Measure, measure, measure: BRDF, BTF, Light Fields

Lecture #6

Appearance Modeling, Fall 2005

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Thanks to Steve Marschner, Shree Nayar, Ravi Ramamoorthi,
Marc Levoy, Pat Hanrahan, Kristin Dana, Ken Perlin, Debevec, Matusik

Measuring BRDFs

Why bother modeling BRDFs?

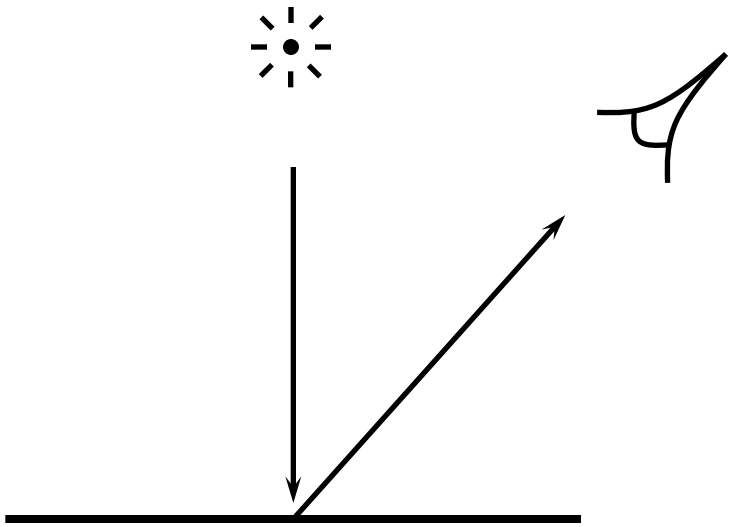
Why not directly measure BRDFs?

- True knowledge of surface properties
- Accurate models for graphics

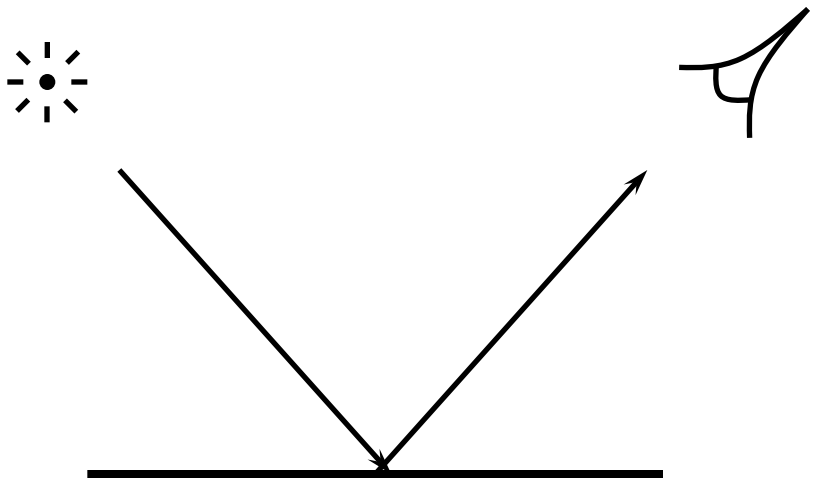
Measuring BRDFs

- A full BRDF is 4-dimensional
- Simpler measurements (0D/1D/2D/3D) often useful
- Lets start with simplest and get more complex

Measuring Reflectance



0º/45º
Diffuse Measurement

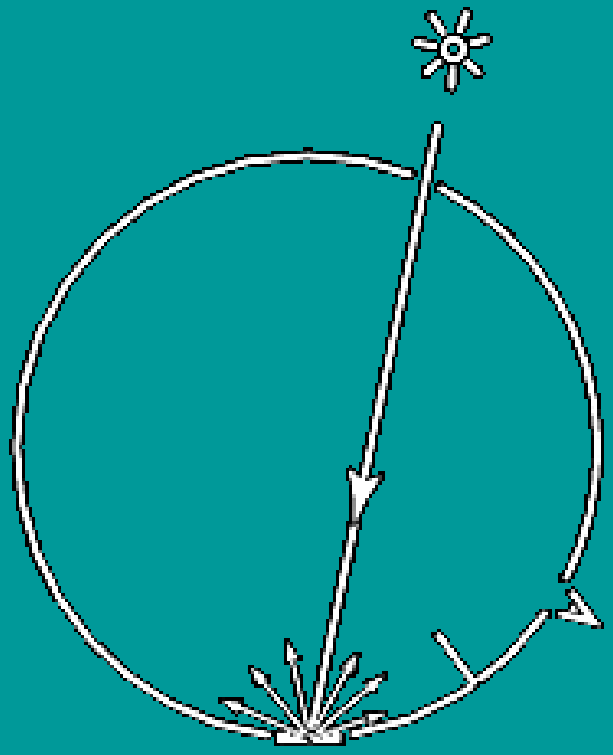


45º/45º
Specular Measurement

Integrating Spheres

- Sphere with diffuse material on inside
- Geometry ensures even illumination
- More accurate measure of diffuse reflectance

- Remember the white-out condition!

