On the Role of Surface Microstructure in Modeling and Rendering of Material Appearance

by

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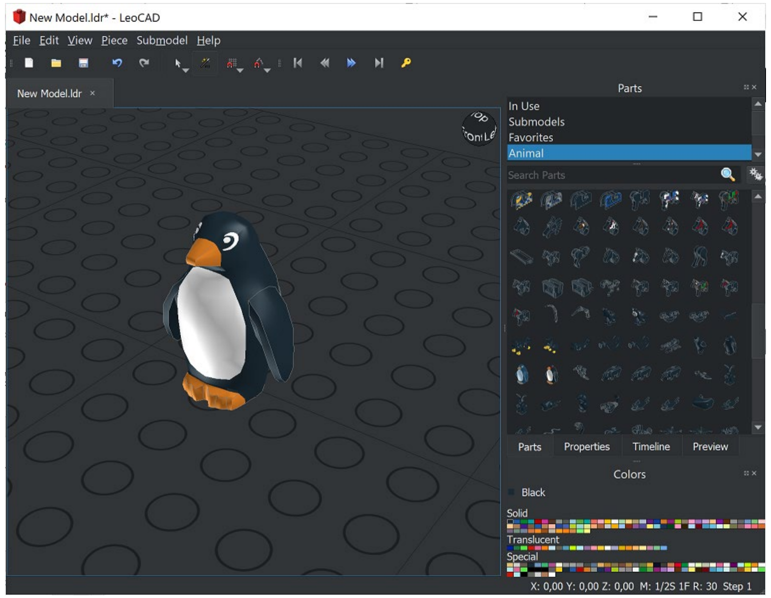
SCIENTIFIC TECHNICAL COMMITTEE meeting
"S“ (SURFACES) 17 February 2021 13.00 - 15.30

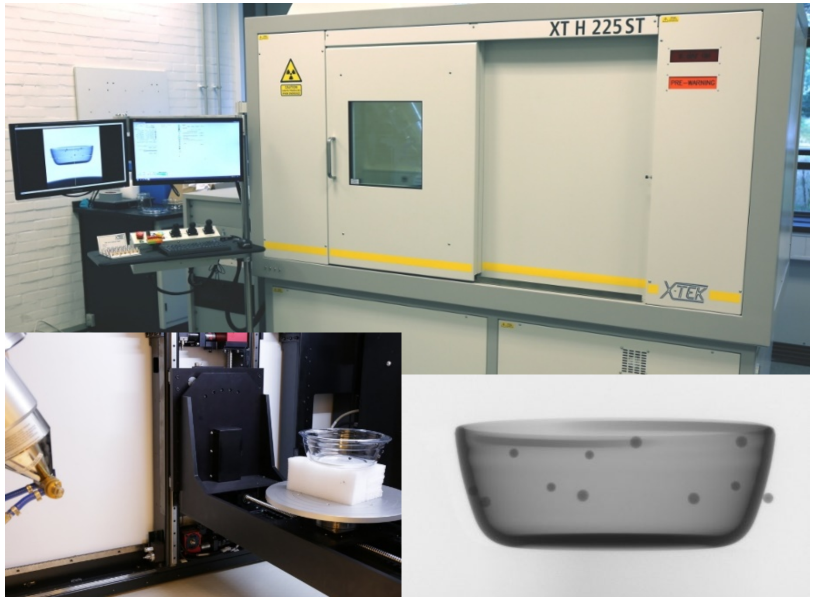
Digitizing object shape

[Stets et al. 2017]



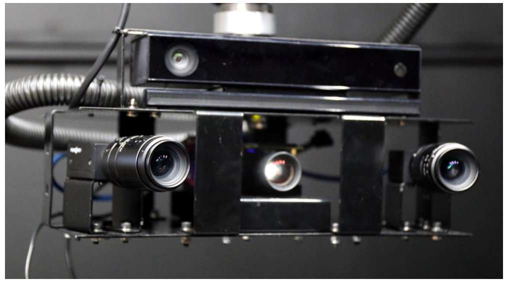
CAD (LeoCAD)

