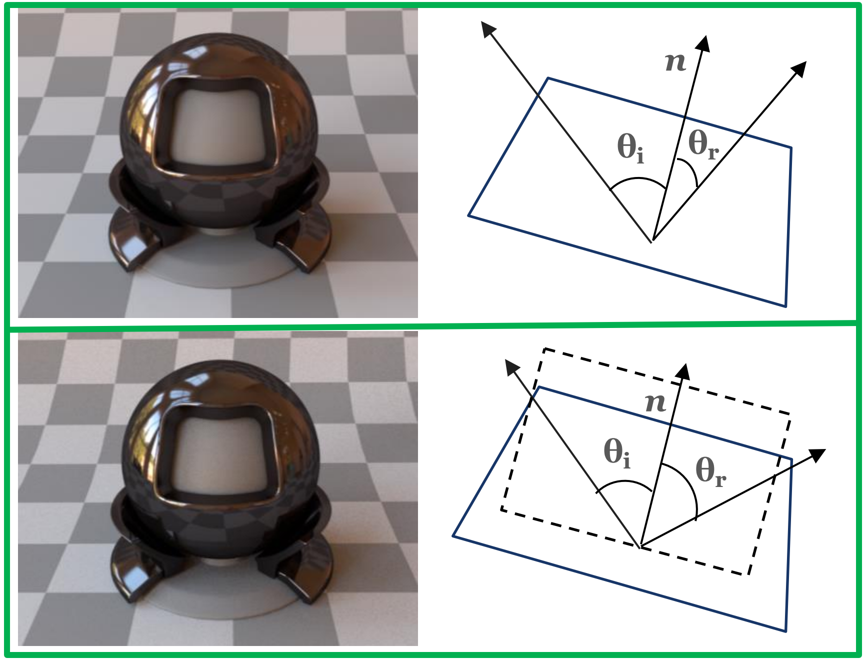
Simplifying BRDF Acquisition

Dual Degree Project

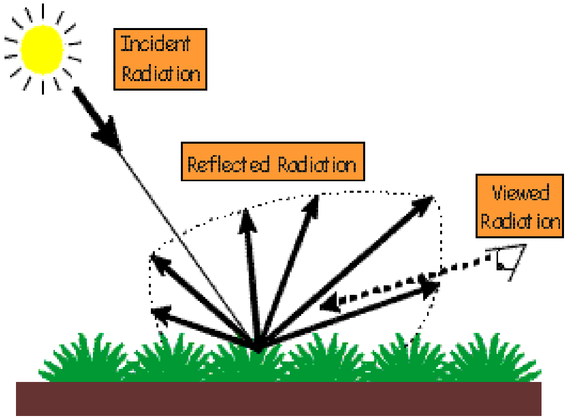


Presented by: Shubham Chitnis

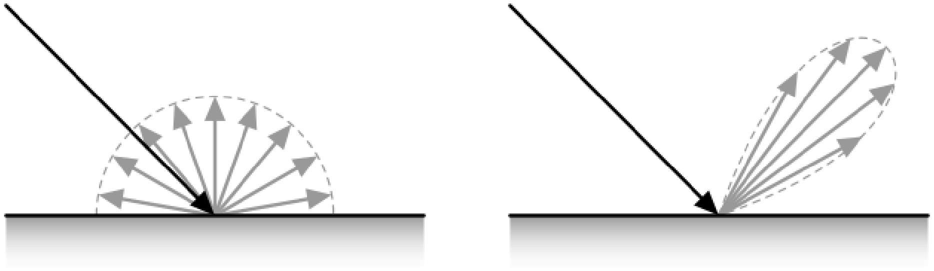
Supervised by: Prof. Sharat Chandran

Background

What is BRDF?



Determines how we perceive objects



Matte/Diffuse

Glossy/Specular

Formal definition	The ratio of the outgoing radiance from a point on the material to the incoming irradiance for a given incidence and reflection angle pair.

[1]

Background

Parametric Representation

ABC model based on **Microfacet theory**

Parameter estimation: 9 total (k_d^{RGB}, A^{RGB}, B, C, *eta*) estimated using least squares optimization on BRDF data with a weighted L2 loss function.

Here,

k_d: diffuse albedo

A,B,C: microfacet distribution parameters

η: index of refraction

ABC distribution variant of Cook-Torrance

$$f_r(\mathbf{l}, \mathbf{v}) = \frac{k_d}{\pi} + \frac{F(\theta_h) G(\mathbf{n}\cdot\mathbf{l}, \mathbf{n}\cdot\mathbf{v}) S(\sqrt{1-(\mathbf{n}\cdot\mathbf{h})}}{(\mathbf{n}\cdot\mathbf{l})(\mathbf{n}\cdot\mathbf{v})}$$

(Geometric attenuation)

$$G = \min\left\{1, \frac{2(\mathbf{n}\cdot\mathbf{h})(\mathbf{n}\cdot\mathbf{v})}{(\mathbf{v}\cdot\mathbf{h})}, \frac{2(\mathbf{n}\cdot\mathbf{h})(\mathbf{n}\cdot\mathbf{l})}{(\mathbf{v}\cdot\mathbf{h})}\right\}$$

(Fresnel factor)

$$F = \frac{(g-c)^2}{2(g+c)^2}\left\{1 + \frac{[c(g+c)-1]^2}{[c(g-c)+1]^2}\right\}$$

(ABC distribution)

$$S(f) = \frac{A}{(1+Bf^2)^C}$$

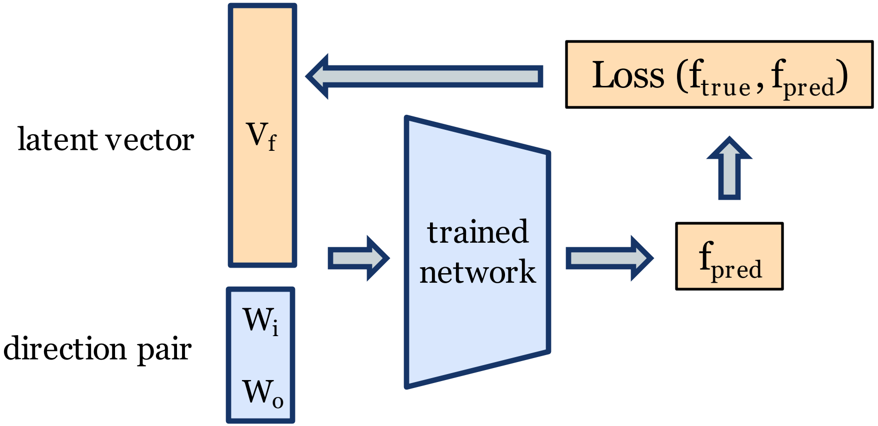
n: surface normal
l: incoming angle
v: outgoing angle
h: half angle

c: **v.h**
g: $\eta^2 + c^2 - 1$
η: index of refraction

[2]

Background

Neural Layered BRDF



Inputs
- Incoming direction
- Outgoing direction
- Material-specific latent vector

Back-propagation
- For learning a new material
- Freeze network weights
- Optimize V_f using BRDF data

[4]

Problem Description

Motivations:

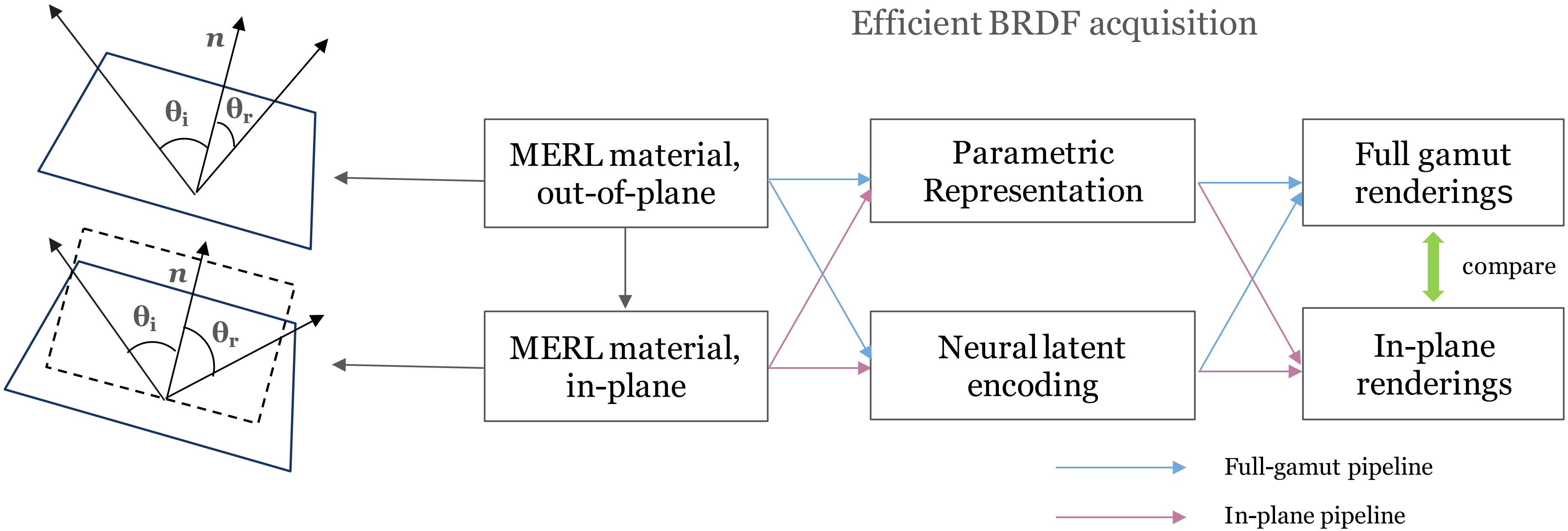
BRDF acquisition is expensive, requiring multiple hours (even days) for material capture forcing us to devise more efficient ways for BRDF capture.

Action items:

- We demonstrate that a small subset of *in-plane* angles sufficiently represents isotropic BRDFs.
- We further generate reduced BRDF datasets and compare their fit qualities using parametric models.

Scope	Prove in-plane comparable to full-data ✔	Test existing models for reduced data ✔
Out-of-scope	Propose completely new BRDF representations ✘	Compare between existing representations ✘

Problem Description



Method

Data Description (MERL)

Publicly available dataset for 100+ isotropic materials

BRDF datapoints in millions (tristimulus domain)

Granularity (polar and azimuthal angles):

- 10° intervals for incoming polar angle
- 1° intervals for outgoing polar angle
- 1° intervals for outgoing azimuthal angle

Samples: *tungsten carbide, blue acrylic, brass, nylon, specular black phenolic*

[5]

Method

Data Description (Packaging print)

BRDF measured for 31 wavelengths (390–730 nm at 10 nm intervals)

Granularity (incident and viewing angles):

- 5° intervals for diffuse region
- 1° intervals for specular region.