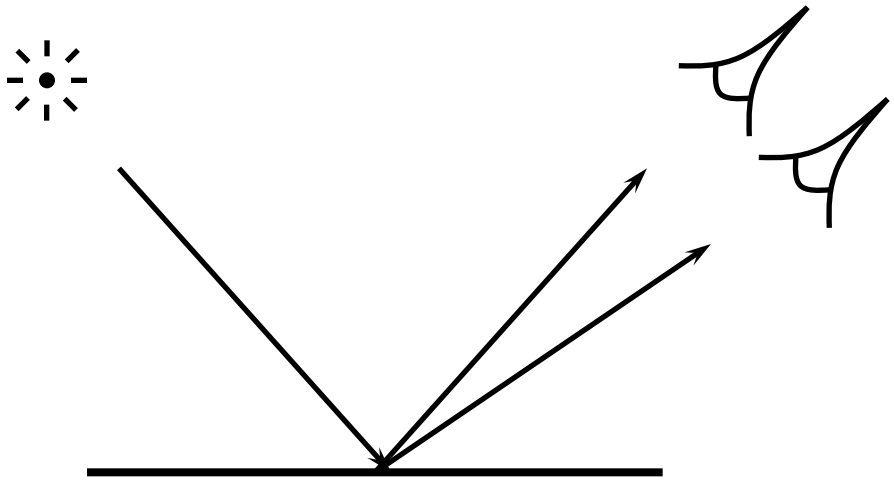


Gloss Measurements

- Standardized for applications such as paint manufacturing
- Example: “contrast gloss” is essentially ratio of specular to diffuse
- “Sheen” is specular measurement at 85°

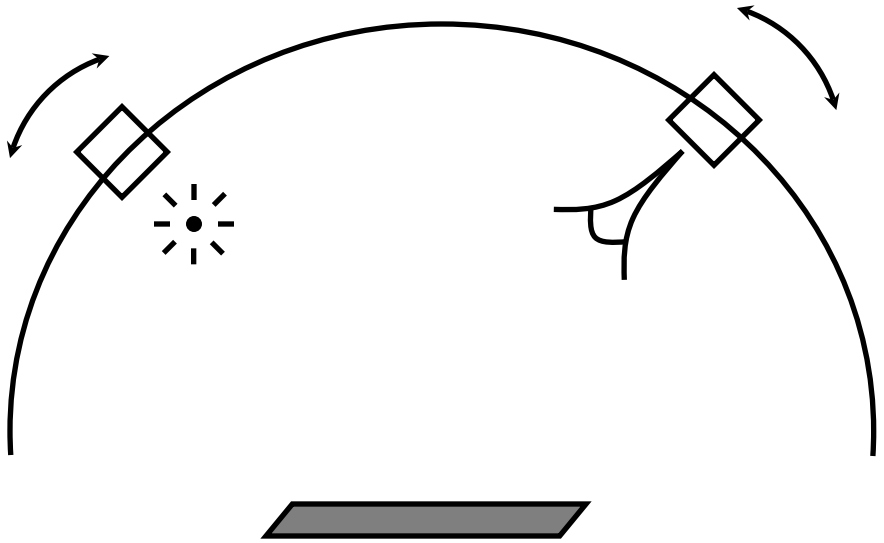
Gloss Measurements

- “Haze” and “distinctness of image” are measurements of width of specular peak



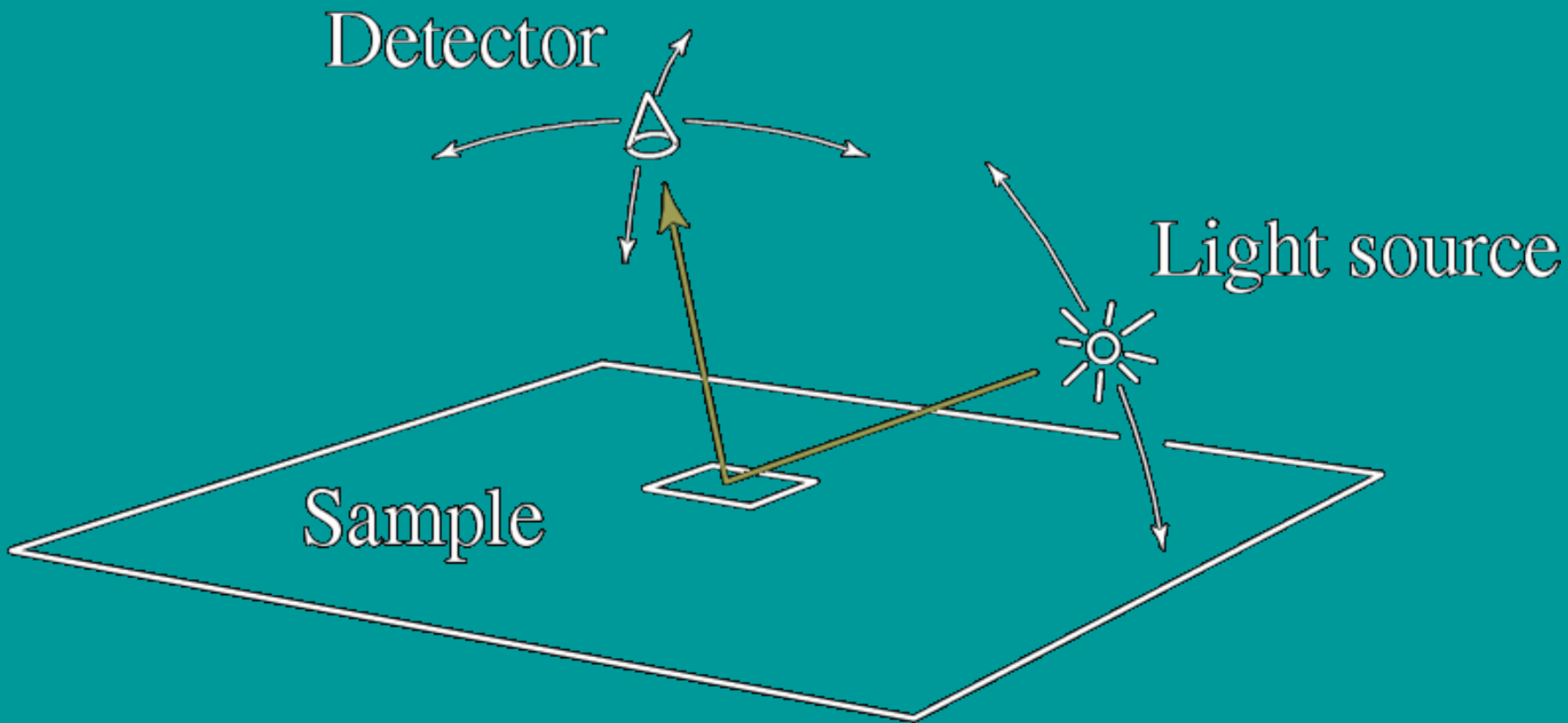
BRDF Measurements

- Next step up in complexity: measure BRDF in plane of incidence (1- or 2-D)