3D scan (structured light)



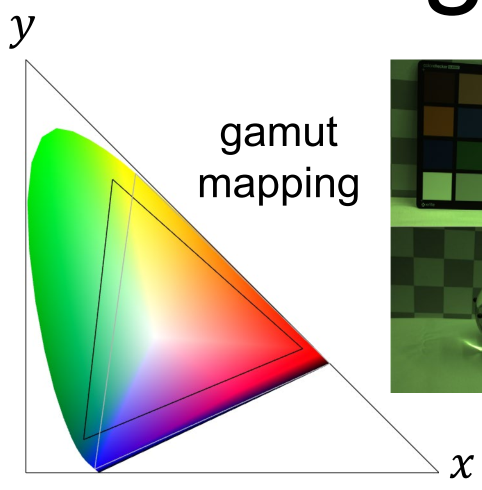
CT (Nikon XT H 225)

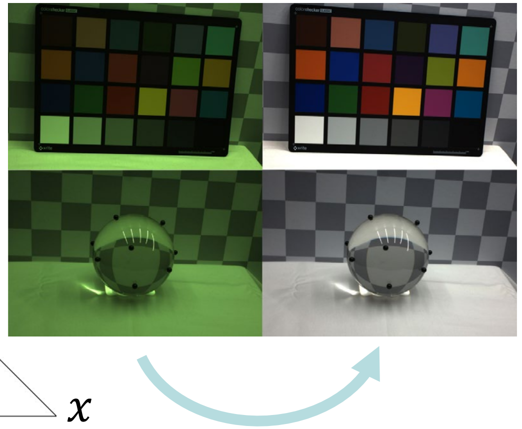
- Computer-Aided Design (CAD) creations
- Optical 3D scanning
- Computed Tomography (CT) scan



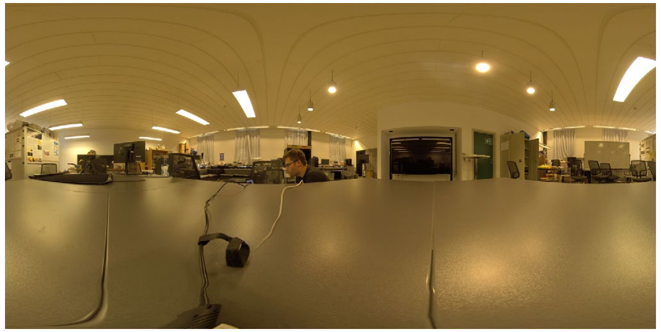
stereo camera rig and projector

Digitizing object appearance





[Stets et al. 2017]



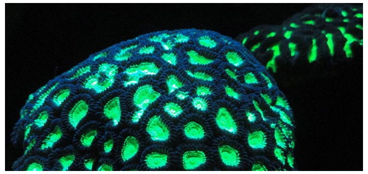
Insta360 Pro 2 environment capture

photograph

shaded rendering
with uniform color

- Colors observed by a camera (shade, tone and gamut)
- The issue of lighting environment (irradiation)
- The issue of spatial variation (texture)
- The issue of directional dependency (gloss)
- The issue of positional dependency (translucency)
- The issue of spectral dependency (fluorescence)
- Material appearance has many dimensions. How to do appearance specification?

