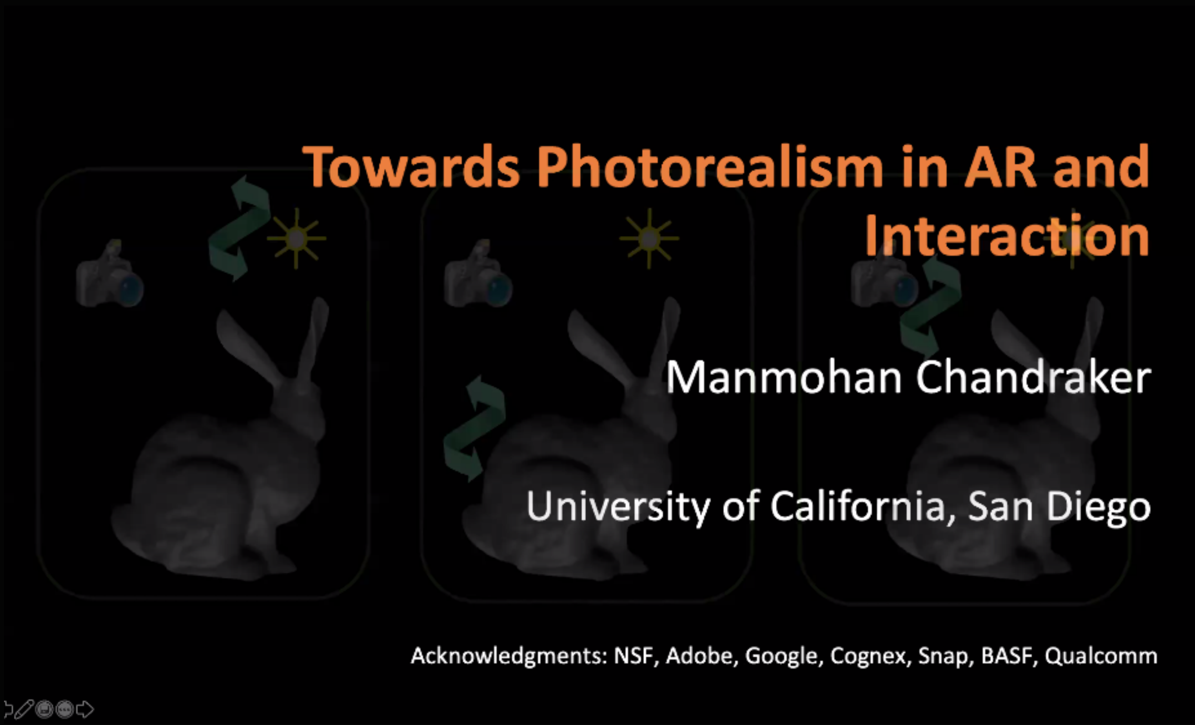
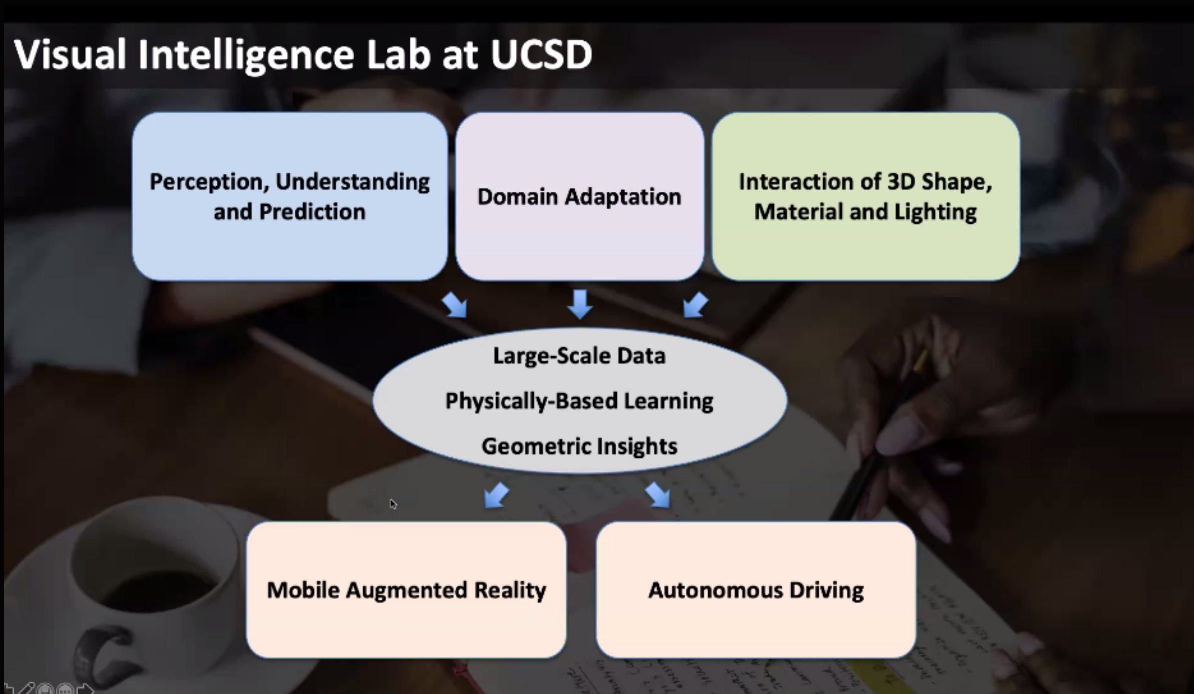
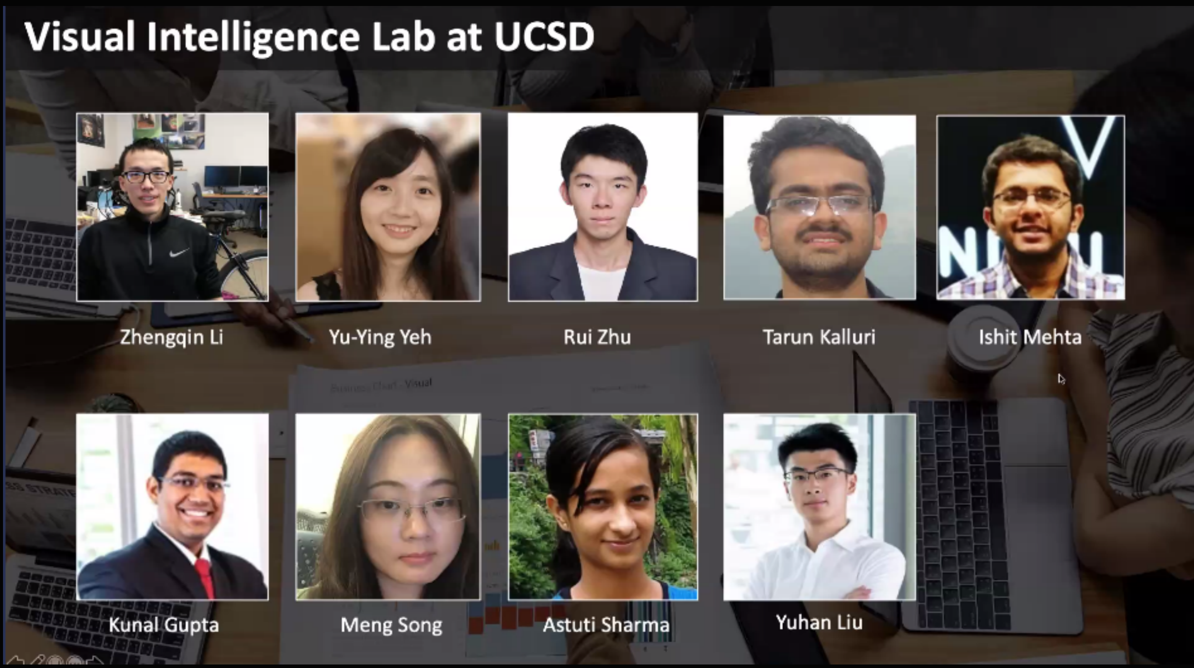
Day 17

Speaker: Prof. Manmohan Chandraker, University of California, San Diego

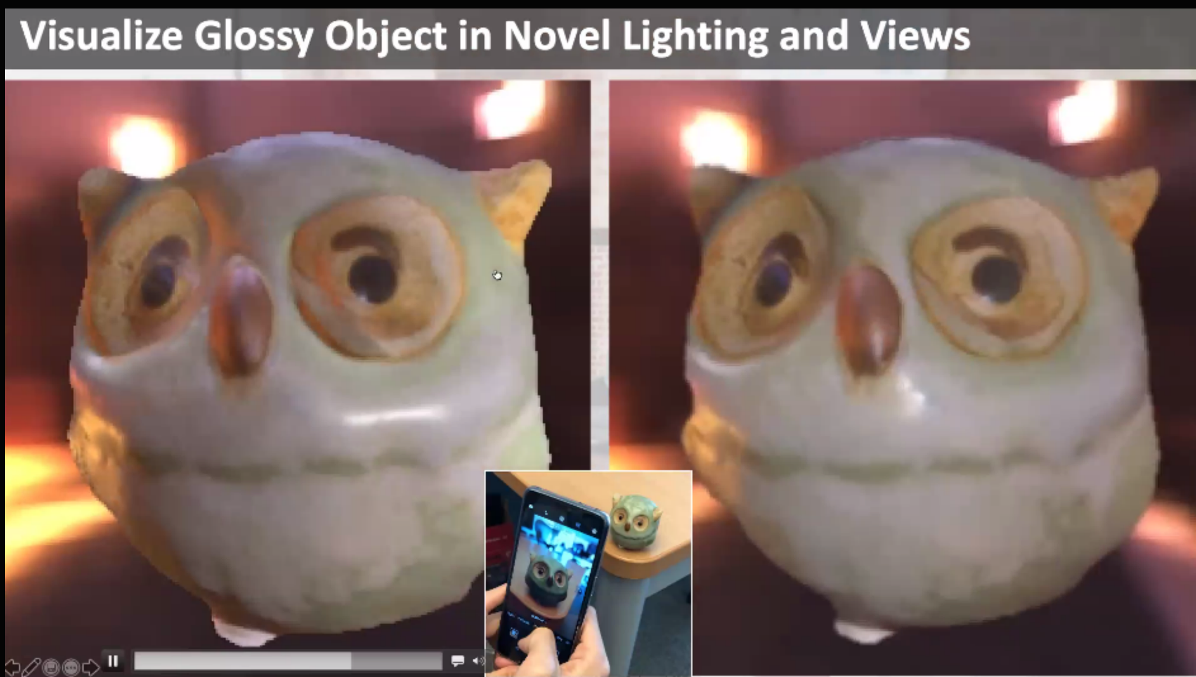
Title: Towards Photorealism in AR & Interaction