Gonioreflectometers

- Three degrees of freedom spread among light source, detector, and/or sample



Gonioreflectometers

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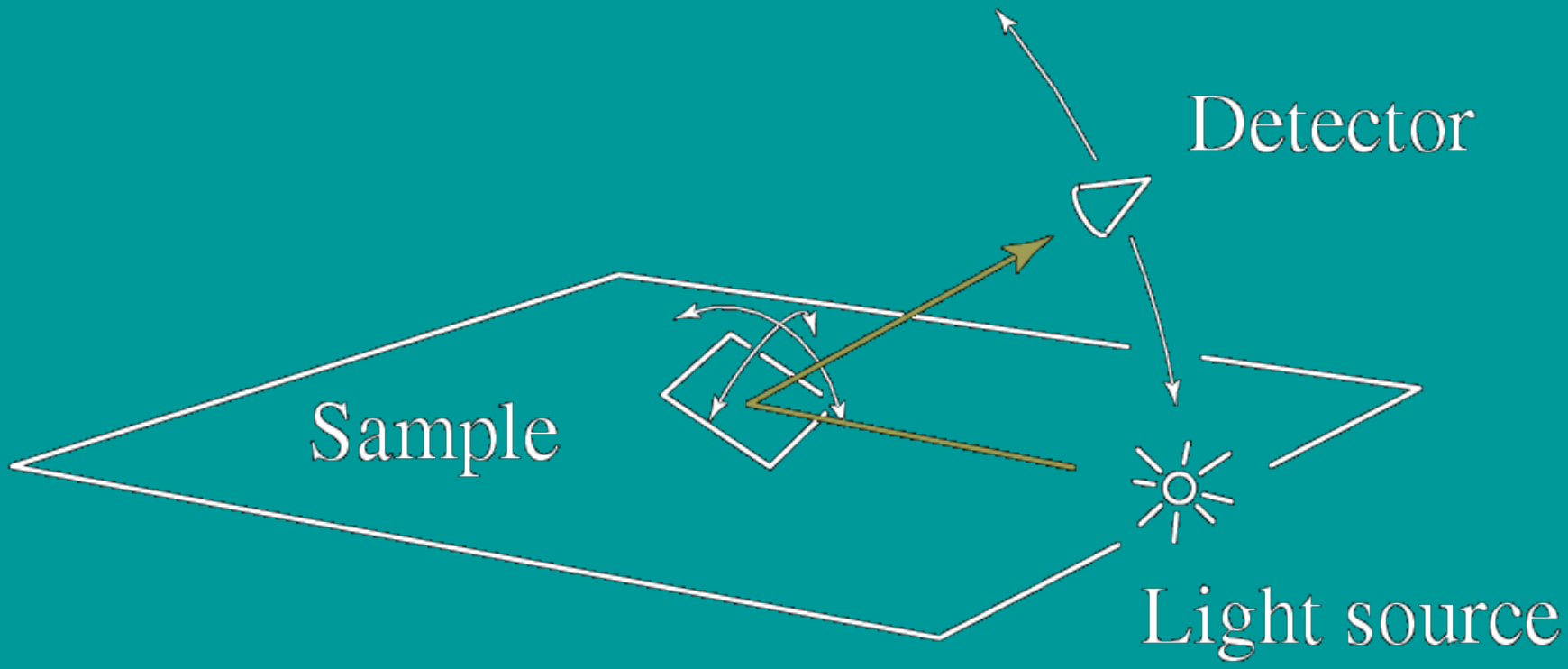


Gonioreflectometers

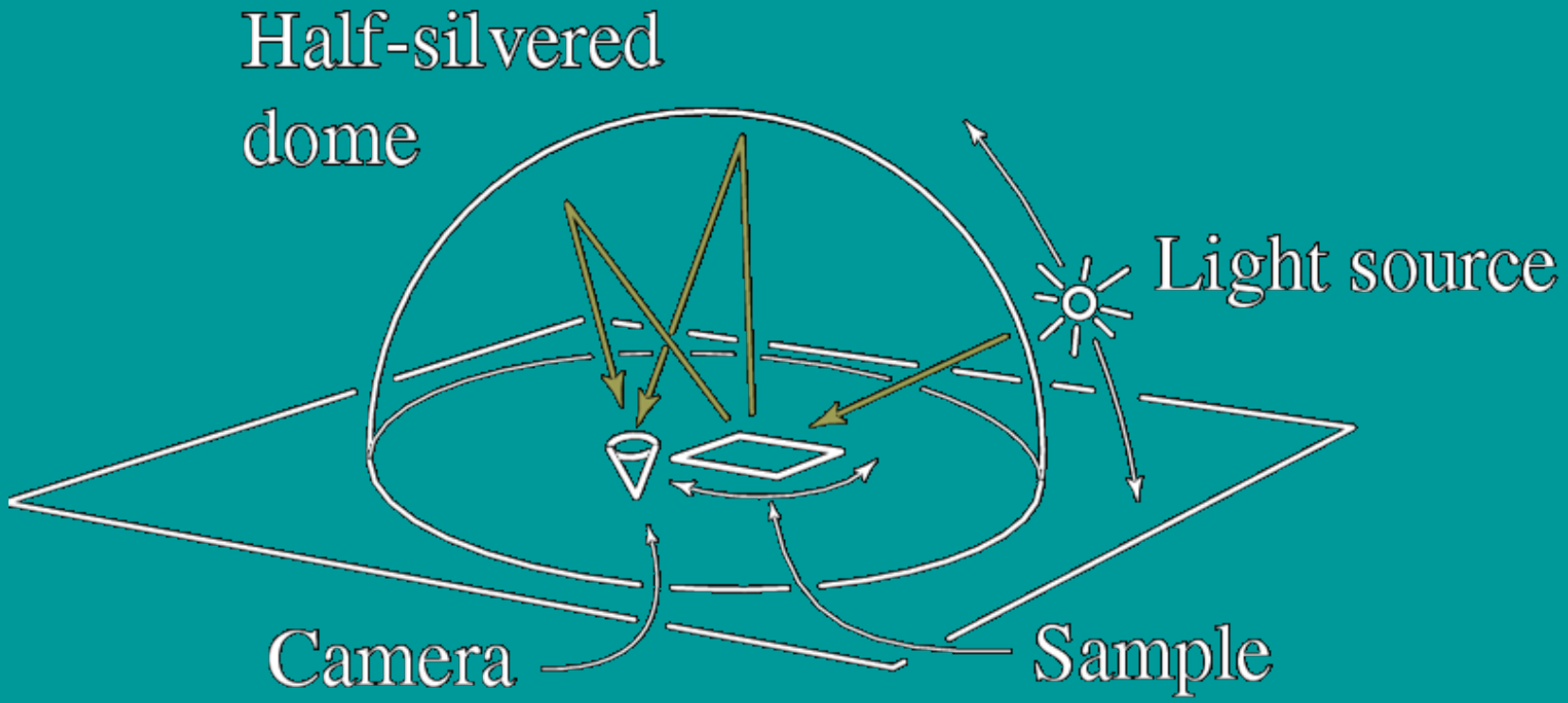
- Can add fourth degree of freedom to measure anisotropic BRDFs