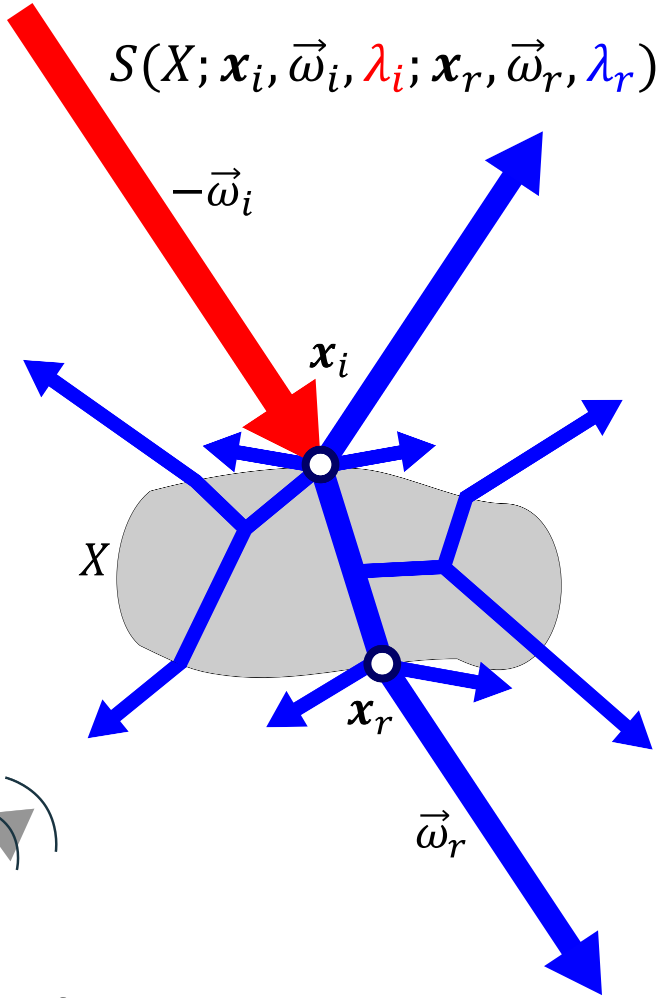
diffuse ←→ translucent ←→ transparent

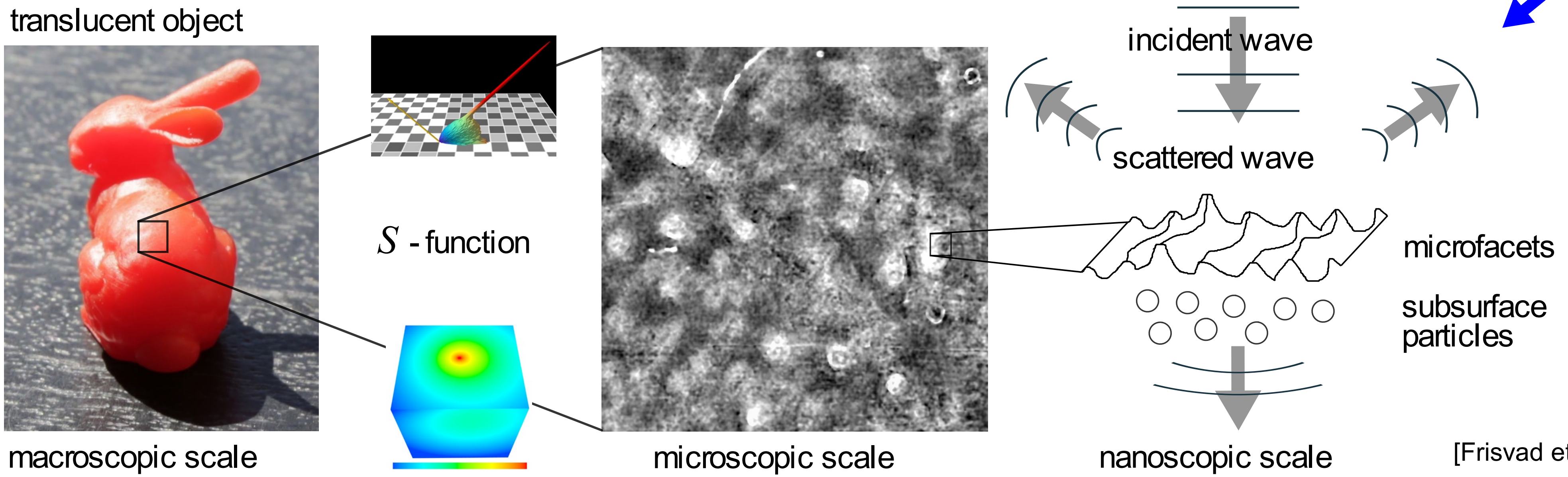


coral
fluorescence

Macroscopic optical properties

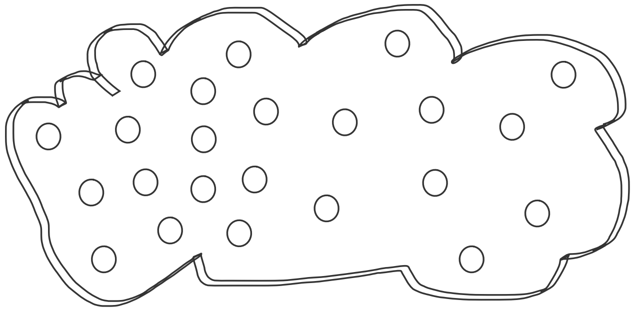
- The scattering function S (an “appearance descriptor”).
- The macroscopic S-function depends on both object shape (X) and microgeometry.
- Measurement is challenging due to the dimensionality.
- Microgeometry is challenging due to its abundance.



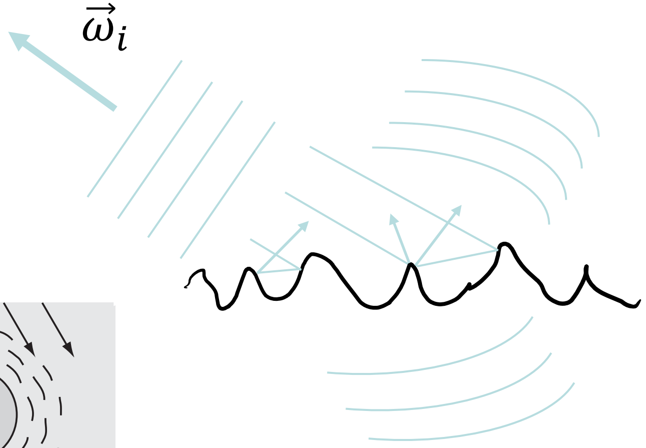


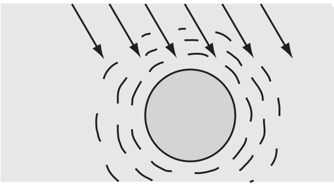
[Frisvad et al. 2020]

Separability of optical effects



- Surface and volume
  - Surface reflection is local $\delta(\boldsymbol{x}_r - \boldsymbol{x}_i)$ and shape (X) independent.
  - Volume effects are given by absorption and subsurface scattering.
