Inverse Shade Trees for Non-Parametric Material Representation and Editing

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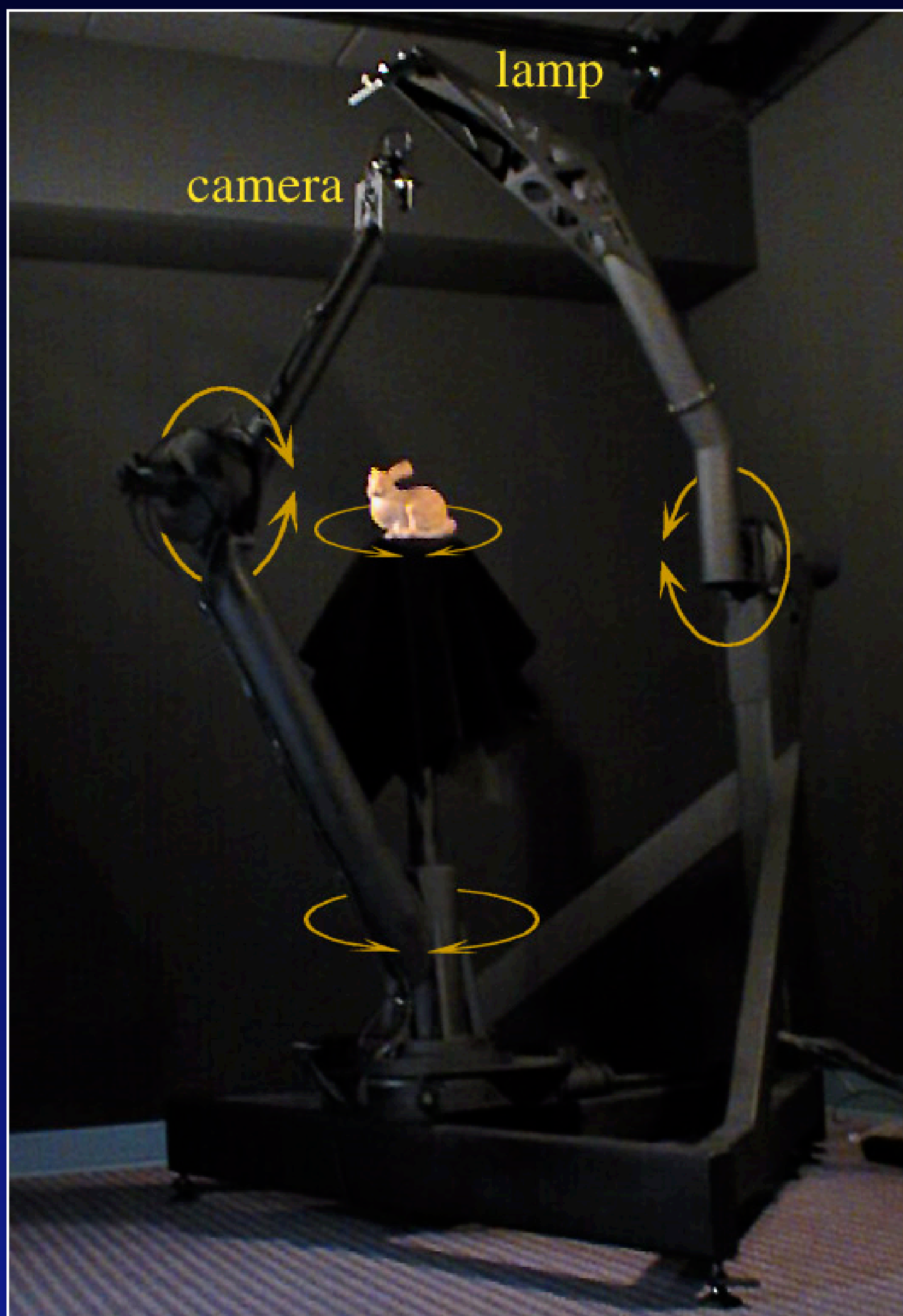
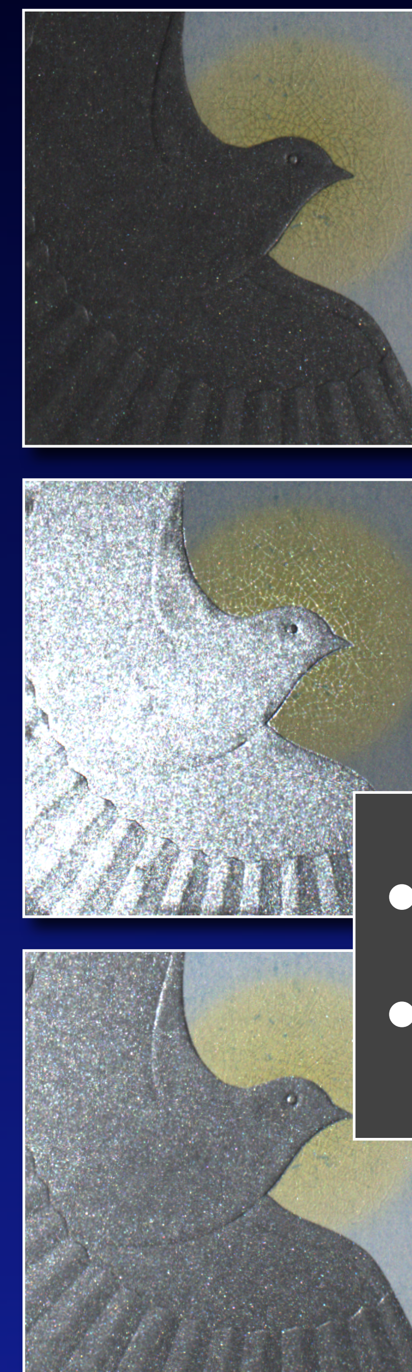
Complex Appearance

