BRDFs and Example-Based Shading

CS535

Daniel G. Aliaga

Department of Computer Science

Purdue University

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

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

(this diagram thanks to Srinivasa Narasimhan)

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

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

Assume Lambertian

3D

Measure plane of incidence

Texture Maps = 2D

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

2D

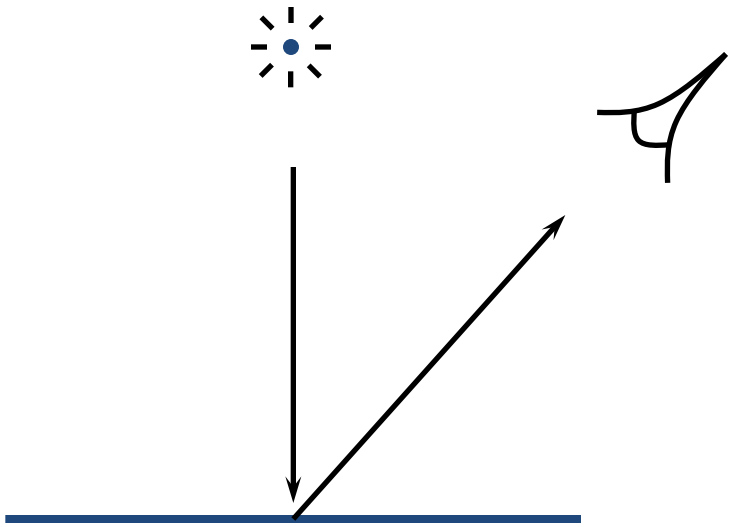
Low-parameter BRDF model

0D

Measuring BRDFs

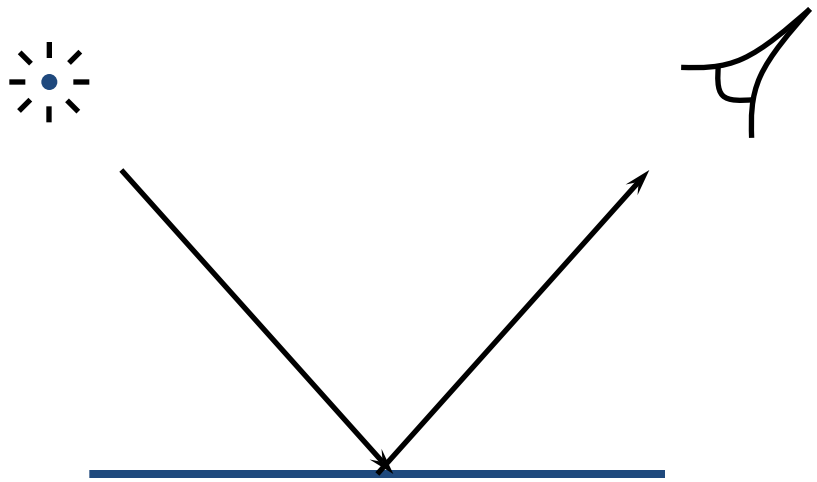
- BRDF is 4-dimensional, though simpler measurements (0D/1D/2D/3D) are often useful

