.
- Diffuse($\vert$) or directional($\backslash$) subsurface scattering.
- Forward simulation($\rightarrow$) and/or inverse technique($\leftarrow$).

Paper title	author-year	ref. marker	nano/micro	micro/milli	BSSRDF	BRDF/BTDF
Off-specular peaks in the directional distribution of reflected thermal radiation	Torrance and Sparrow [1966]	[TS66]				$x2\lambda i\cdot\vert$
Theory for off-specular reflection from roughened surfaces	Torrance and Sparrow [1967]	[TS67]		$t\lambda i\cdot\vert \rightarrow$		$t\lambda i\cdot\vert$
Models of light reflections for computer synthesized pictures	Blinn [1977]	[Bli77]		$tci\cdot\vert \rightarrow$		$tci\cdot\vert$
A reflectance model for computer graphics	Cook and Torrance [1981]	[CT81]		$t\lambda i\cdot\vert \rightarrow$		$tci\cdot\vert$

Models at different scales

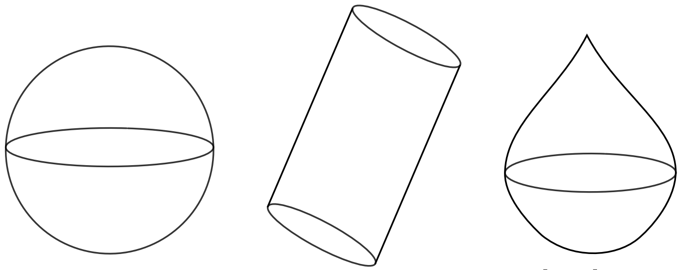
- We divide the microscopic scale into
  - Nano/micro: models considering explicit microgeometry.
  - Micro/milli: models using particle size or microfacet normal distribution functions.
- We divide the macroscopic scale into
  - BSSRDF: models where the points of incidence and emergence are different.
  - BRDF/BTDF: local models for opaque/thin objects.

microsurface

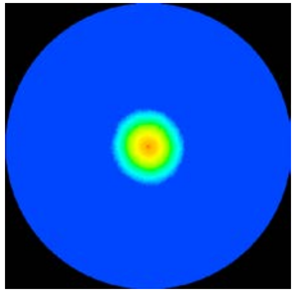


profilometry

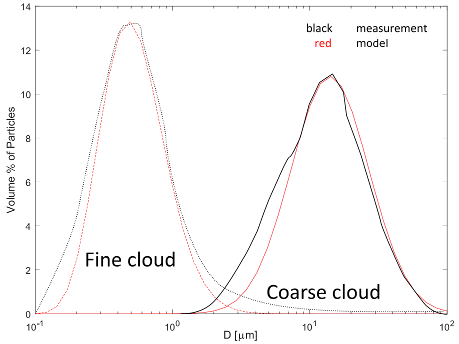
particles



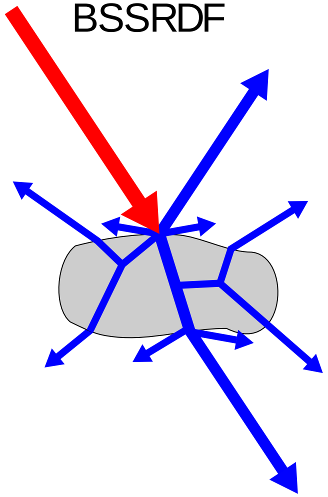
sphere cylinder raindrop

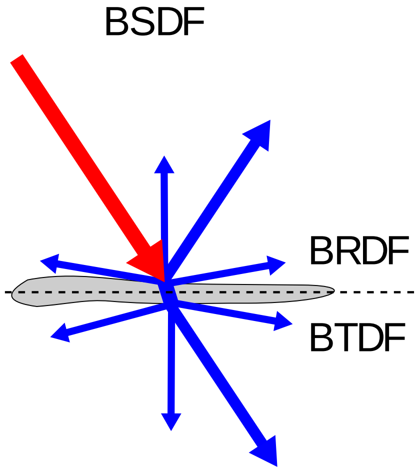


normal distribution



particle size distribution



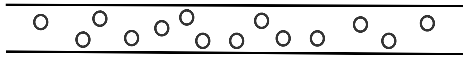


Formal models based on theory(t)