Appearance Acquisition





- 2,000 Images
- 6 GB

Image courtesy of Stanford Graphics Laboratory

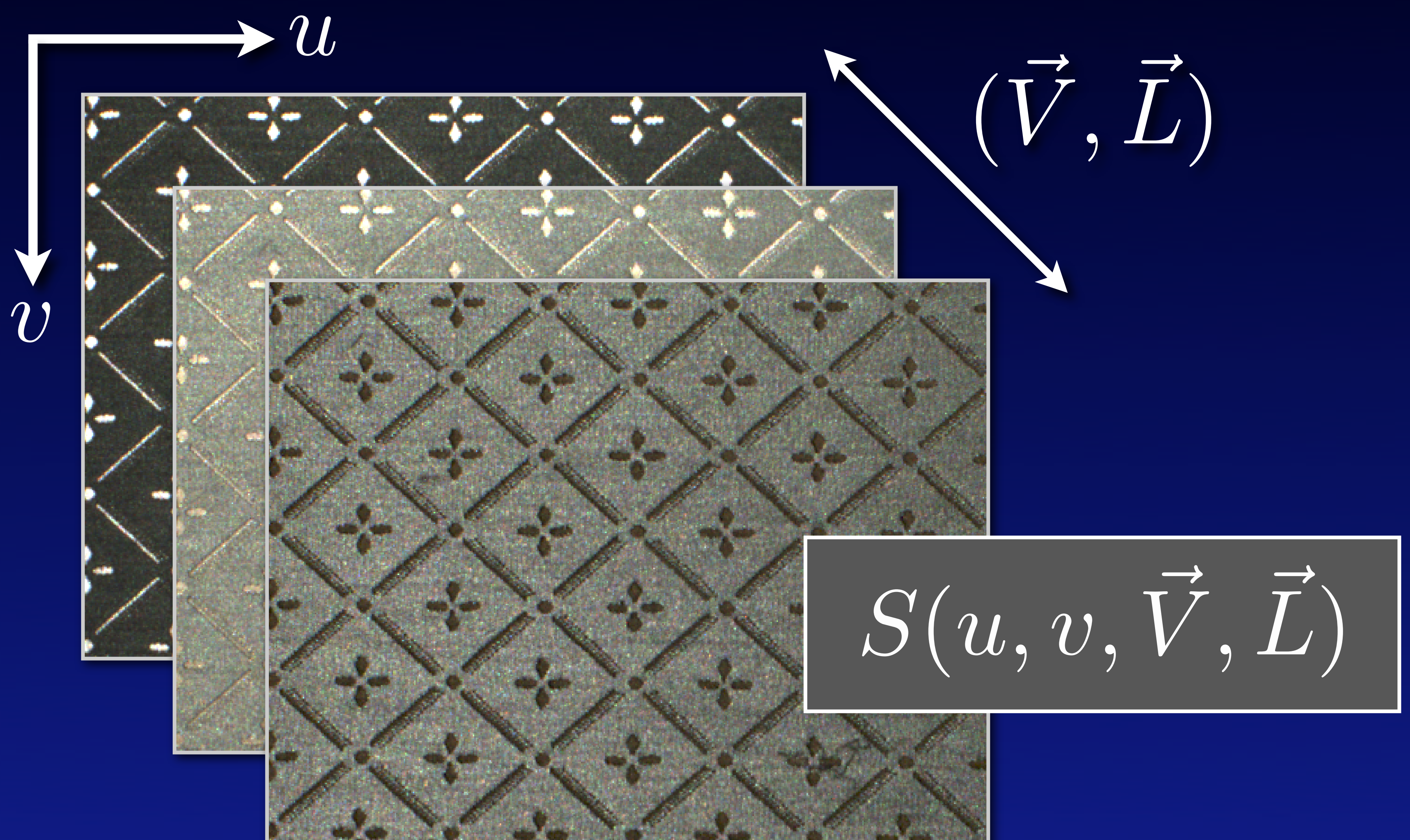
Challenge

- Given: dense set of measurements of light transport function.
- Provide: intuitive representation that is compact and allows editing.