Measuring Reflectance



0º/45º

Diffuse Measurement

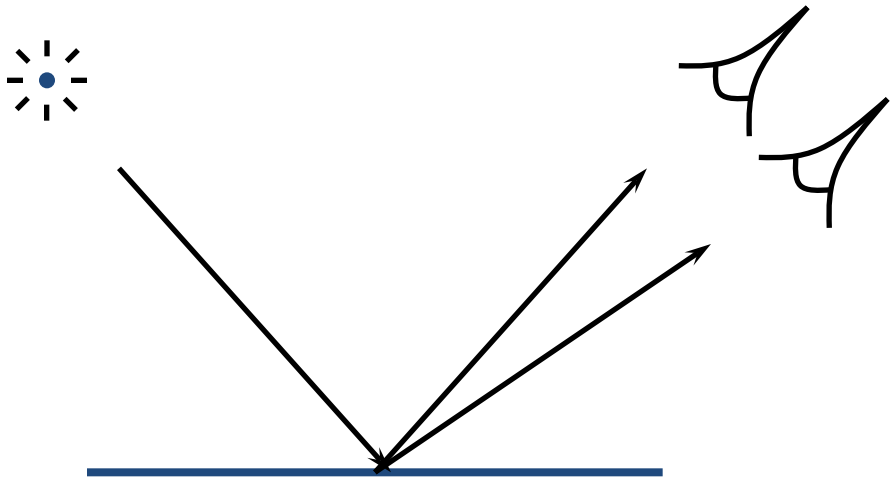


45º/45º

Specular Measurement

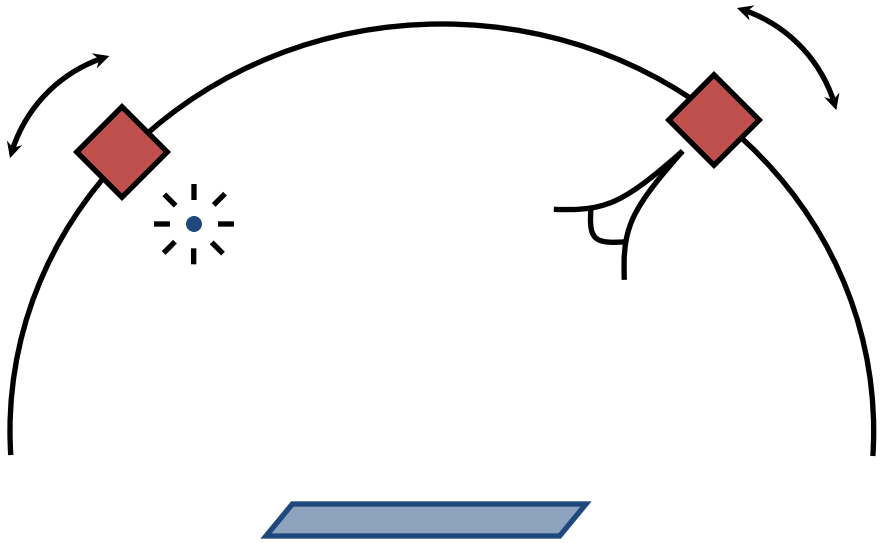
Gloss Measurements

- “Haze” is the width of a specular peak



BRDF Measurements

- Next step up: measure over a 1- or 2-D space



