EFFICIENT REFLECTANCE CAPTURE USING AN AUTOENCODER

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Sinovation Ventures

Introduction

INTRODUCTION

- Realistic Material Appearance is Important

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Visual Effects

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e-Commerce

https://www.coinsshopy.com/product/classic-brand-shoes-women-casual-pointed-toe-black-oxford-shoes-for-women-flats-comfortable-slip-on-women-shoes/

Cultural Heritage

https://pro.europeana.eu/post/inspire-makers-to-creatively-transform-europe-s-digital-cultural-heritage

INTRODUCTION

- Realistic Material Appearance is Important
  - 6D SVBRDF (Location, Lighting & View Directions)

INTRODUCTION

- Realistic Material Appearance is Important
  - 6D SVBRDF (Location, Lighting & View Directions)
- Reflectance Acquisition is Challenging
  - Directly Sampling the 6D Domain is Inefficient

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LIGHTING-PATTERN-BASED REFLECTANCE ACQUISITION

- One Successful Class for High-Quality Capture
- Program Many Lights Simultaneously
  - Forming Different Lighting Patterns

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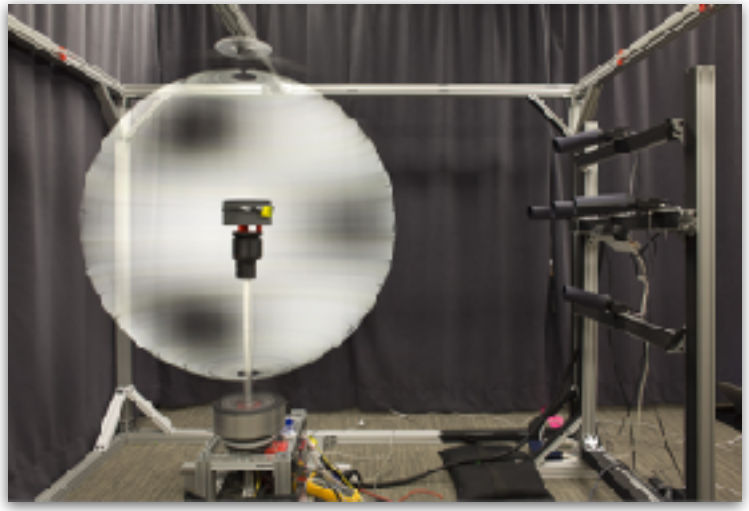
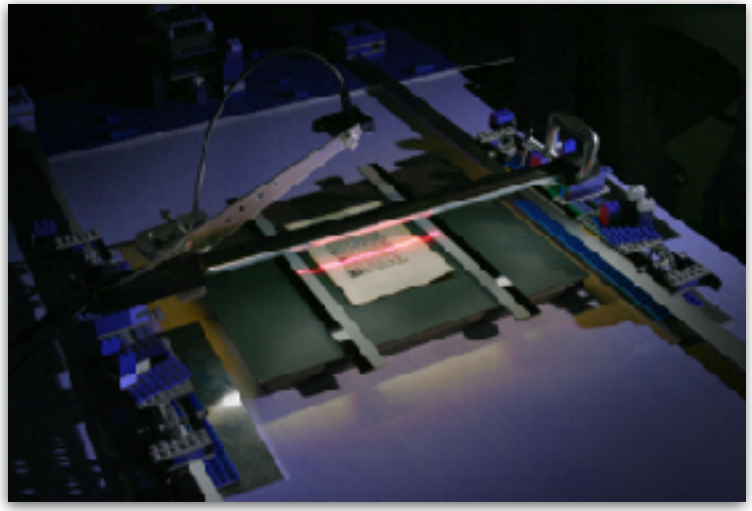
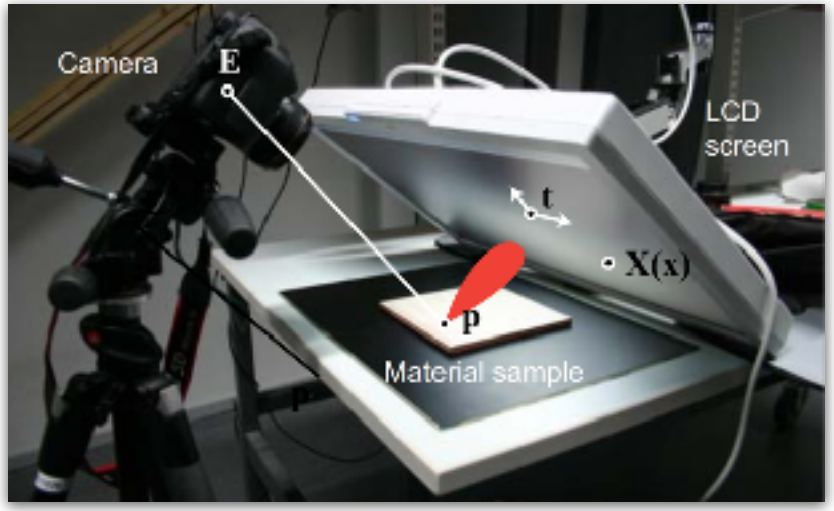


Lightstage
[Ghosh et al. 2009; Tunwattanapong et al. 2013]



Linear Light Source
[Gardner et al. 2003; Chen et al. 2014]

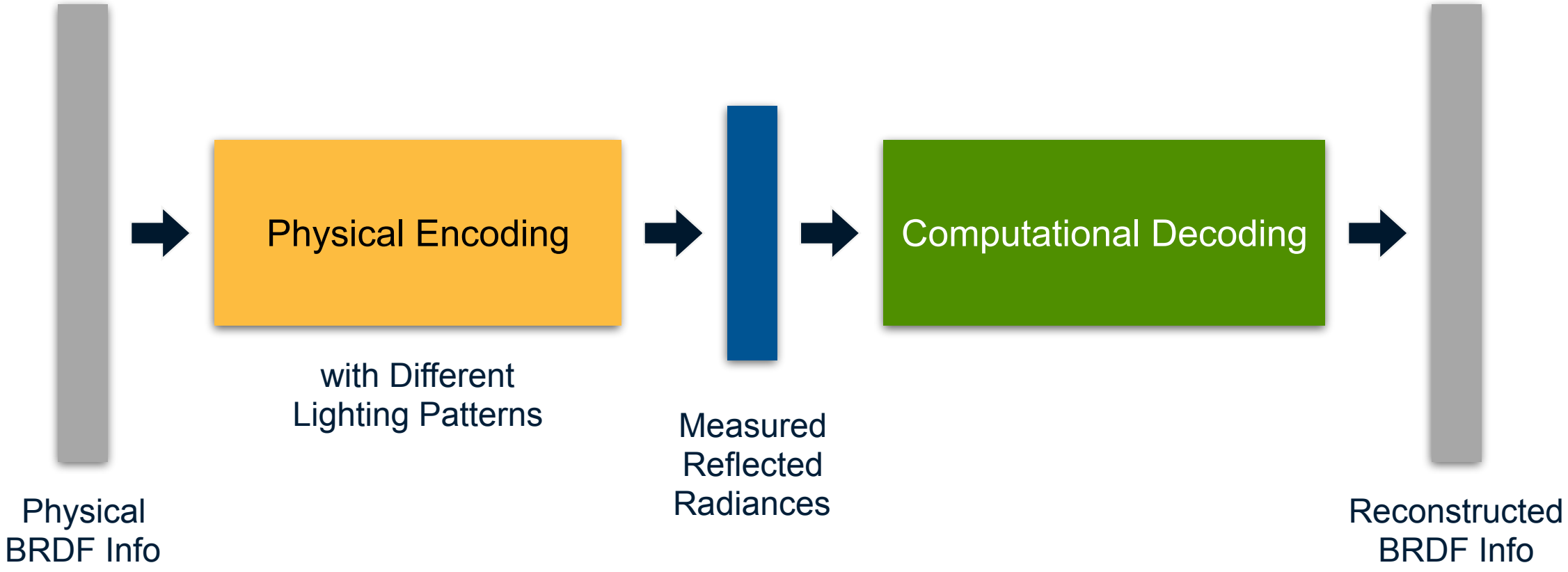


LCD-based Setup
[Aittala et al. 2013]

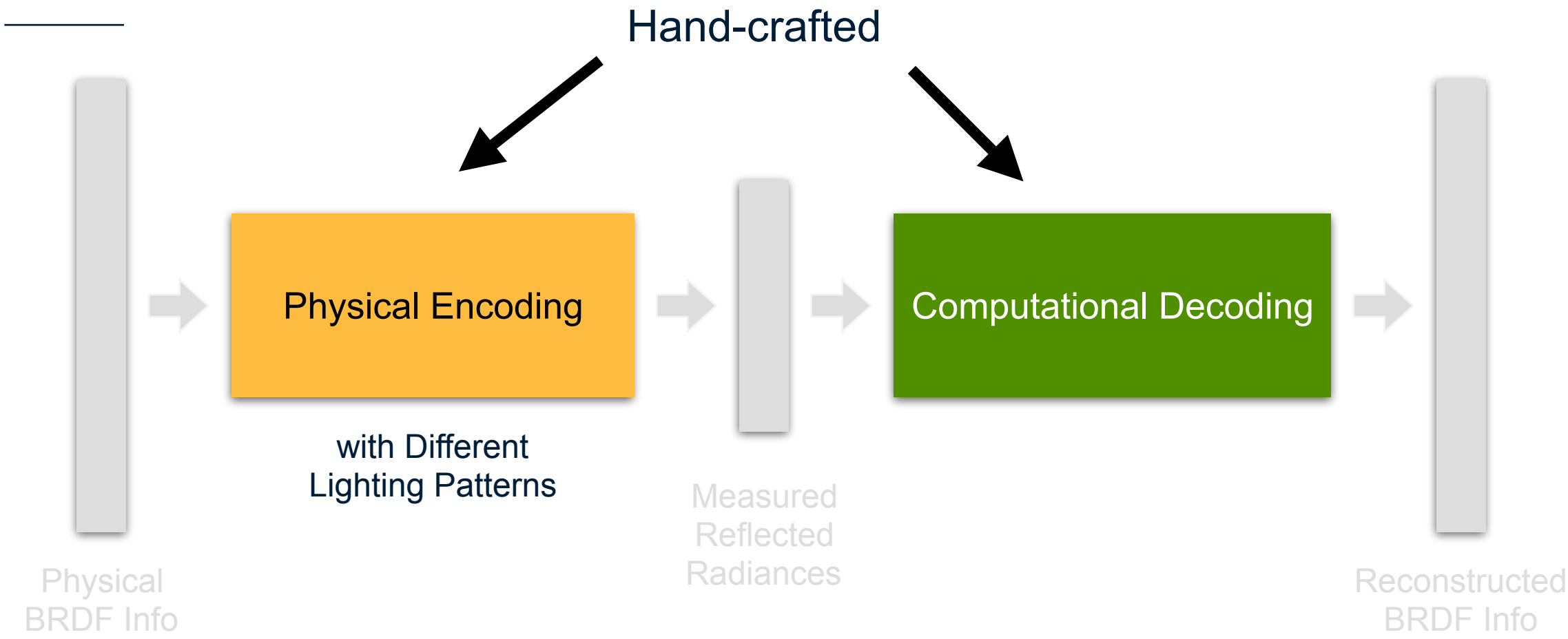
LIGHTING-PATTERN-BASED REFLECTANCE ACQUISITION

- One Successful Class for High-Quality Capture
- Program Many Lights Simultaneously
  - Forming Different Lighting Patterns
- 240 Lighting Patterns / Photos Needed [Chen et al. 2014]
- Our Goal
  - **To Improve Efficiency for SVBRDF Acquisition**