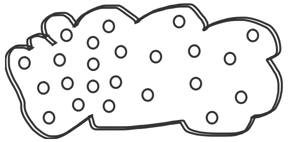
- Mathematical models for optical properties.
- Based on optics or radiative transfer theory.
- Early examples:
  - Torrance-Sparrow BRDF [TS67,Bli77,CT81]
  - Chandrasekhar single-scattering BRDF/BTDF for layers [Bli82,HK93]
  - Scattering properties from densities [KV84,NIDN97,DEJ*99]
  - Kirchhoff approximation BRDF [Kaj85,HTSG91,Sta99]
  - BRDF/BTDF from ray tracing of microgeometry [CMS87,WAT92,GMN94]
  - Fibre scattering model (BCSDF) [KK89,MJC*03,ZW07]
  - Lorenz-Mie scattering properties [Cal96,JW97,FCJ07]
  - Diffusion dipole BSSRDF [JMLH01,DJ05]

V-grooves

single scattering in a layer

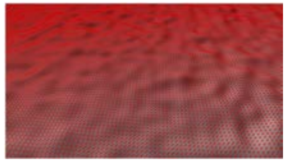


volume densities

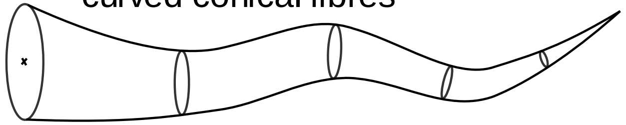


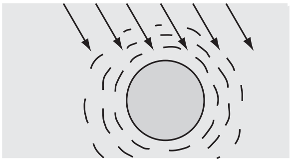
scalar diffraction by surface elements around a plane