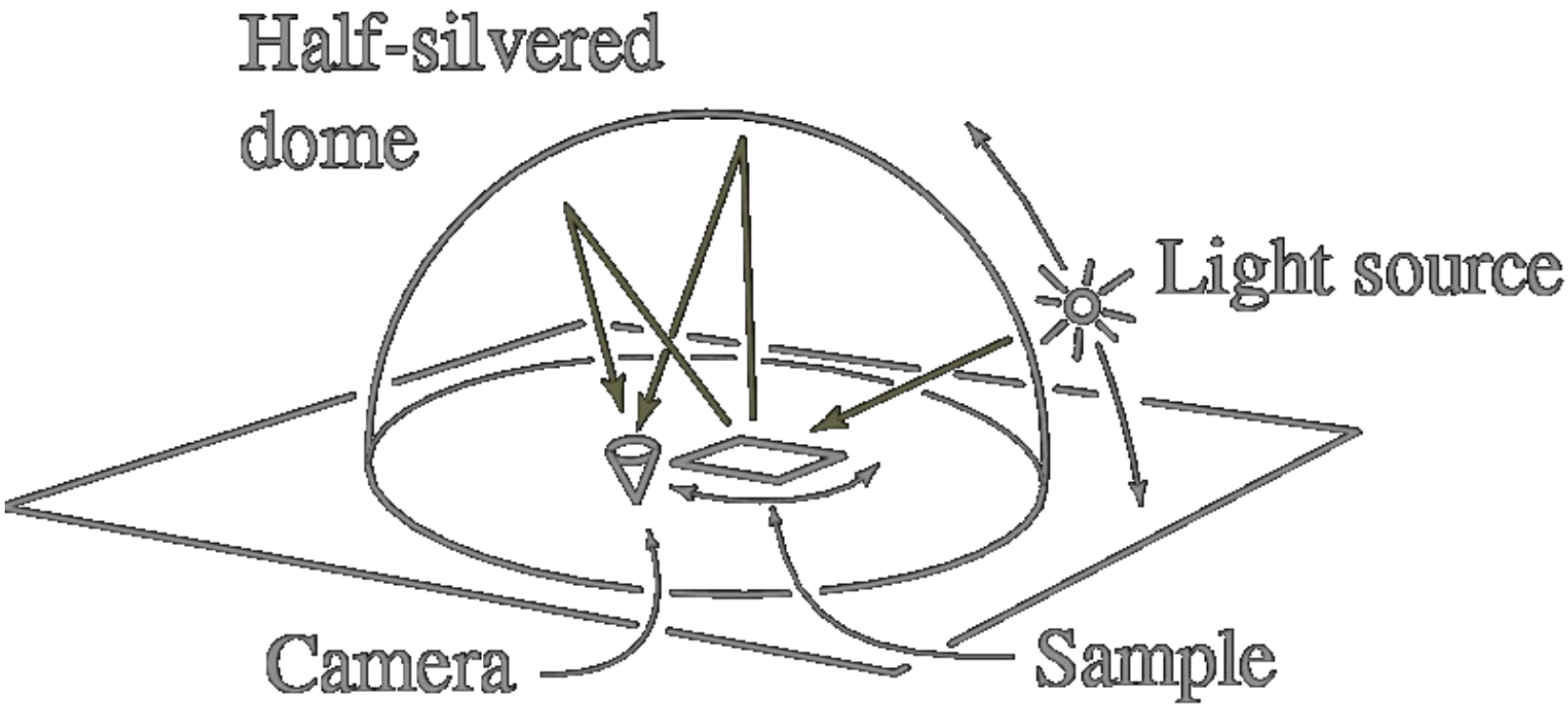
Gonioreflectometers

- Or a 4D space

Image-Based BRDF Measurement

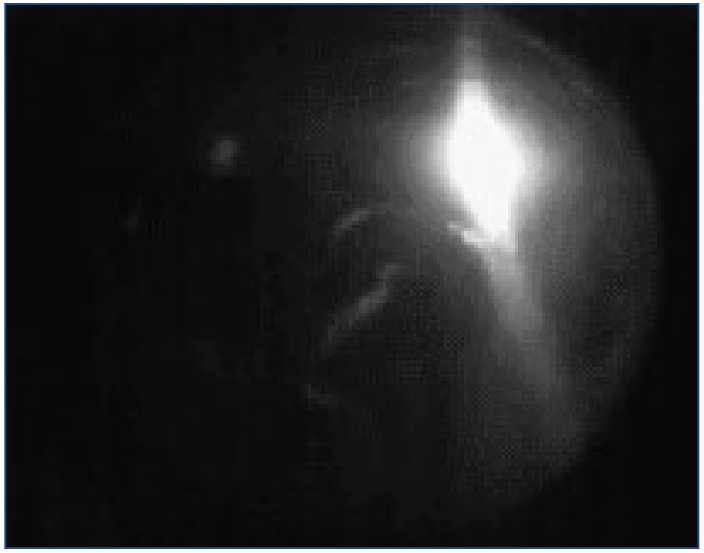
- A camera acquires with each picture a 2D image of sampled measurements
  - Requires mapping light angles to camera pixels