Image-Based BRDF Measurement

- Reduce acquisition time by obtaining larger (e.g. 2-D) slices of BRDF at once
- Idea: Camera can acquire 2D image
- Requires mapping of angles of light to camera pixels

Ward's BRDF Measurement Setup

- Collect reflected light with hemispherical mirror

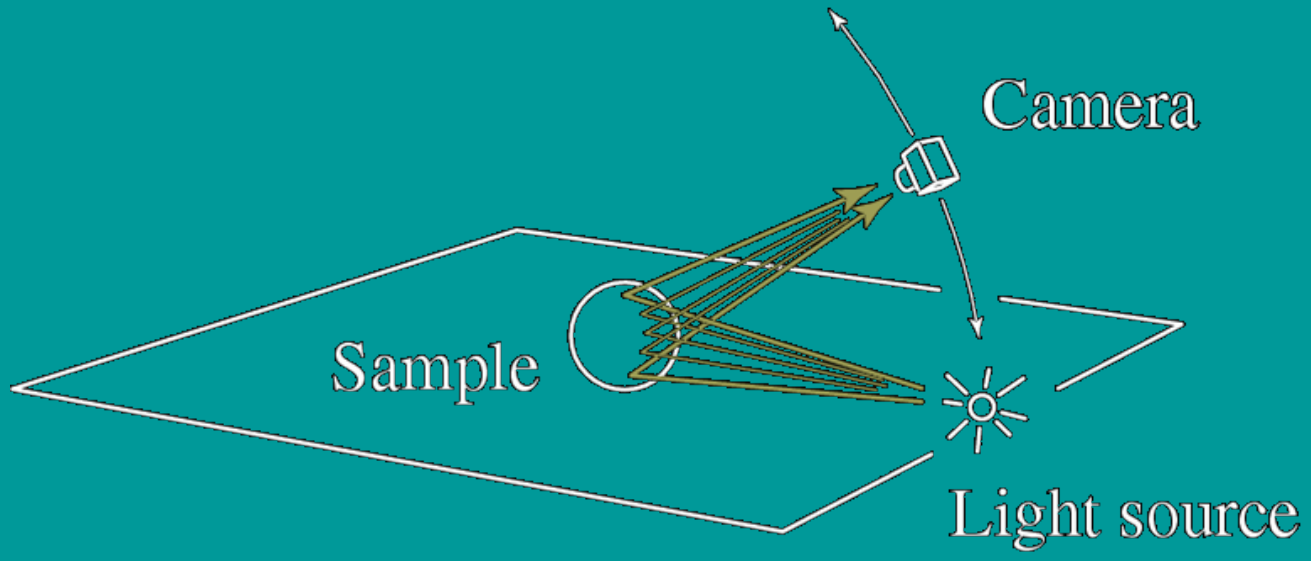


Ward's BRDF Measurement Setup

- Result: each image captures light at all exitant angles

Image-Based BRDF Measurement

- For uniform BRDF, capture 2-D slice corresponding to variations in normals (Marschner et al)