microsurface

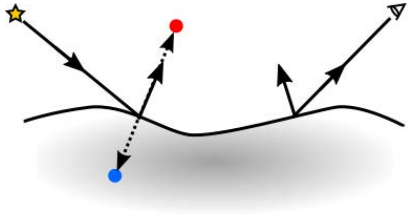


curved conical fibres





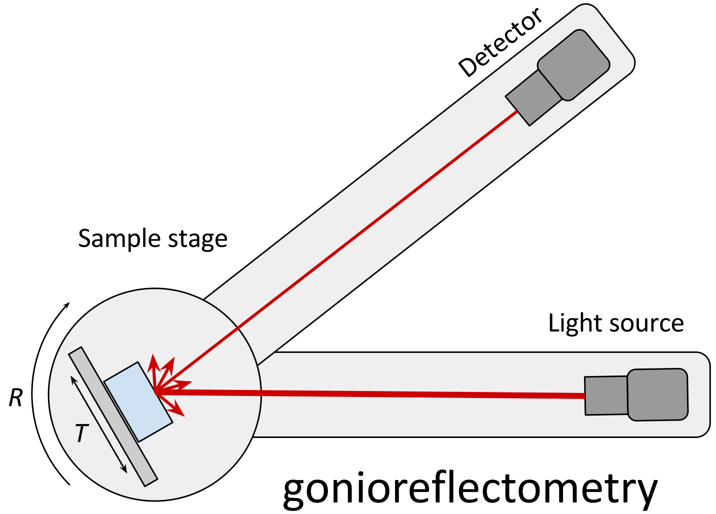
scattering by spherical particles



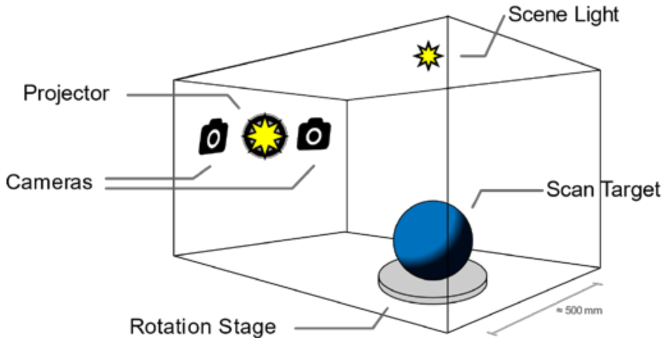
dipole models

Experimental(x) measurements

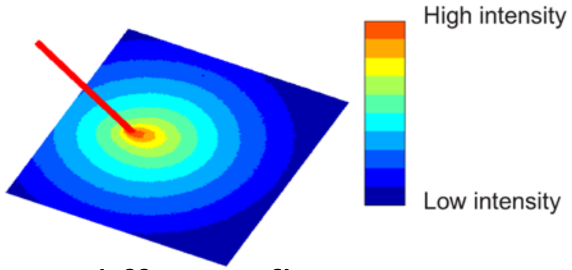
- Instrumentation for acquiring optical properties.
- Based on radiometry or one of the formal models.
- Early examples:
  - (x2) Gonioreflectometric BRDF measurement [TS66,War92]
  - (x2/x3) Bidirectional Texture Function (BTF)
    [DVGNK99,DHT*00,TWL*05]
  - (x3) SVBRDF on 3D surface (structured light)
    [MWL*99,LKG*01,WMP*06]
  - (x2/x3) Diffuse reflectometry for scattering properties
    [JMLH01,GLL*04,TWL*05]
  - (x2) BRDF from curved sample geometry [MPBM03,NDM05]
  - (x1) Fibre scattering measurement [MJC*03,ZRL*09]



gonioreflectometry



structured light scanning



diffuse reflectometry

Colour/density(c) or wavelength(λ)

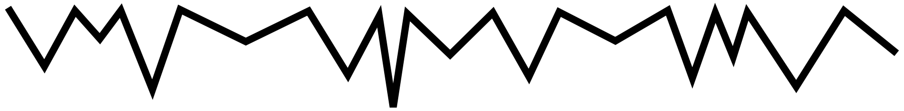
- Measurements in colour bands(c) or at particular wavelengths(λ).
- Scattering properties based on density(c) or spectral optical properties(λ).

- Methods from optics typically operate with wavelengths(λ).
- Camera-based measurements typically operate with colour bands(c).
- Graphics often convert wavelengths(λ) to colour bands(c).
- Examples:
  - (λ) Torrance-Sparrow BRDF measurement and model [TS66,TS67]
  - (c) Blinn’s version of the Torrance-Sparrow model [Bli77]
  - (λ to c) Cook-Torrance version of the Torrance-Sparrow model [CT81]
  - (λ to c) Kubelka-Munk theory for calculating diffuse reflectance colours [HM92]
  - (c) BRDF/BTF measurement [War92,DVGNK99,MWL*99]

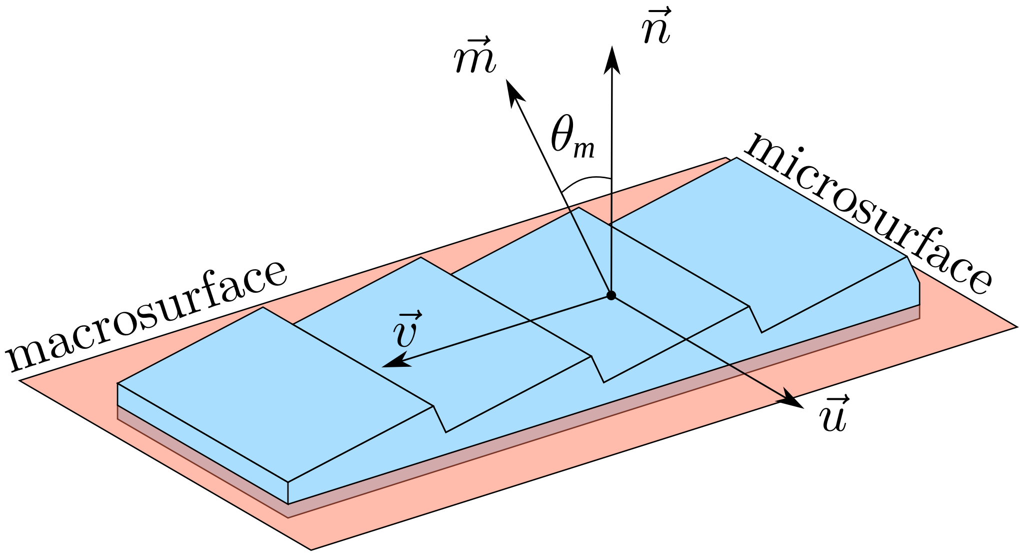
Isotropic(i) or anisotropic(a) surface reflectance

- Random rough surfaces produce isotropic reflections.
- Scattering is independent of sample orientation.