Ward's BRDF Measurement Setup

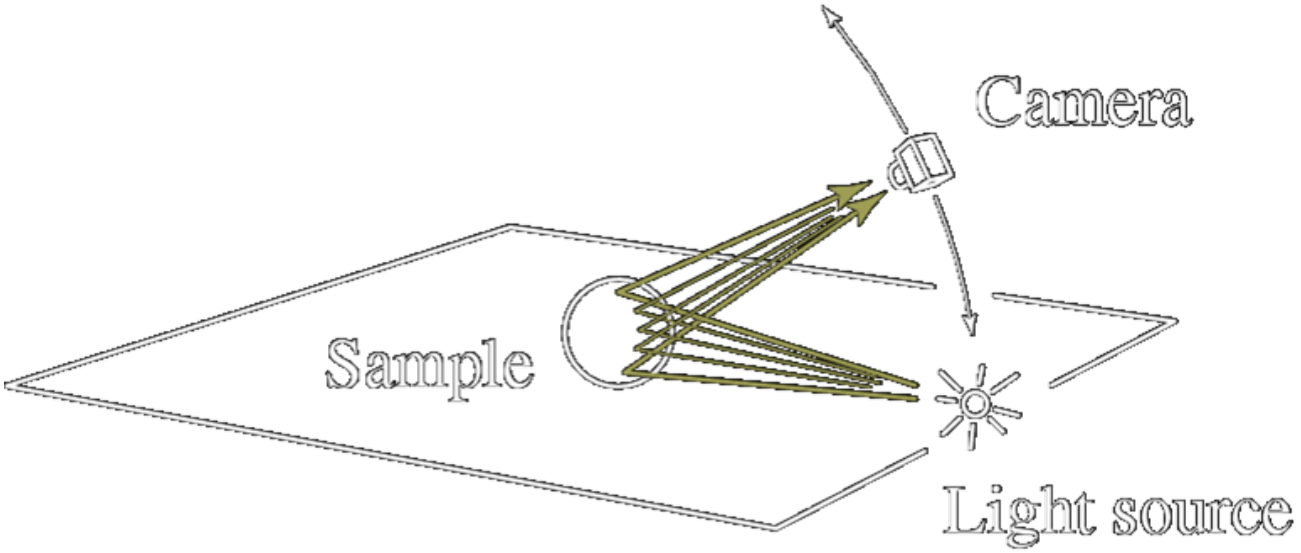


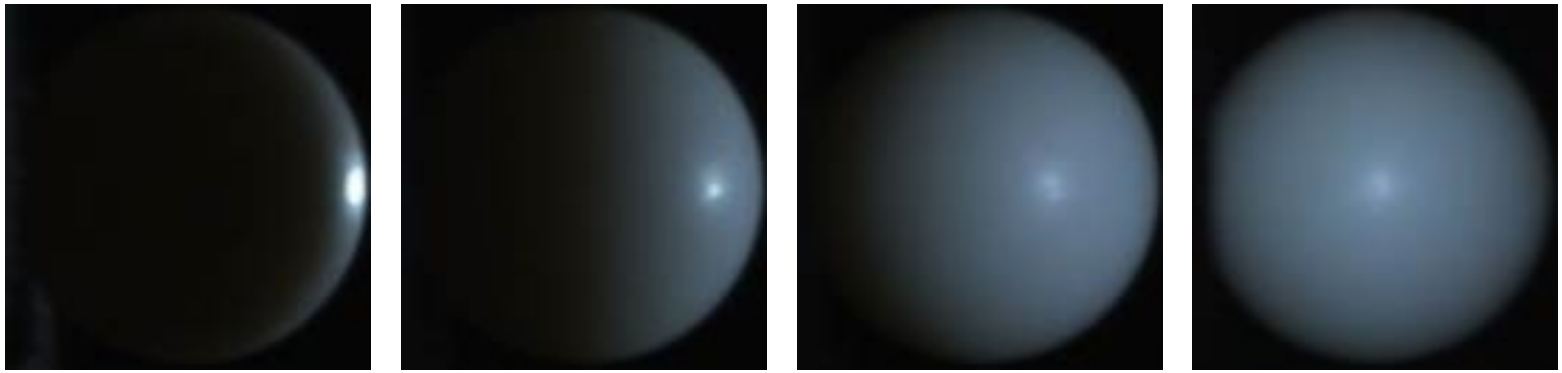
Ward's BRDF Measurement Setup

- Each picture captures light from a hemisphere of angles



Marschner et al.’s Modification





Example Measurement Process

Measurement

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

Measurement

SIGGRAPH2005

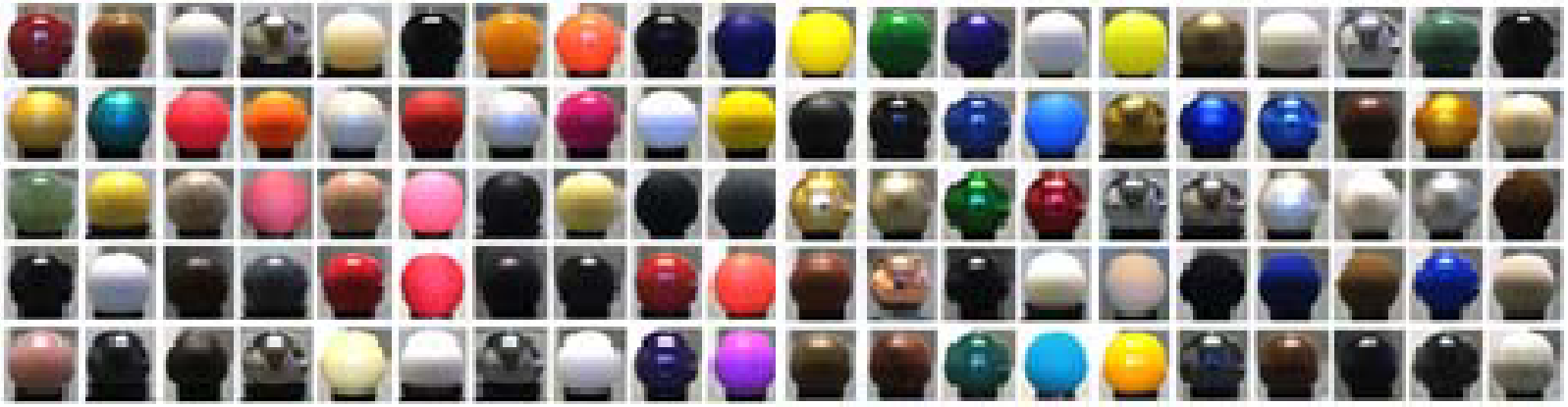
- Turntable
  - Kaidan MD-19
  - Computer-controlled
- Dark Room
  - Walls painted with flat black paint
- Spherical Samples