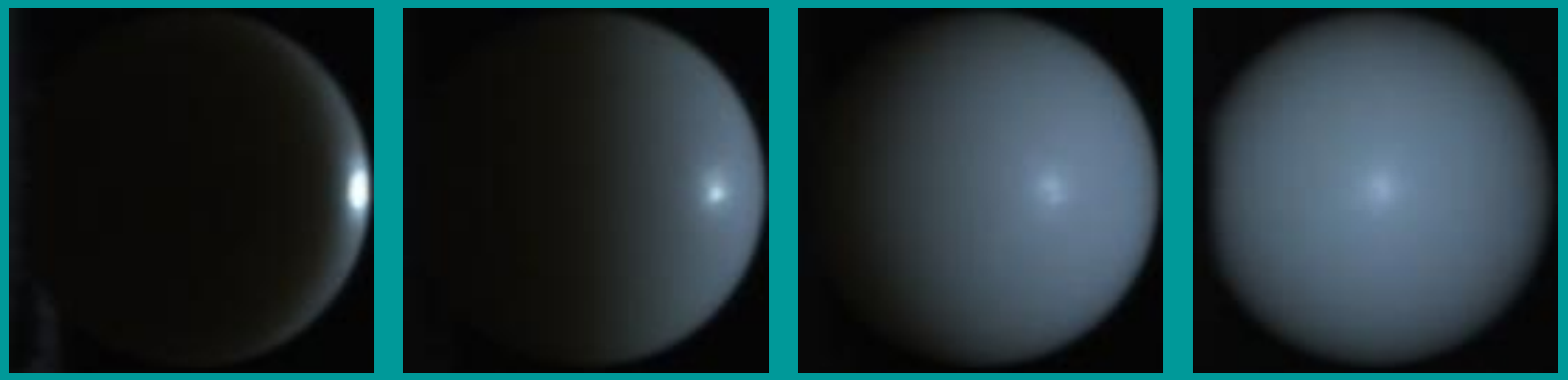
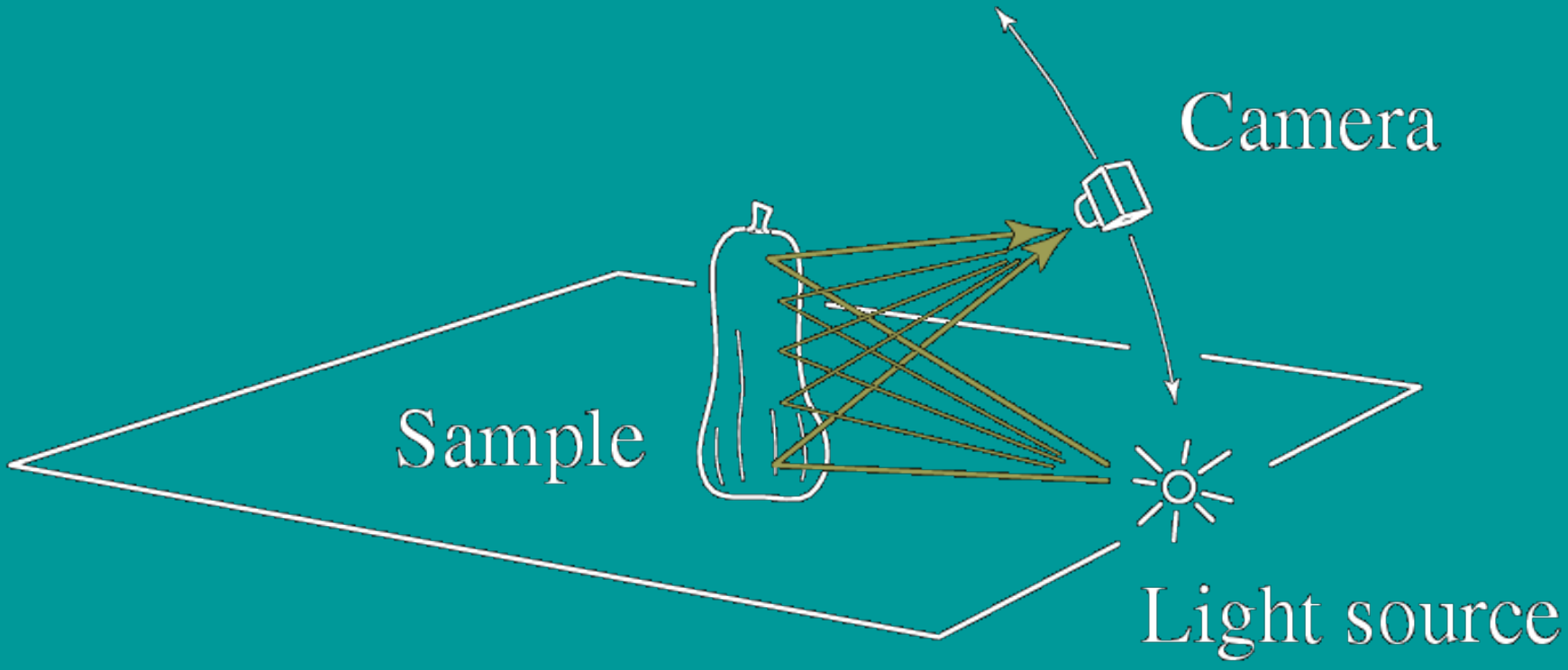