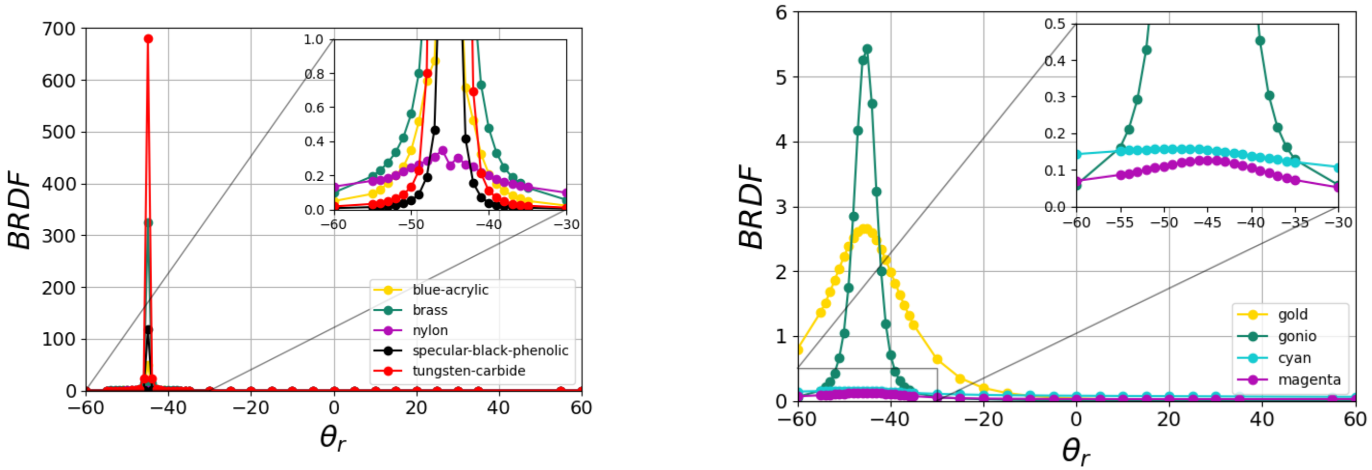
Samples: *Gold, Cyan, Magenta, Gonio*

[6]

Method

Data Description

Picked materials with diverse optical properties: diffuse, light-specular, heavy-specular, goniochromatic



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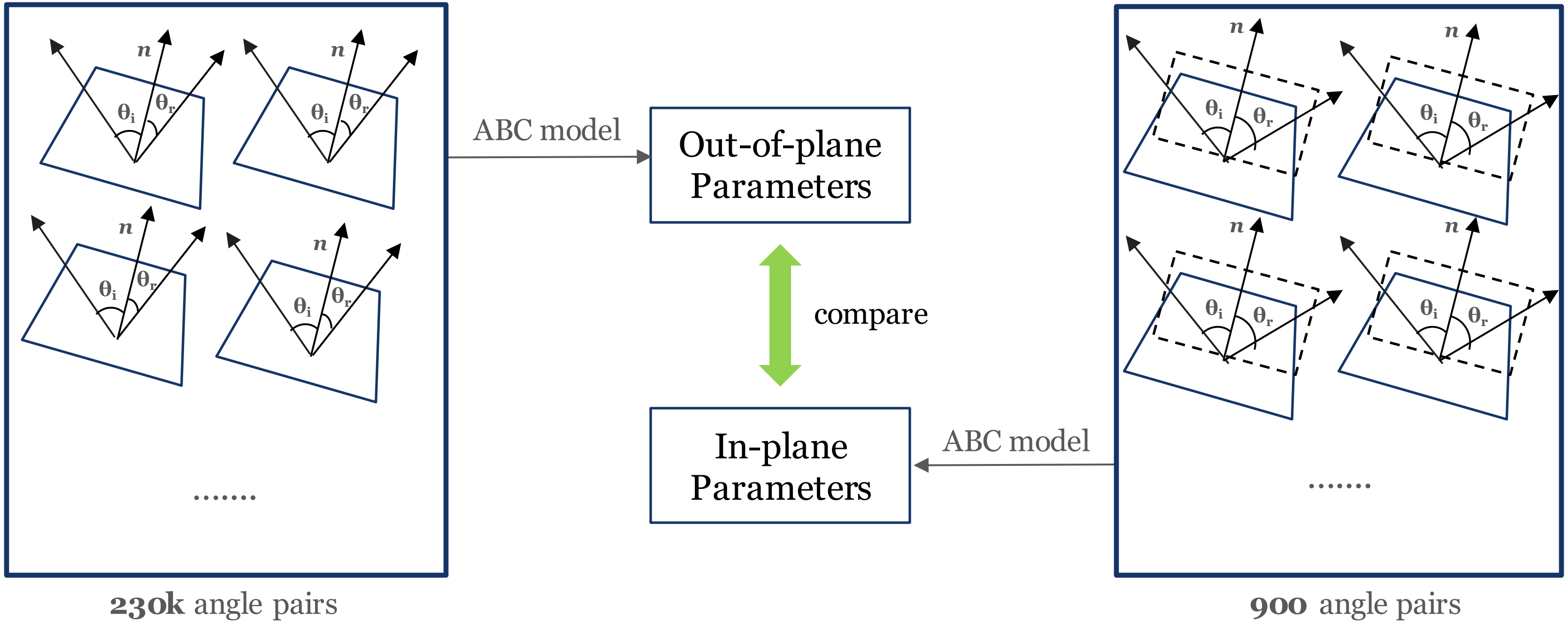
[2]

Method

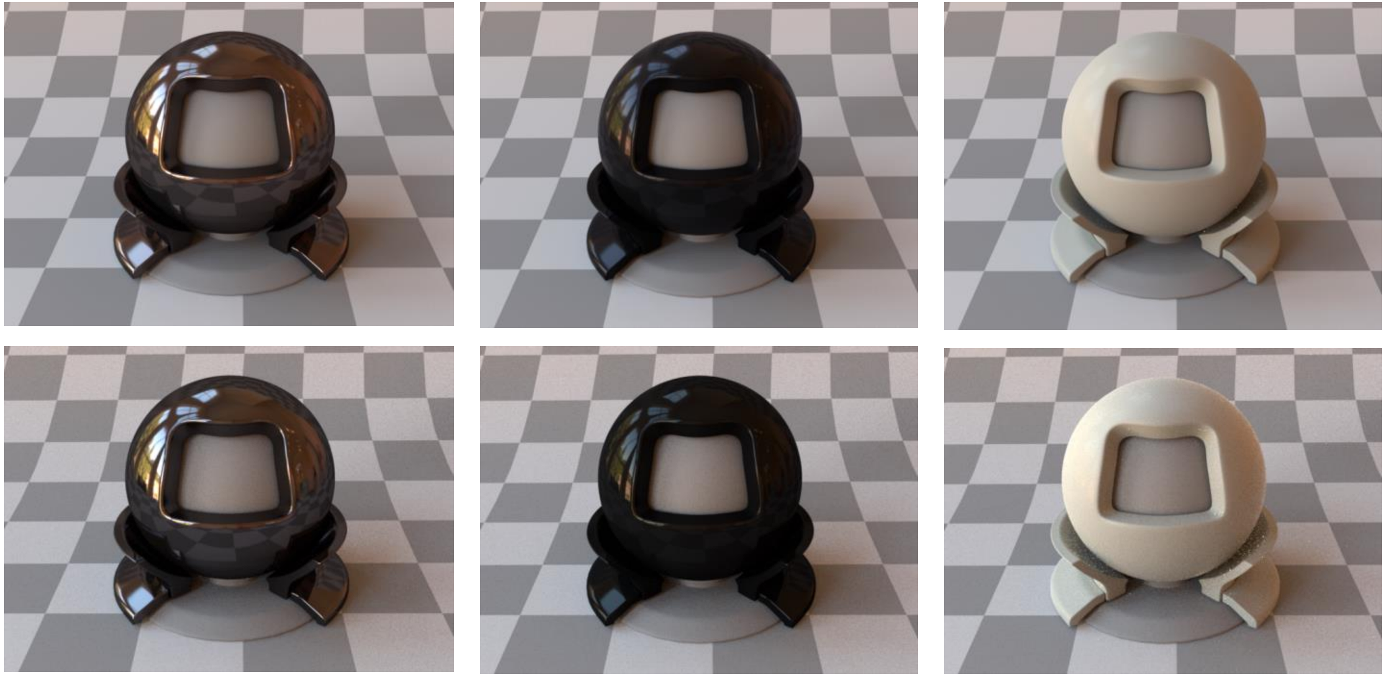
In-plane vs Out-of-plane (ABC Model)



Results (ABC Model)

Renderings (MERL)

tungsten-carbide | specular-black-phenolic | nylon



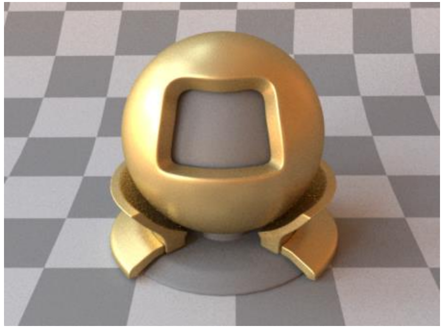
out-of-plane

in-plane

Results (ABC Model)

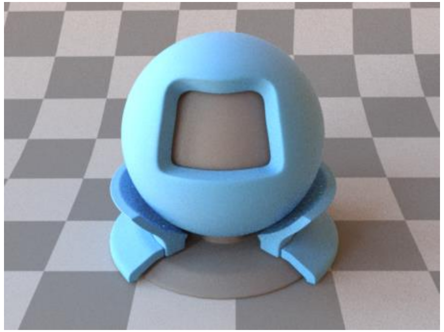
Renderings (Packaging)