Calibration

- 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

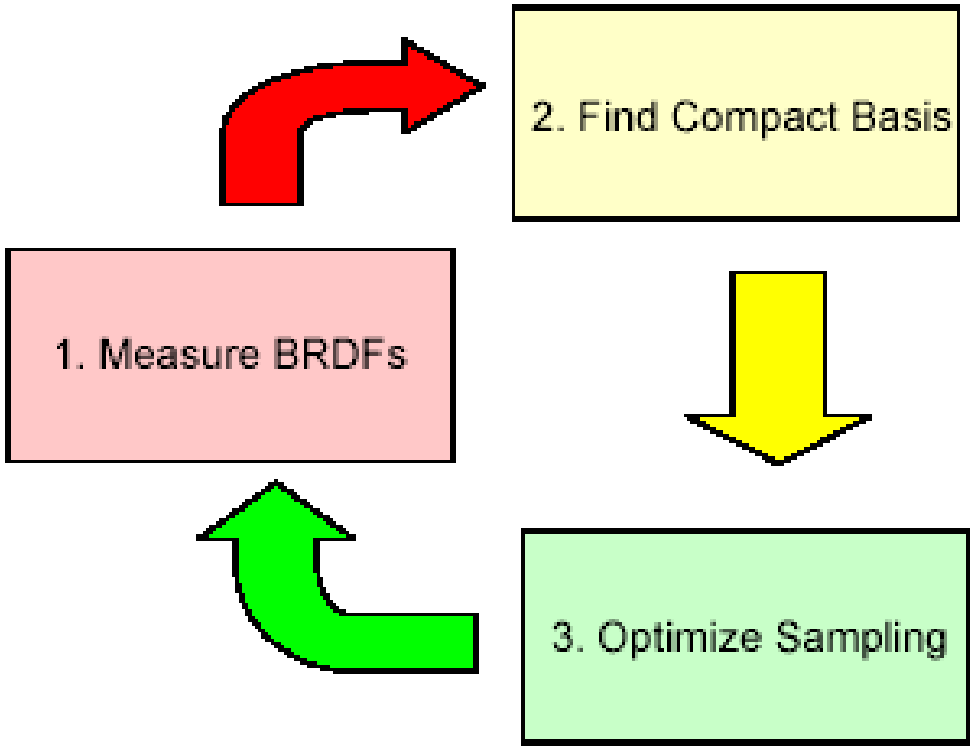

Nickel


Hematite


Gold Paint


Pink Felt

Measurement Process



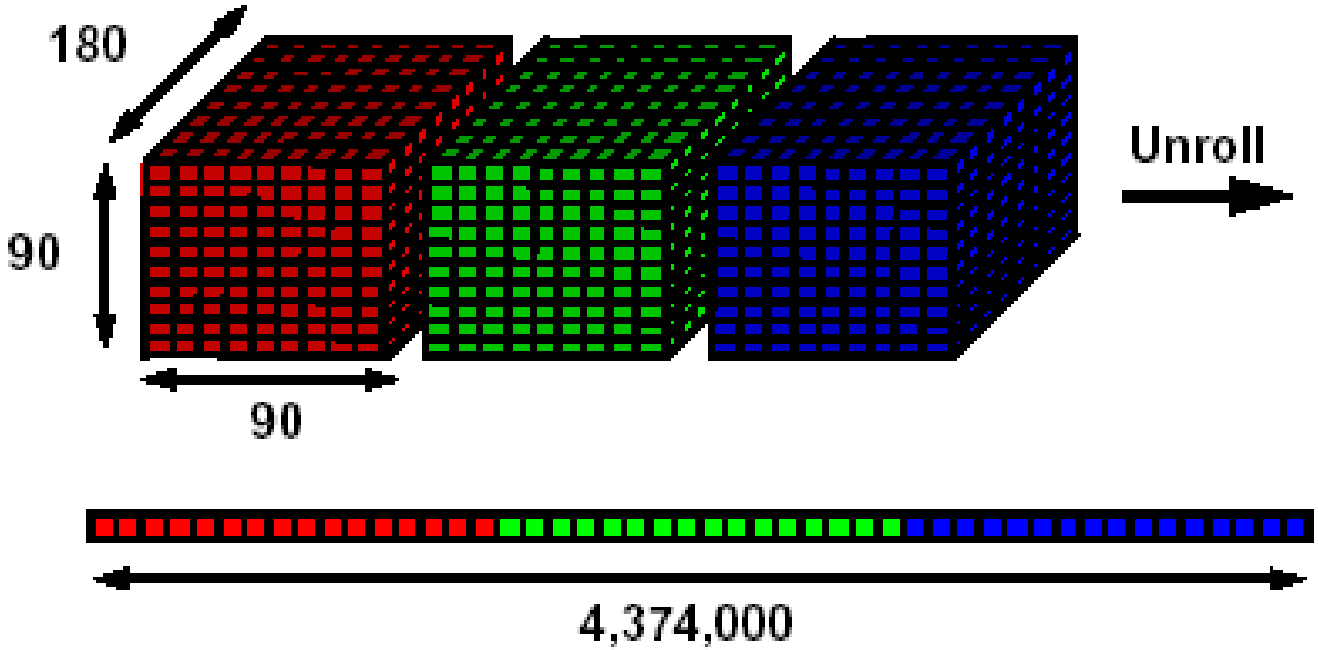