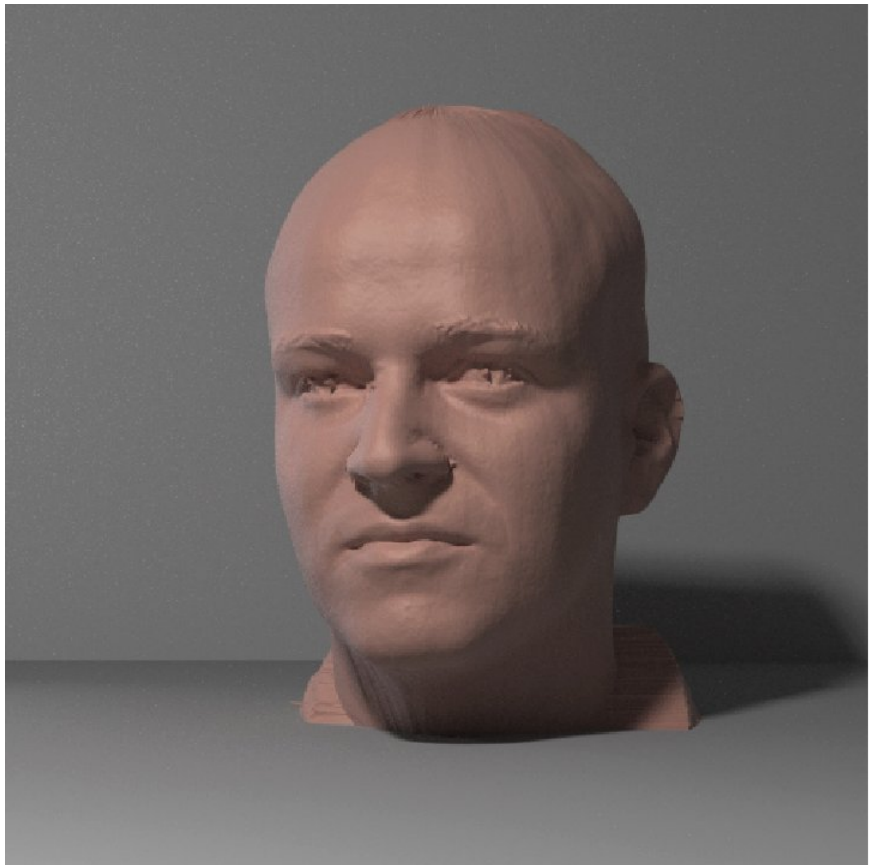
Image-Based BRDF Measurement

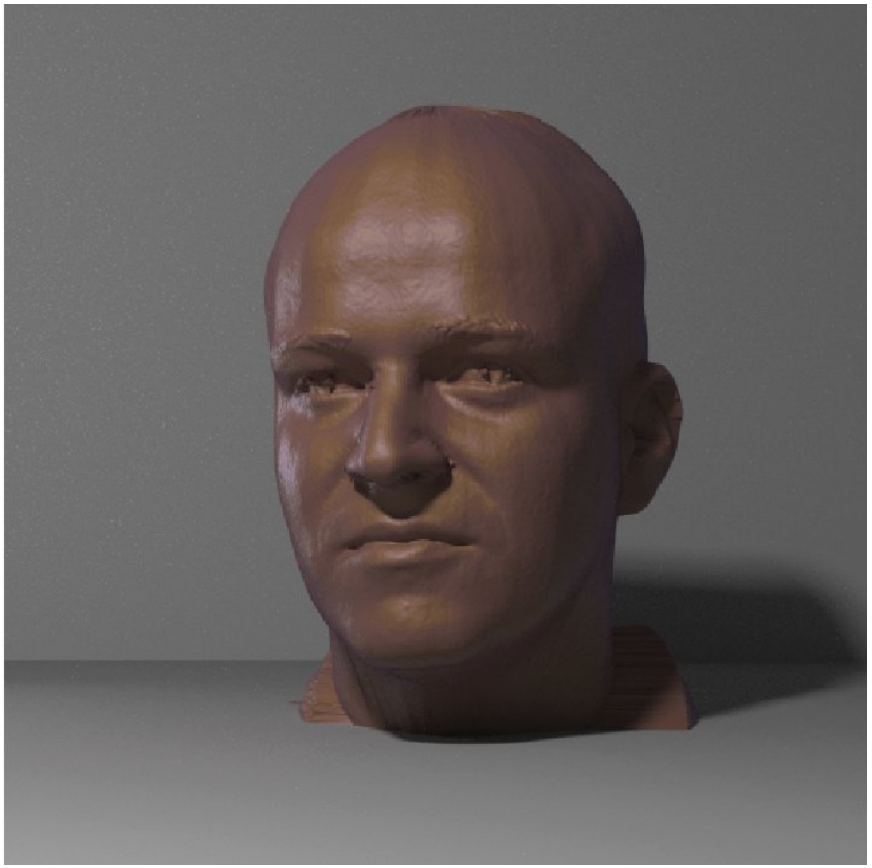
- Any object with known geometry



Marschner et al.

Image-based measurement of skin





Marschner et al. 2000

Measurement

- Light Source
  - Hamamatsu SQ Xenon lamp
    - Stable emission output
    - Continuous and relatively constant radiation spectrum

Measurement

- Turntable
  - Kaidan MD-19
  - Computer-controlled
- Dark Room
  - Walls painted with flat black paint
- Spherical Samples

Calibration

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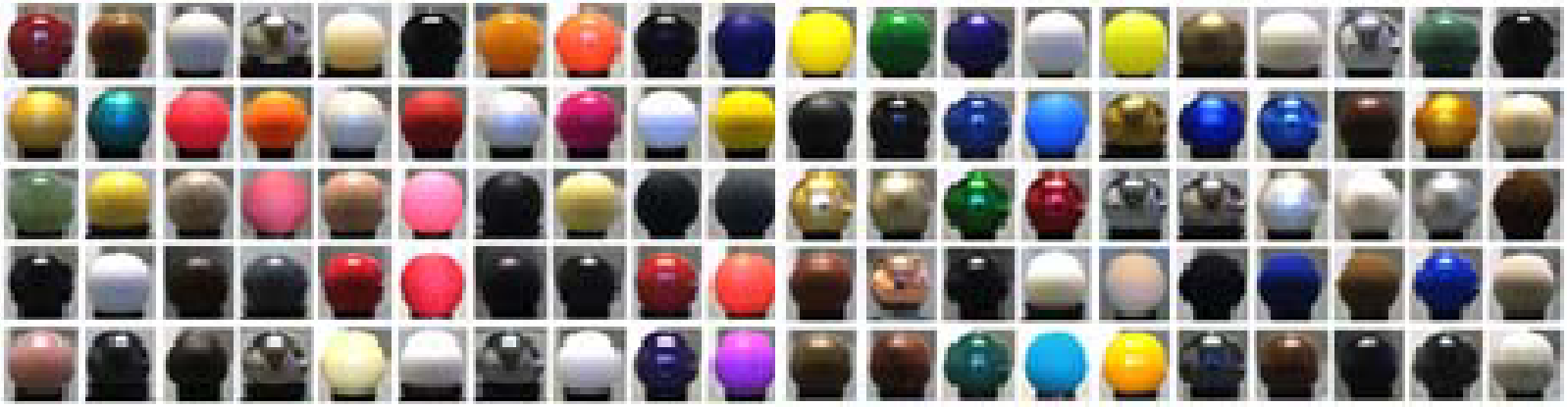
- Geometric calibration
  - Contact digitizer
    - Faro Arm
  - Intrinsic & extrinsic camera parameters
  - Sphere center & radius
  - Light Position
    - parameterized on a circle in 3D