- Subsurface scattering and absorption
  - Scattering events are local and shape (X) independent.
  - Absorption and scattering lead to the probability that light follows a particular path in X.





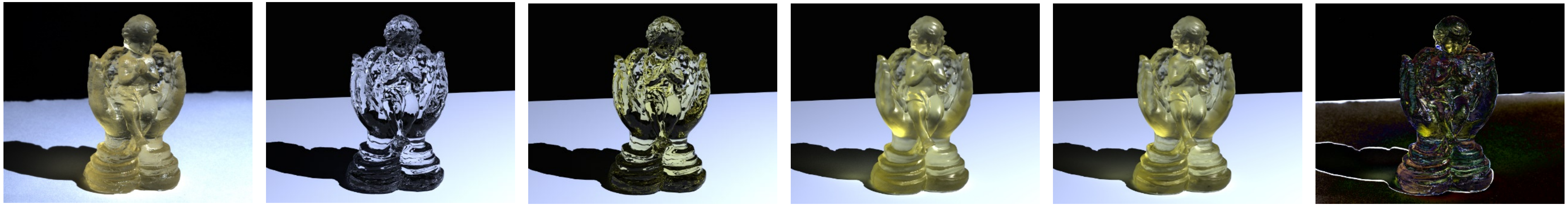
- Waves and rays
  - Wave effects are for coherent light in local geomety around the size of the wavelength.
  - Rays are sufficient for dealing with macroscopic paths in X.
- Coherence area and Rayleigh criterion of optical smoothness
  - Coherence area limits the areal extent in which we would need to consider wave effects.
  - The Rayleigh criterion limits the resolution of the microgeometry that we would need for computing local bidirectional $(\vec{\omega}_i, \vec{\omega}_r)$ scattering/reflectance distributions.