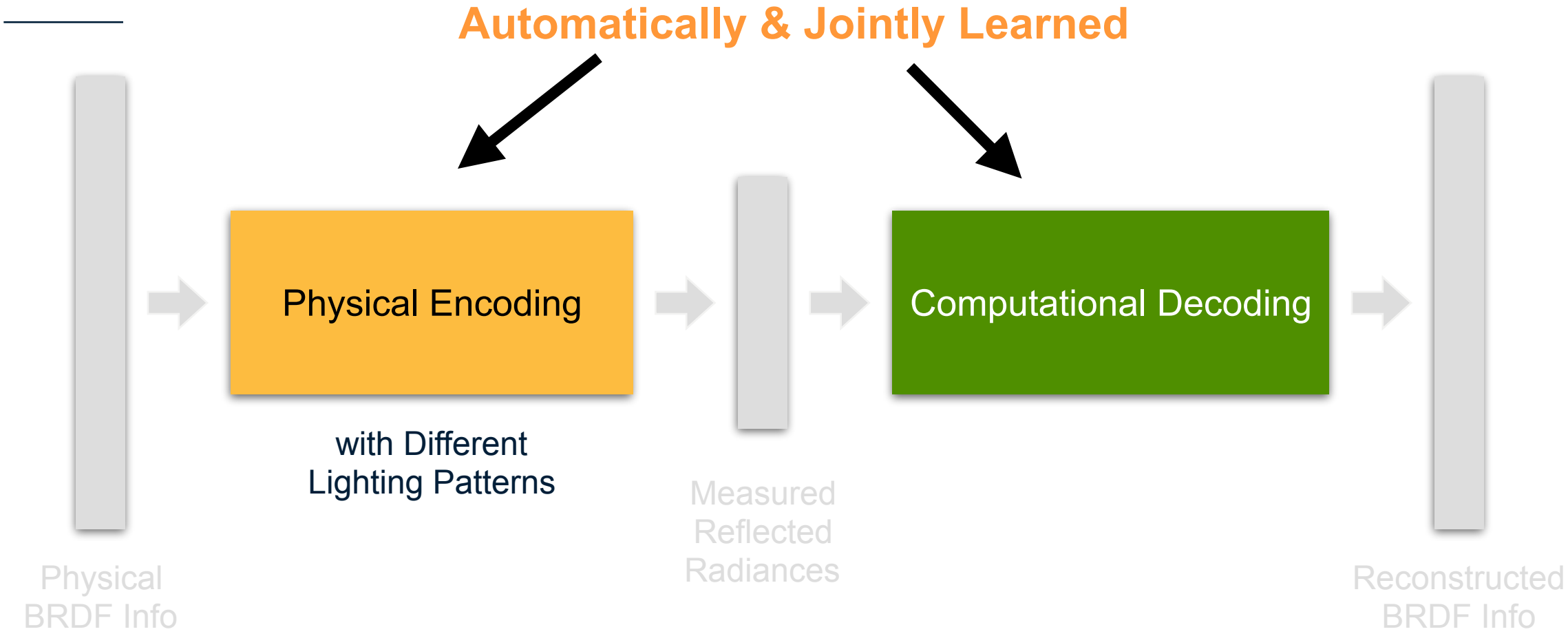
REFLECTANCE ACQUISITION = ENCODING + DECODING



PREVIOUS WORK



OUR APPROACH



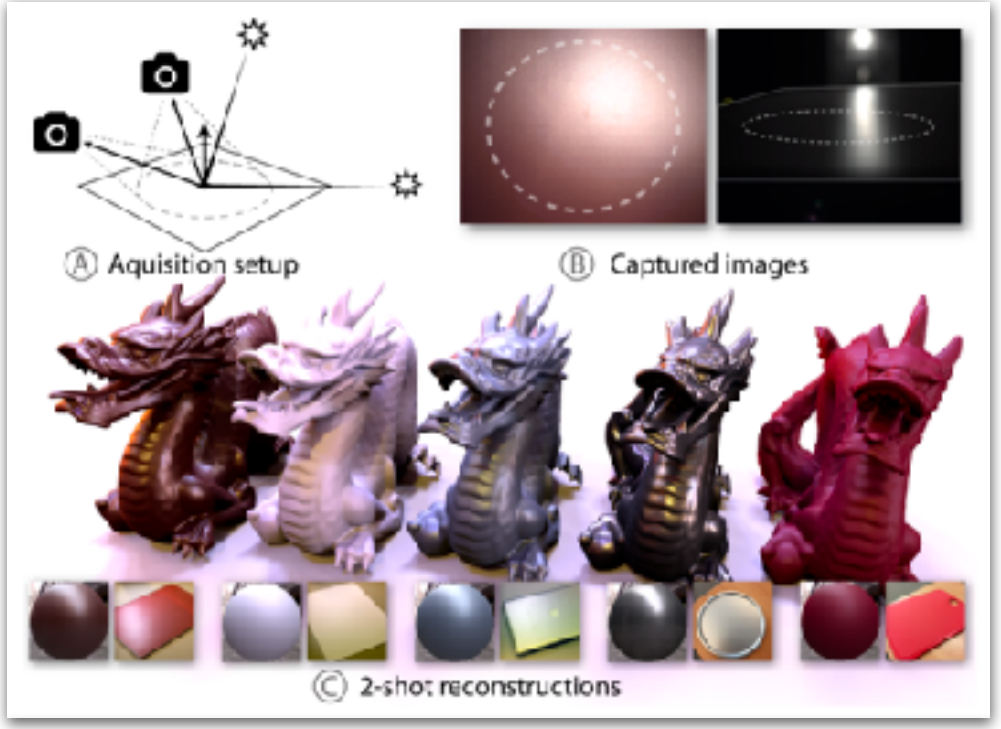
OUR APPROACH

- Lighting Pattern #: 16~32
- Acquisition Time: 12~25s
- Faithfully Recovers General Reflectance under Near-field Lighting
- Automatically Adapt to Various Factors
  - Setup's Geometry
  - Properties of Appearance

Related Work

RELATED WORK

- Optimal BRDF Sampling
  - [Matusik et al. 2003; Nielsen et al. 2015; Xu et al. 2016]
  - Distant Lighting
  - Isotropic BRDF
  - Limited Support for Spatial / Normal Variations



[Xu et al. 2016]

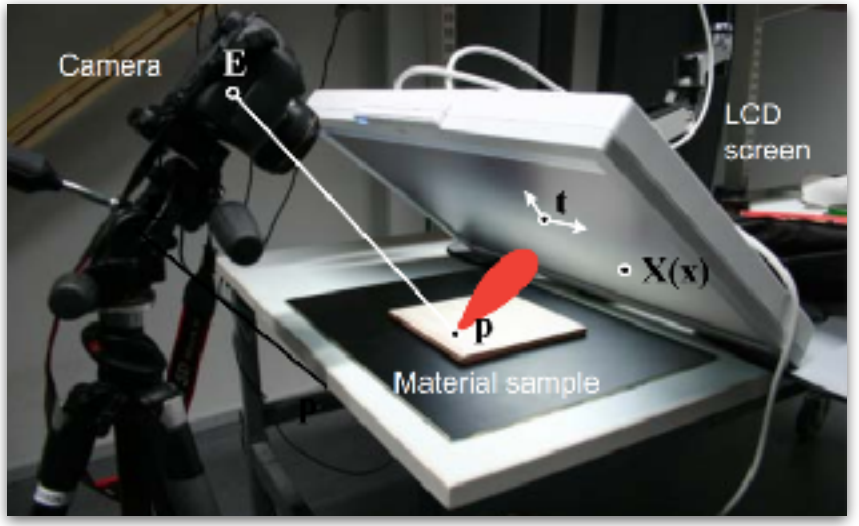
RELATED WORK

- Optimal BRDF Sampling
- Direct Sampling
  - Gonioreflectometer [Dana et al. 1999; Lawrence et al. 2006]
  - Prior over Reflectance [Lensch et al. 2003; Aittala et al. 2015]

[Aittala et al. 2015]

RELATED WORK

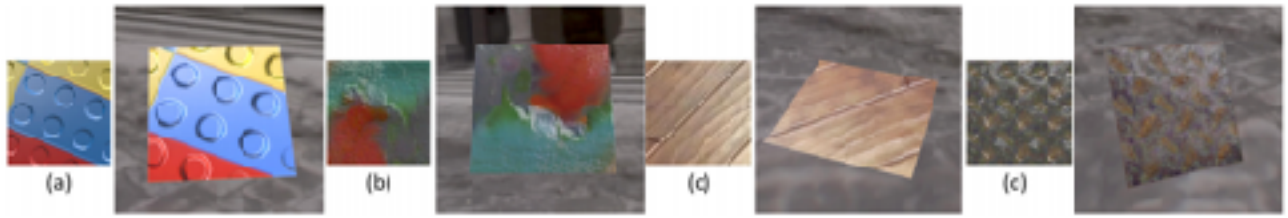
- Optimal BRDF Sampling
- Direct Sampling
- Complex Lighting Patterns
  - [Gardener et al. 2003; Ghosh et al. 2009; Aittala et al. 2013]
  - Manually Derive Lighting Patterns & Reconstruction Algorithms



[Aittala et al. 2013]

RELATED WORK

- Optimal BRDF Sampling
- Direct Sampling
- Complex Lighting Patterns



[Li et al. 2017]

- Deep-Learning-Assisted Reflectance Modeling
  - [Aittala et al. 2016; Li et al. 2017]
  - Single Input Image
  - Less controlled Lighting
  - Assumptions over Reflectance

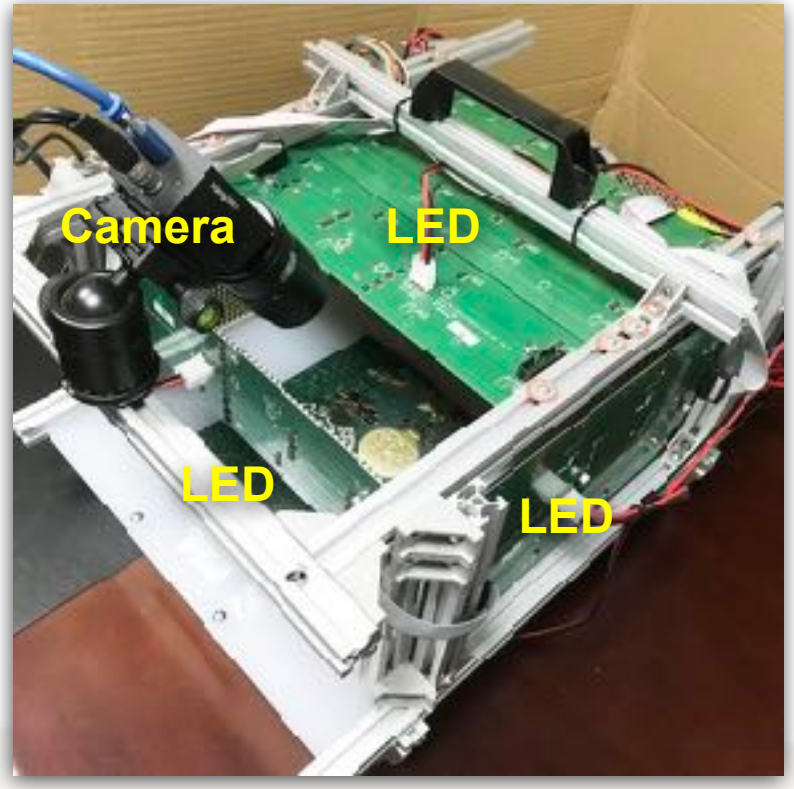
Our Framework

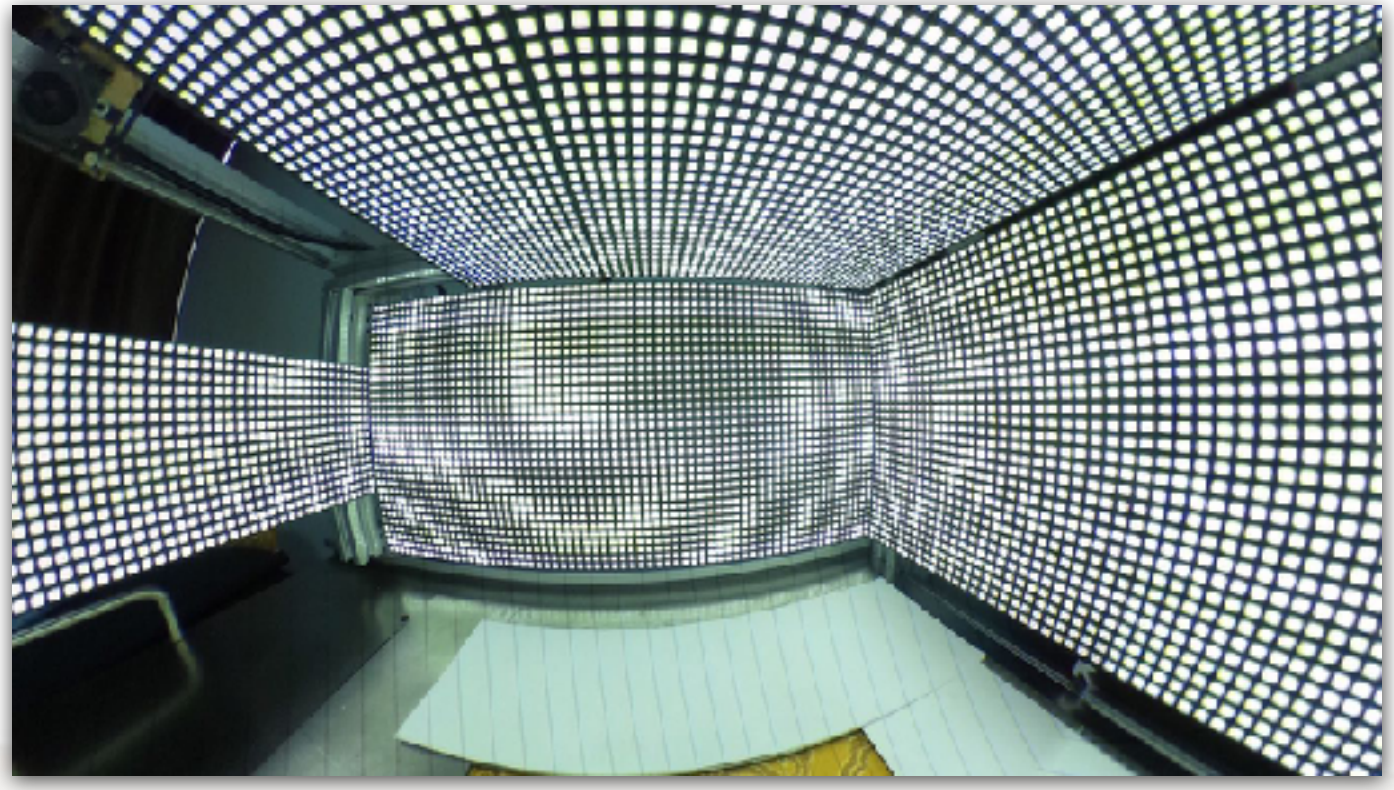
ASSUMPTIONS

- A Mostly Planar Sample
- Independent Reflectance Reconstruction on Each Location
- For a Single Channel