Measurement

- 20-80 million reflectance measurements per material
- Each tabulated BRDF entails 90x90x180x3=4,374,000 measurement bins

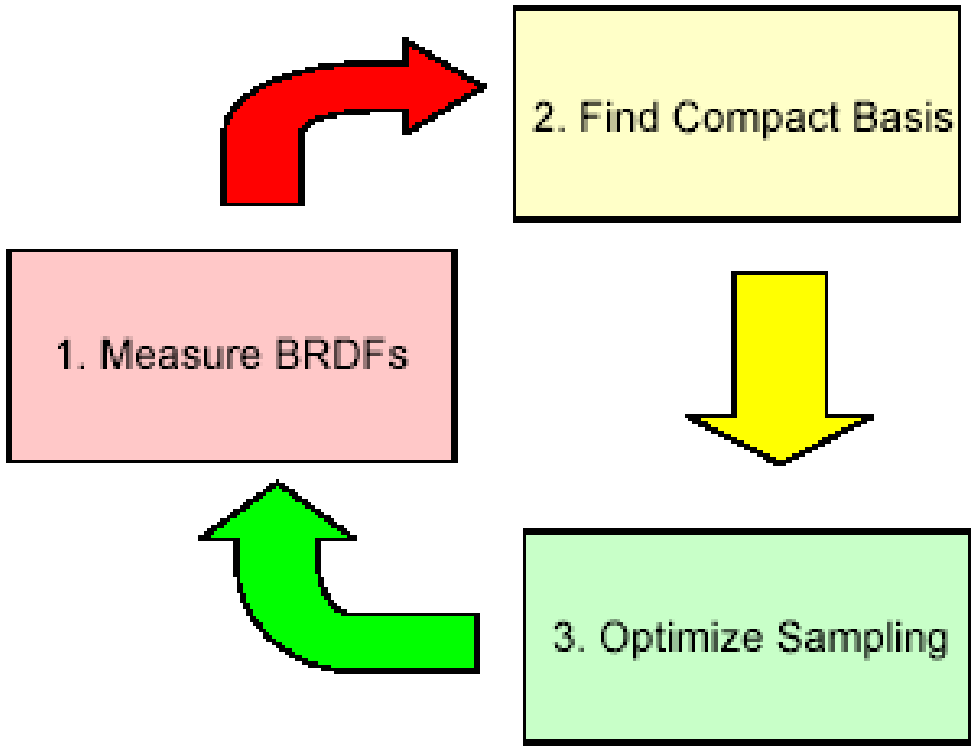


Rendering from Tabulated BRDFs

- These BRDFs are immediately useful
- Direct renderings from measurements

Nickel | Hematite | Gold Paint | Pink Felt

Measurement Process



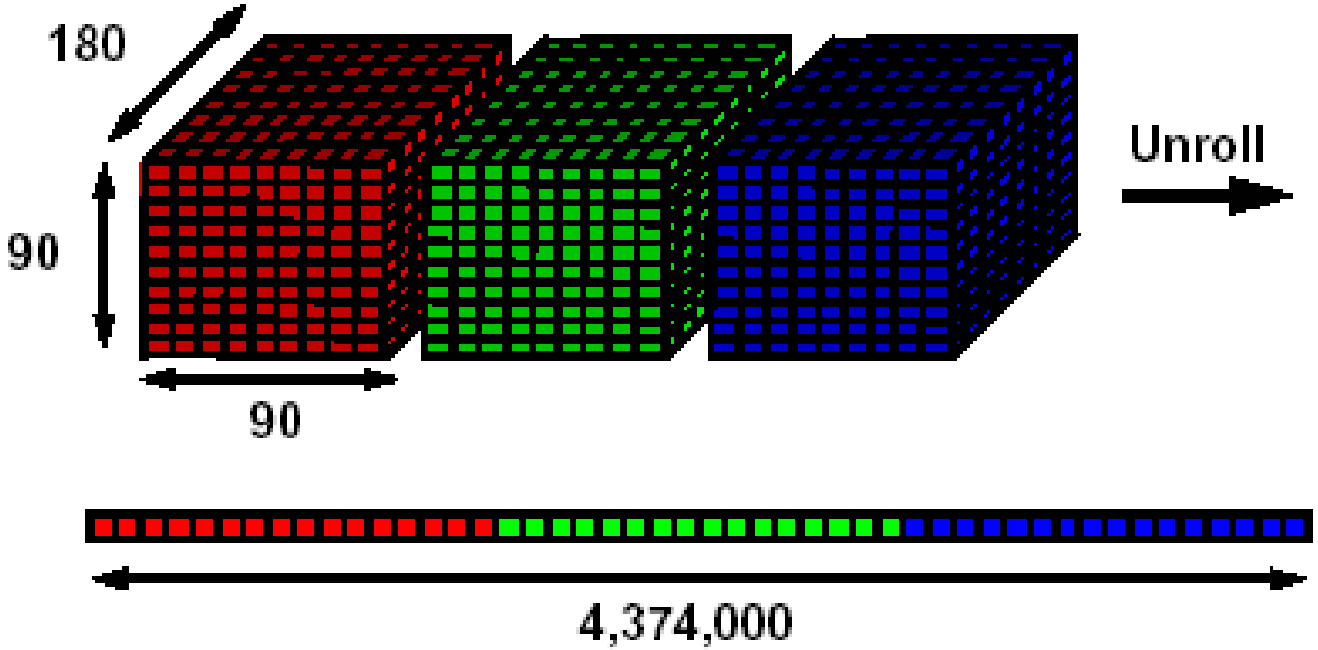
Linear Combinations of BRDFs (LCB)