Digital twinning

- Imprecise modeling of surface microstructure results in significant appearance differences.
- Procedural modeling of spatial variation in the microstructure is an improvement.

photograph | CAD model rendering | absolute difference × 2

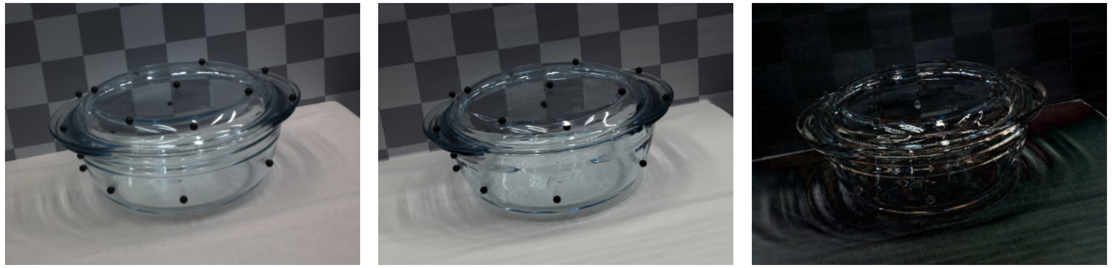
[Dal Corso et al. 2016]



photograph of 3D print | rendering of 3D scan | absorption | random roughness | layered variation of roughness | absolute difference × 2

[Hannemose et al. 2020]

- CT scanning has other issues.



photograph | CT scan in 3D scanned scene | absolute difference × 2

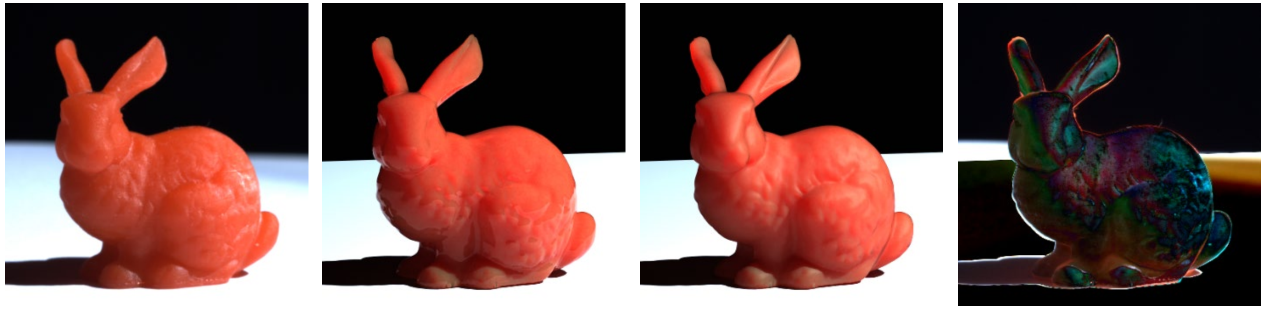
[Stets et al. 2017]

3D scanned figurine

Importance of microstructure

[Hannemose et al. 2020]

3D printed translucent Stanford bunny



photograph smooth rough abs diff × 2

Aluminium bust of H.C. Ørsted (3D scanned)