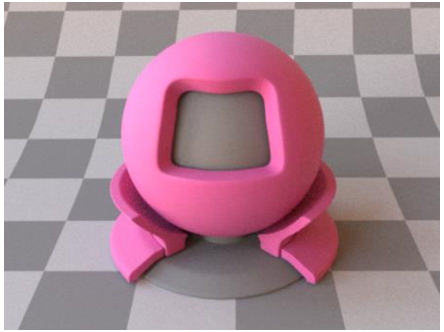
gold



gonio

cyan



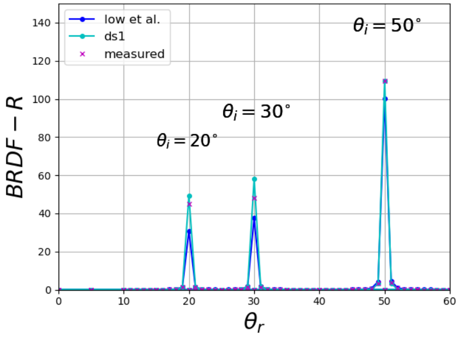


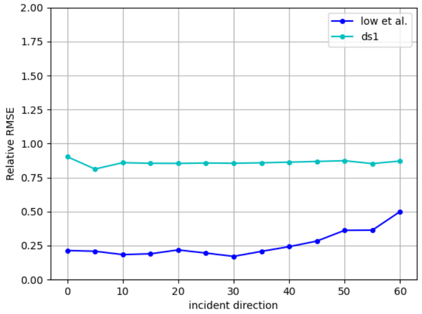
magenta

Results (ABC Model)

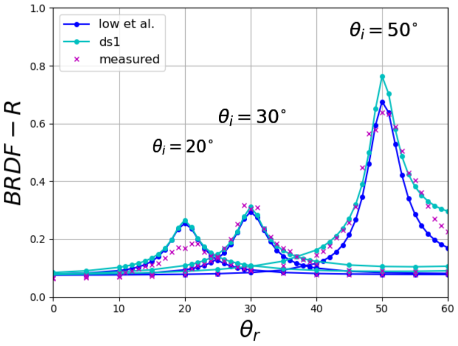
BRDF and relative-rmse plots

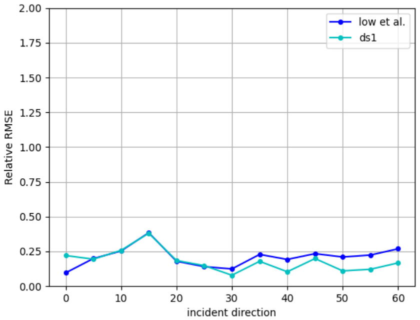
specular-black-phenolic



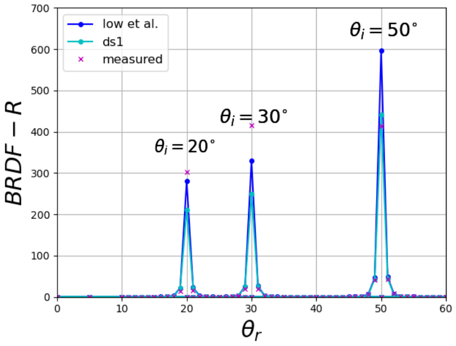


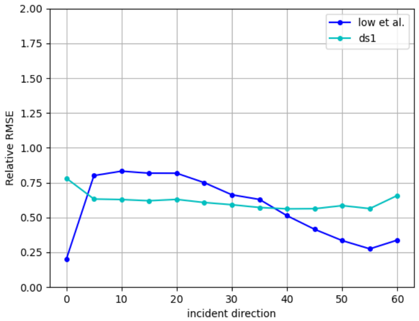
nylon



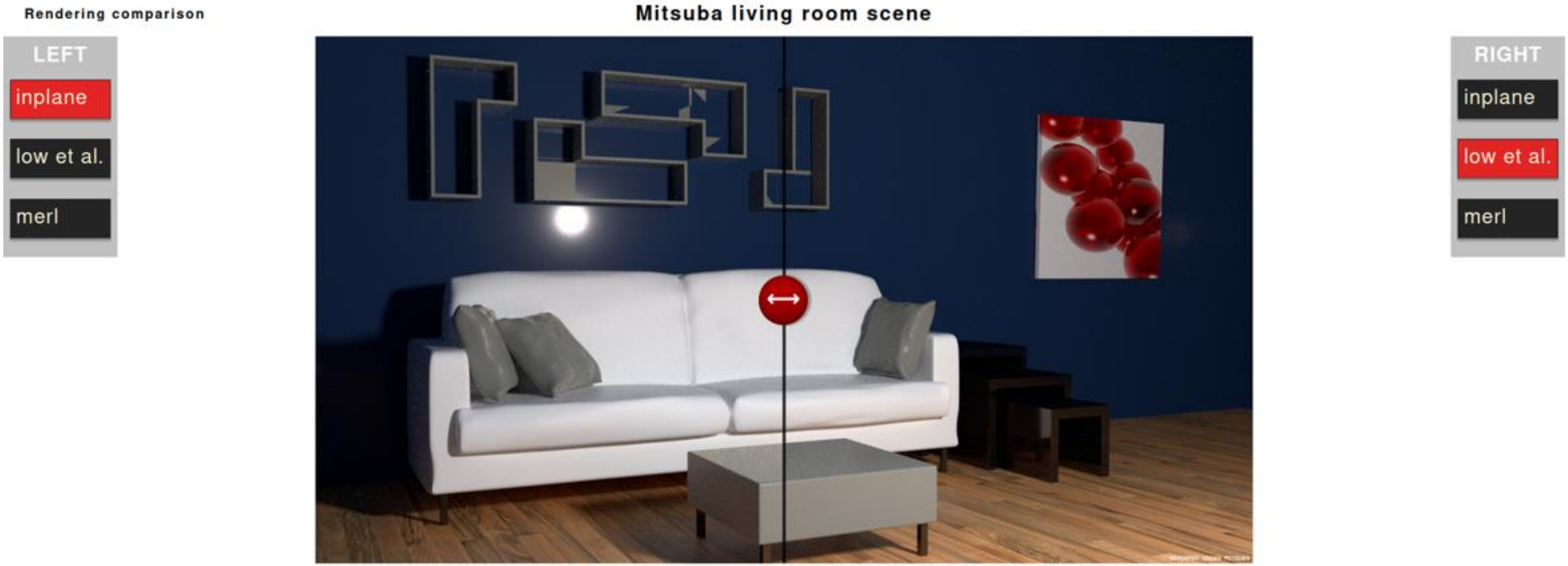


tungsten-carbide





Results (ABC Model)

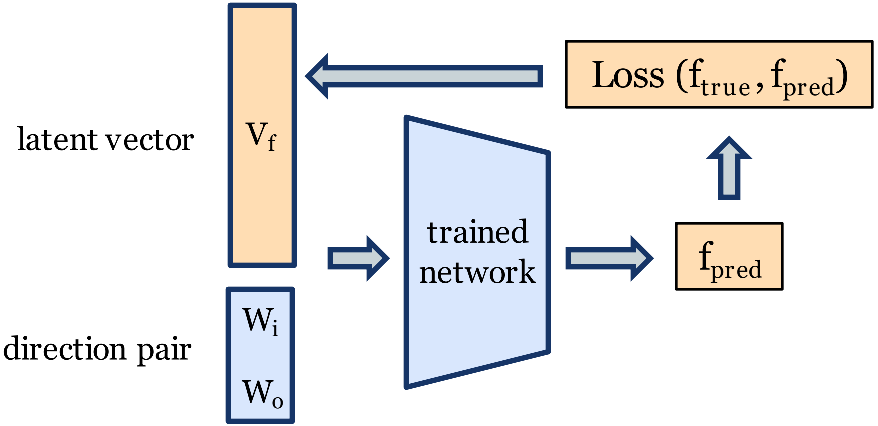


[link]

"Modern living room" by [Wig42]

Background

Neural Layered BRDF



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[4]

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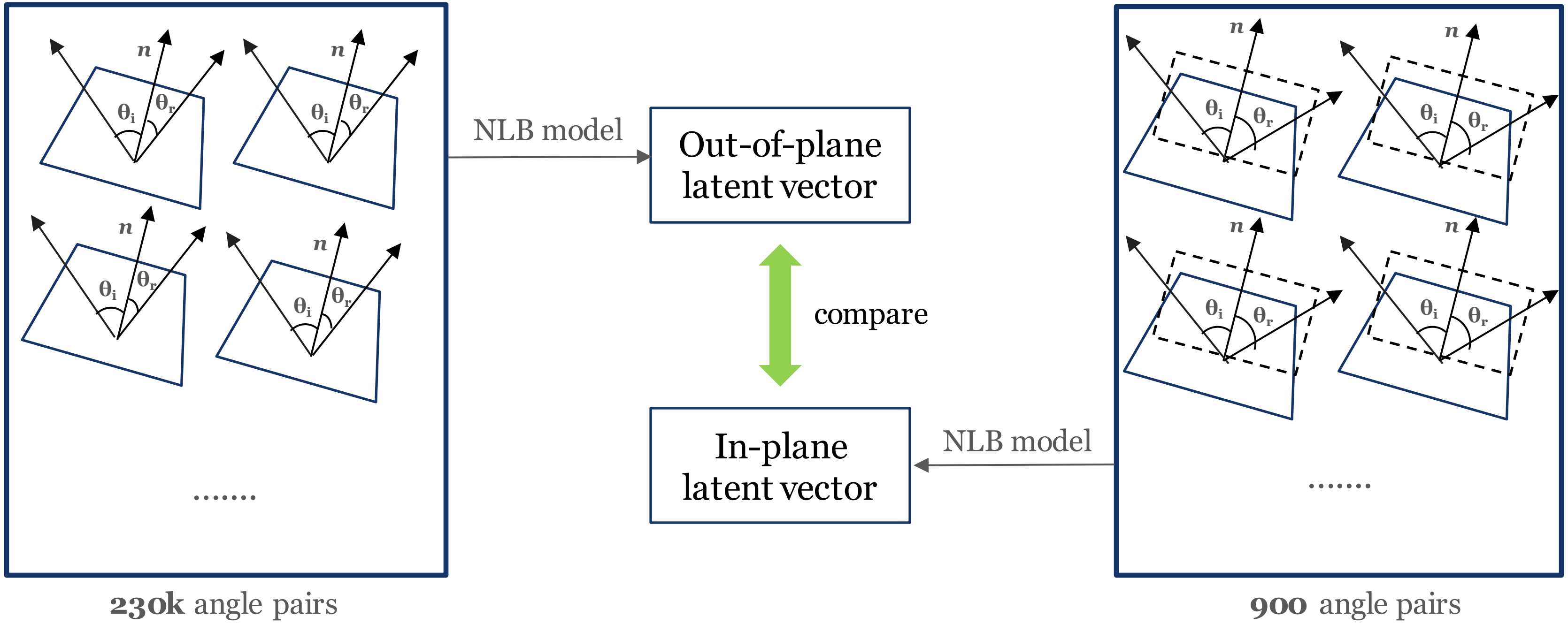
In-plane vs Out-of-plane (NLB Model)