- Can we find a linear combination of our existing BRDFs that match any new one?
- Requires only estimating 100 coefficients for source BRDFs
- Compute a set of 800 constraints that allow estimating these 100 coefficients robustly

α_1 + α_2 + α_3 + α_4 + ...=

BRDFs as Vectors in High Dimensional Space

- Each tabulated BRDF is a vector in 90x90x180x3 =4,374,000 dimensional space



Linear Analysis (PCA)

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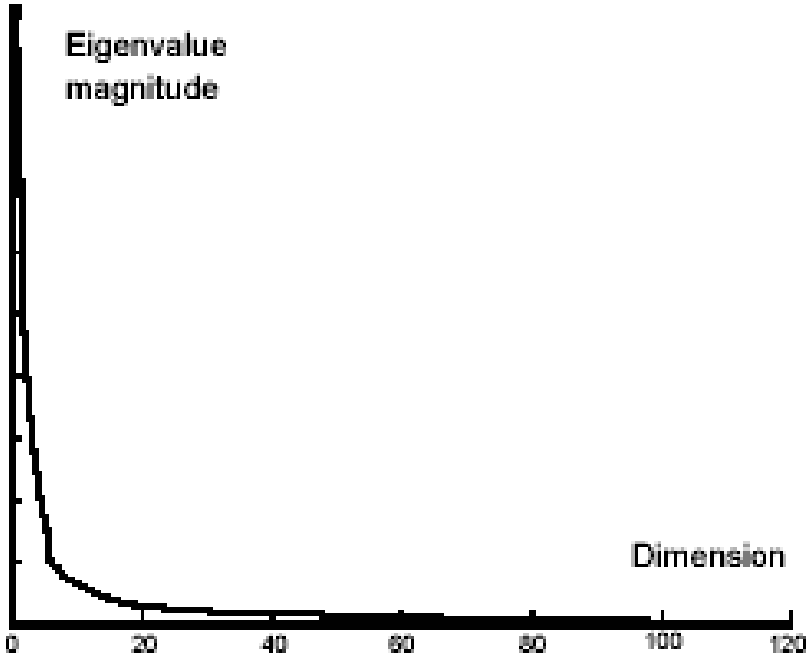
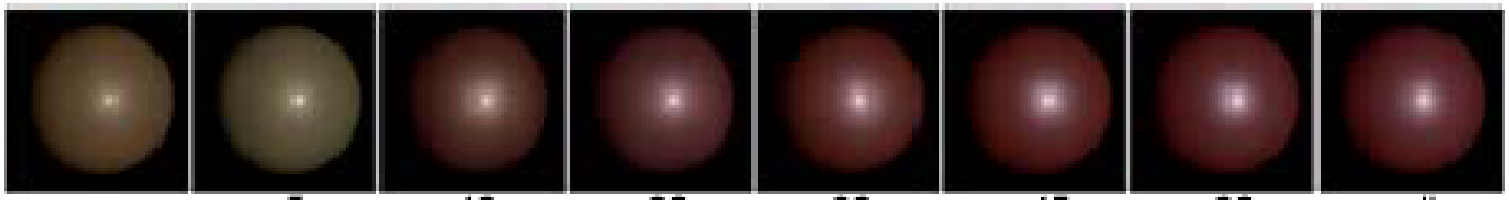
- Find optimal linear basis for our data set
- 45 components needed to reduce residue to under measurement error





Navigation Results

Adding Silver Trait

Navigation Results

Adding Specular Trait

Navigation Results

Adding Metallic Trait

Representing Physical Processes

Steel Oxidation

Next Step in the Appearance Food Chain

Textures

Spatially Varying BRDFs

CURET Database – [Dana, Nayar 96]

Next Step in the Appearance Food Chain

Why bother about measuring patches or spheres?

Why not measure the scenes themselves directly?

- Change only lighting (for Relighting)
- Change only viewpoint (Light Fields)
- Change both lighting and view point

Debevec et al. Siggraph 2000

VIDEO and DEMO for relighting

Next Step in the Appearance Food Chain

- Capture Light Fields directly by changing viewpoint

Levoy &Hanrahan, Gortler et al., Siggraph 96

See great presentation on the Graphics Lab website at Stanford.

Can we measure our way out of misery?

- WYSIWYG – ☺
- WYSIAYG - ☹

Dimensionality of Appearance

$$(x, y, t, \theta, \phi, \lambda)_{in} \rightarrow (x, y, t, \theta, \phi, \lambda)_{out}$$

General function = 12D

↓ Assume time doesn't matter (no phosphorescence)

↓ Assume wavelengths are equal (no fluorescence, raman scattering)

Scattering function = 9D

↓ Assume wavelength is discretized or integrated into RGB (This is a common assumption for computer graphics)

Single-wavelength Scattering function = 8D

$$(x, y, \theta, \phi)_{in} \rightarrow (x, y, \theta, \phi)_{out}$$

$$(x, y, \theta, \phi)_{in} \rightarrow (x, y, \theta, \phi)_{out}$$

Single-wavelength Scattering function = 8D

Ignore subsurface scattering (x,y) in = (x,y) out

Ignore dependence on position

Bidirectional Texture Function (BTF)
Spatially-varying BRDF (SVBRDF) = 6D

Bidirectional Subsurface Scattering Distribution Function (BSSRDF) = 6D

Ignore direction of incident light

Ignore dependence on position

Ignore subsurface scattering

Light Fields, Surface LFs = 4D

$$(x, y, \theta, \phi)_{out}$$

BRDF = 4D

$$(\theta, \phi)_{in} \rightarrow (\theta, \phi)_{out}$$

Assume isotropy

3D

Assume Lambertian

Measure plane of incidence

Texture Maps = 2D

$$(x, y)_{out}$$

2D

Low-parameter BRDF model

0D