V-grooves



- Structured surfaces can produce anisotropic reflections.
- Example: ridged surface



Identical 2x2 cm^2 samples.
Every ridge is 50 μm.
Slope angle is $\theta_m = 5°$.
Two samples have been rotated 90°
as compared with the other two.
[Luongo et al. Modeling the anisotropic reflection of surfaces with microstructure engineered to produce visible contrast after rotation. ICCVW 2017]

Homogeneous($\cdot$) or heterogeneous($\star$) material

- Heterogeneous:
  spatially varying optical properties.
- Homogeneous:
  spatially uniform optical properties.
- Surface and volume are considered disjoint sets.
- Spatial variation is considered different at different scales.
- Examples:
  - A material with homogeneous roughness can have a microsurface with explicitly defined spatial variation (heterogeneity at the nano/micro scale).
  - A material BRDF consisting of a homogeneous distribution of homogeneous spherical particles can be textured onto a surface (BRDF heterogeneity).

$\star$

$\cdot$

fur

$\star$

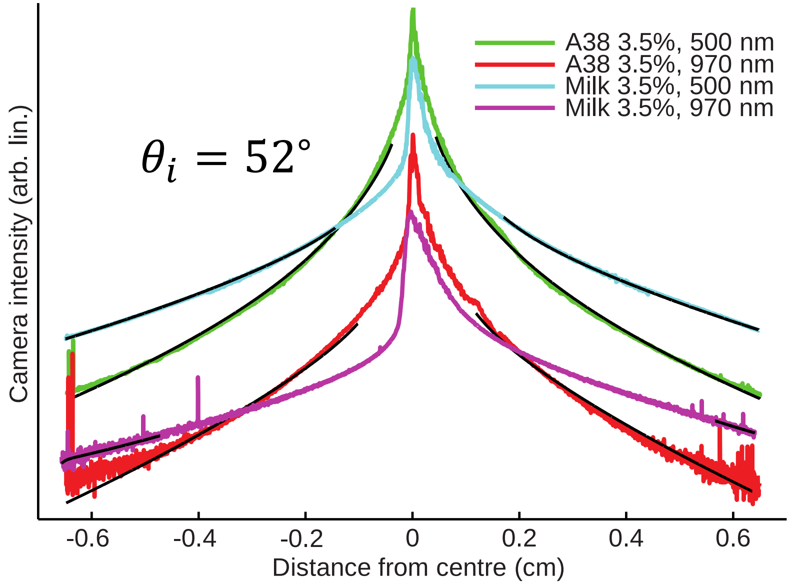
milk

$\cdot$

Diffuse(|) or directional(\) subsurface scattering

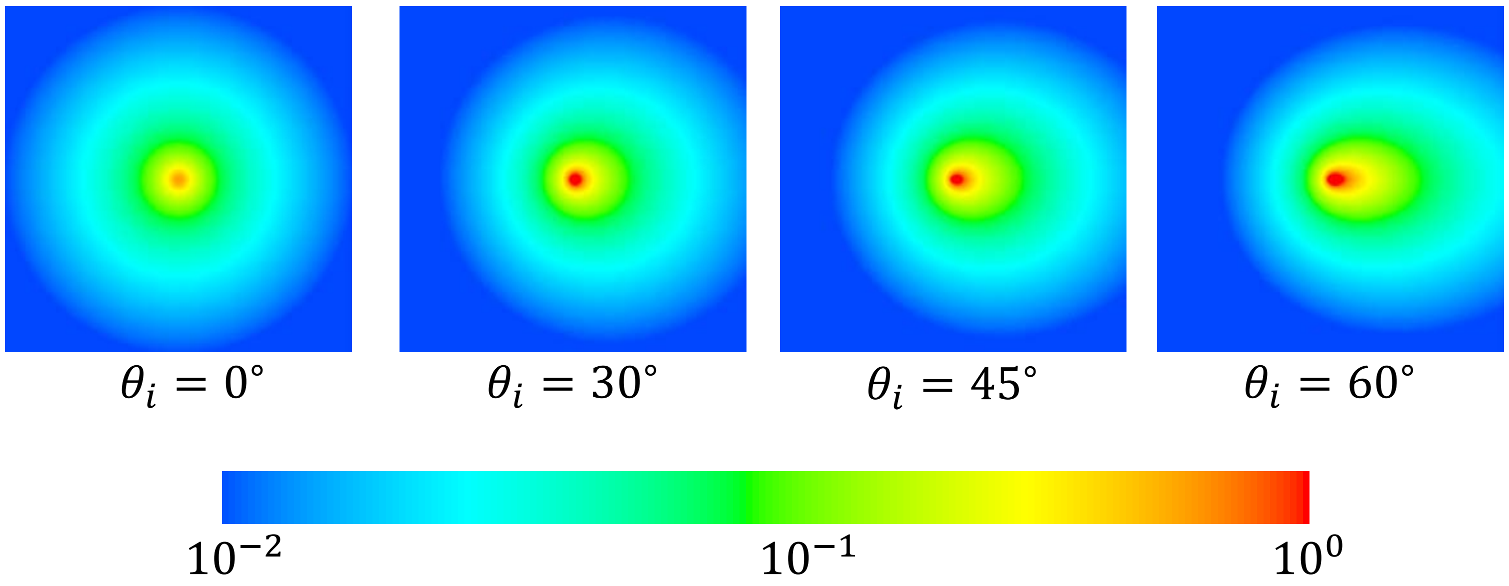
- Subsurface scattering depends on directions of incidence and observation.