Results (NLB Model)

Renderings (MERL)

nylon tungsten-carbide specular-black-phenolic

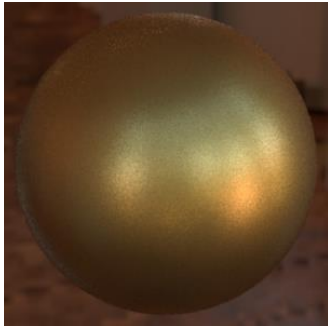
out-of-plane

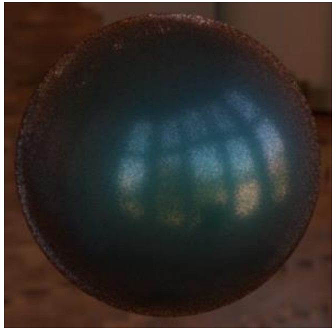
in-plane

Results (NLB Model)

Renderings (Packaging)

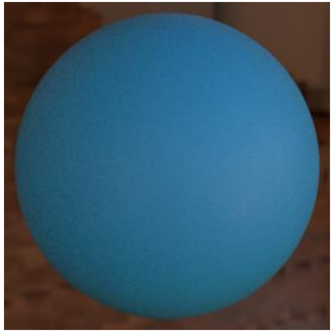
gold

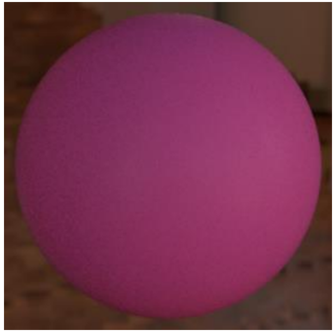




gonio

cyan



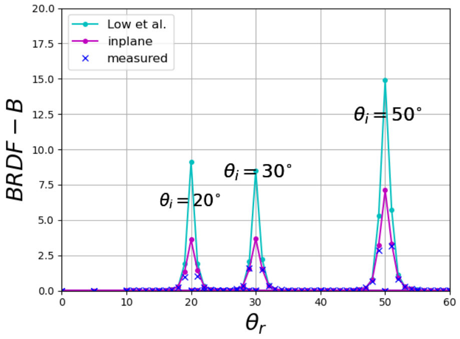


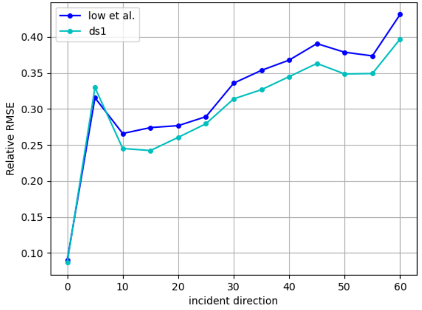
magenta

Results (NLB Model)

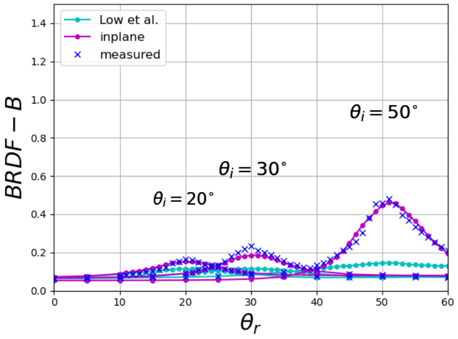
BRDF and relative-rmse plots

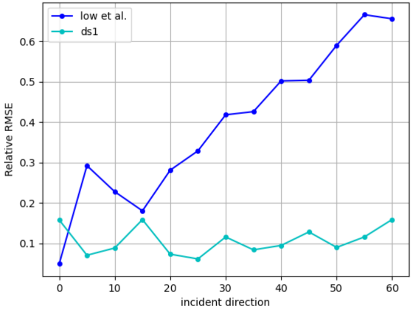
specular-black-phenolic



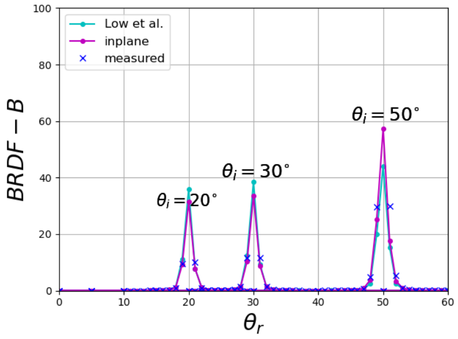


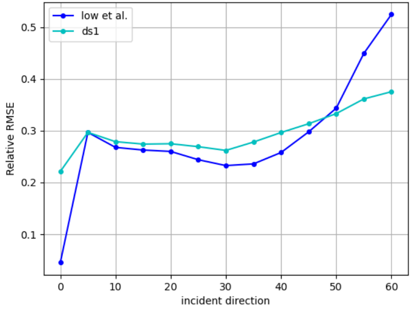
nylon





tungsten-carbide





Ablations

Progressively reduce dataset (DS1-DS4) from 900 angle pairs to 6 angle pairs

ABC parameters obtained through least squares optimization. NLB latent vector obtained using backprop shown earlier.

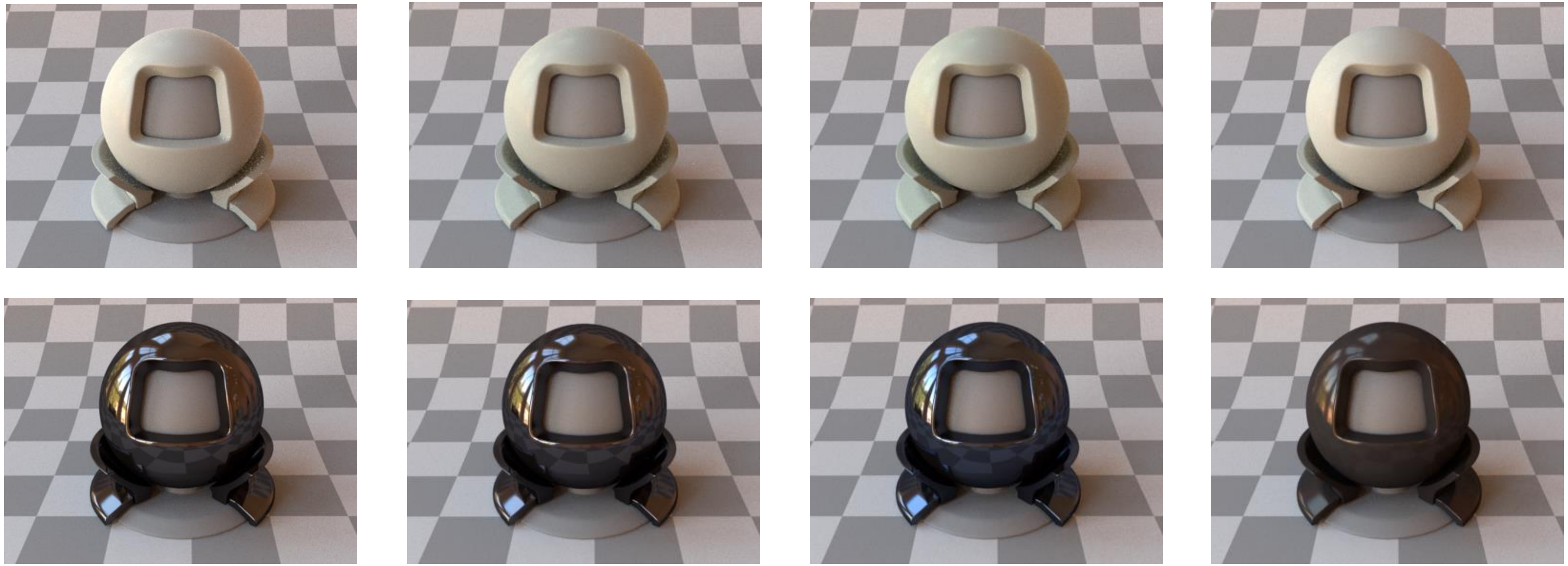
Dataset	θ_i **interval**	θ_r **interval: Diffuse**	θ_r **interval: Glossy**
DS1	5°	5°	1°
DS2	15°	10°	2°
DS3	30°	20°	3°

Dataset	**Incoming angle** (θ_i°)	**Outgoing angle** (θ_r°)
DS4	30°	$-60^\circ, -20^\circ, 20^\circ, 28^\circ, 36^\circ, 60^\circ$

Ablations (ABC Model)

Renderings (MERL)

ds1 ds2 ds3 ds4

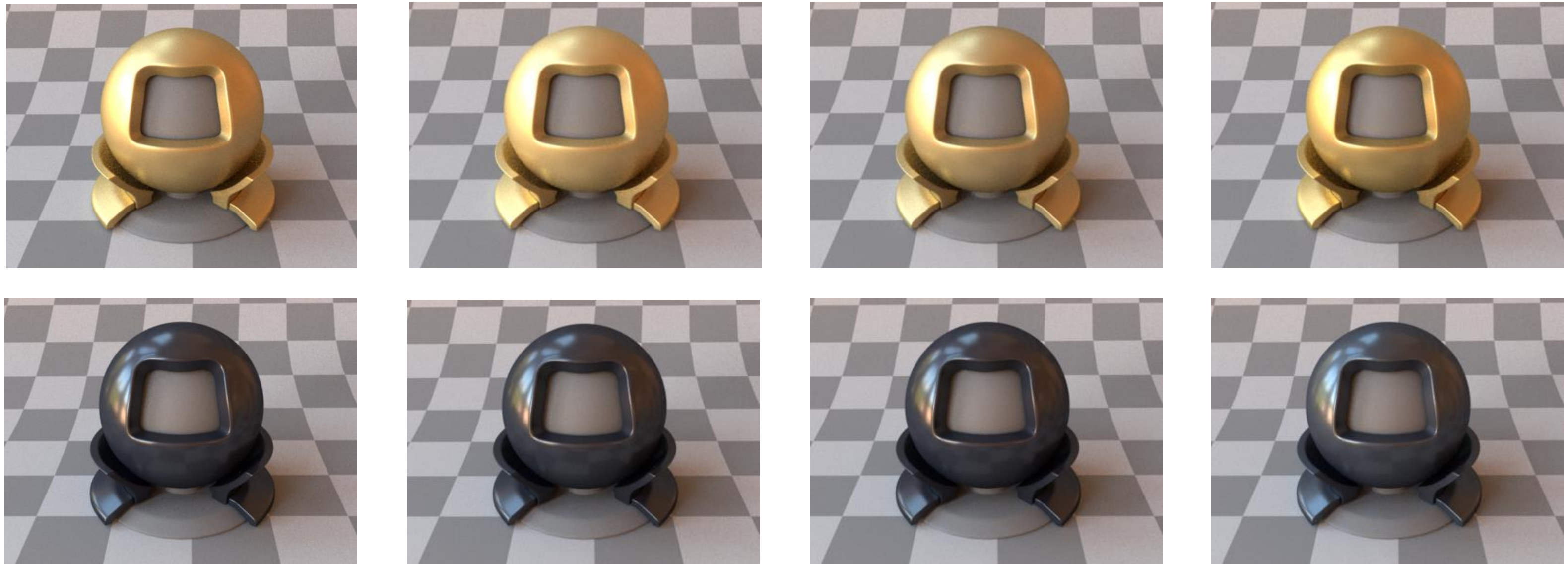


nylon

tungsten-carbide

Ablations (ABC Model)