OUR DEVICE

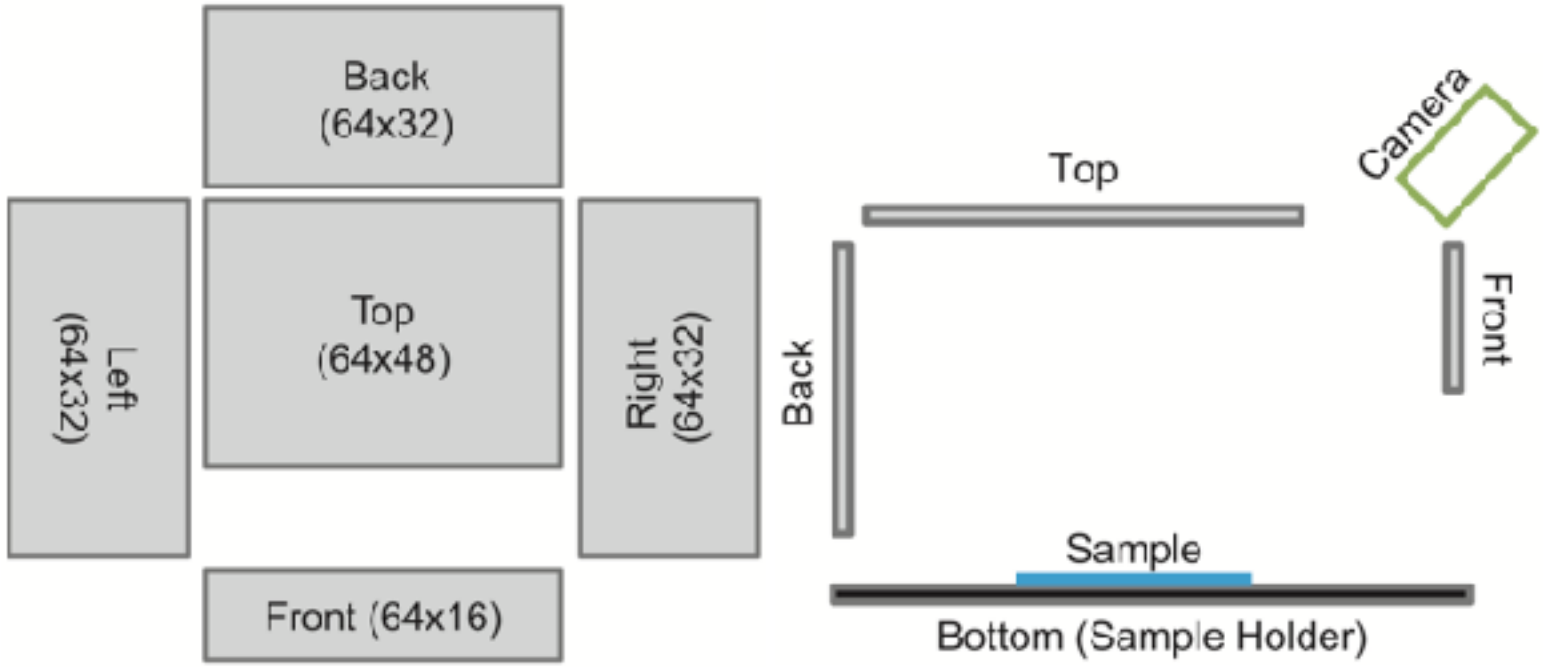
- Mini, Near-field Lightstage



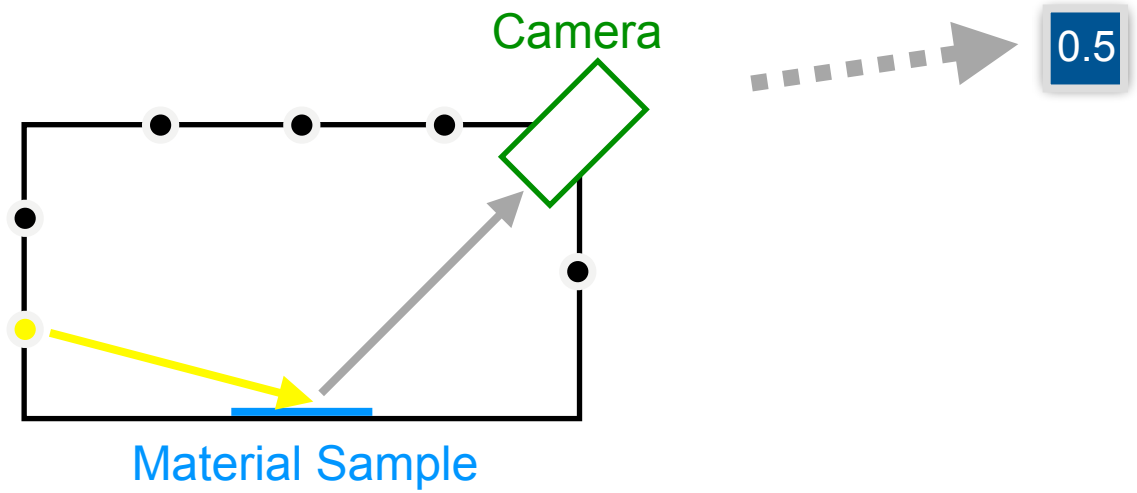


OUR DEVICE

- Mini, Near-field Lightstage
  - 420mm*360mm*210mm
  - Sample Size: 120mm*120mm
  - Single Camera
  - 10,240 LEDs
  - High-Precision Control via FPGA

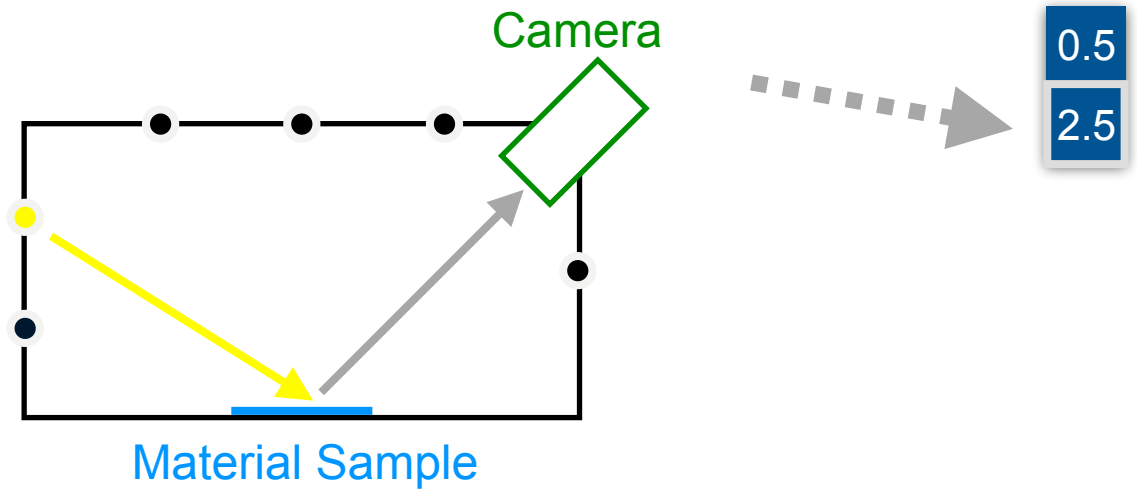


LUMITEXEL



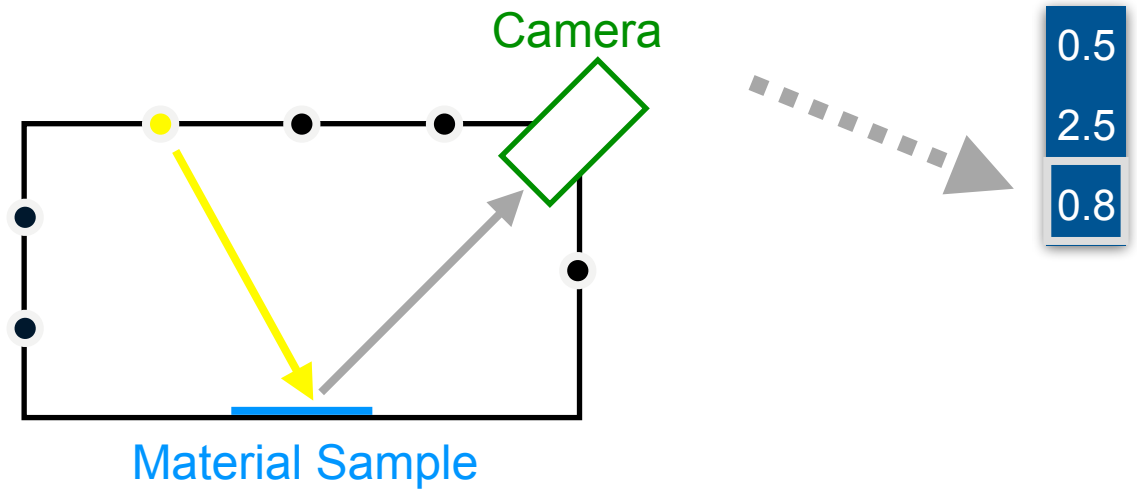
Lumitexel

LUMITEXEL



Lumitexel

LUMITEXEL



Lumitexel

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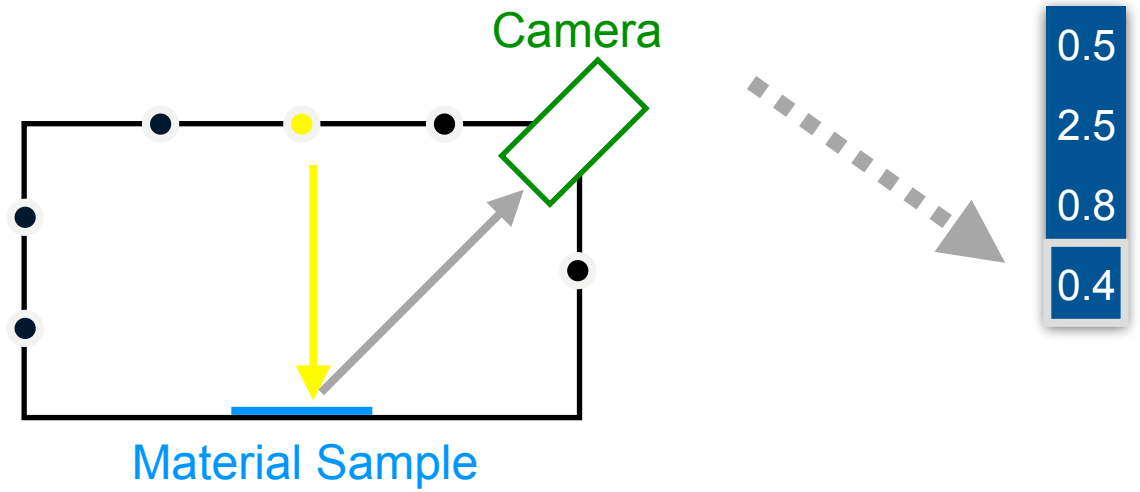