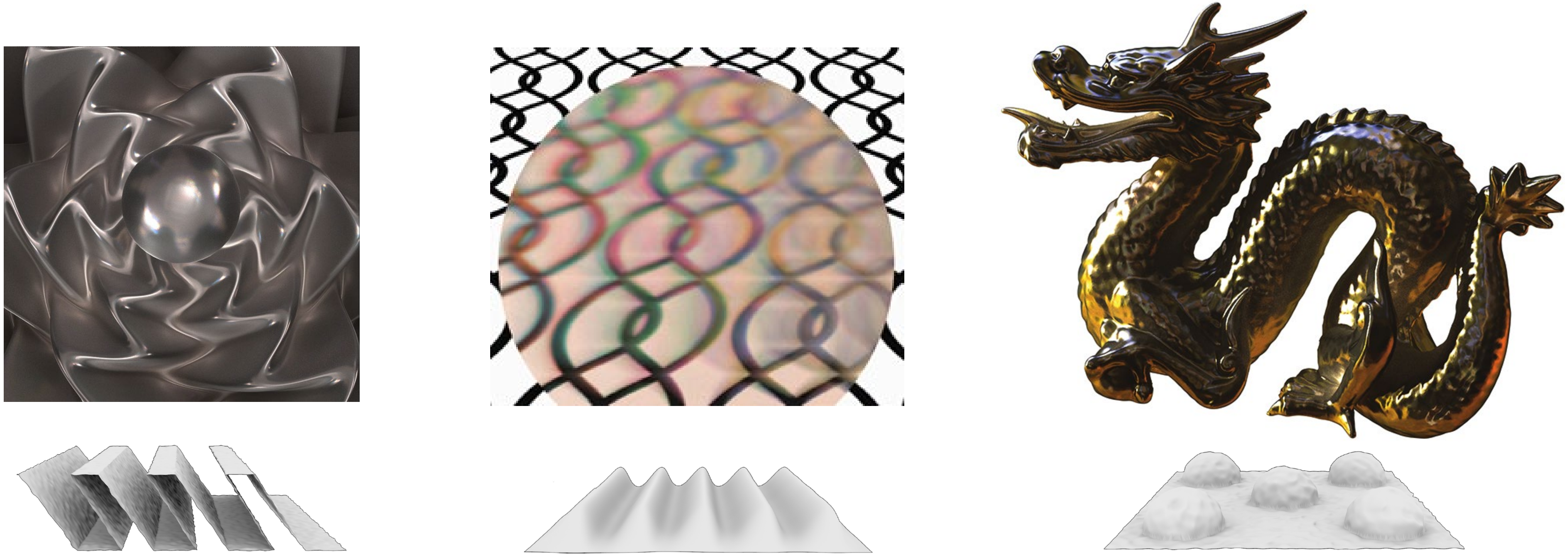
photo smooth rough variation abs diff × 2

- Object appearance is often surprisingly different if surface microstructure is not accounted for.
- For the Ørsted bust, we adjusted surface roughness in regions of high curvature.
- We need a more complete description of the surface microstructure.

Computing regions of high curvarture

signed absolute enhanced

Using a specific surface microstructure

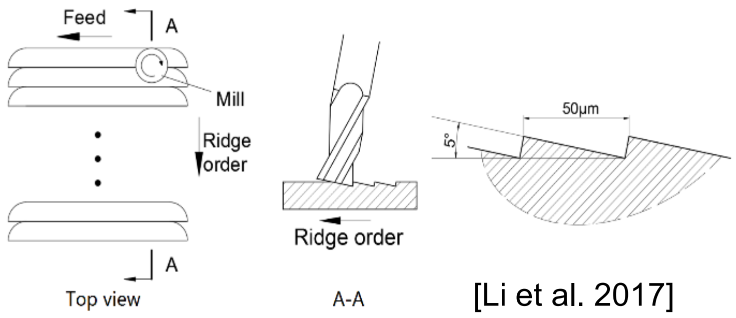


[Falster et al. 2020]

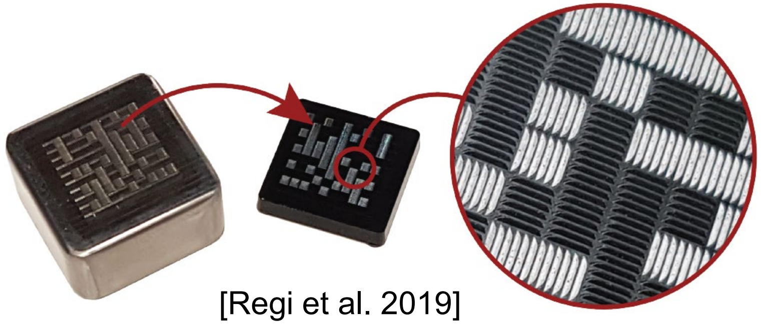
- We can compute a local scattering function for a given surface microstructure (possibly from microscopy).
- How to deal with spatial variation?