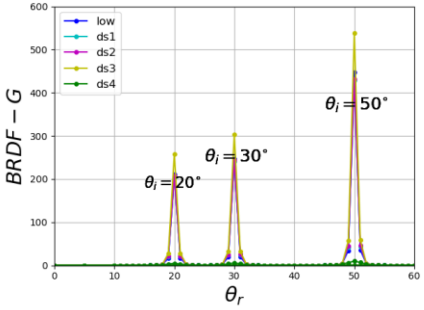
Renderings (Packaging)

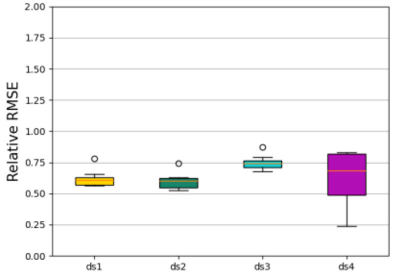


Ablations (ABC Model)

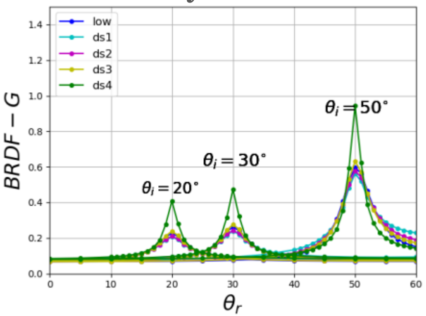
BRDF and relative-rmse plots

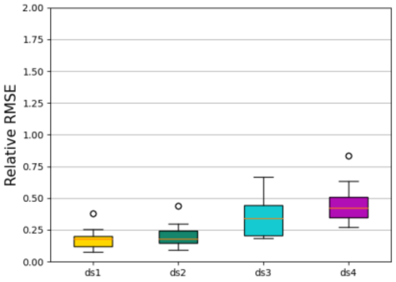
tungsten-carbide



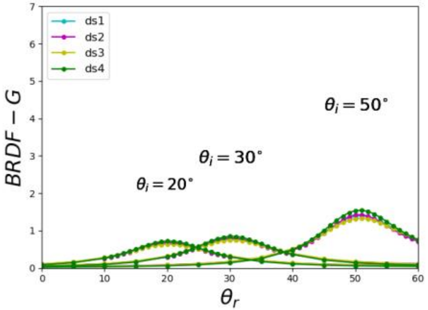


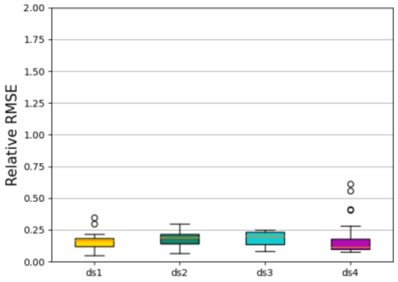
nylon



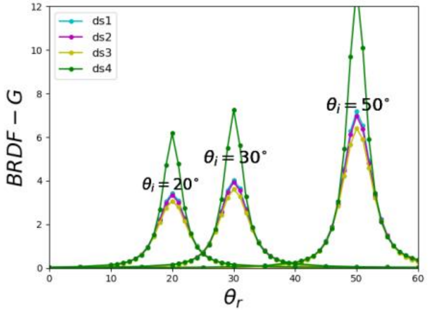


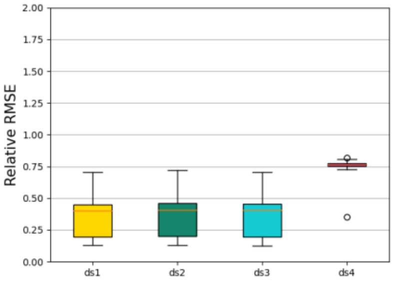
gold





gonio

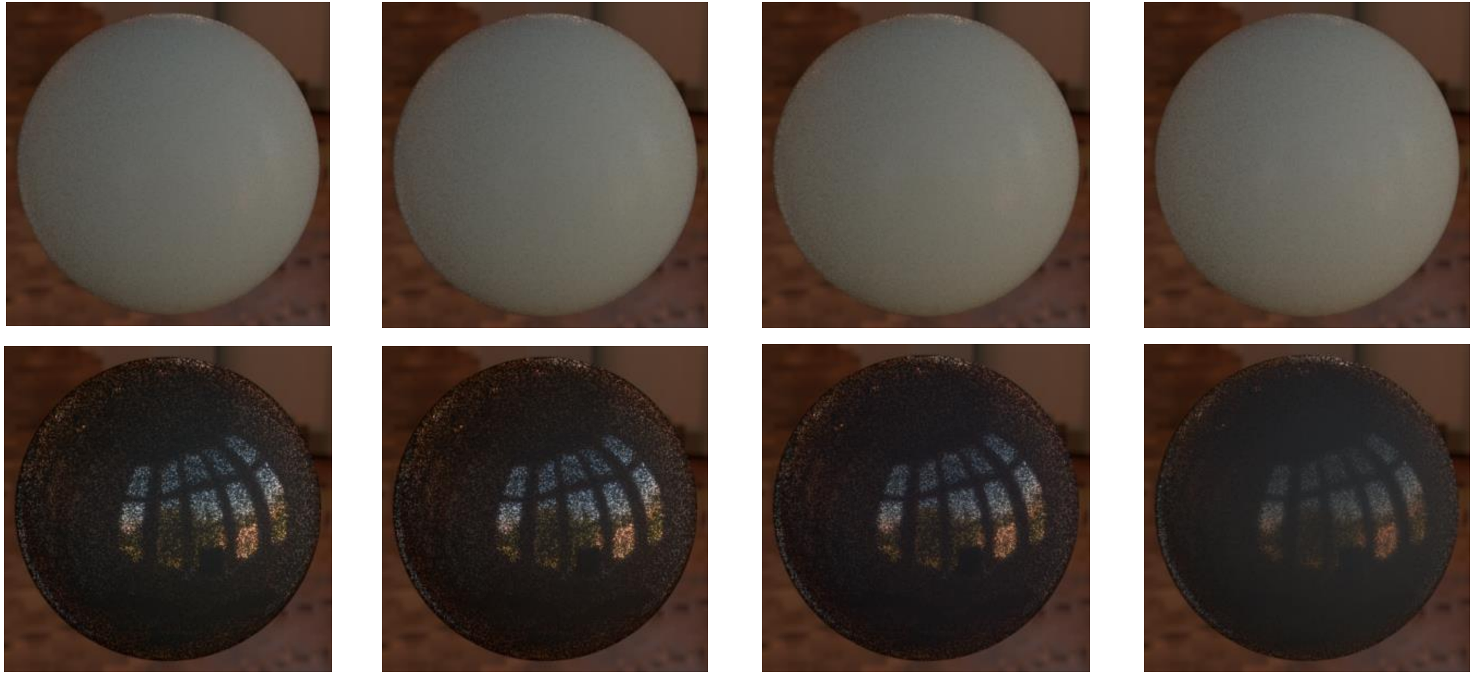




Ablations (NLB Model)

Renderings (MERL)

ds1 ds2 ds3 ds4



nylon

tungsten-carbide

Ablations (NLB Model)

Renderings (Packaging)

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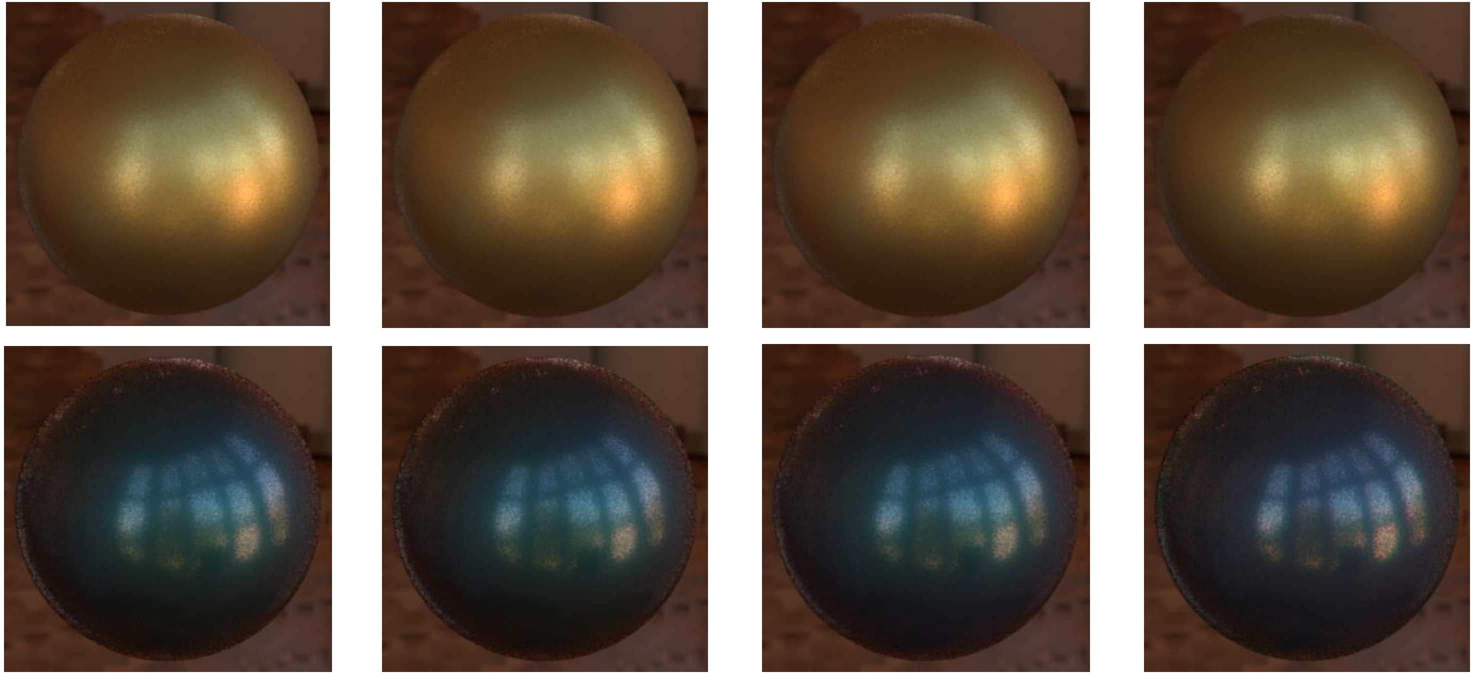