Lumitexel

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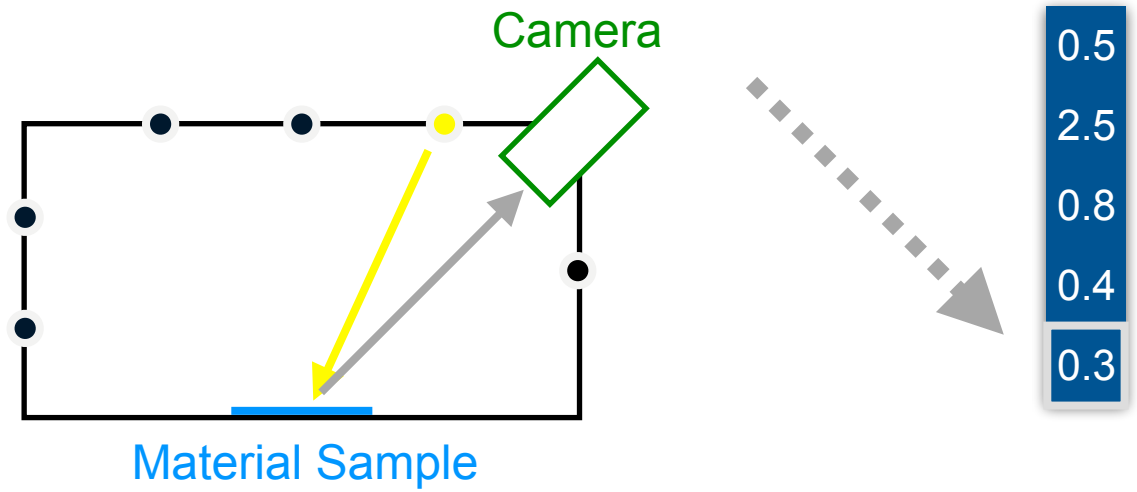

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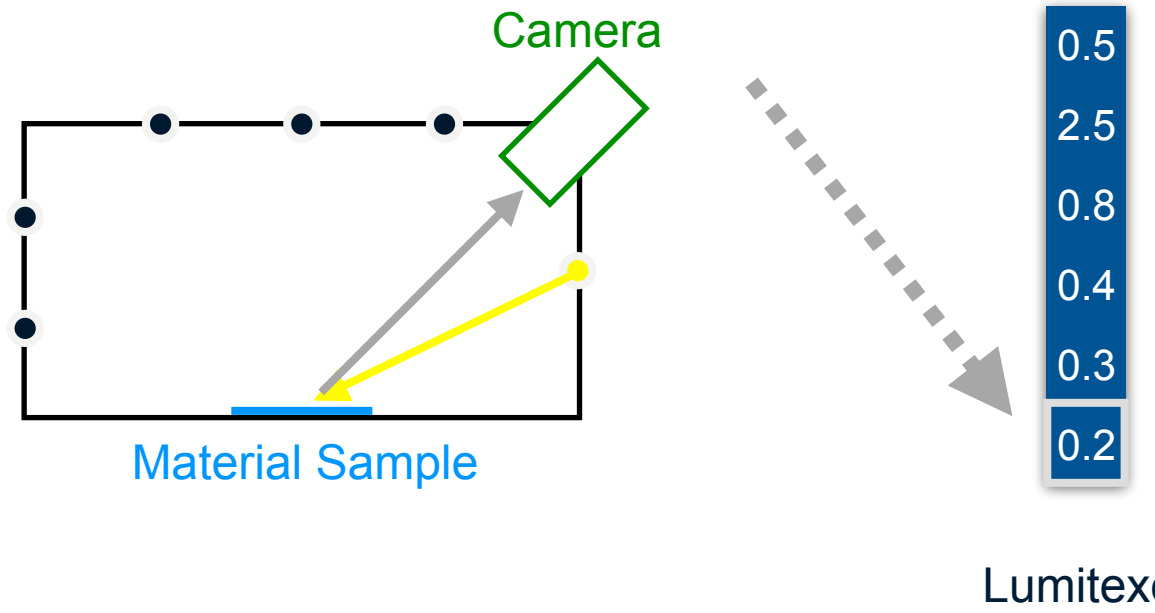
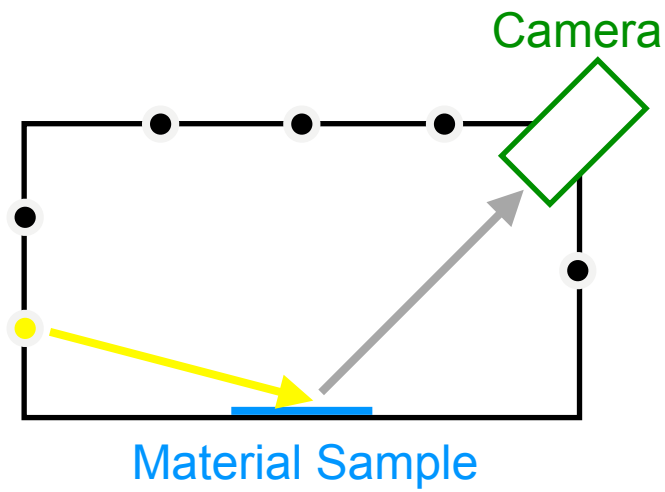


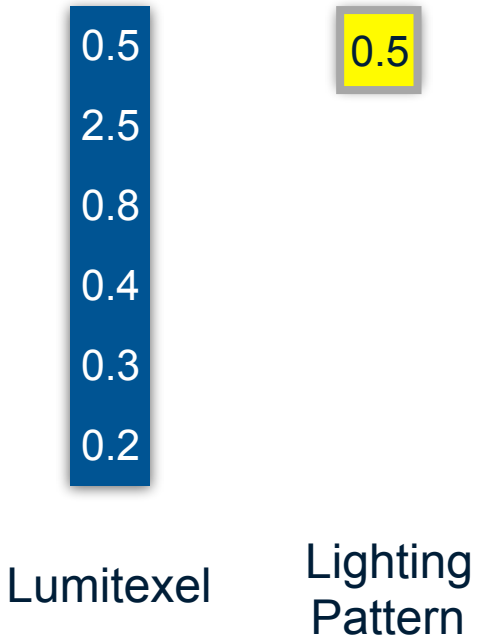
Most Informative

Time Consuming

1. Many Lights
2. Long Exposure

LIGHTING-PATTERN-BASED REFLECTANCE ACQUISITION





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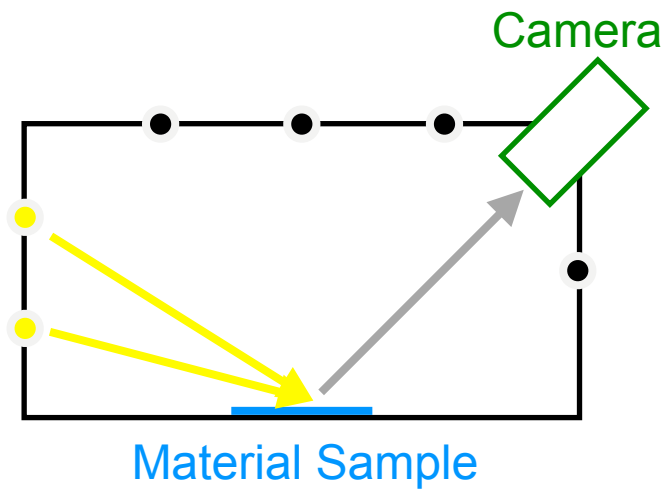

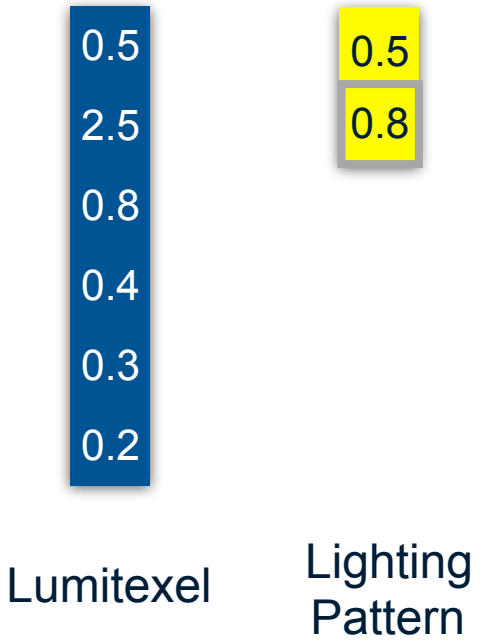

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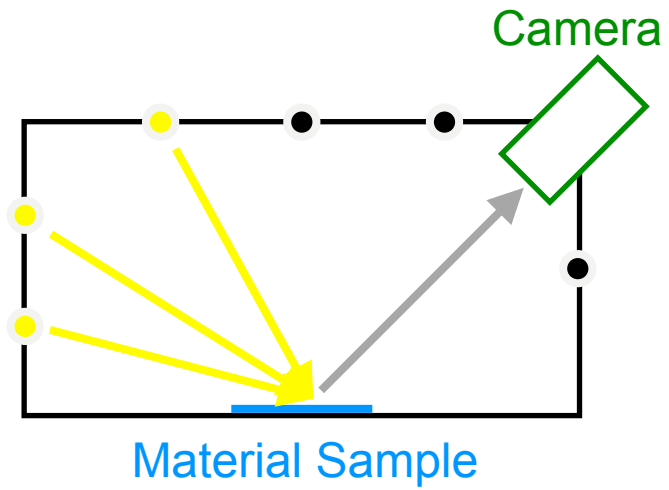

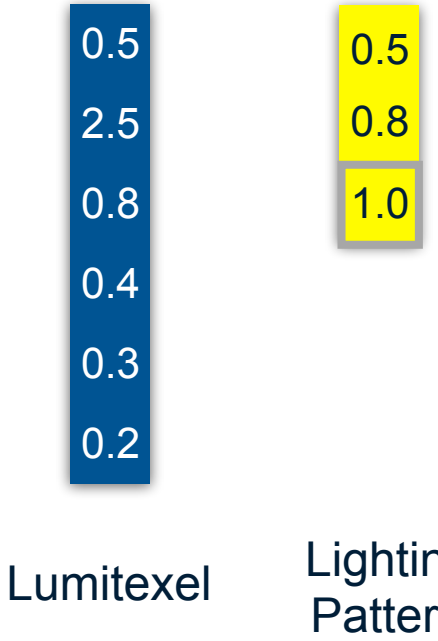

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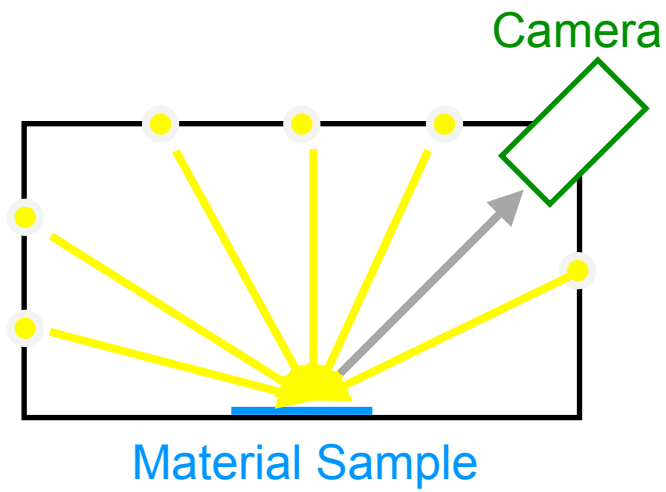