Controlling the microstructure

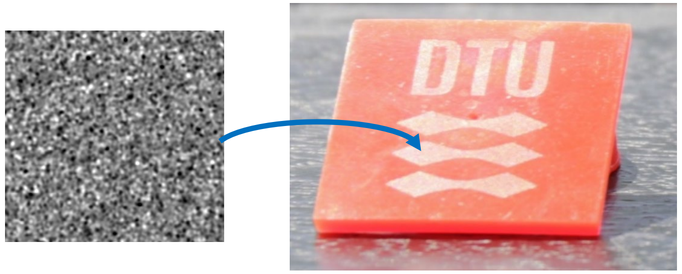
- We can do model validation by predicting appearance of objects with engineered microstructure.



[Li et al. 2017]

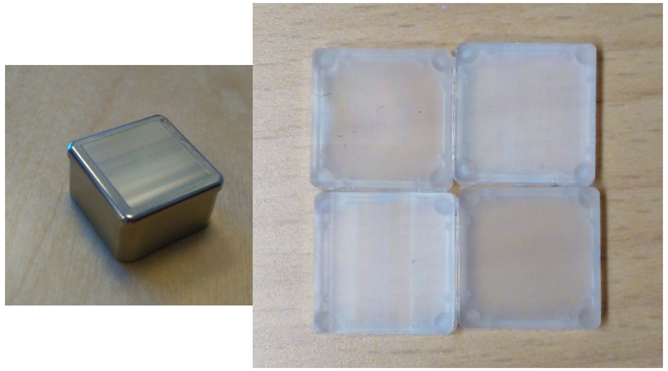


[Regi et al. 2019]

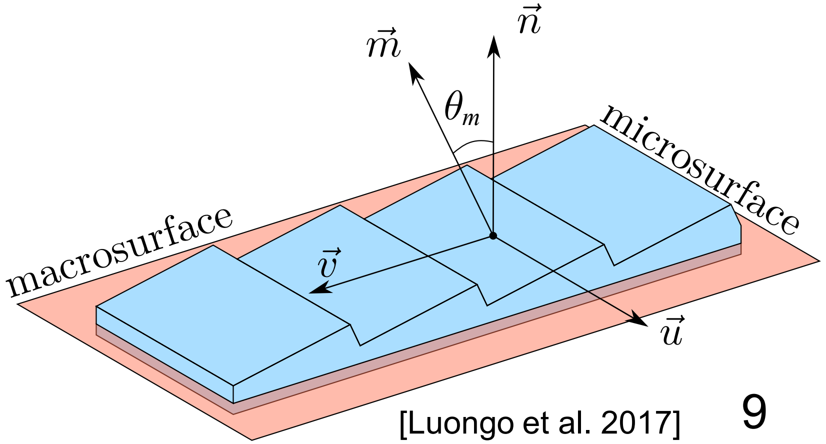


[Luongo et al. 2020]

- What is a good model? What is a good reference sample?



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.
[samples are courtesy of Yang Zhang]



[Luongo et al. 2017]

Discussion of future directions

- Current approach:
  - Assumption of separability and use of a conglomerate of models with a mapping from physical sample properties to the various input parameters of the models.
- Other options:
  - Compact representation of the full scattering function (S) of an object?
  - Multiscale rendering with procedural generation of explicit microgeometry everywhere on an object?

Thank you for your attention

- And thanks to my co-authors in the following references!

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