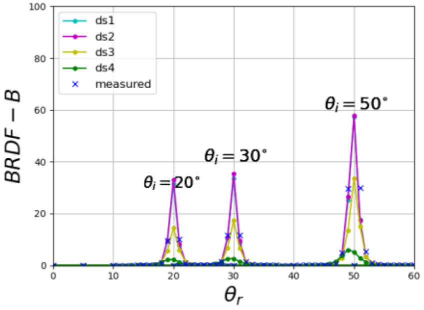
gold

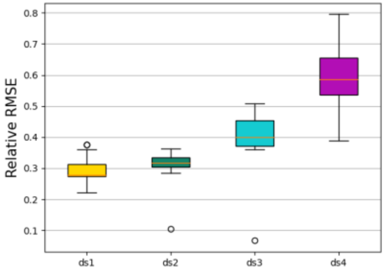
gonio

Ablations (NLB Model)

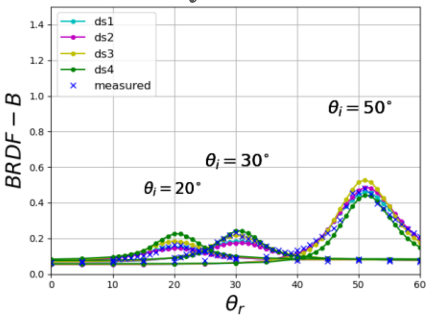
BRDF and relative-rmse plots

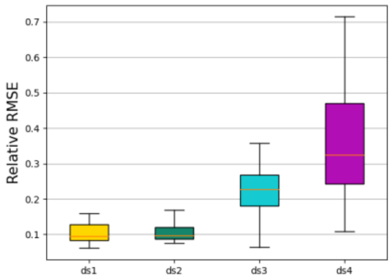
tungsten-carbide



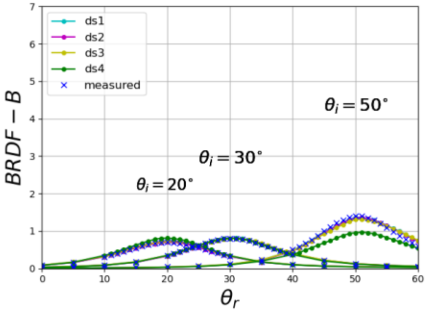


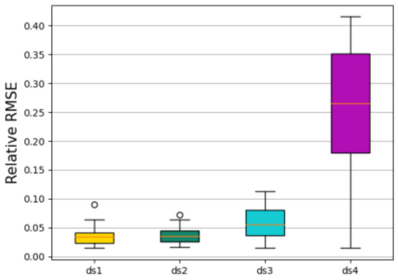
nylon



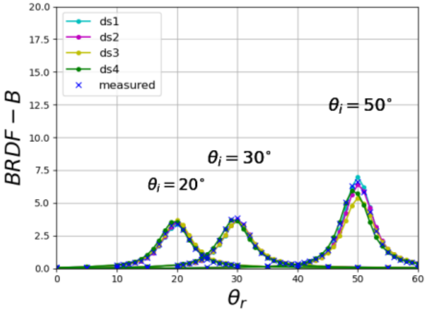


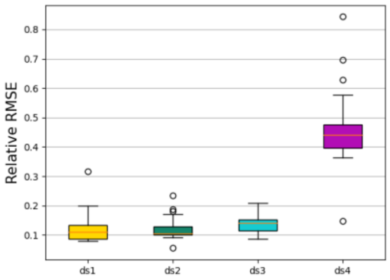
gold





gonio





Problem Description

Motivations:
Parametric representations for BRDFs lie in the tristimulus domain, forcing premature wavelength compression of spectral data and loss of information.

Action items:
We propose an MLP architecture that suitably learns underlying BRDF trends and provides good estimates for unseen angular and wavelength configurations.

Background

Radiometry to Photometry

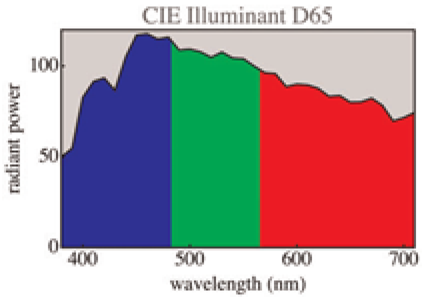
Spectral Data → Radiance Values → Tone Reduction → XYZ to sRGB

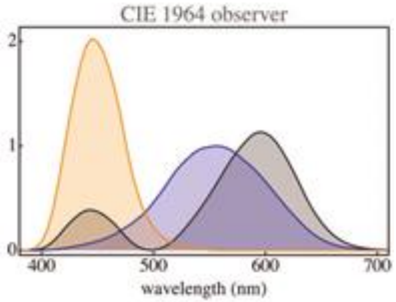
Data with 31 wavelengths for a sample

Weighting D65 spectral power distribution

CIE standard observer color matching functions applied across wavelength

Scaling and matrix (M) multiplication performed across tristimulus values





$$M = \begin{bmatrix} 3.2404542 & -1.5371385 & -0.4985314 \\ -0.9692660 & 1.8760108 & 0.0415560 \\ 0.0556434 & -0.2040259 & 1.0572252 \end{bmatrix}$$

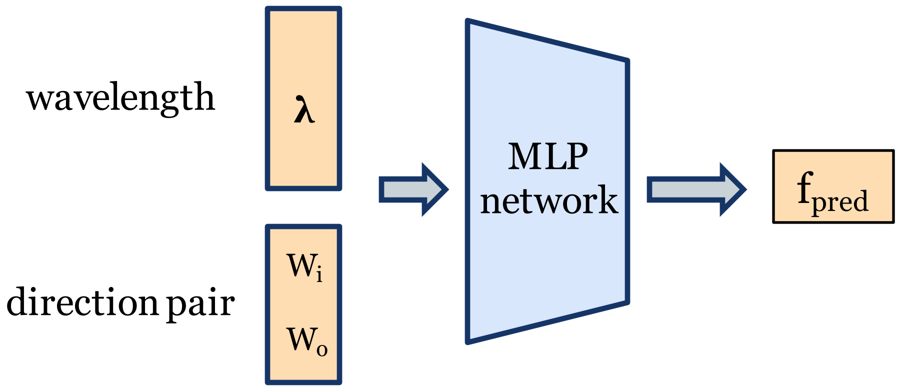
Method

Spectral BRDF matching

Input (normalized): Incident angle, viewing angle, wavelength

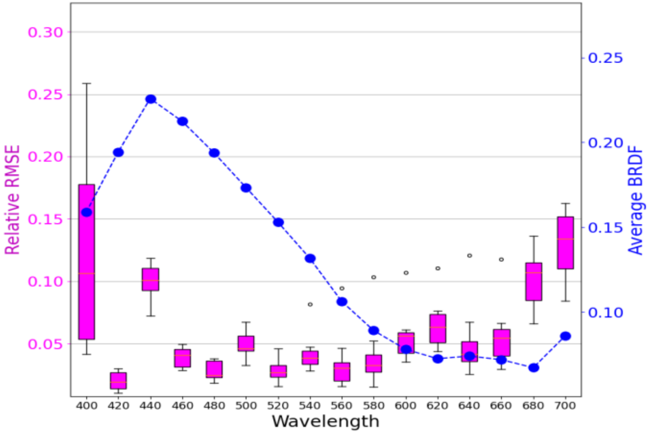
Output: BRDF value

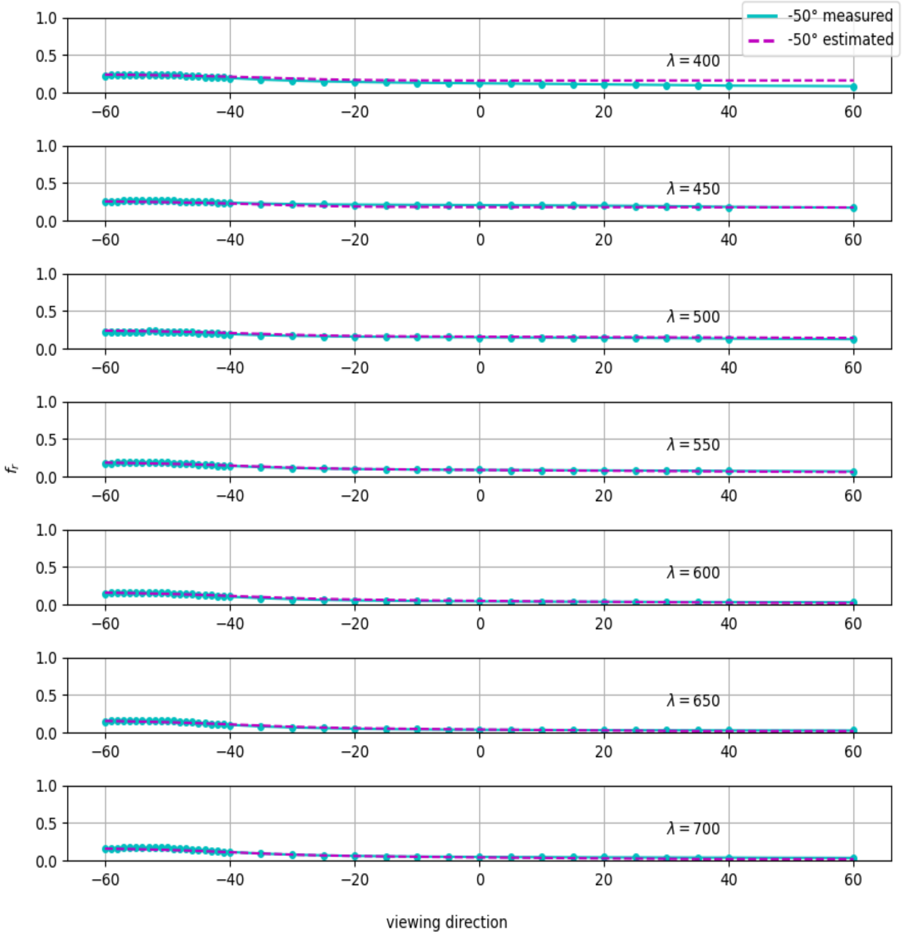
Network: 3 layer MLP, 10 nodes each layer