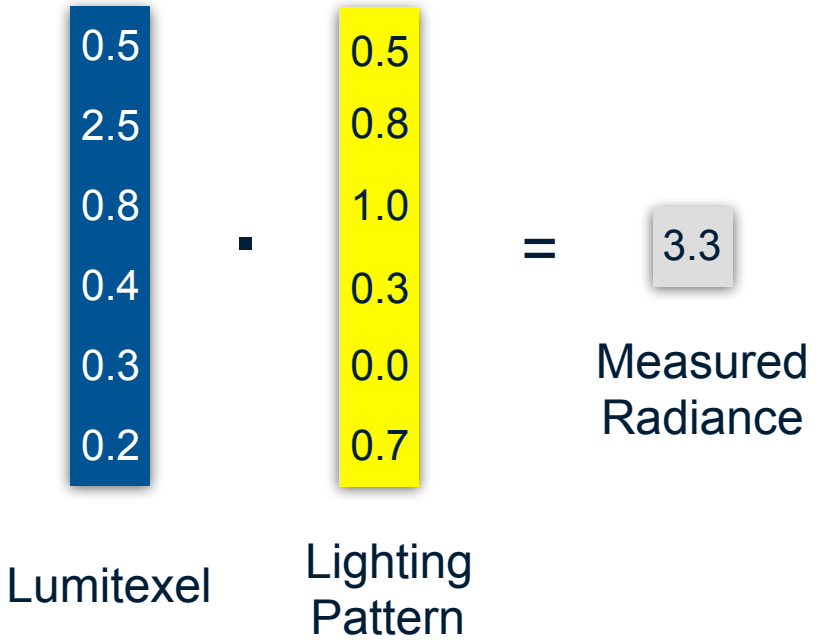

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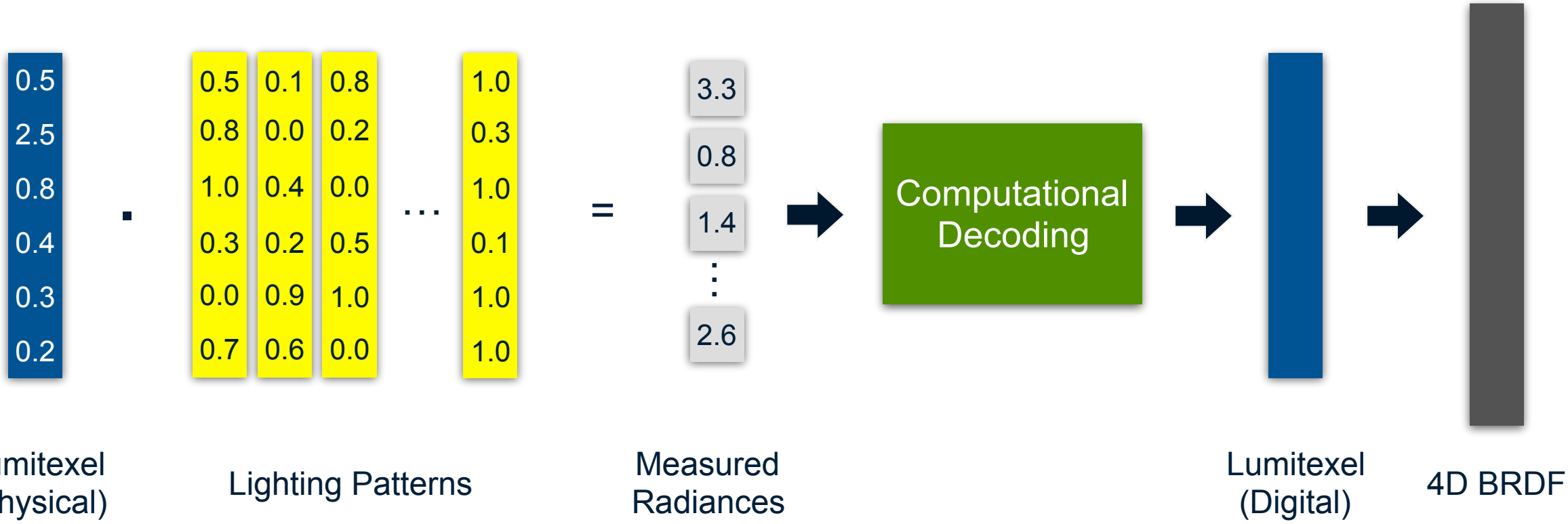


Lumitexel (Physical)

Lighting Patterns

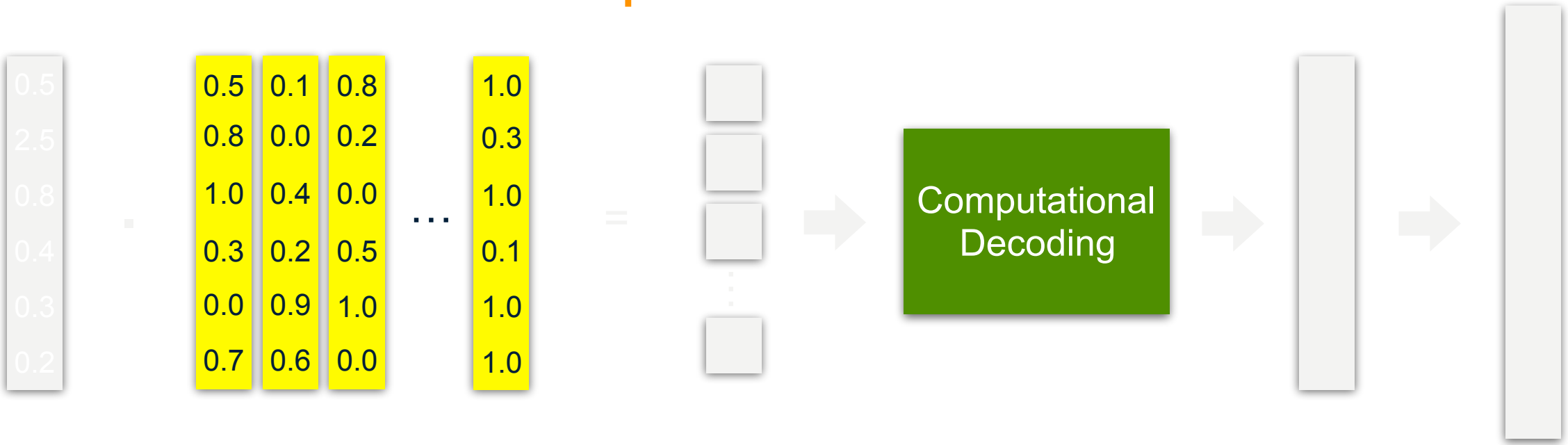
Measured Radiances

Lumitexel (Digital)

4D BRDF

LIGHTING-PATTERN-BASED REFLECTANCE ACQUISITION

Deep Autoencoder



Lumitexel (Physical)

Lighting Patterns

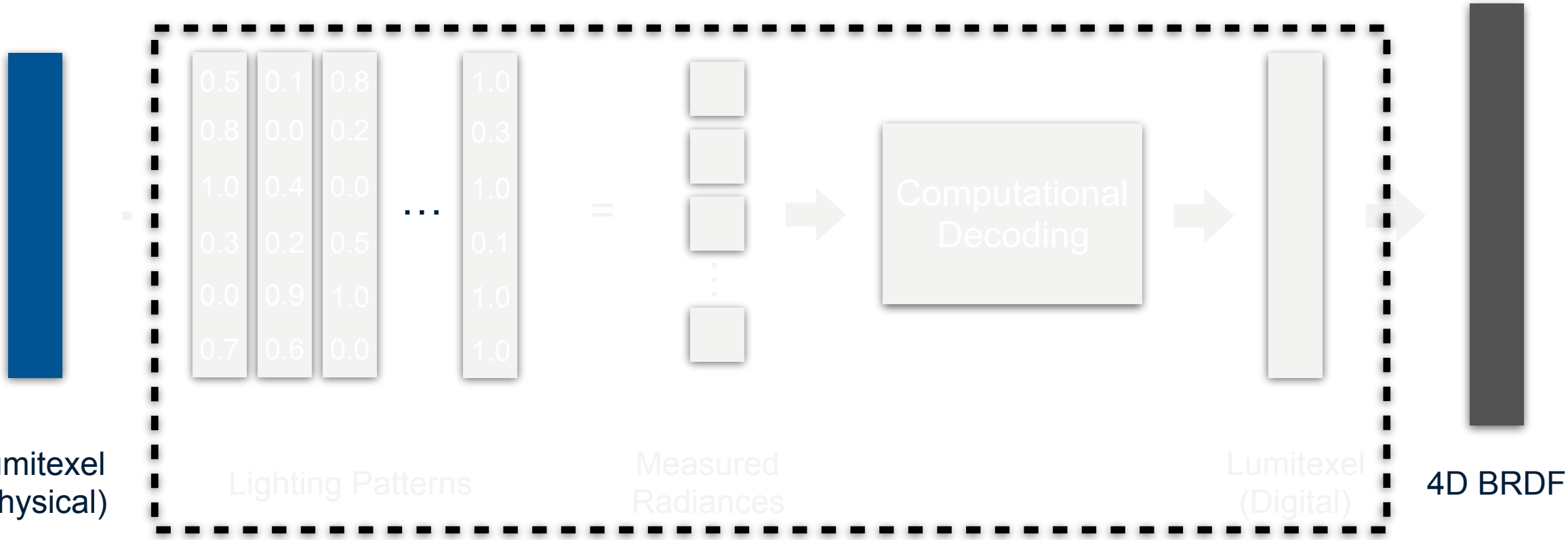
Measured Radiances

Lumitexel (Digital)