Original Measured Appearance

Result of Editing Material Properties

Spatially-Varying Reflectance

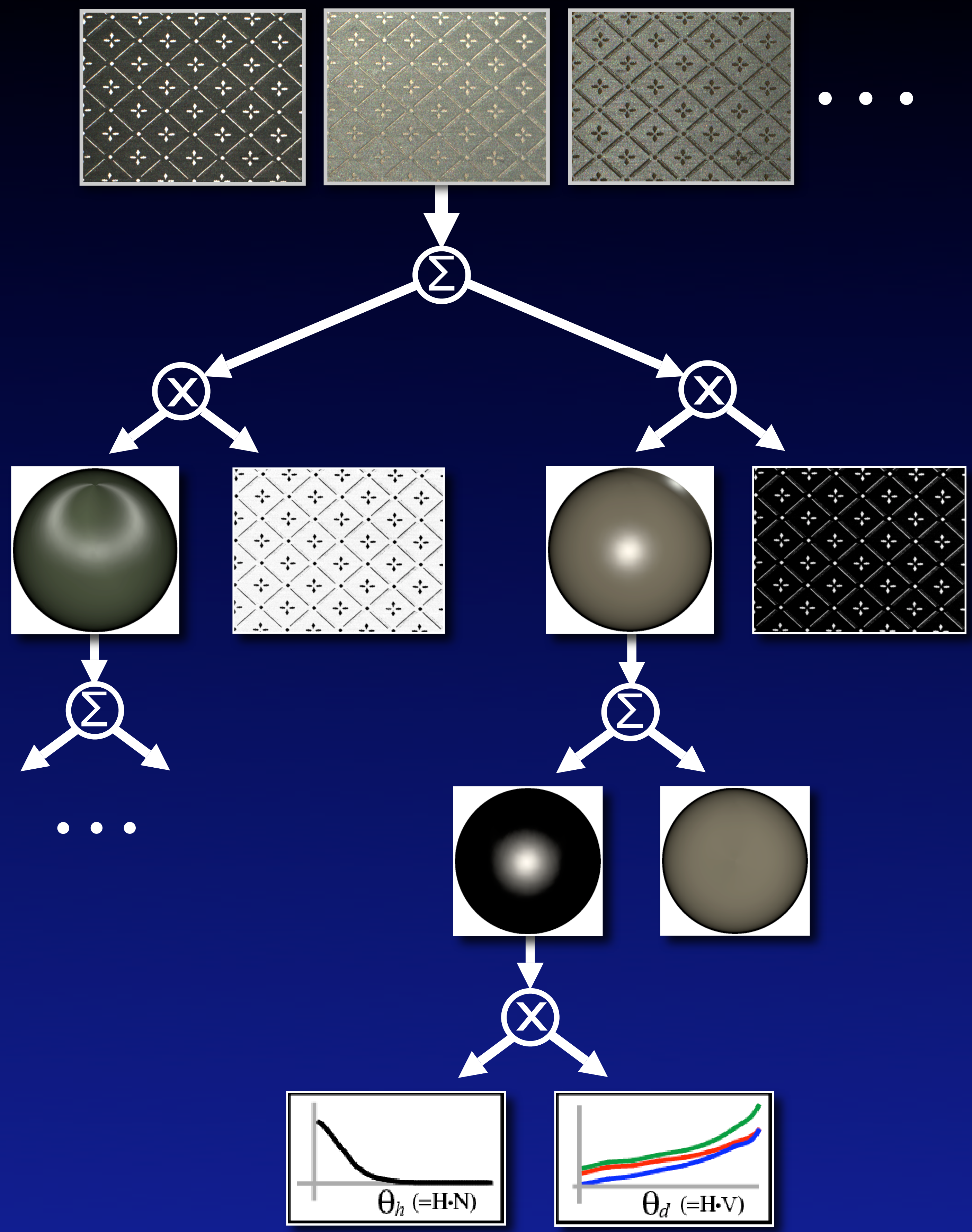


Spatially-Varying Bidirectional Reflectance Distribution Function

Observation #1:
Represent high-dimensional measured function as tree-structured collection of lower-dimensional parts.

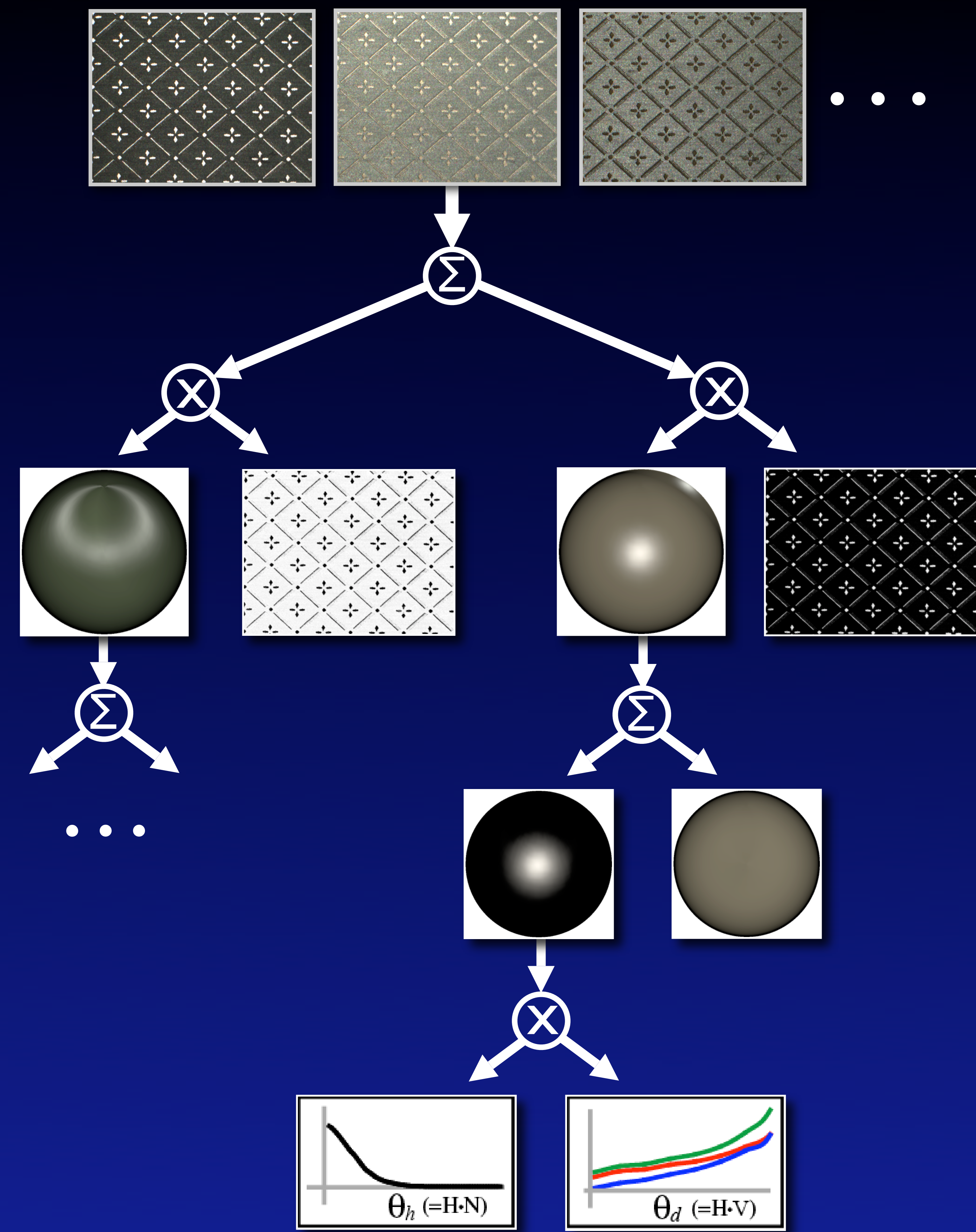
Observation #2:
Decomposition at each level is matrix factorization.