Linear Combinations of BRDFs (LCB)

- 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 + ...=

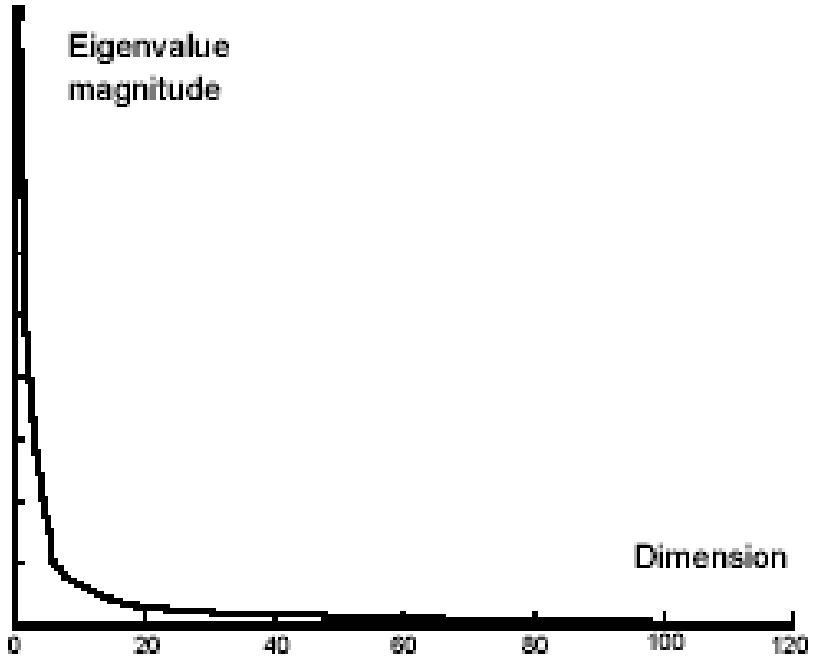
BRDFs as Vectors in High Dimensional Space