4D BRDF

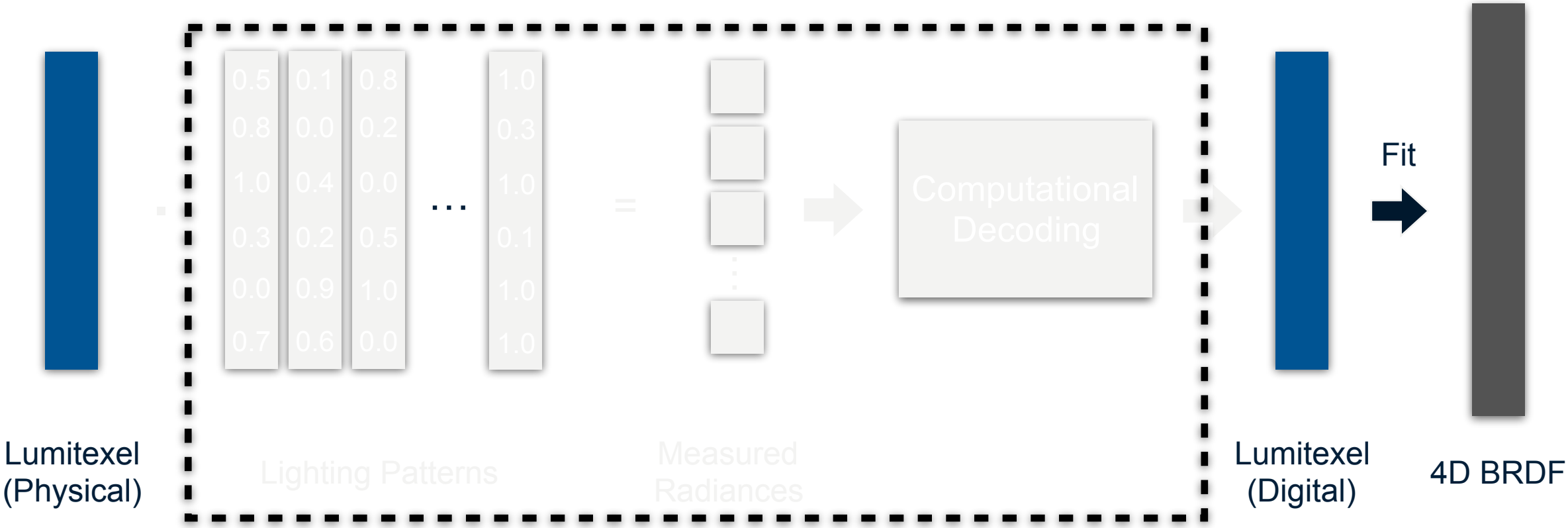
WHAT TO LEARN

1. Straightforward / Most End-to-end
2. Difficult to Learn the Complex Mapping



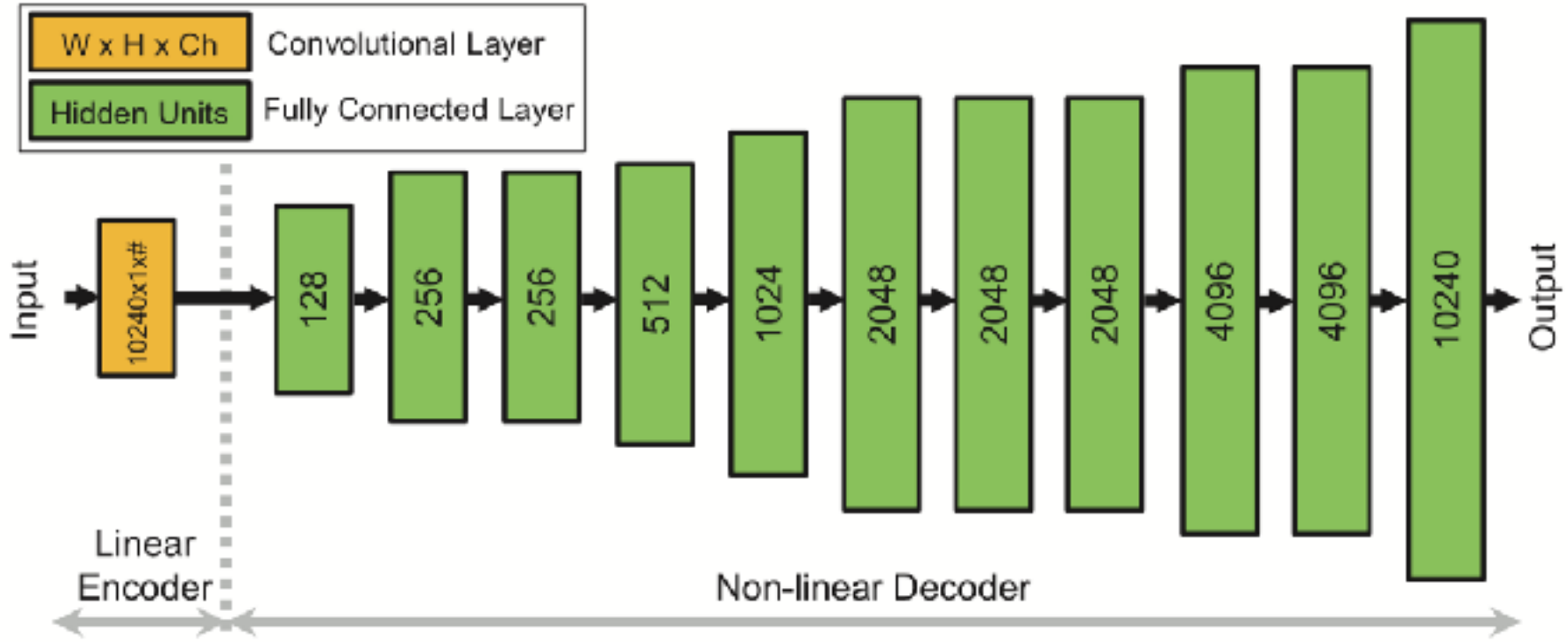
WHAT TO LEARN

1. Easy to Learn the One-to-one Mapping (Autoencoder)
2. Nonlinear Fitting to Obtain the 4D BRDF
3. Shift the Complexity to Fitting to Handle Near-field Lighting



DEEP AUTOENCODER FOR LUMITEXELS (L-DAE)

- Input/Output
  - Lumitexels
- Encoder
  - Bounded, Linear
  - 1 conv Layer
- Decoder
  - Nonlinear
  - 11 fc Layers
- Asymmetric & Mixed Domain



LOSS FUNCTION

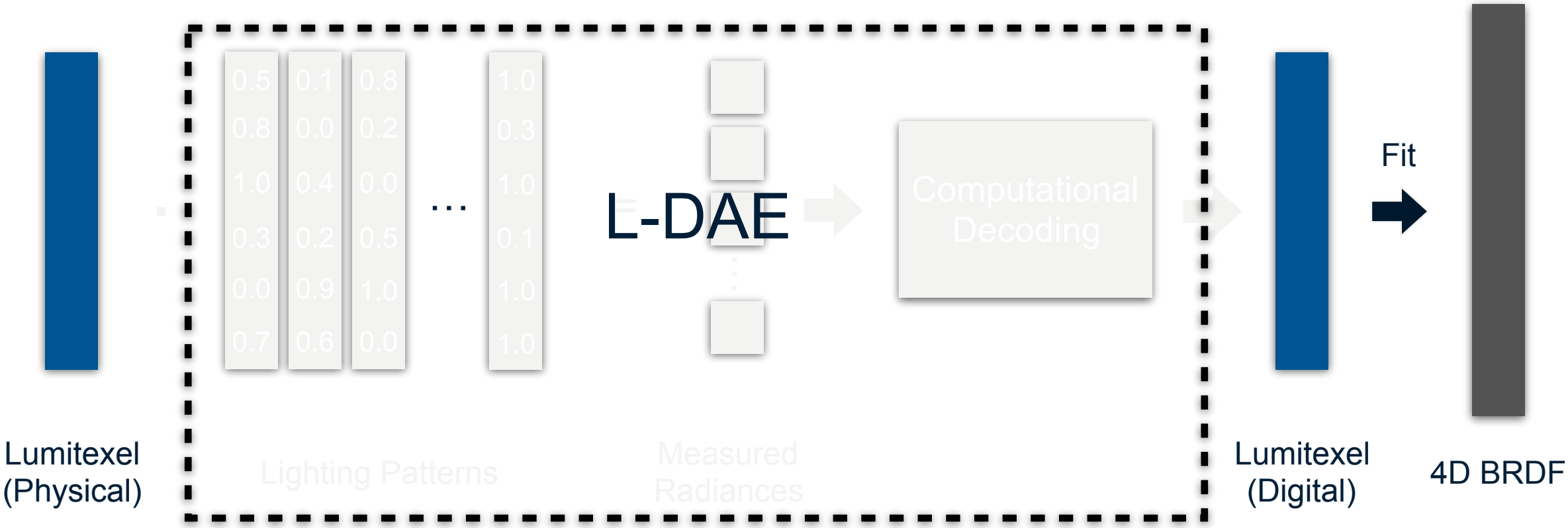
$$L = L_{\text{auto}}(m) + \lambda \sum_{w \in \text{enc.}} L_{\text{barrier}}(w).$$

- Reconstruction Error Term $L_{\text{auto}}(m) = \sum_j [\log(1 + m(j)) - \log(1 + m_{\text{gt}}(j))]^2.$
- Encoder Plausibility Term $L_{\text{barrier}}(w) = \tanh(\frac{w - (1 - \epsilon)}{\epsilon}) + \tanh(\frac{-w + \epsilon}{\epsilon}) + 2.$

TRAINING DATA

- 1 Million Synthetic Lumitexels
  - Randomly Sampled Location on the Sample Plane, Local Frame, BRDF Parameters (anisotropic GGX)
  - Based on Calibration Data of the Acquisition Device

BRDF FITTING



BRDF FITTING

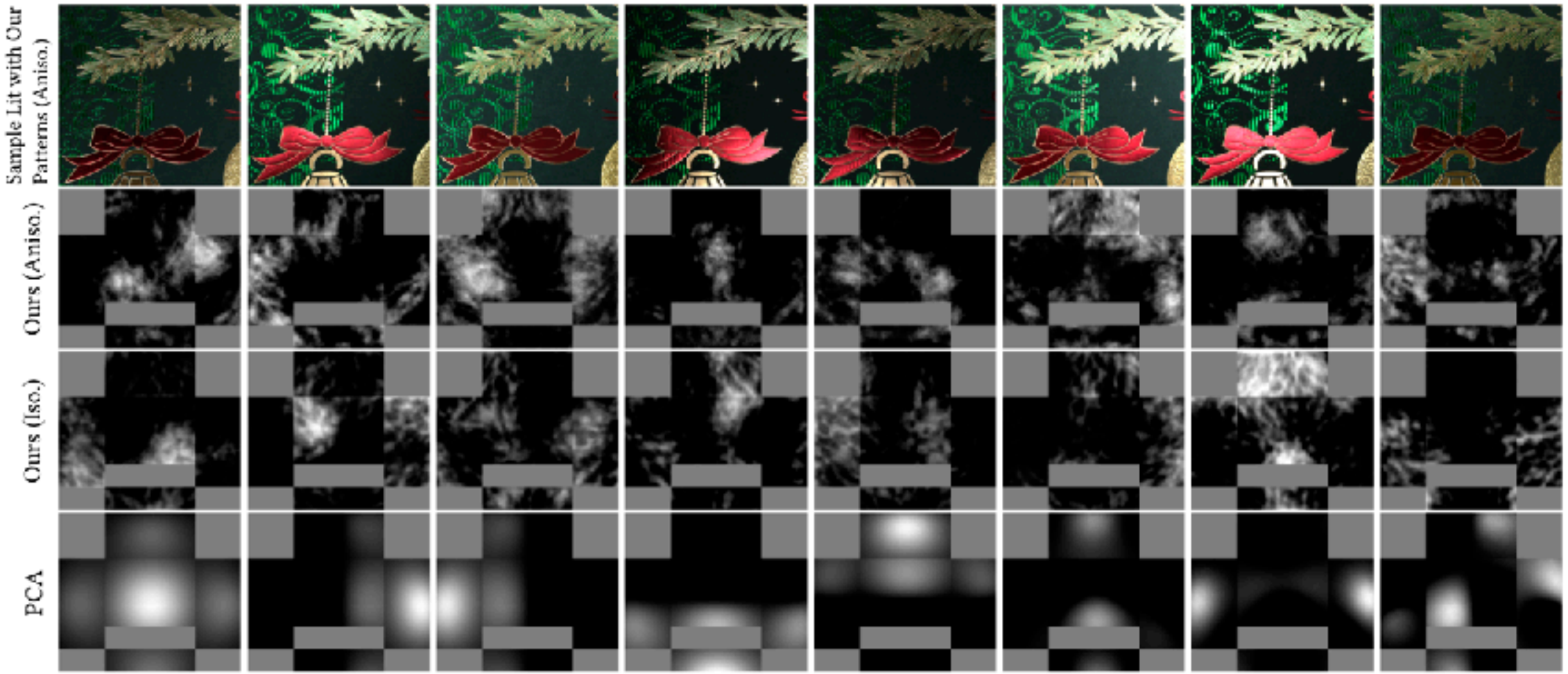
- Input: Decoded Lumitexel
- Output: GGX BRDF Parameters
  - Diffuse / Specular Albedo, Roughnesses, Normal, Tangent
- Nonlinear Optimization
  - Levenberg-Marquardt

Results

TIMING

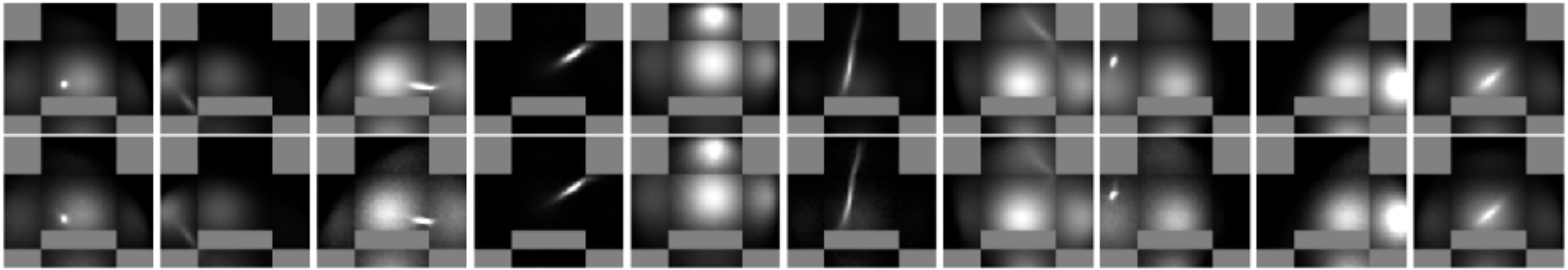
- Training Time: 5h
- Encoding Time: 12~25s
- Decoding Speed: 4m / 1M Lumitexels
- Fitting Speed: 1.6h / 1M Lumitexels