Observation #3:
Intuitive decomposition achieved using constrained factorization.



Shade Trees
Cook 1984

Inverse
Shade Trees

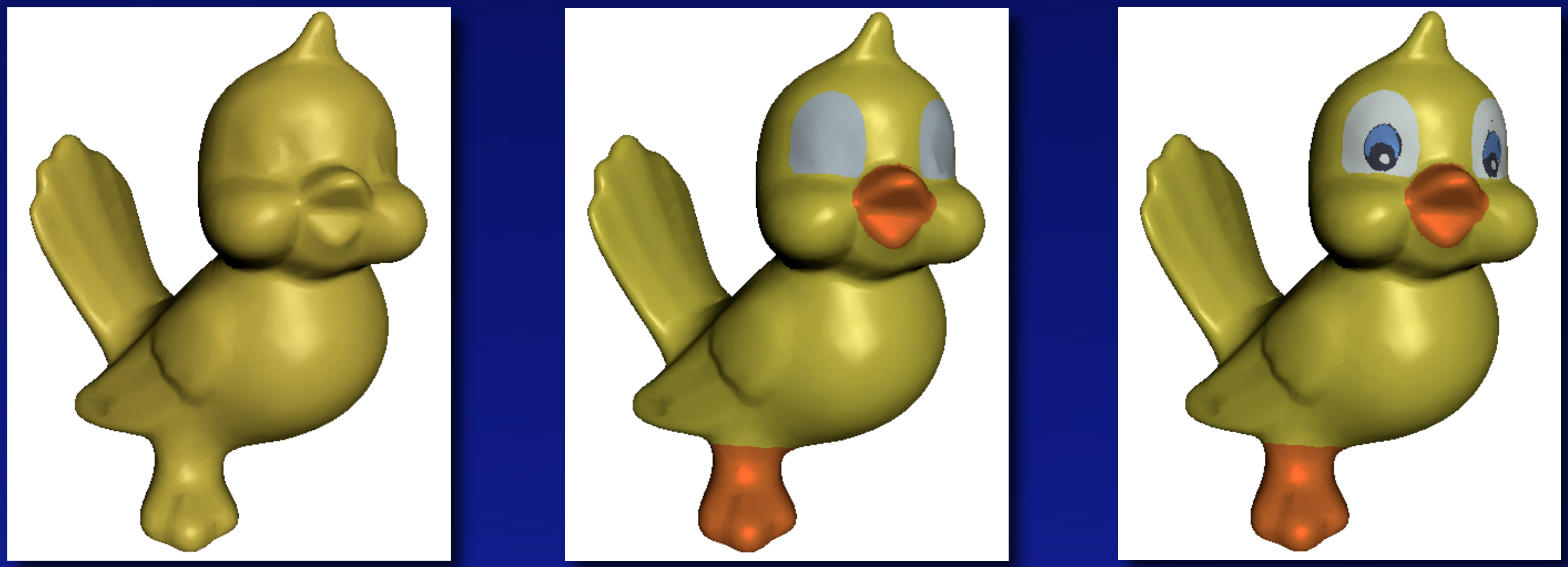


Outline

- Introduction
- Prior Work
- Factorization
- Editing
- Conclusions and Future Work

Fitting Parametric Models

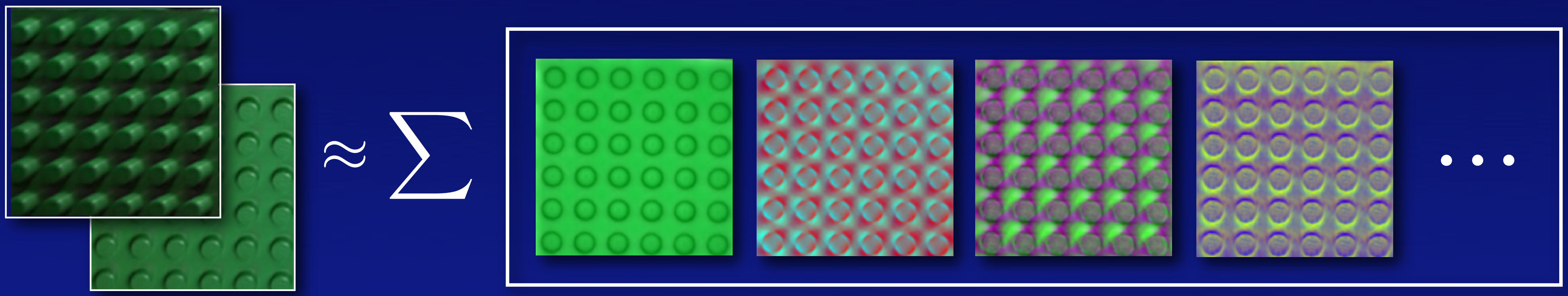
- Cluster fits of parametric BRDF: [Lensch et al. 03], [Goldman et al. 05].
- Editable **if** nice clusters
- Single analytic BRDF limits accuracy



Lensch et al. 2003

Dimensionality Reduction

- Apply rank-reduction algorithms to data matrix: [Dana et al. 99], [Chen et al. 02], [Tsumura et al. 03]
- Compact and accurate
- Cannot be directly edited