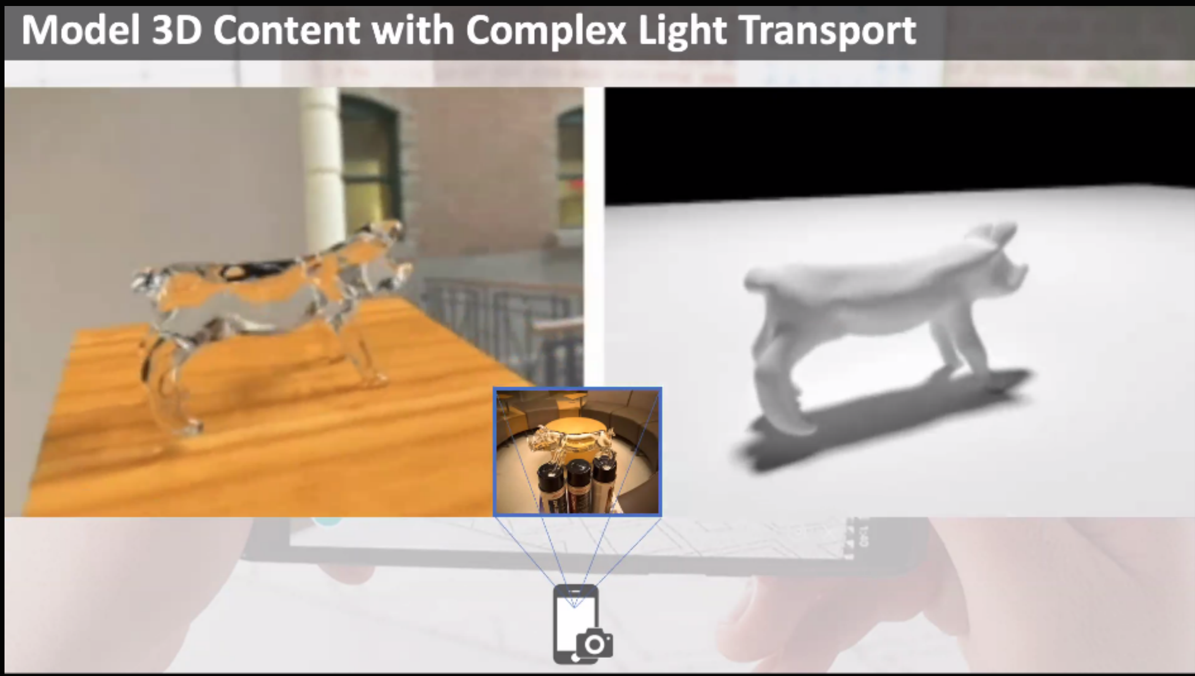




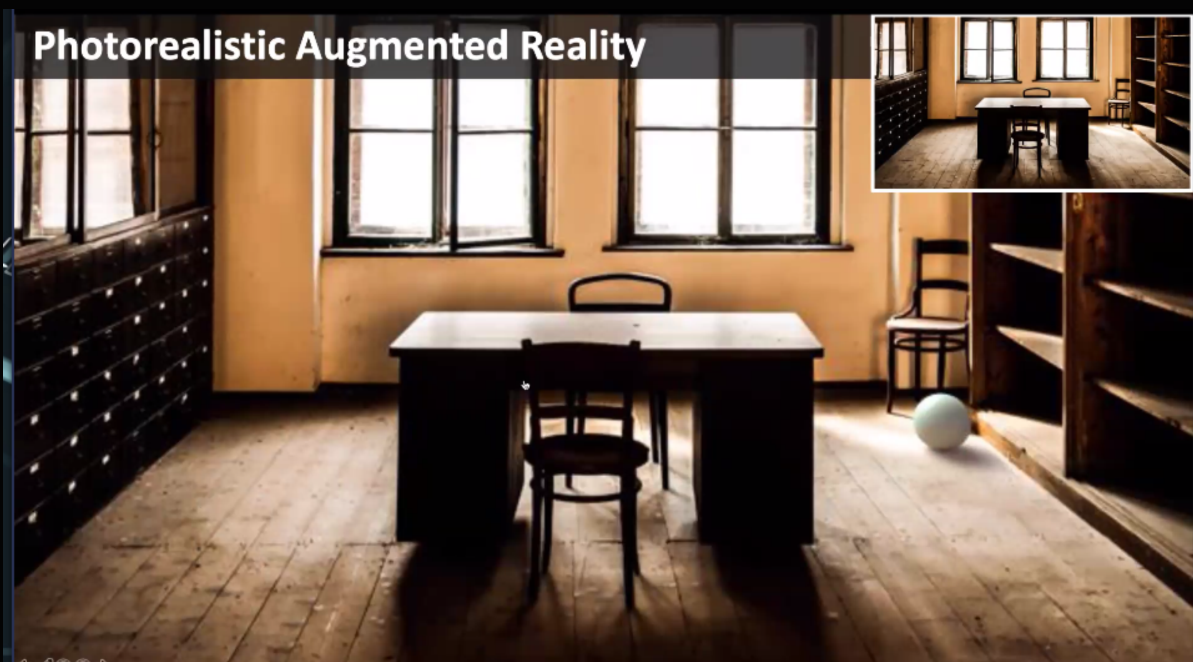

Visual Intelligence Lab at UCSD
Zhengqin Li
Yu-Ying Yeh
Rui Zhu
Tarun Kalluri
Ishit Mehta
Kunal Gupta
Meng Song
Astuti Sharma
Yuhan Liu


Mobile Phones Are Making Technology More Accessible


Visualize Glossy Object in Novel Lighting and Views


Model 3D Content with Complex Light Transport


Photorealistic Augmented Reality


Photorealistic Augmented Reality


The Demands of Photorealism
Shadows on surfaces in the scene
Variations in lighting
Reflections from scene surfaces
Specular highlights
Shadows due to objects in the scene