LIGHTING PATTERNS



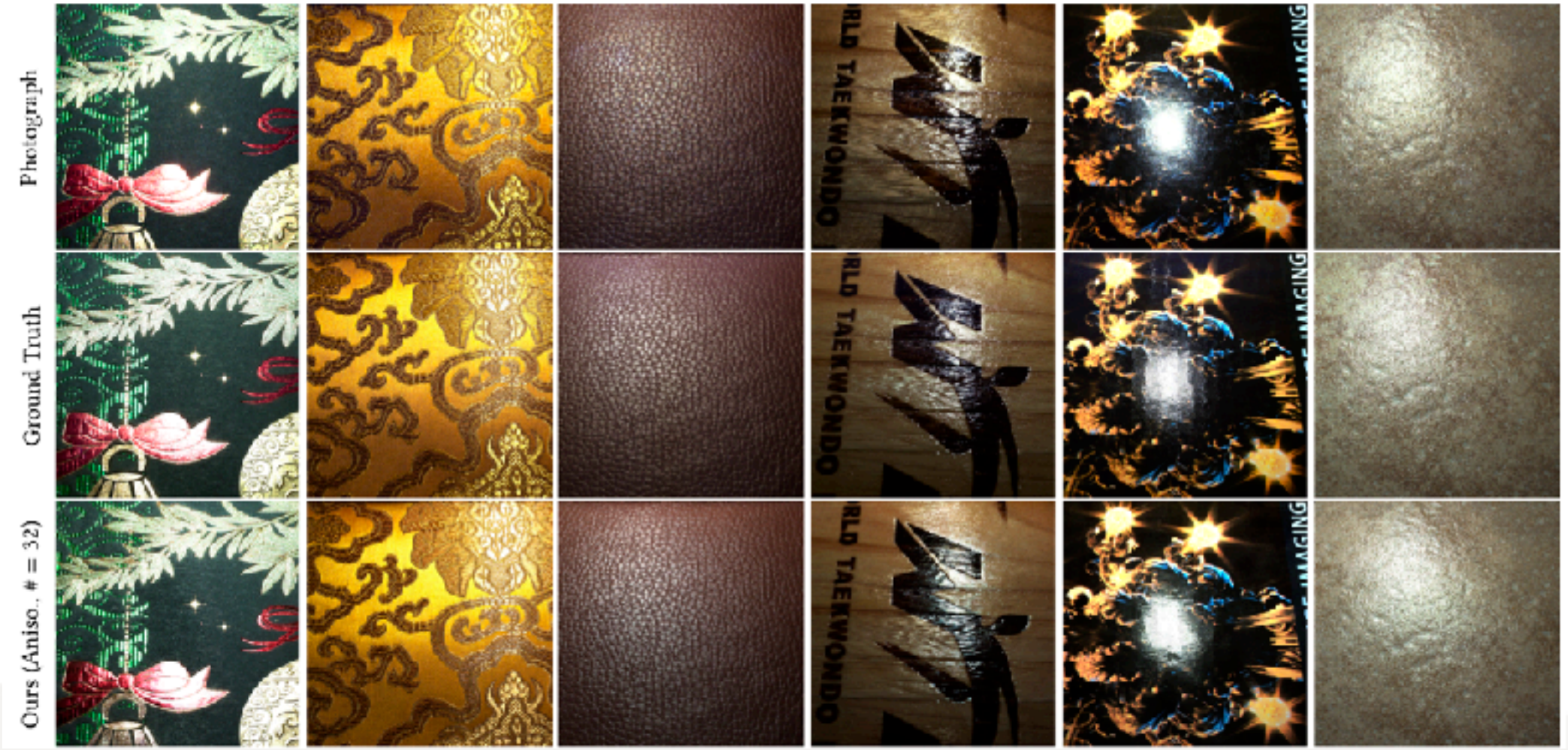
SYNTHETIC LUMITEXEL RECONSTRUCTION

Input Lumitexels



Reconstructed Lumitexels
with 32 Lighting Patterns

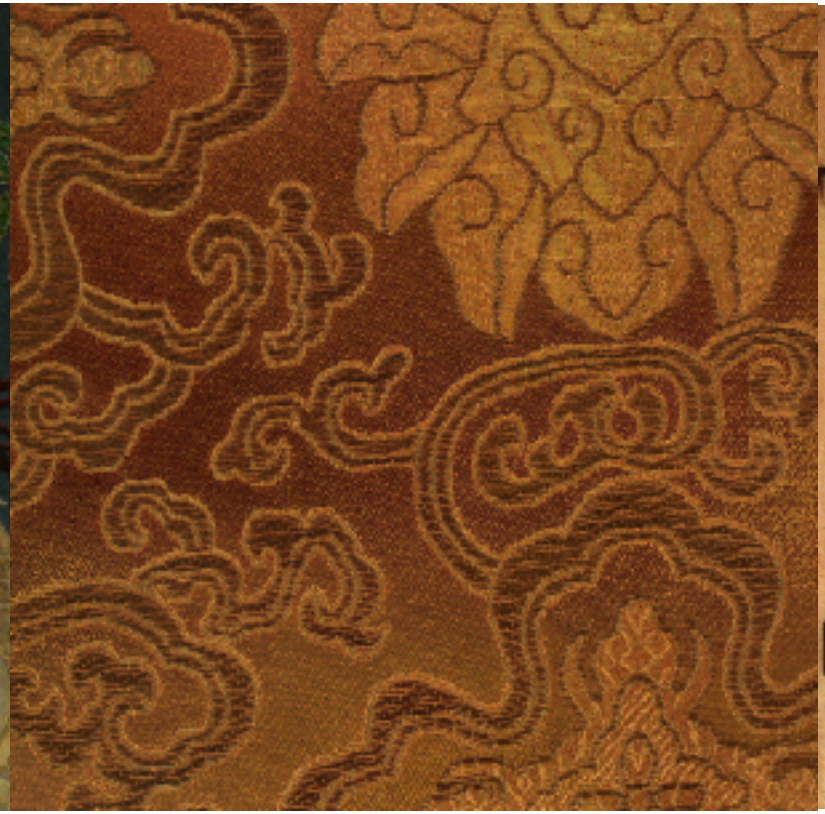
VALIDATION ON PHYSICAL SAMPLES



Complete Acquisition Using
32 Learned Lighting Patterns

DIFFUSE ALBEDO

Xmas-card



Fabric

Wood

SPECULAR ALBEDO

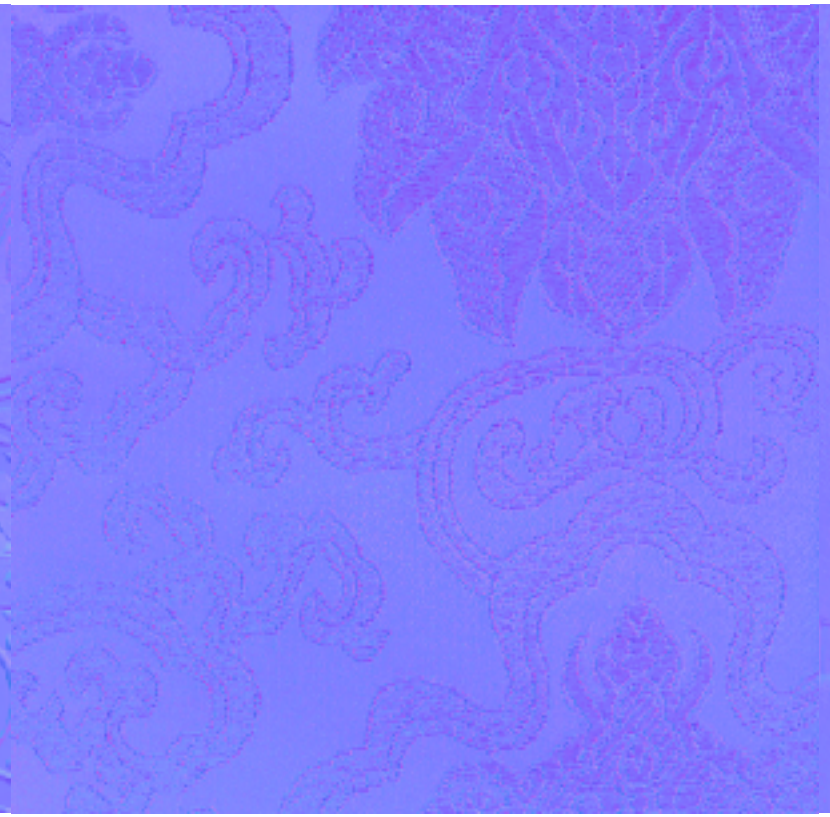
Xmas-card

Fabric

Wood

NORMAL

Xmas-card

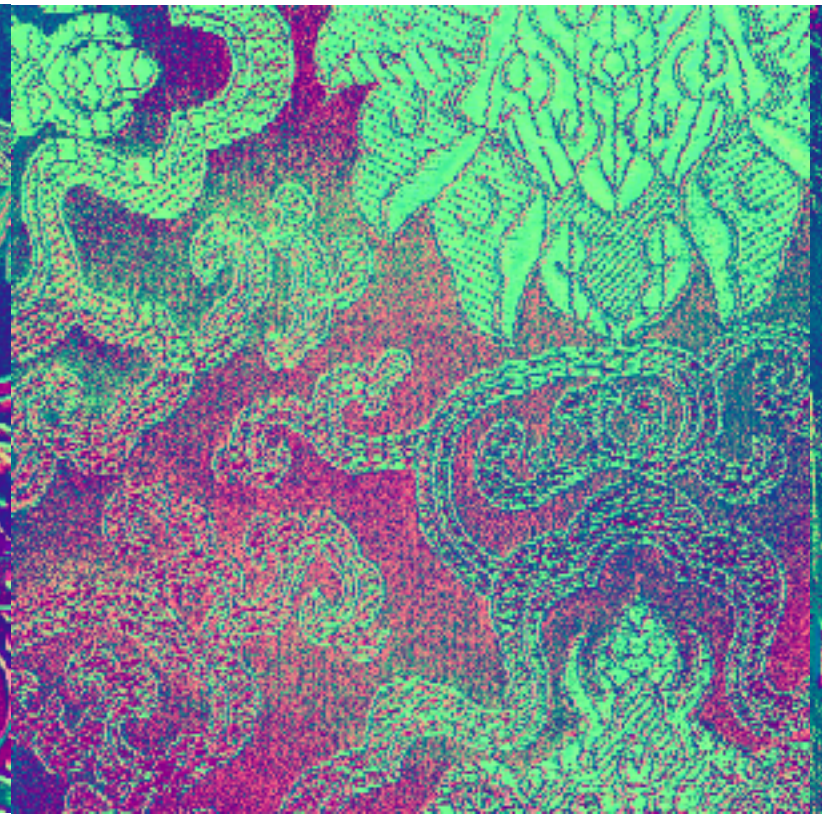


Fabric

Wood

TANGENT

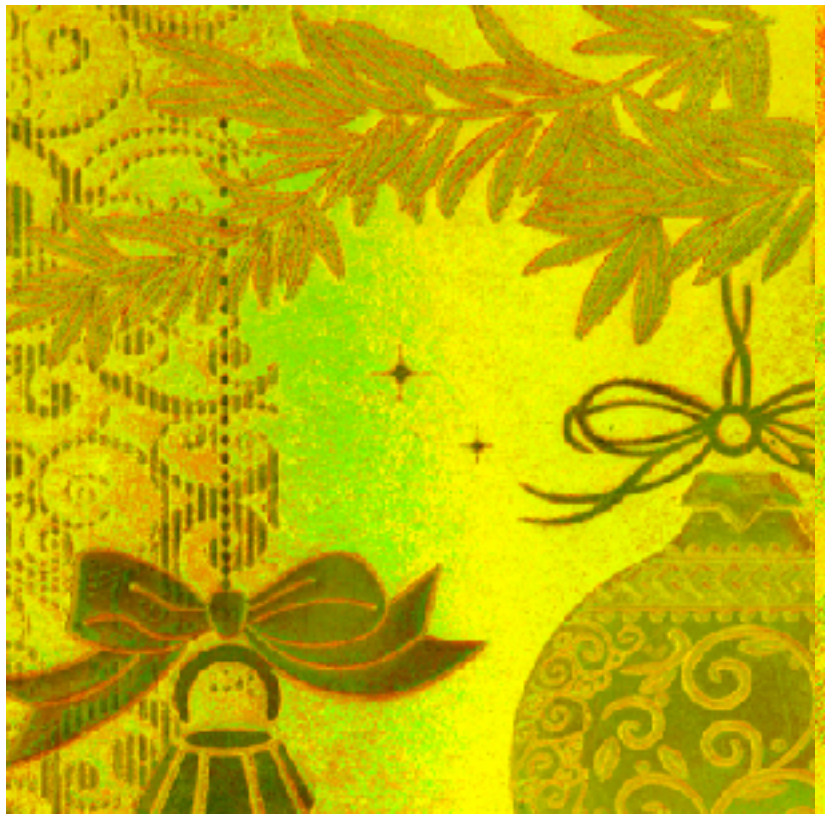
Xmas-card



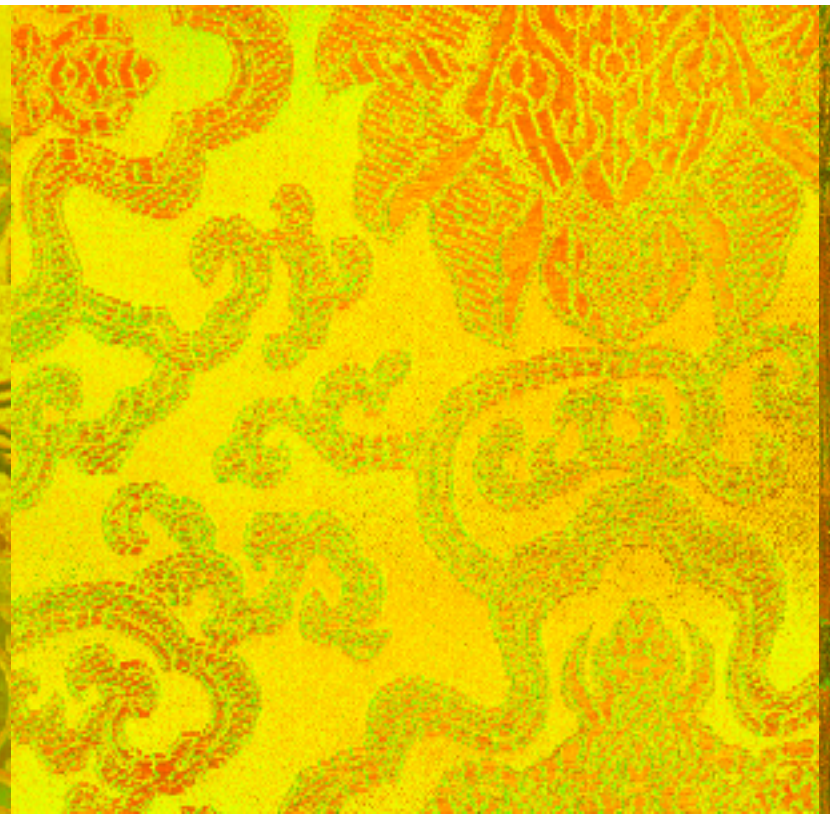
Fabric

Wood

ROUGHNESS



Xmas-card



Fabric

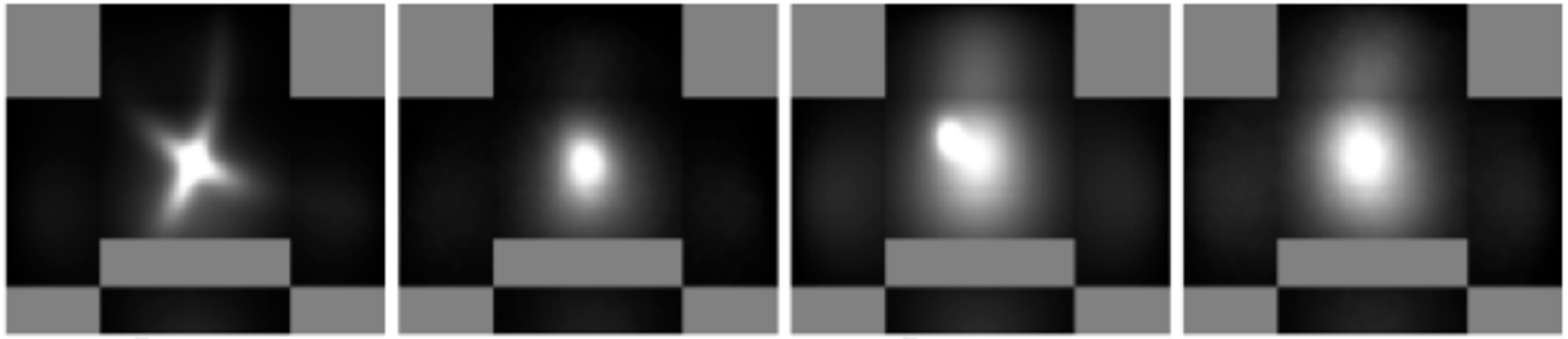
Wood

IMPACT OF TRAINING DATA

Ground Truth (# = 2, 560) | Aniso. (# = 32) | Iso. (# = 24) | Prior Dist. (# = 16)

LIMITATIONS

- Cannot Reconstruct Lumitexels Substantially Deviated from Training Data



LIMITATIONS

- Cannot Reconstruct Lumitexels Substantially Deviated from Training Data
- Mostly Planar Samples

LIMITATIONS