Results

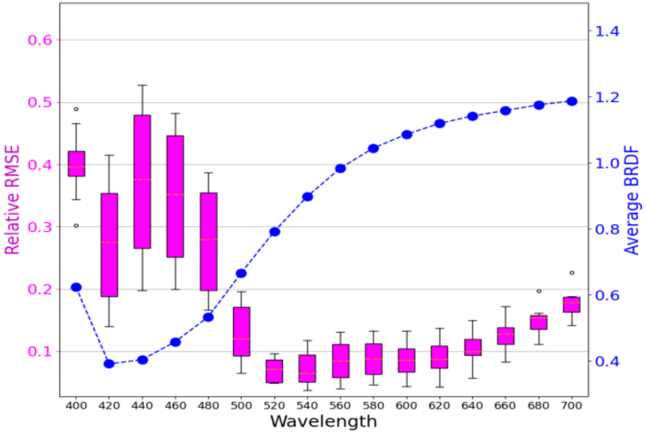
Cyan Sample

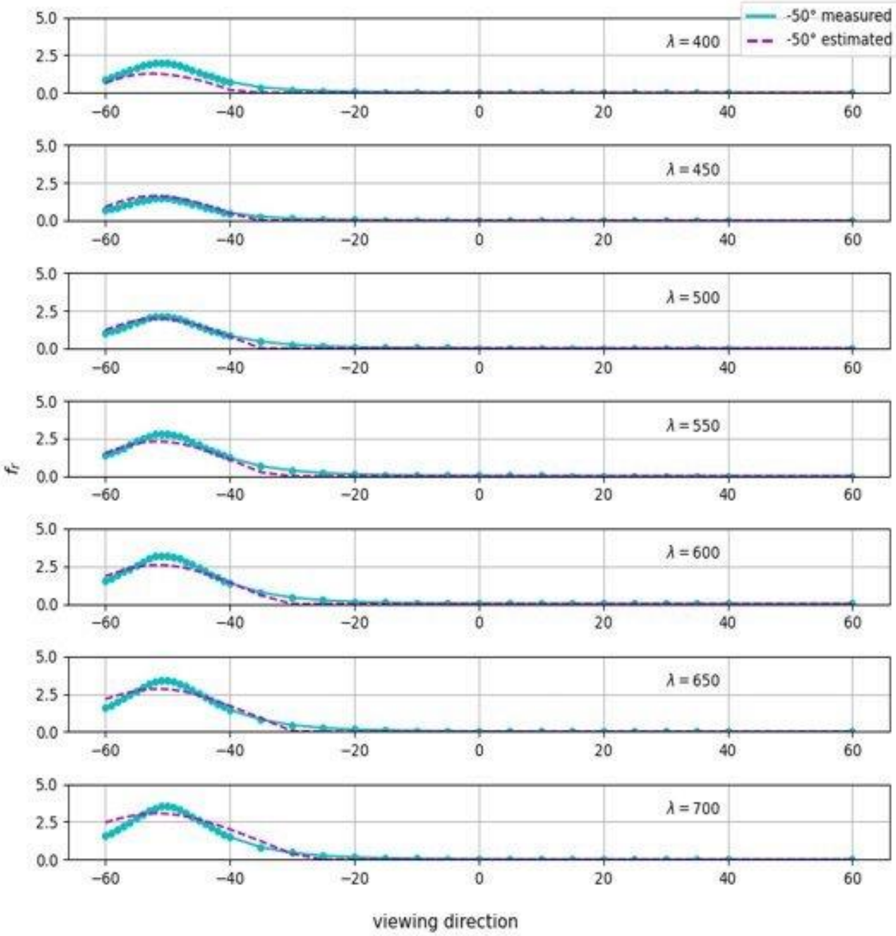




Results

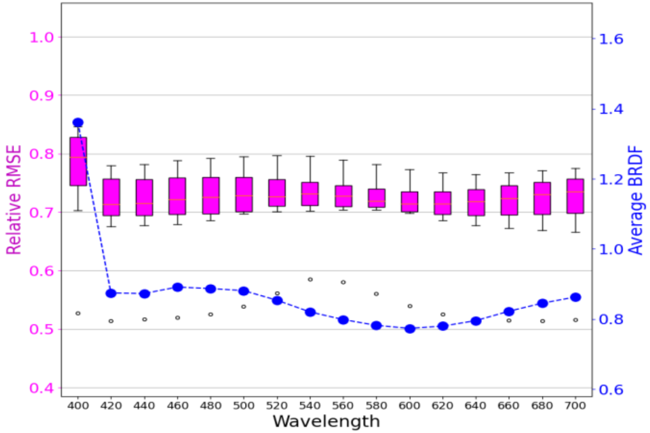
***Gold* Sample**

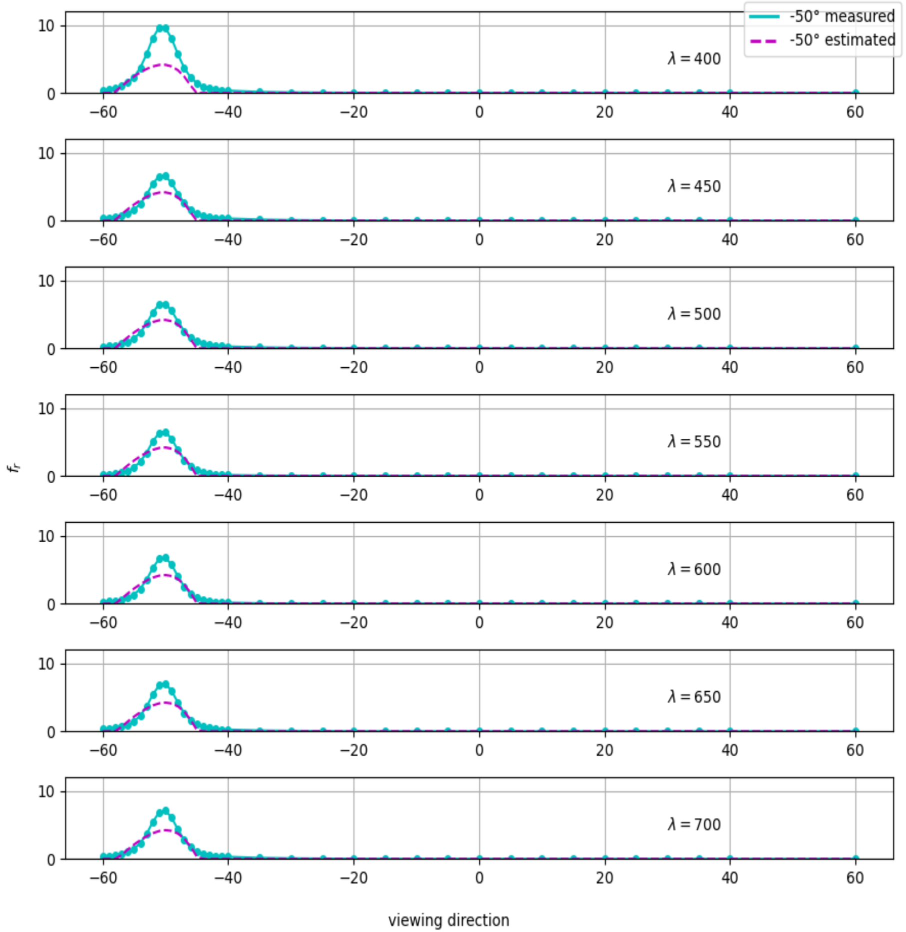




Results

Gonio Sample





Summarizing

- For isotropic materials, we demonstrate the sufficiency of in-plane angles for material capture.
- Both physics-based and network-based models were used to show comparable results between our chosen angles and 256x larger out-of-plane ones.
- The effect of data reduction on material capture was studied with the findings suggesting that even six angle pairs are enough in simpler materials.

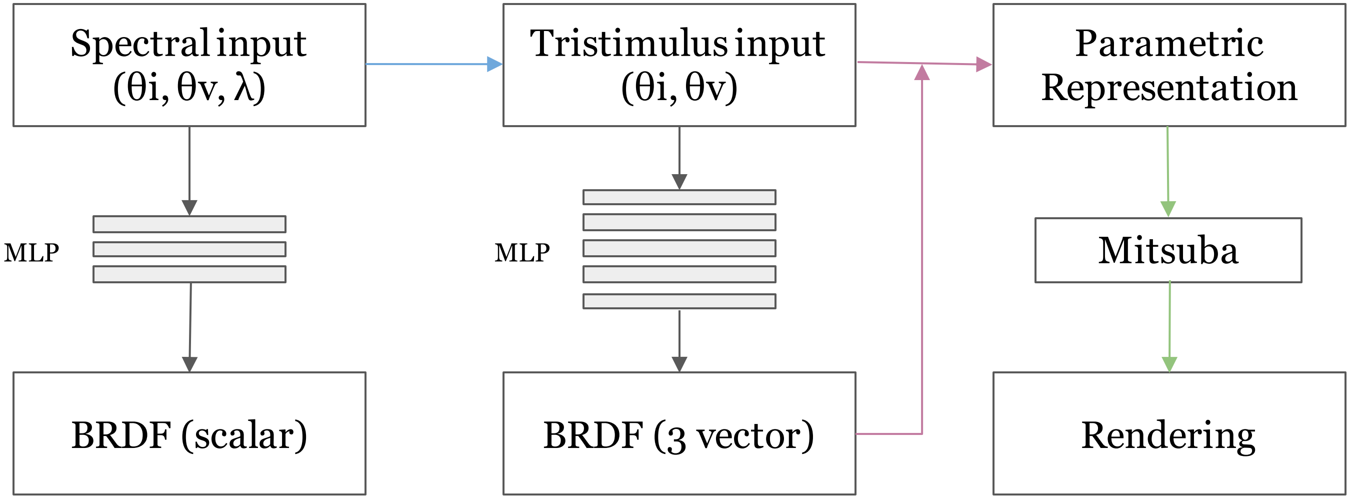
Thank You!