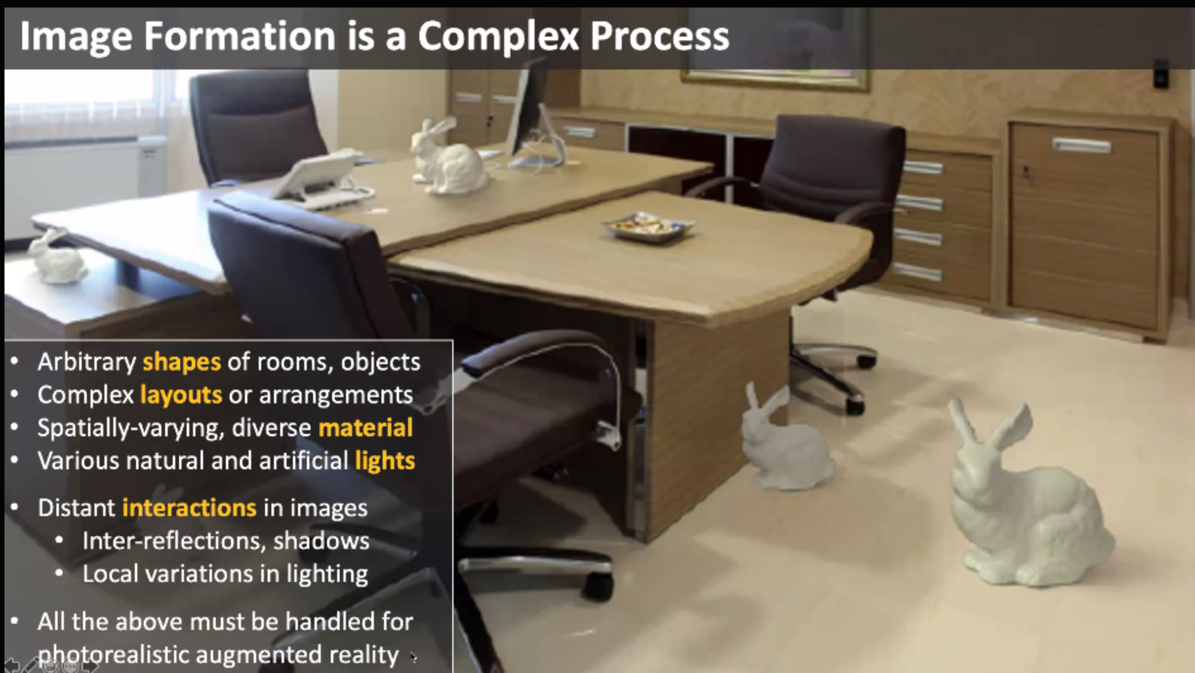
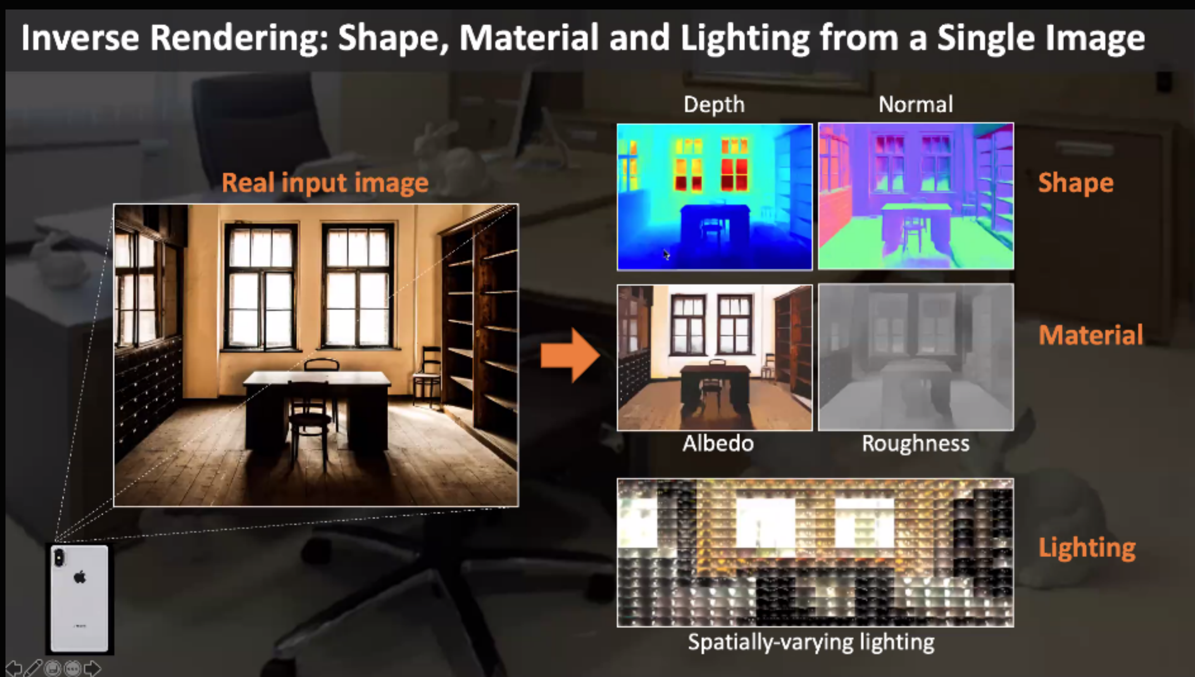
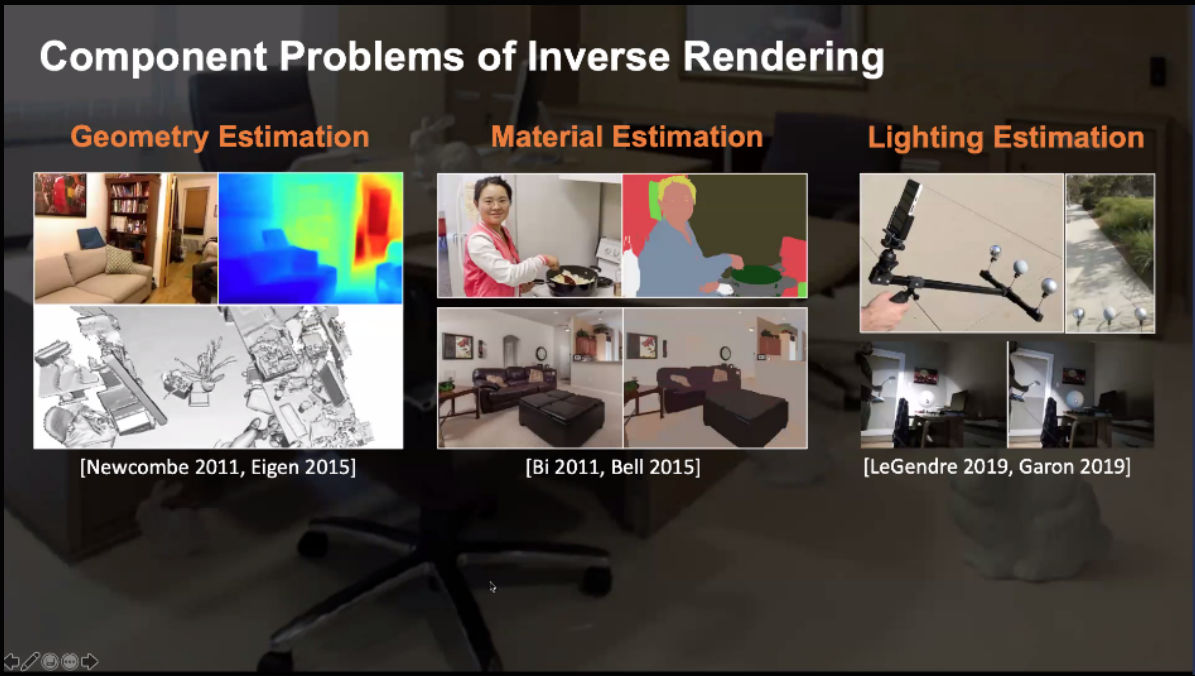
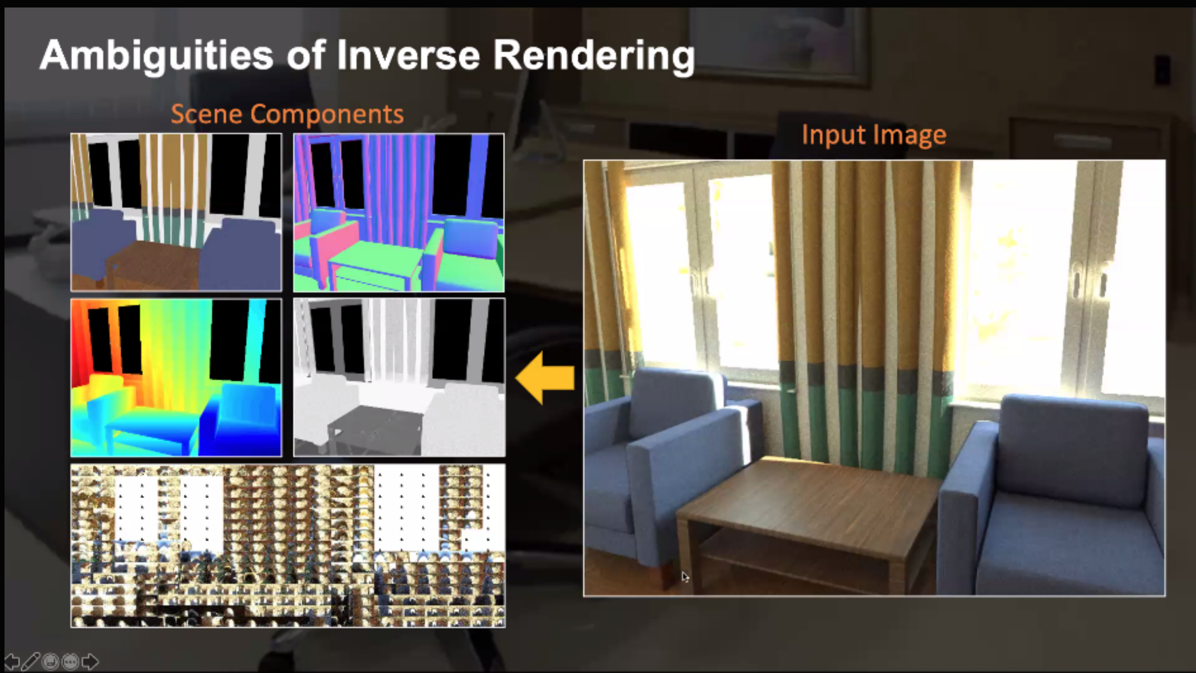
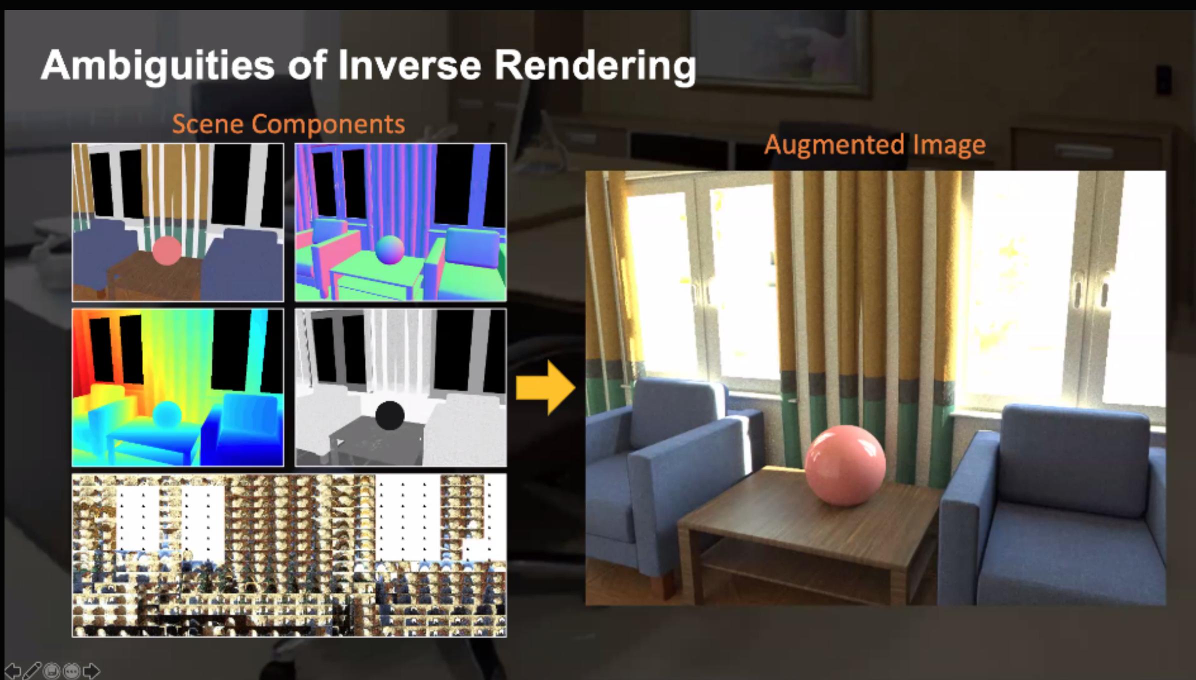