- Cannot Reconstruct Lumitexels Substantially Deviated from Training Data
- Mostly Planar Samples
- One Fixed View

Conclusions

CONCLUSIONS & FUTURE WORK

- A Framework that Automatically Learns to Capture SVBRDF Efficiently
- Towards AI-Assisted Optimal & Joint Design of Hardware + Software

CONCLUSIONS & FUTURE WORK

- A Framework that Automatically Learns to Capture SVBRDF Efficiently
- Towards AI-Assisted Optimal & Joint Design of Hardware + Software
- Future Directions
  - Apply to Existing Setup (e.g., Lightstage, Linear Light Source)
  - View Optimization
  - Beyond Reflectance (e.g., Image Relighting [Xu et al. 2018])

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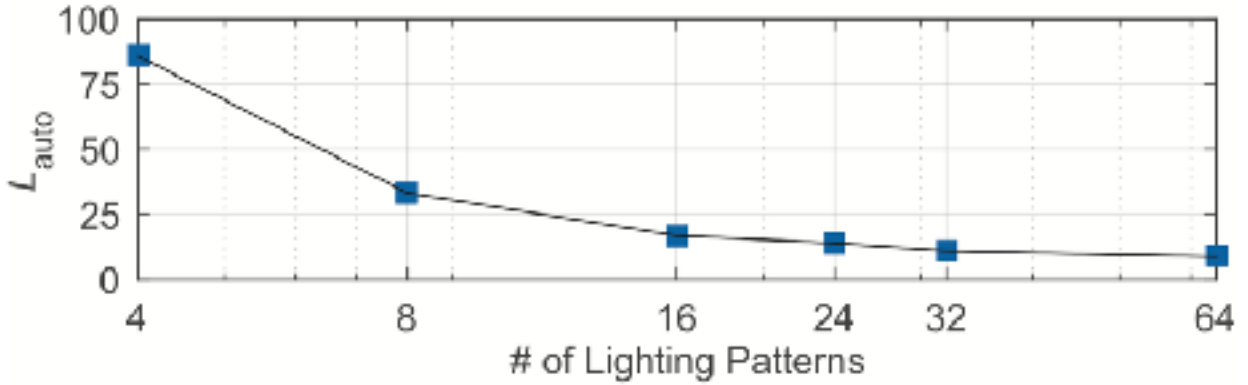
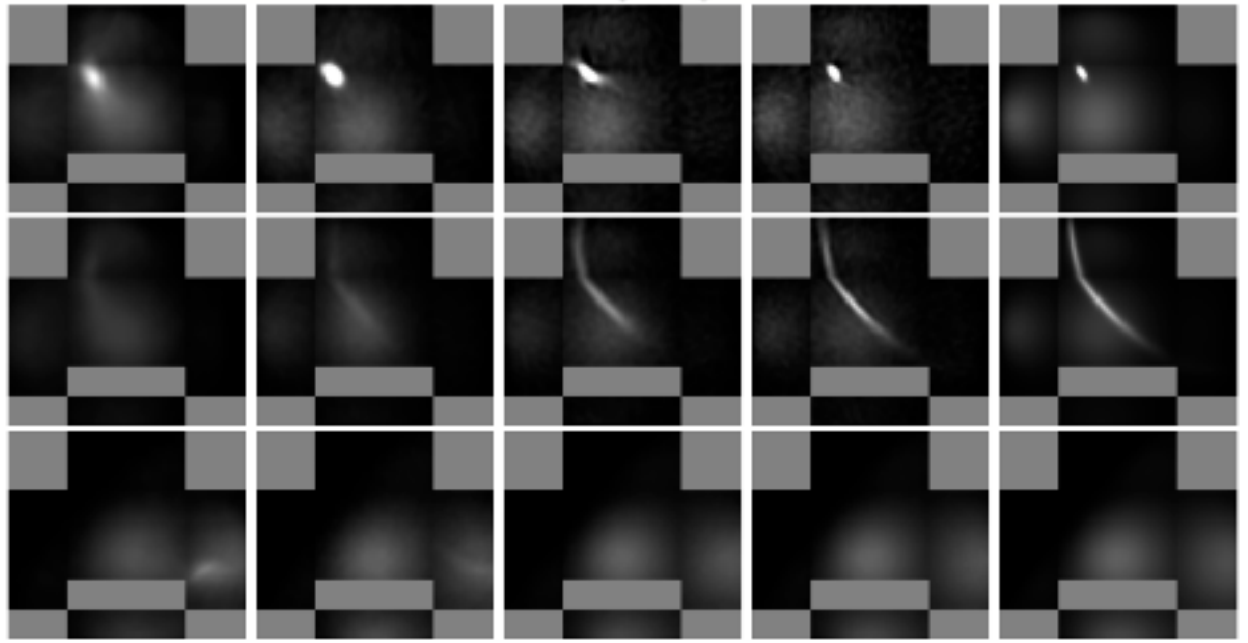
謝謝 / MERCI

Email: hwu@acm.org

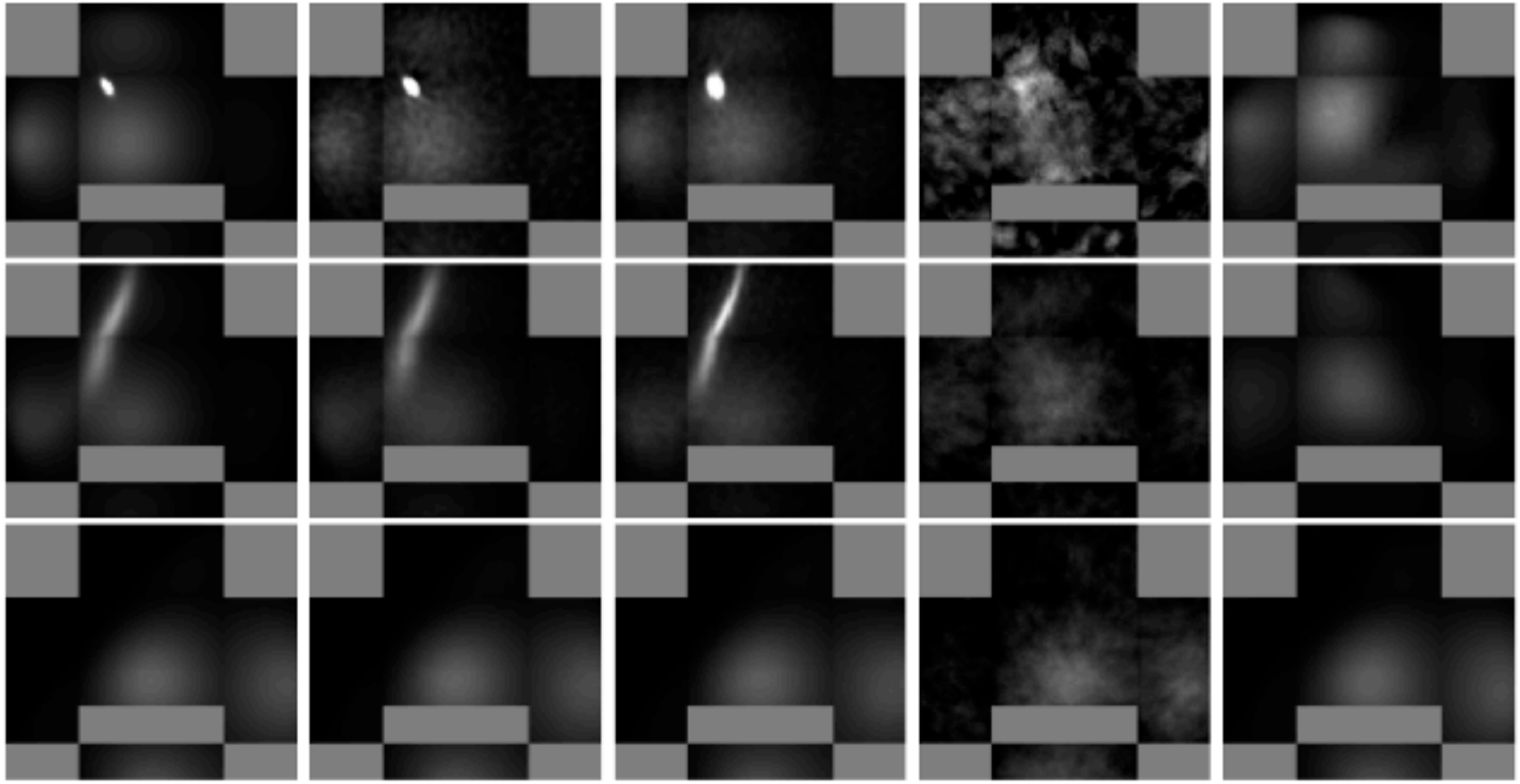
Project Webpage

BACKUP


100
75
50
25
0
L_{auto}
4
8
16
24
32
64
# of Lighting Patterns


= 4
= 8
= 16
= 32
Input

BACKUP


Input Lumitexel
Our Enc. + Nonlin. Dec.
PCA Enc. + Nonlin. Dec.
Our Enc. + Lin. Dec.
PCA Enc. + Lin. Dec.

BACKUP