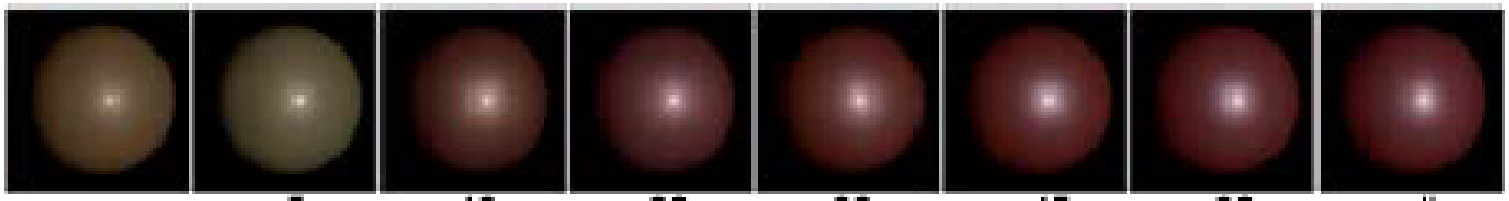
- Each tabulated BRDF is a vector in 90x90x180x3 =4,374,000 dimensional space



Linear Analysis (PCA)

- 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

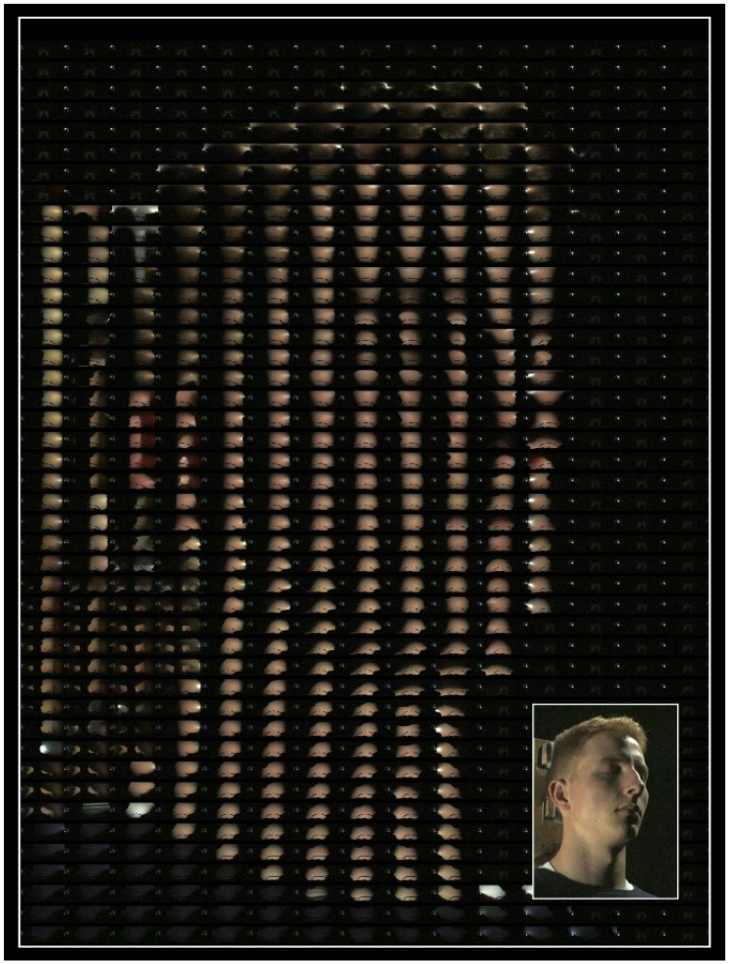
Adding Metallic Trait

Representing Physical Processes

Steel Oxidation

Human Face

- Don’t both with resampling, just acquire all options!