measurements and fits



[Abildgaard et al. 2015]

path tracing simulation



- Diffuse subsurface scattering(|) assumes normal incidence ($\theta_i = 0°$).
- Directional subsurface scattering(\) models directional dependency.

Forward simulation(→)

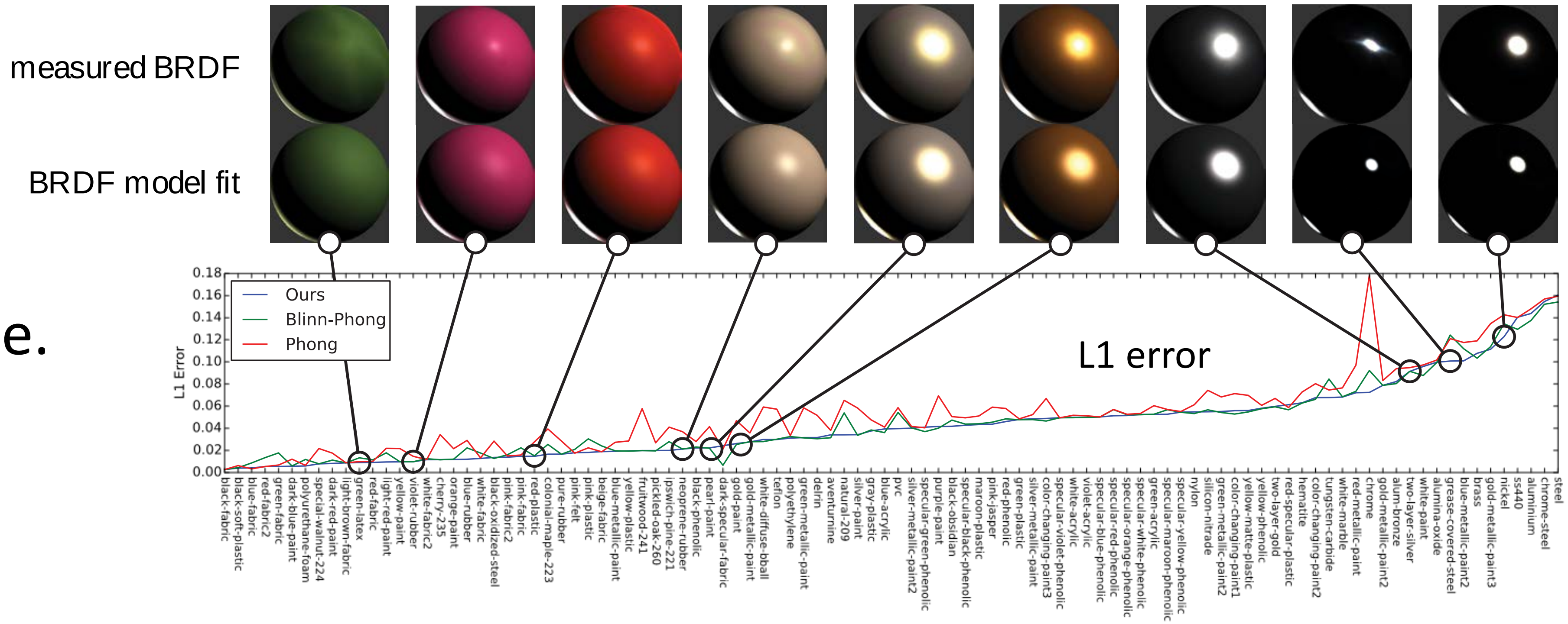
- Computing optical properties at a more macroscopic scale.
- Formulate a measurement equation and evaluate it by simulation.
- Use microscale information to find a macroscopic function.
- Examples:
    - Microfacet normal distribution → BRDF/BTDF [TS67,Bli77,CT81,HTSG91,Sta99]
    - Explicitly defined microsurface → BRDF/BTDF [Kaj85,CMS87,WAT92,GMN94]
    - Fibre geometry → scattering properties [KK89]
    - particle concentrations → BRDF [HM92,Cal96]
    - Spherical particle → scattering properties [Cal96,JW97]
    - Explicitly defined microsurface → microfacet normal distribution [Sta99]
    - BSSRDF → BRDF [JMLH01]