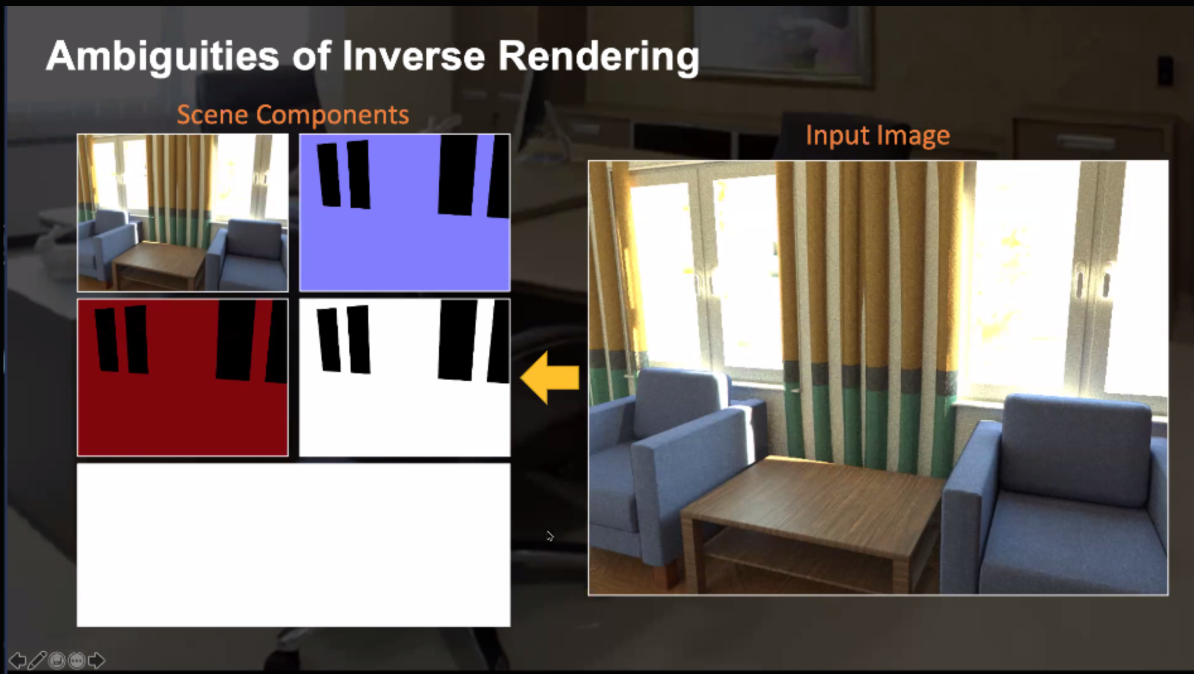
Image Formation is a Complex Process
• Arbitrary shapes of rooms, objects
• Complex layouts or arrangements
• Spatially-varying, diverse material
• Various natural and artificial lights
• Distant interactions in images
• Inter-reflections, shadows
• Local variations in lighting
• All the above must be handled for photorealistic augmented reality


Inverse Rendering: Shape, Material and Lighting from a Single Image
Real input image
Depth
Normal
Shape
Albedo
Roughness
Material
Lighting
Spatially-varying lighting


Component Problems of Inverse Rendering
Geometry Estimation
Material Estimation
Lighting Estimation
[Newcombe 2011, Eigen 2015]
[Bi 2011, Bell 2015]
[LeGendre 2019, Garon 2019]