Overview

- Problem description
- Method
- Results
- Ablations
- Summarizing

Recap

Neural networks for efficient BRDF acquisition and rendering



Radiometry-to-Photometry pipeline

Genetic algorithm parameter estimation

Scene rendering using mitsuba plugin

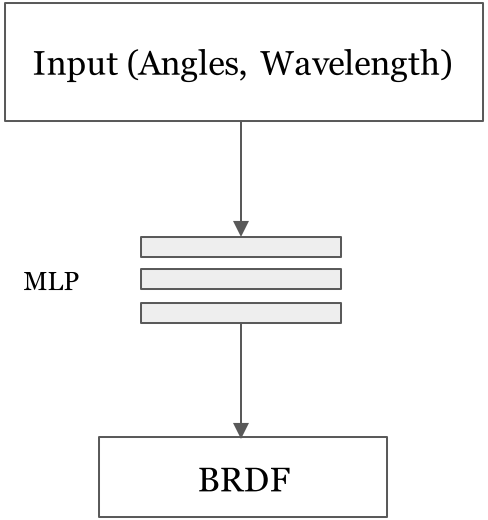
Recap

Radiometry BRDF matching

Input (normalized): Incident angle, viewing angle, wavelength

Output: BRDF value

Network: 3 layer MLP, 10 nodes each layer



Photometry BRDF matching

Input (normalized): Incident angle, viewing angle

Output: tristimulus BRDF value

Network: 5 layer MLP, 20 nodes each layer

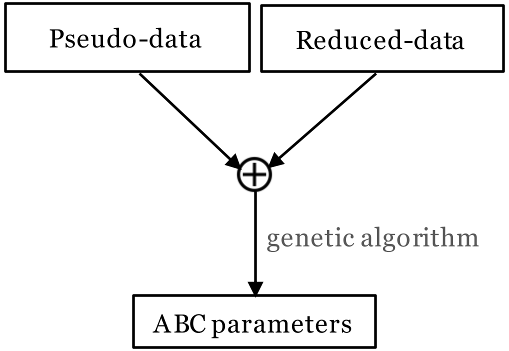
Recap

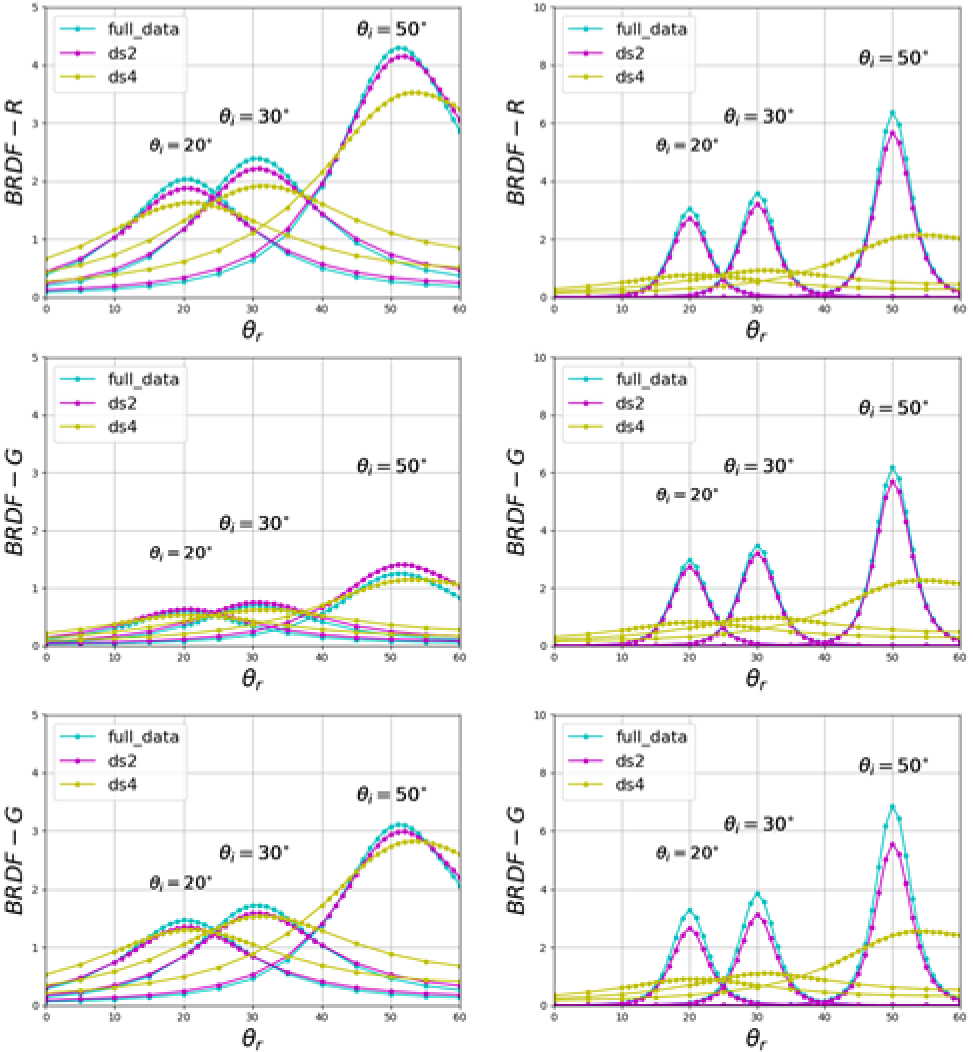
Parametric Representation

Pseudo-data: Network predictions acting as a proxy for true measurements

Reduced-data: Data left after dropping certain measurements (downsampling)

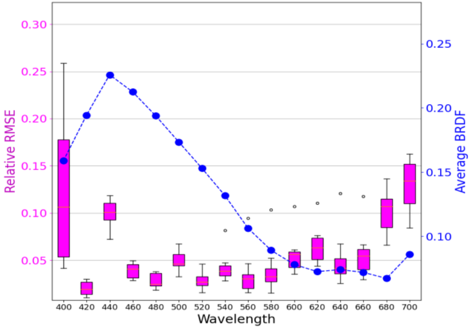
- ds2: 4x downsampling
- ds4: 16x downsampling



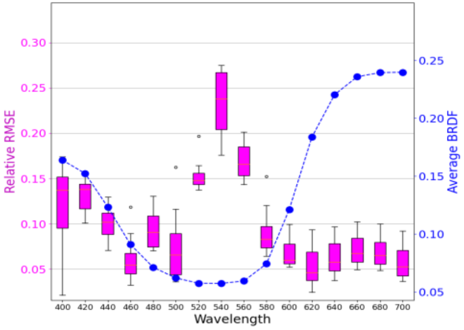


Recap

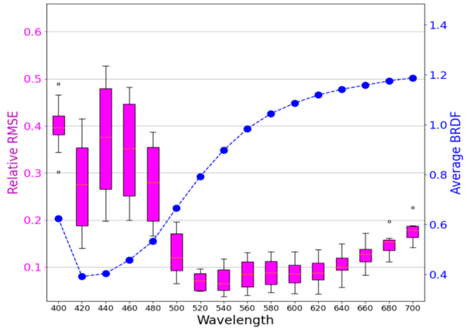
Spectral Network Results



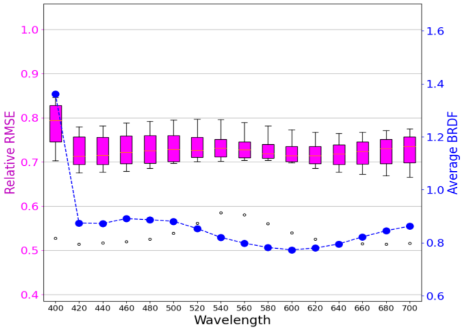
Cyan



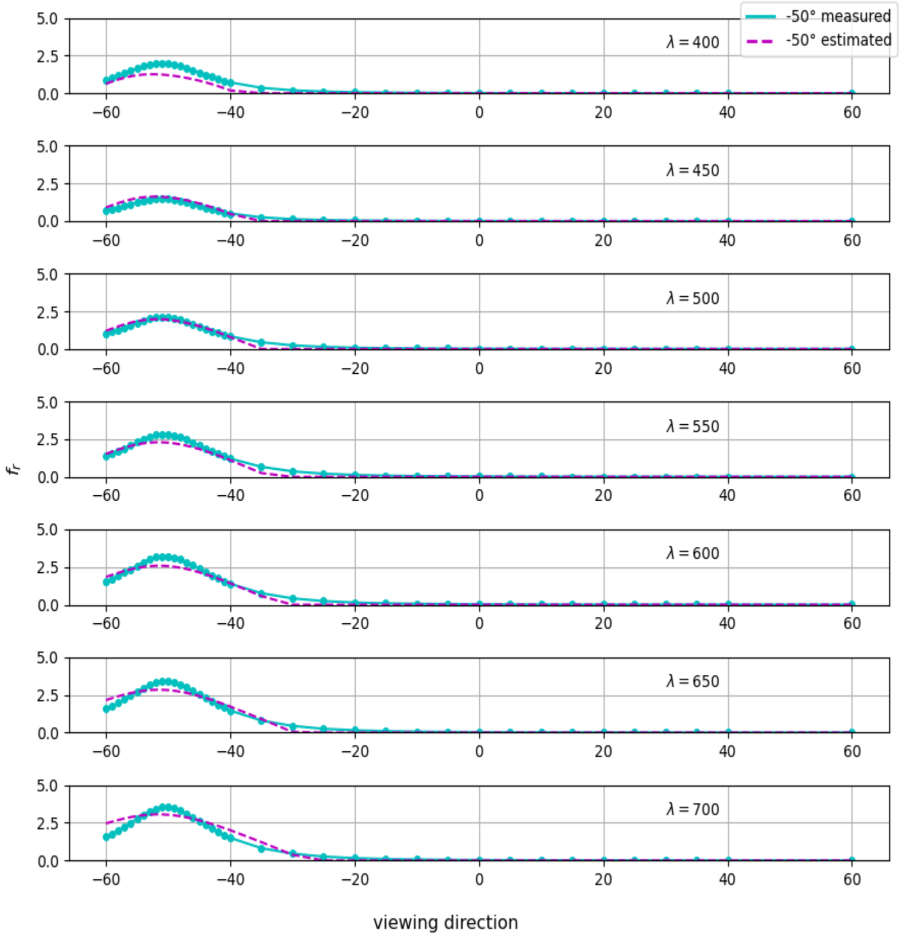
Magenta



Gold



Gonio



Recap

Parametric Renderings

ds2 renderings: visually appear similar to the full data

ds4 renderings: change in visual appearance for Gold and Gonio more pronounced (specular nature)