Inverse technique(←)

[Nielsen et al. SIGGRAPH Asia 2014 Posters]

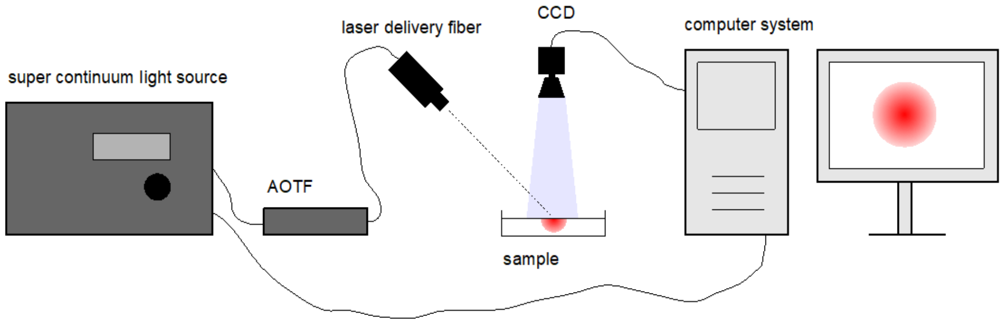
Example: model parameters ← BRDF

- Compute microscale information by measuring at a macroscopic scale.

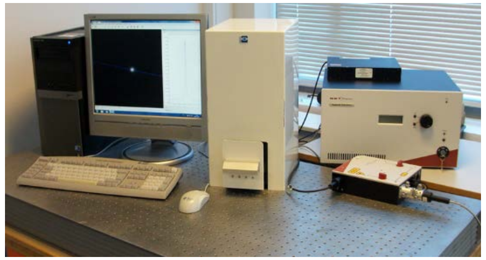


- Examples:
  - BSSRDF ← diffuse reflectometry [JMLH01,GLL*04,TWL*05,DWd*08]
  - Composition parameters ← BRDF/BTDF measurement [EĎKM04,NDM05,WMLT07]
  - BSSRDF ← structured light scan [PVBM*06,WMP*06,WZT*08,GHP*08]
  - Scattering properties ← photographing diluted liquid [NGD*06]
  - Fibre assembly microgeometry ← multiview photography [JMM09]

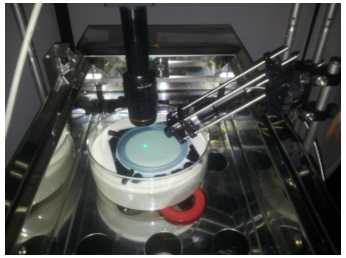
Example: spectral scattering properties ← diffuse reflectance



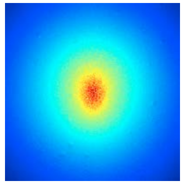
lab setup

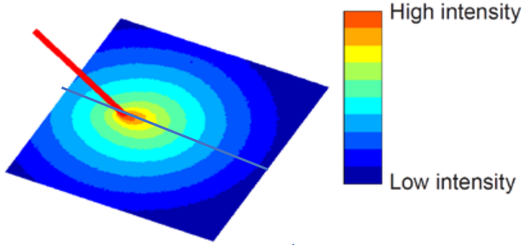


in situ setup



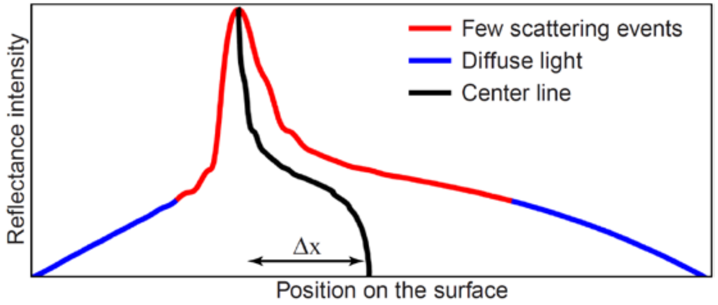
sample image
(log transformed,
false colours)