Ambiguities of Inverse Rendering
Scene Components
Input Image


Ambiguities of Inverse Rendering
Scene Components
Augmented Image


Ambiguities of Inverse Rendering
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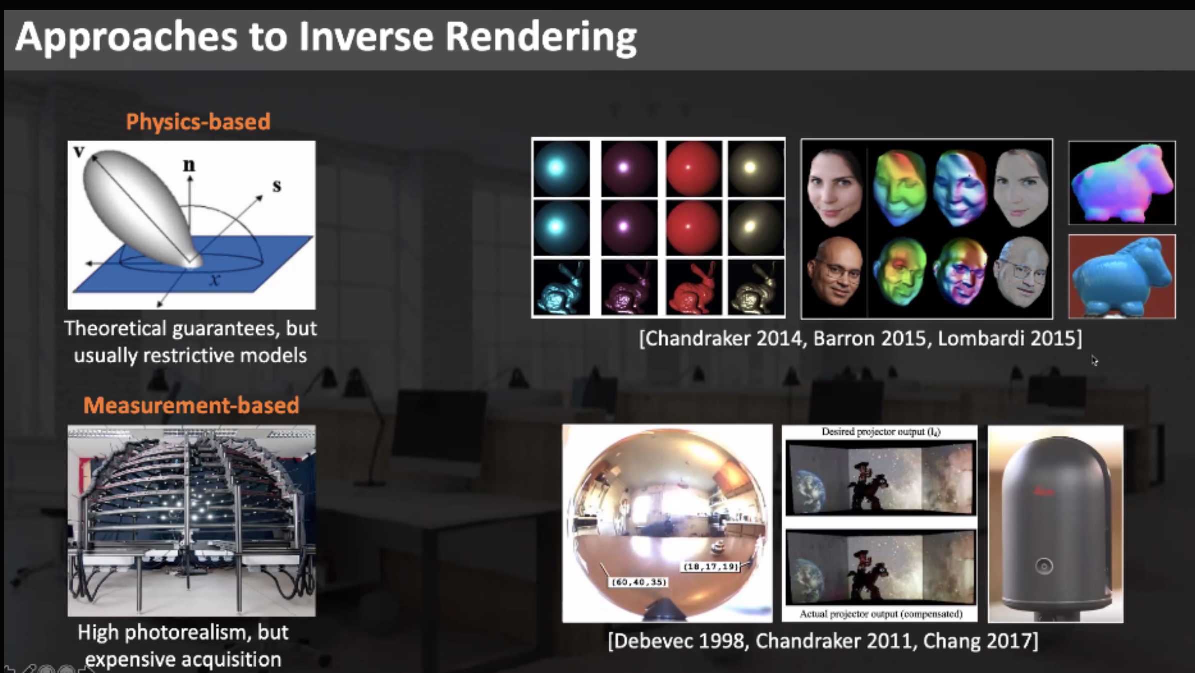
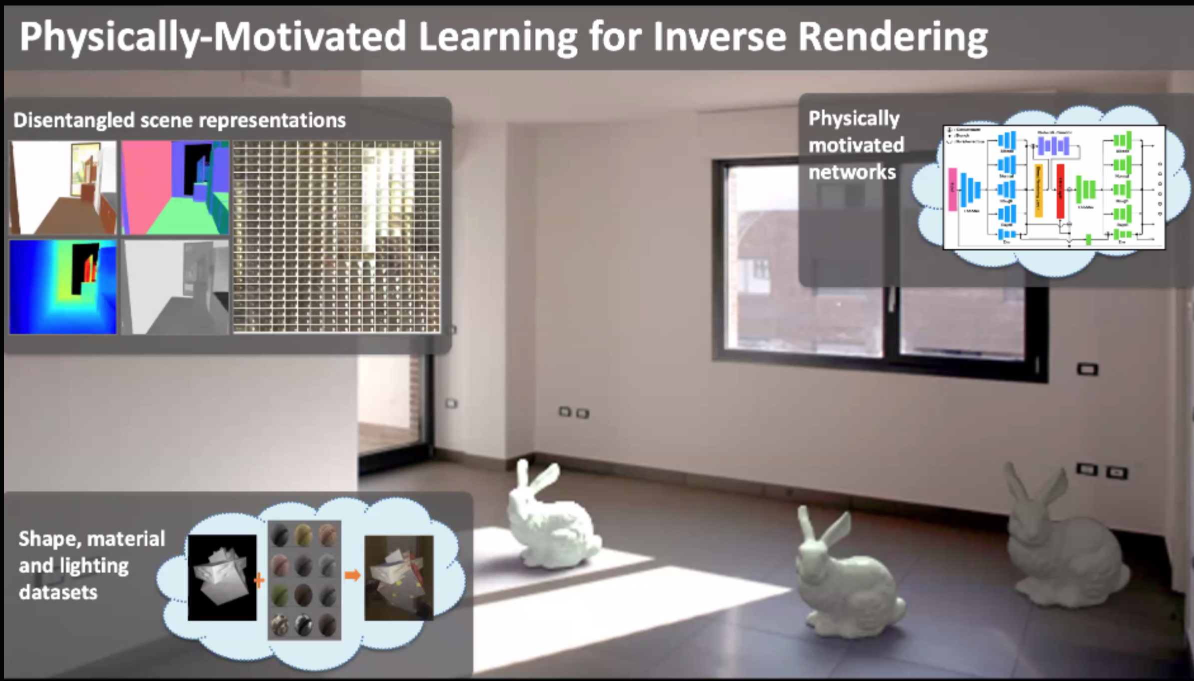
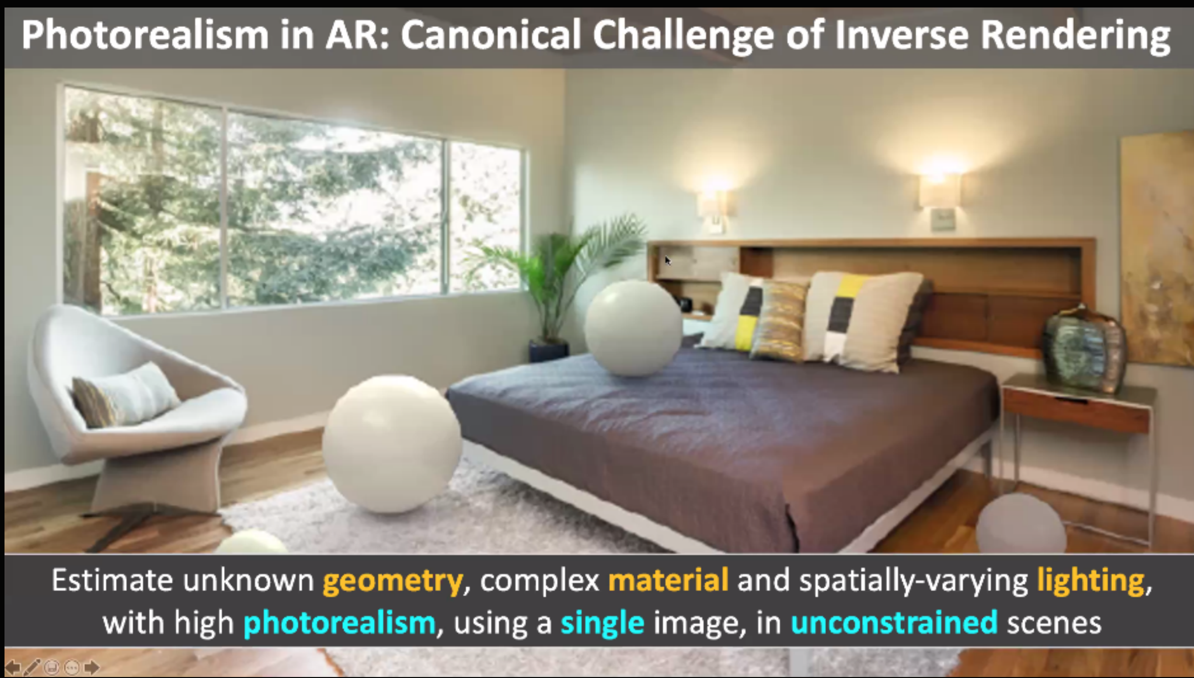
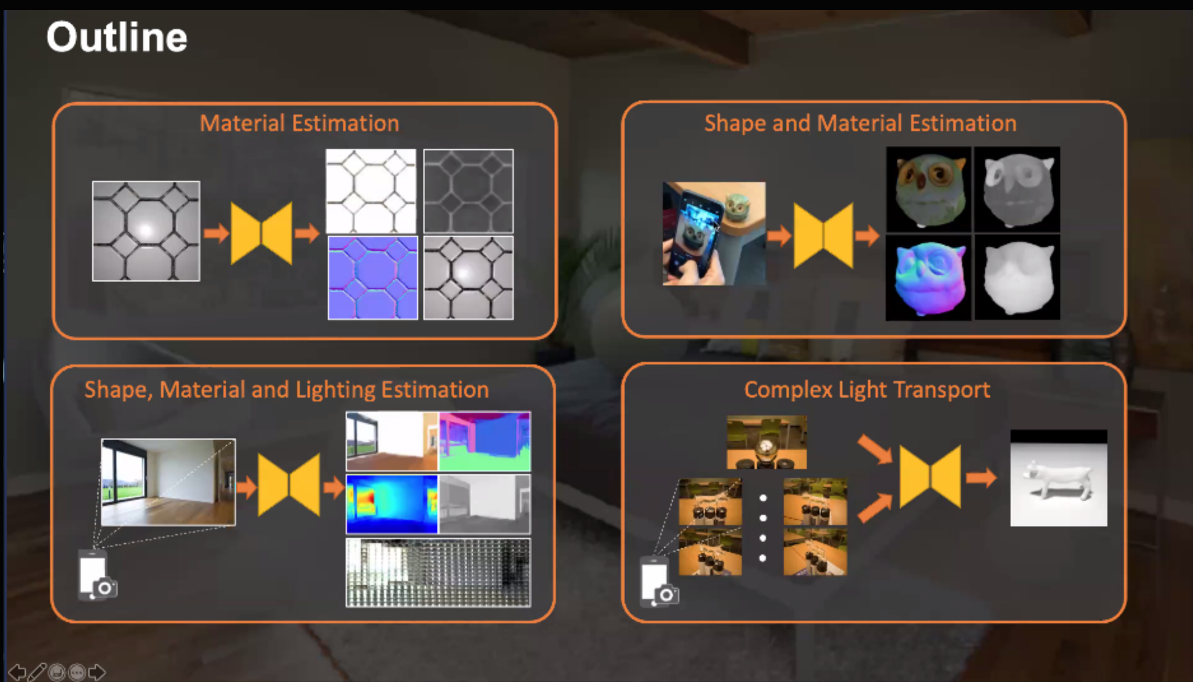
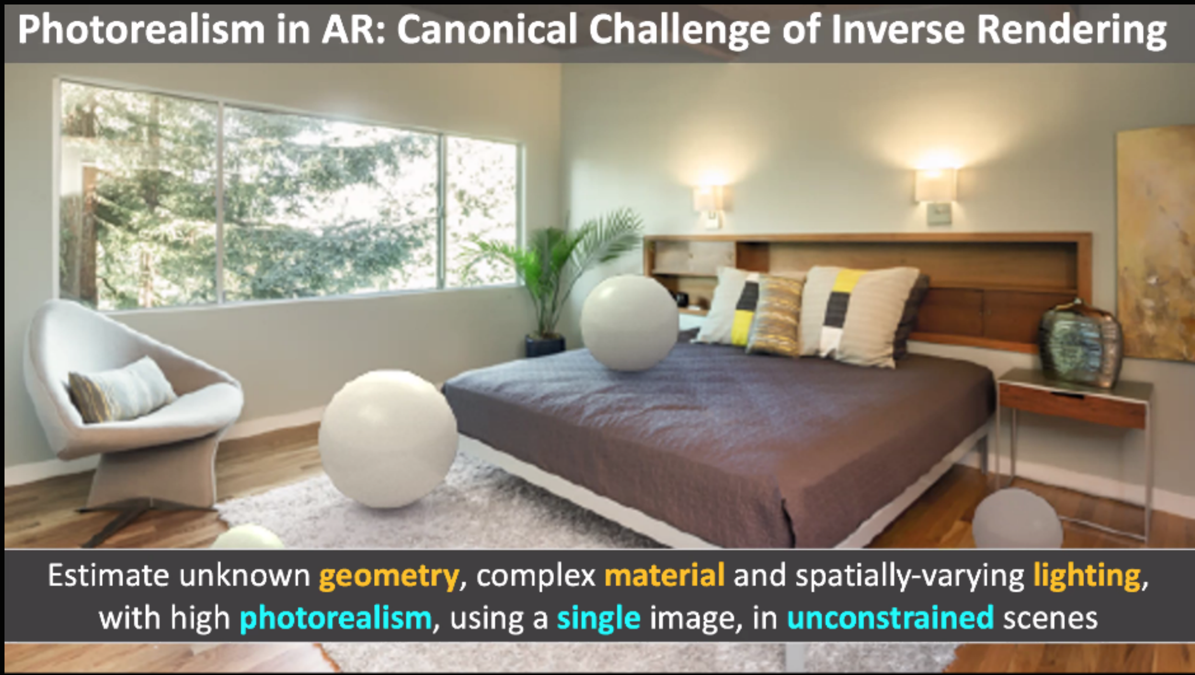
Approaches to Inverse Rendering


Approaches to Inverse Rendering
Physics-based
v
n
s
x
Theoretical guarantees, but usually restrictive models
[Chandraker 2014, Barron 2015, Lombardi 2015]
Measurement-based
High photorealism, but expensive acquisition
Desired projector output
Actual projector output (compensated)
[Debevec 1998, Chandraker 2011, Chang 2017]


Physically-Motivated Learning for Inverse Rendering
Disentangled scene representations
Physically motivated networks
Shape, material and lighting datasets


Photorealism in AR: Canonical Challenge of Inverse Rendering
Estimate unknown geometry, complex material and spatially-varying lighting,
with high photorealism, using a single image, in unconstrained scenes