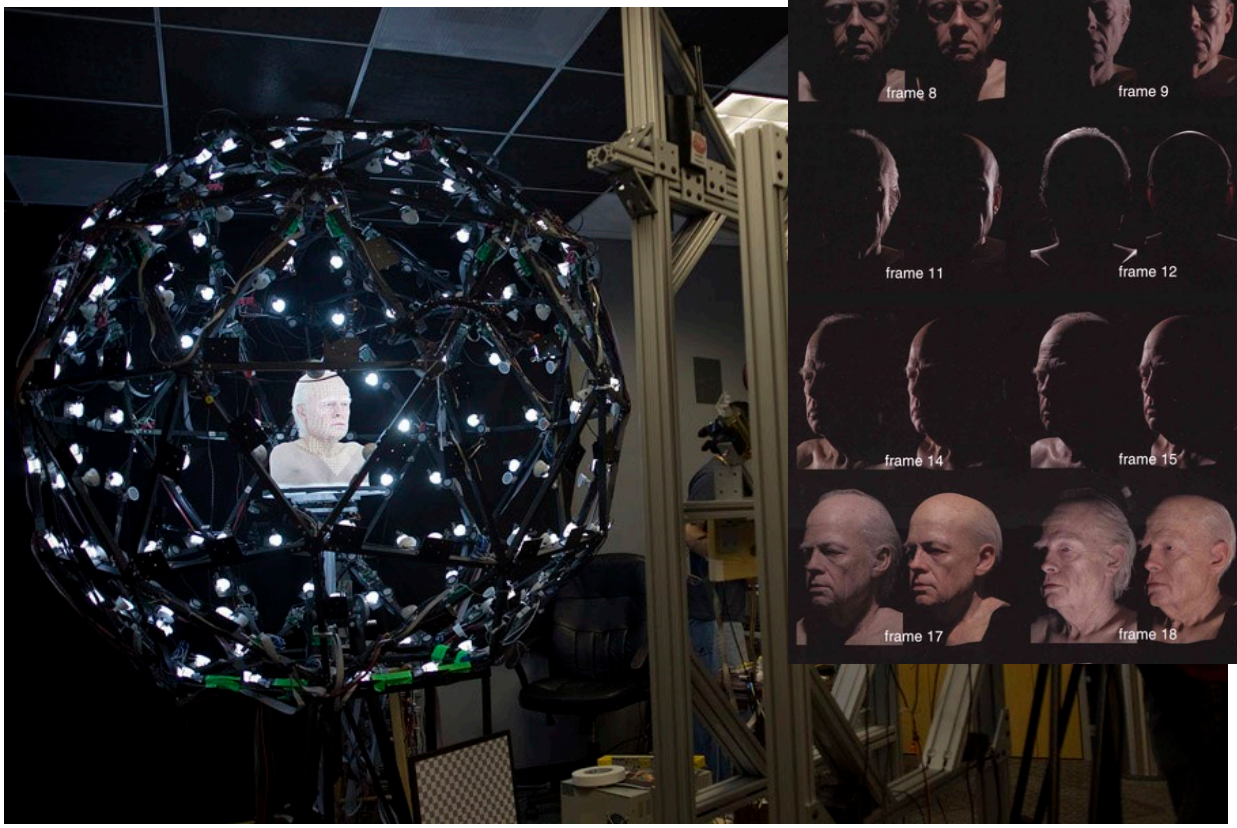
Debevec et al.: Light Stage 1

[**demo**]

[demo]

Benjamin Button…

- Light Stages



Light Stages

- Up to 8M in diameter
- Up to 6,666 LED lights
- Up to 990 Hz frames per second

  (33 repeating light conditions)

Shape and Material by Example

- http://grail.cs.washington.edu/pub/papers/HertzmannSeitzCVPR2003.pdf
- Method:
  - Performs photometric reconstruction
  - But they ALSO exploit “orientation consistency” so that material can be copied (i.e., propagated) from example to reconstruction
  - They also cluster the occurrences to one of the determined distinct materials