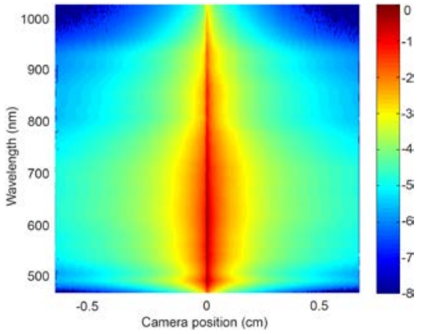


Infer optical properties using an analytic subsurface scattering model

extract profile

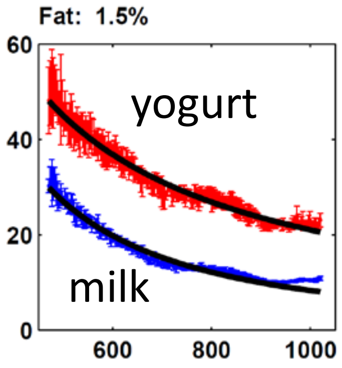


spectroscopy

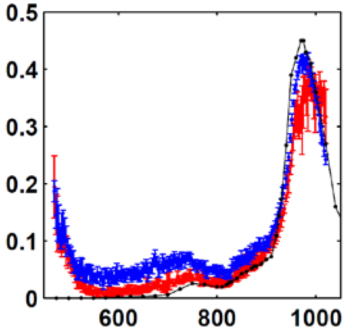


oblique incidence reflectometry

reduced scattering [1/cm]



absorption [1/cm]



wavelength [nm] wavelength [nm]

[Abildgaard et al. Non-invasive assessment of dairy products using spatially resolved diffuse reflectance spectroscopy. *Applied Spectroscopy 69*(9):1096-1105, 2015.]

Chronological table to show development

Survey of Models for Acquiring t

people.compute.dtu.dk/jerf/cg-opt-props.html

The layer laboratory: a calculus for additive and subtractive composition of anisotropic surface reflectance	Zeltner and Jakob [2018]	[ZJ18]				tca·\
Rendering specular microgeometry with wave optics	Yan et al. [2018]	[YHW*18]		tλa⋆| →		tλa⋆|
Computational design of nanostructural color for additive manufacturing	Auzinger et al. [2018]	[AHB18]	tx2λi⋆| →			←tx2ci·|
An adaptive parameterization for efficient material acquisition and rendering	Dupuy and Jakob [2018]	[DJ18]				x2λa·|
Appearance capture and modeling of human teeth	Velinov et al. [2018]	[VPB*18]	tx3ci⋆| →		←tci⋆\	←x3ca⋆\
Microfacet BSDFs generated from NDFs and explicit microgeometry	Ribardière et al. [2019]	[RBSM19]	tx2ca·| →	←tca·| →		←tca·|
A learned shape-adaptive subsurface scattering model	Vicini et al. [2019]	[VKJ19]			tci·\	
Learning generative models for rendering specular microgeometry	Kuznetsov et al. [2019]	[KHZ*19]		tλa⋆| →		←tx2λa⋆|

This is the table as it appeared in the state of the art report at Eurographics 2020.

Discussion of trends

Trend	80s	90s	00s	10s
All theory(t)	6 (100%)	11 (79%)	12 (38%)	20 (45%)
Use of experiment/measurement(x)	0 (0%)	3 (21%)	20 (63%)	24 (55%)
Anisotropy(a)	3 (50%)	5 (36%)	9 (28%)	23 (52%)
Wavelength(λ)	2 (33%)	7 (50%)	5 (16%)	10 (23%)
Directional scattering(\)	3 (50%)	6 (43%)	13 (41%)	32 (52%)
Inverse technique($\leftarrow$)	0 (0%)	0 (0%)	13 (41%)	13 (30%)
Multiscale modelling (a$\rightarrow$b$\rightarrow$c)	0 (0%)	2 (14%)	1 (3%)	4 (9%)
Explicit microgeometry (nano/micro)	3 (50%)	5 (36%)	5 (16%)	12 (27%)
Subsurface scattering model (BSSRDF)	0 (0%)	1 (7%)	15 (47%)	18 (41%)

- What trends do you see?