Outline
Material Estimation
Shape and Material Estimation
Shape, Material and Lighting Estimation
Complex Light Transport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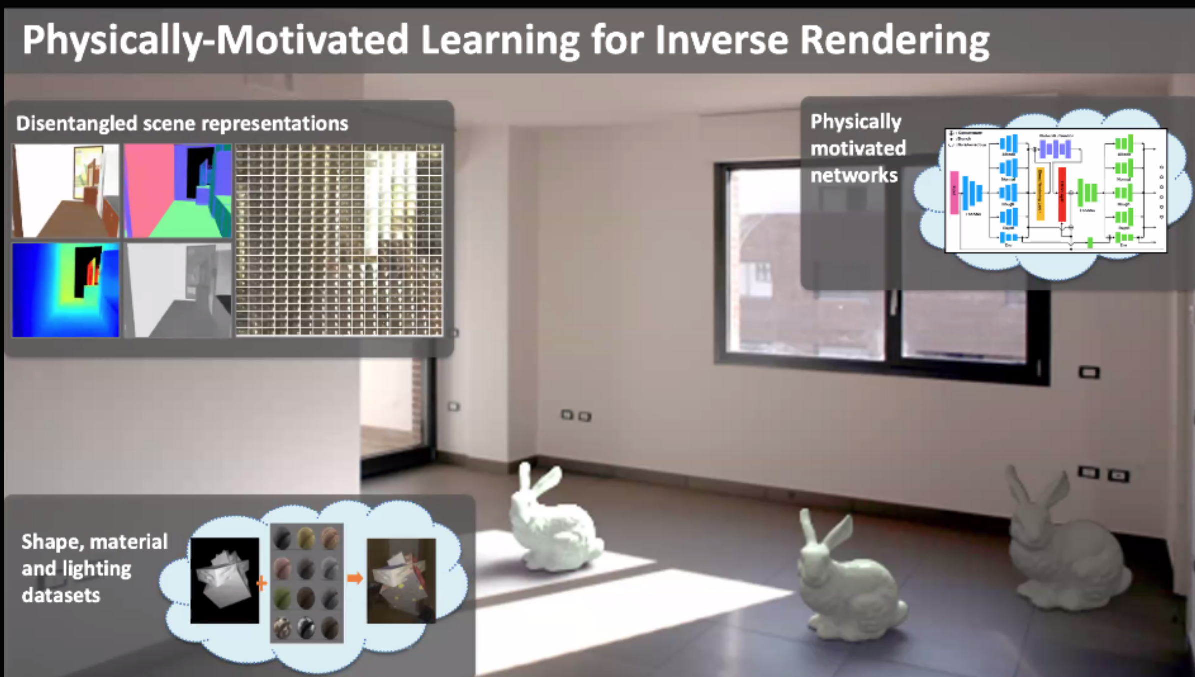
Approaches to Inverse Rendering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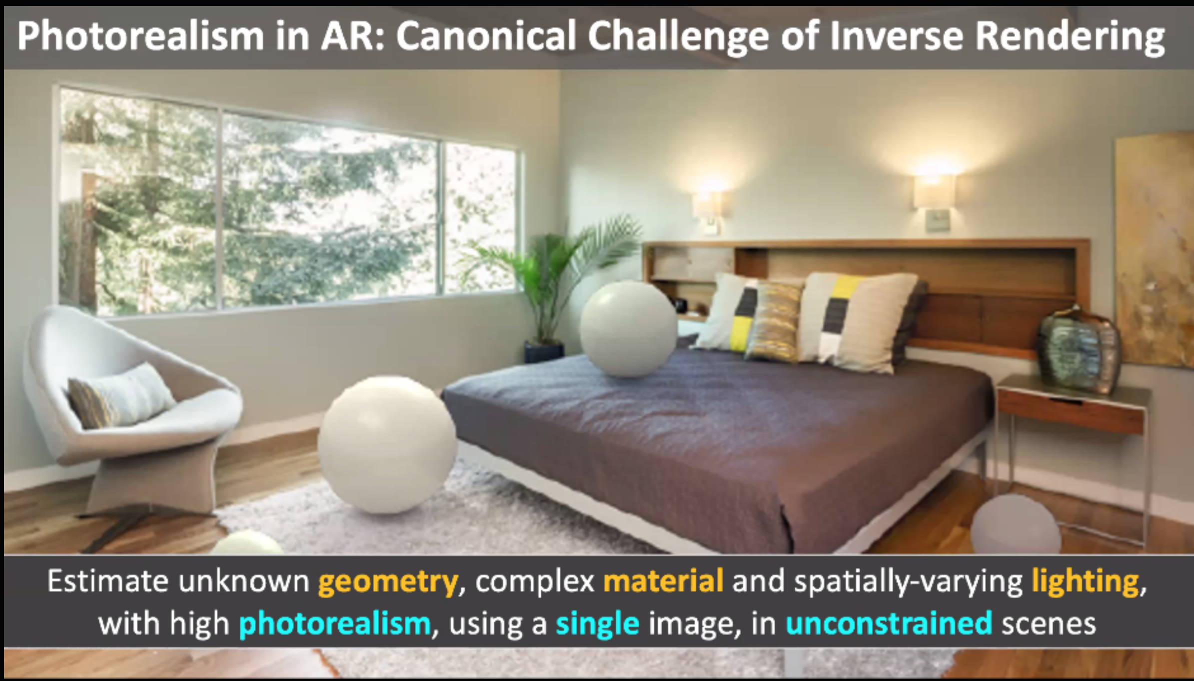
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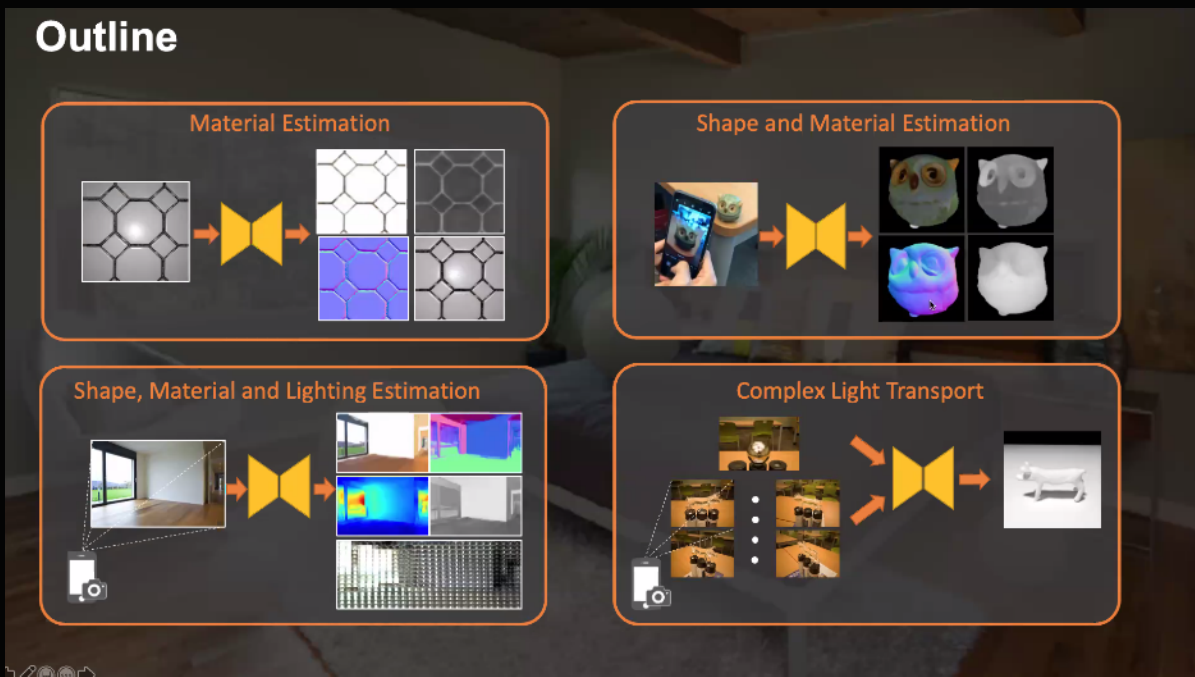
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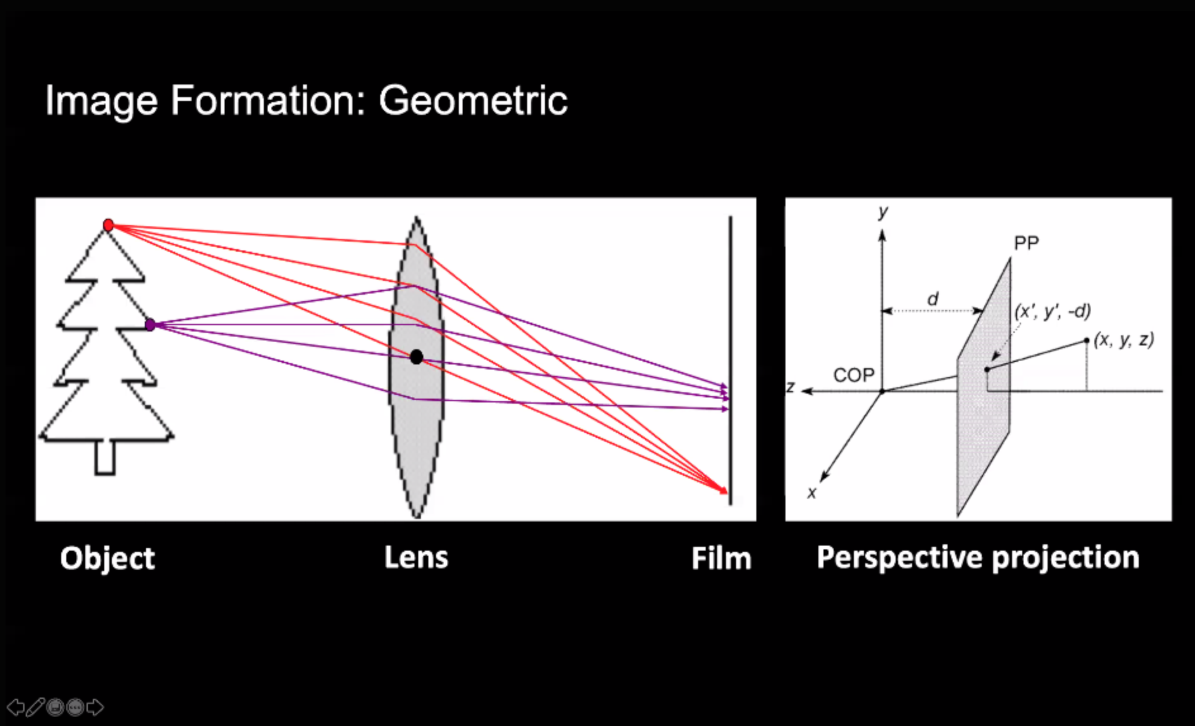


Image Formation: Geometric
y
PP
d
(x', y', -d)
(x, y, z)
COP
z
x
Object
Lens
Film
Perspective projection

Geometric Models Do Not Explain Appearance

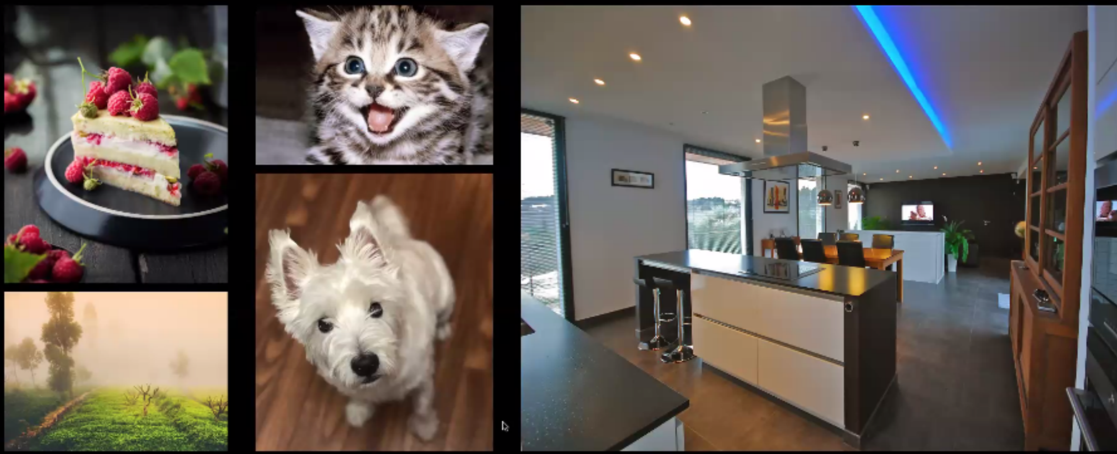
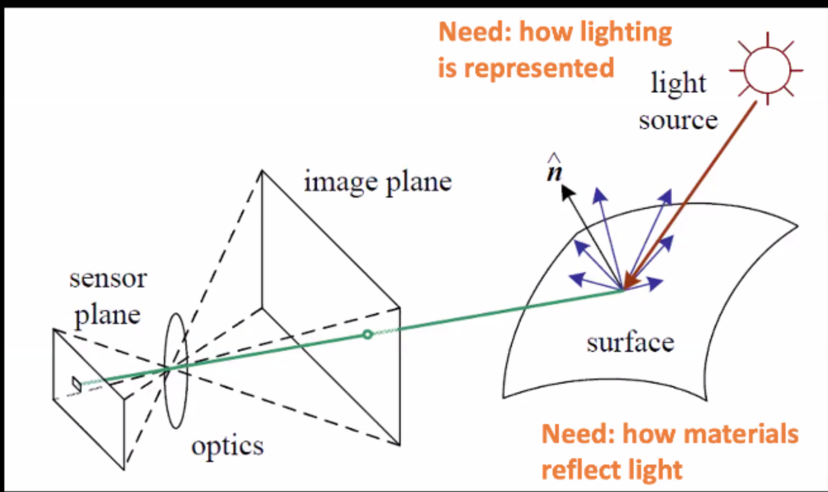
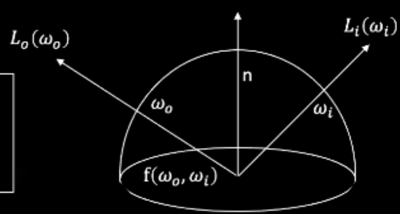


Image Formation: Photometric



Background: BRDF

Bidirectional Reflectance Distribution Function
- Ratio of outgoing and incident energies
- Depends on viewing and lighting directions



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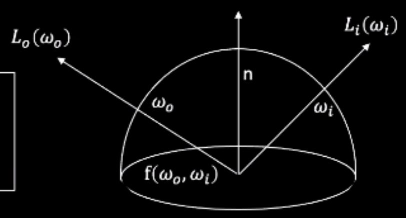


Traditional assumptions: diffuse, Lambertian BRDF

Real-world materials: complex, unknown BRDF

Lambertian BRDF : $\frac{\rho}{\pi}$

Microfacet BRDF : $\frac{\rho}{\pi} + \frac{D(\omega_o, \omega_i, R) F(\omega_o, \omega_i) G(\omega_o, \omega_i, R)}{4(\omega_o \cdot \mathrm{n})(\omega_i \cdot \mathrm{n})}$

Microfacet BRDF

- Microfacet theory: Assume the surface is made up of microscopic grooves

- Assume the faces of these grooves (called microfacets) are perfect reflectors
- Take into account 3 phenomena

Shadowing

Masking

Interreflection

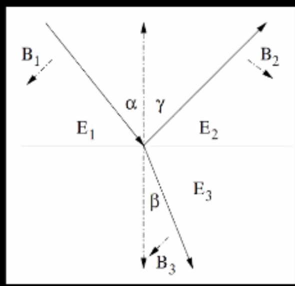
Microfacet BRDF

Microfacet BRDF

Reflection greater at more oblique angle

[Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 1997]

- Beam splits into reflected and refracted
- Determined by Snell's Law



$$\sin\alpha = n\sin\beta$$

$$\alpha = \gamma$$

$$r_\perp = \frac{\cos\alpha - n\cos\beta}{\cos\alpha + n\cos\beta}$$

$$r_\parallel = \frac{n\cos\alpha - \cos\beta}{n\cos\alpha + \cos\beta}$$

Microfacet BRDF

Distribution function
Percentage of microfacets oriented towards light

Fresnel term
Accounts for wavelength

Geometric attenuation
Reduces output based on extent of shadowing

$$\mathrm{f}(\omega_o, \omega_i) = \frac{\rho}{\pi} + \frac{D(\omega_o, \omega_i, R)F(\omega_o, \omega_i)G(\omega_o, \omega_i, R)}{4(\omega_o \cdot \mathrm{n})(\omega_i \cdot \mathrm{n})}$$

Diffuse albedo

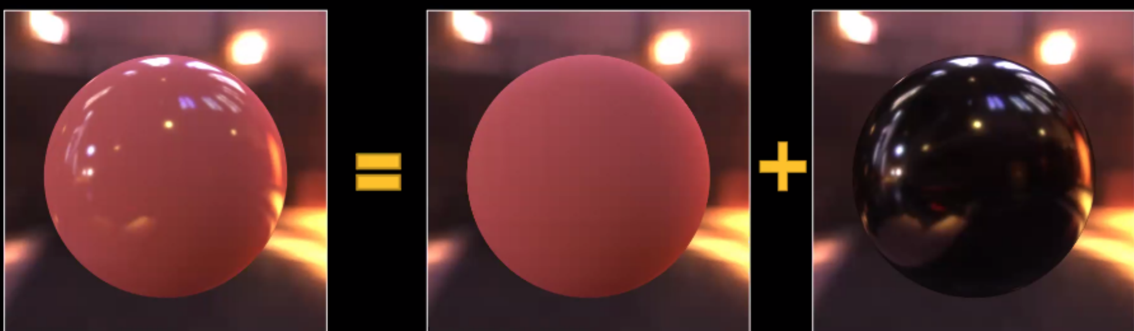
Specular roughness

How much of macroscopic surface is visible to viewer

How much of macroscopic surface is visible to light source

Background: BRDF

Microfacet BRDF : $\mathrm{f}(\omega_o, \omega_i) = \frac{\rho}{\pi} + \frac{D(\omega_o, \omega_i, R)F(\omega_o, \omega_i)G(\omega_o, \omega_i, R)}{4(\omega_o \cdot \mathrm{n})(\omega_i \cdot \mathrm{n})}$



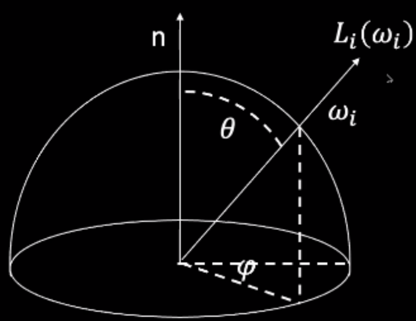
Microfacet BRDF = Diffuse Reflectance + Specular Reflectance

Local and Global Illumination

- Local illumination
  - Light directly from light sources
  - No shadows or interreflections
- Global illumination
  - Effect of light sources, interactions with rest of scene and participating media
  - Hard and soft shadows
  - Reflections, refractions and scattering
  - Diffuse and glossy interreflections

Background: Lighting

- Light as a function of direction, from entire environment



Background: Lighting

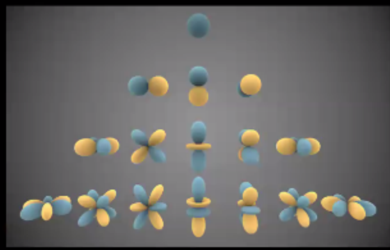
- Light as a function of direction, from entire environment
- Captured by photographing a chrome steel or mirror sphere
- Accurate only for one point, but nearly same at all scene points for distant lighting

[Blinn and Newell 1976, Miller and Hoffman, 1984]

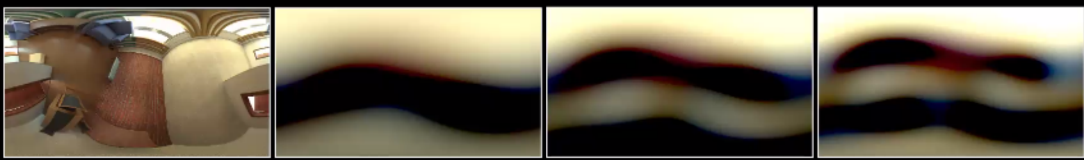
Background: Spherical Harmonics Lighting

Distant lighting can be approximated by N order spherical harmonics:

$$L_i(\omega_i) = \sum_{l=1}^{N} \sum_{m=-l}^{l} K_{lm} Y_{lm}(\omega_i)$$



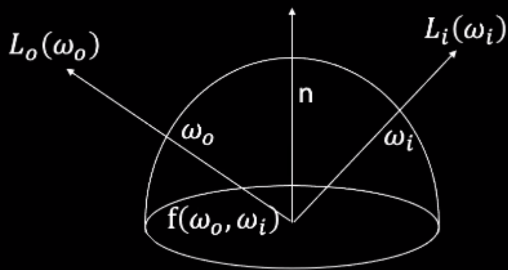
Larger N can preserve higher angular frequency



Environment map	3 order spherical harmonics (27 paras)	4 order spherical harmonics (48 paras)	5 order spherical harmonics (75 paras)

Image Formation: Rendering Equation

$$L_o(\omega_o) = \int_{\Omega} L_i(\omega_i)\, \mathrm{f}(\omega_o, \omega_i)(\omega_i \cdot \mathrm{n}) \mathrm{d}\omega_i$$



n	Normal direction, geometry
ω_i	Direction of incoming light
ω_o	Direction of outgoing light
Ω	Hemisphere
$\mathrm{f}(\omega_o, \omega_i)$	Bidirectional reflectance distribution function (BRDF)
$L_o(\omega_o)$	Outgoing radiance, the observation
$L_i(\omega_i)$	Incoming radiance

Image Formation: Rendering Equation

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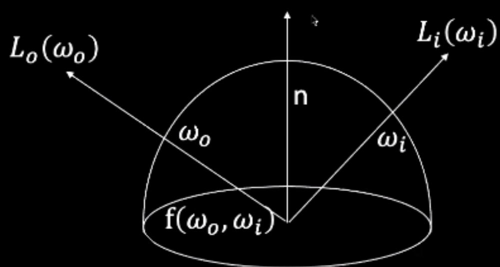

n	**Normal direction, geometry**
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$\mathrm{f}(\omega_o, \omega_i)$	**Bidirectional reflectance distribution function (BRDF)**
$L_o(\omega_o)$	Outgoing radiance, the observation
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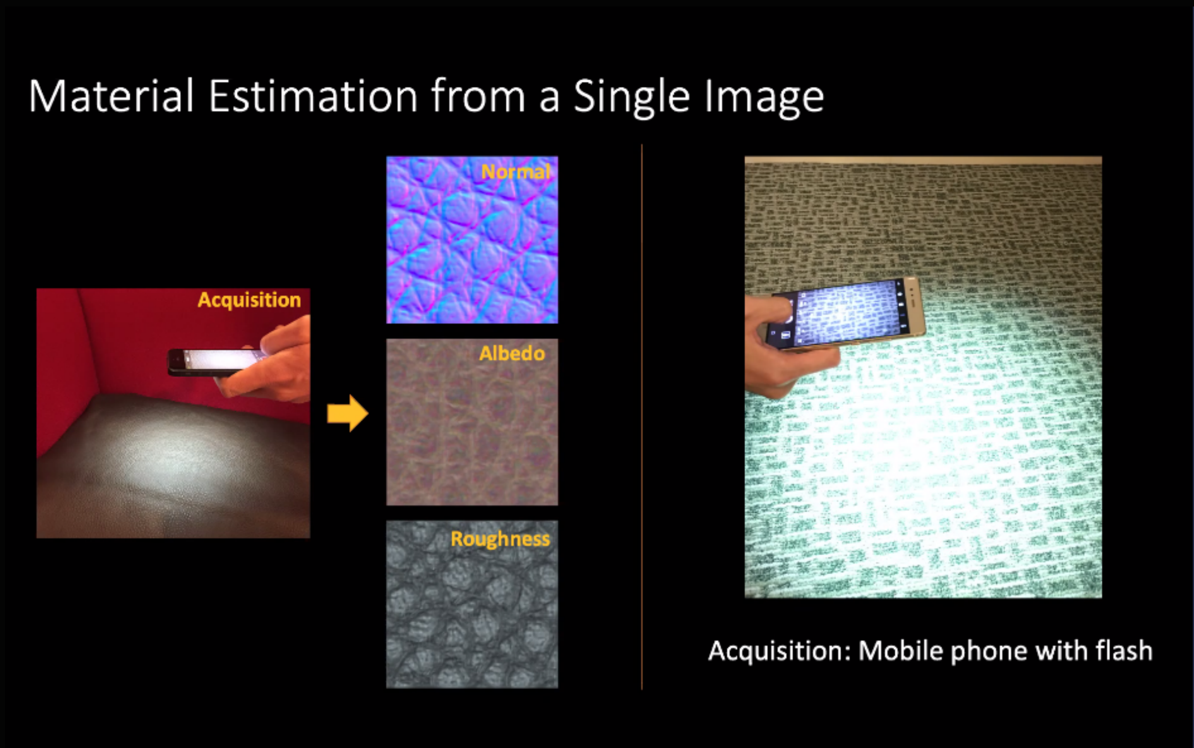
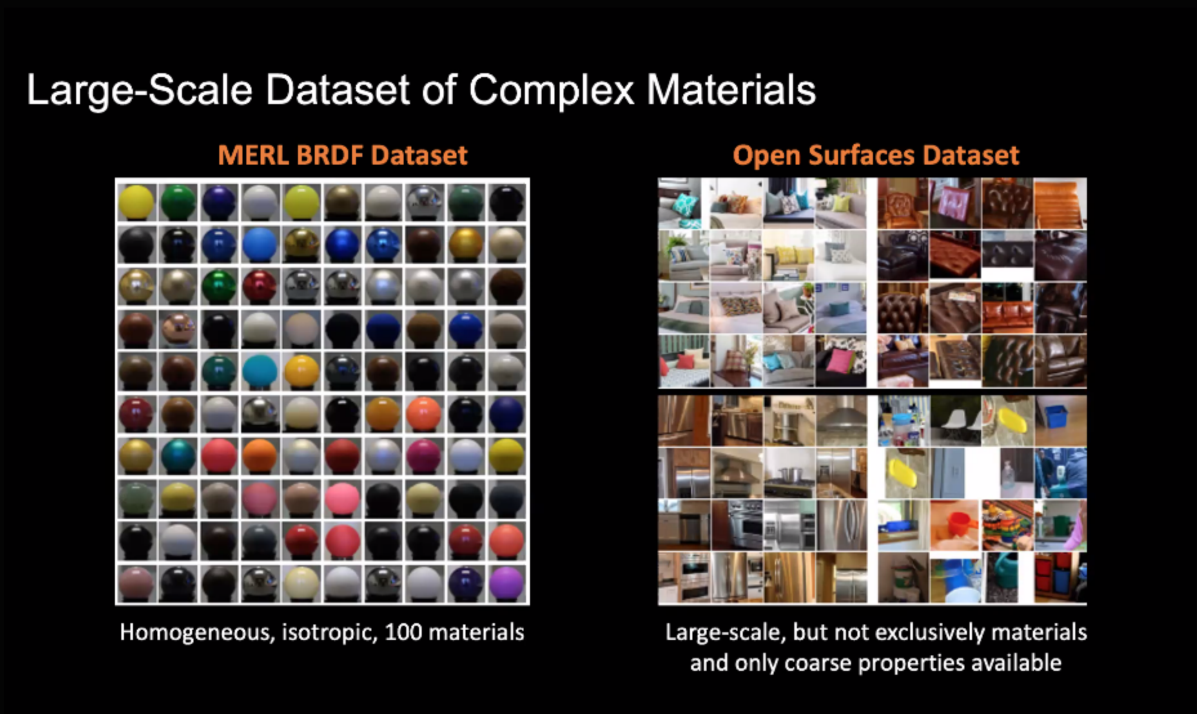
Material Estimation
Shape and Material Estimation
Shape, Material and Lighting Estimation
Complex Light Transport
[Zhengqin Li, Kalyan Sunkavalli and Manmohan Chandraker, ECCV 2018]



Material Estimation from a Single Image
Acquisition
Normal
Albedo
Roughness
Acquisition: Mobile phone with flash



Large-Scale Dataset of Complex Materials
MERL BRDF Dataset
Open Surfaces Dataset
Homogeneous, isotropic, 100 materials
Large-scale, but not exclusively materials
and only coarse properties available