HOSVD "Basis Images" from Wang et al. 2005

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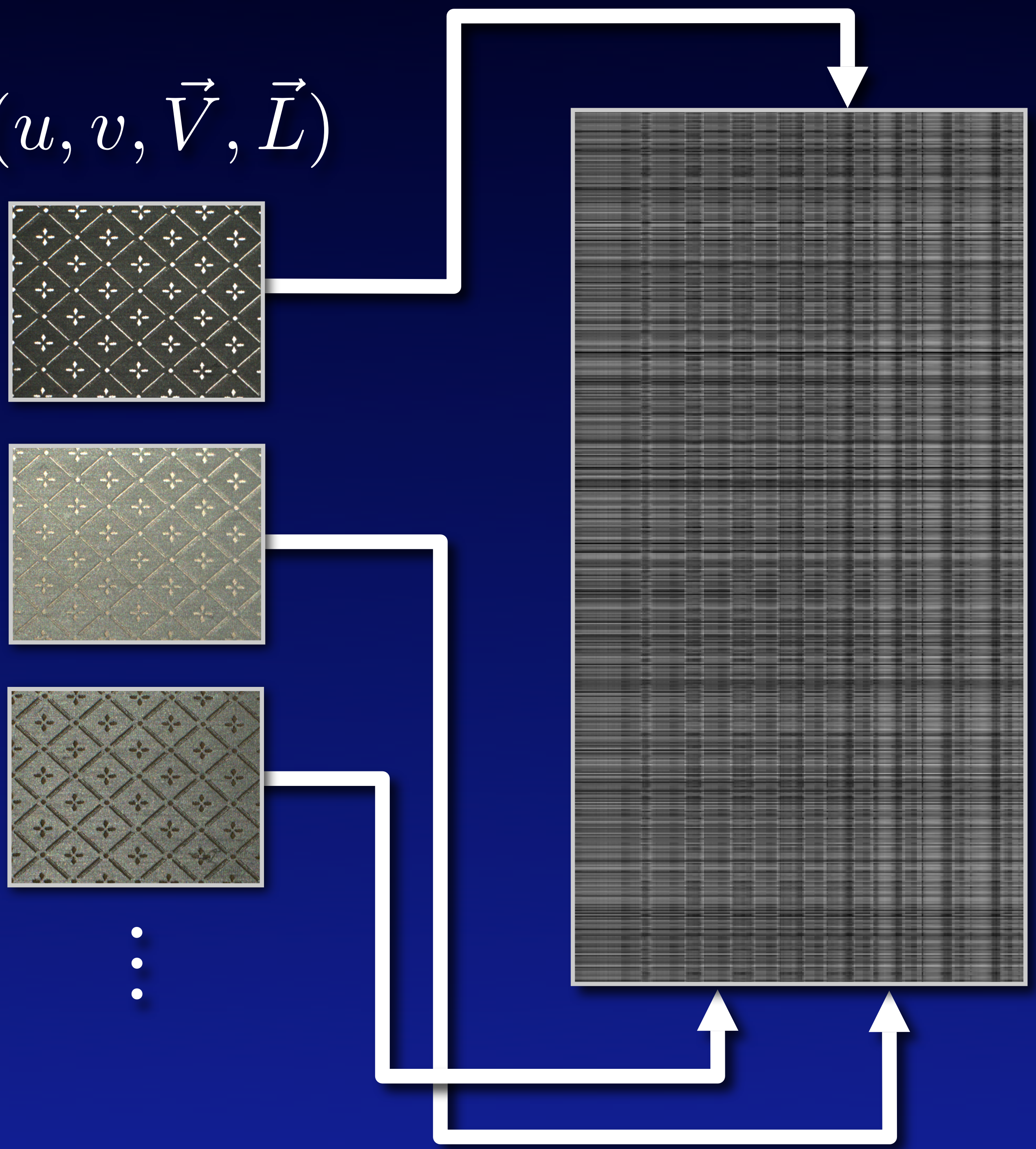
Tabulate Raw Data

$S(u, v, \vec{V}, \vec{L})$



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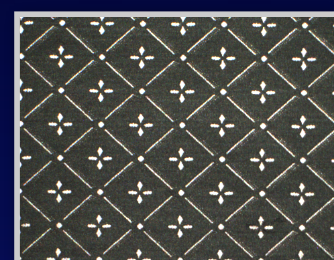
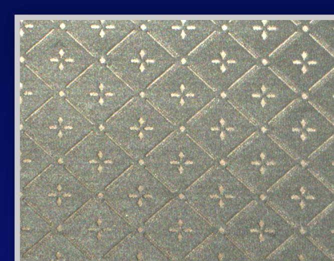
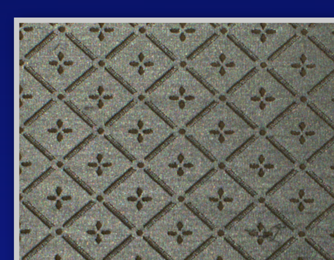


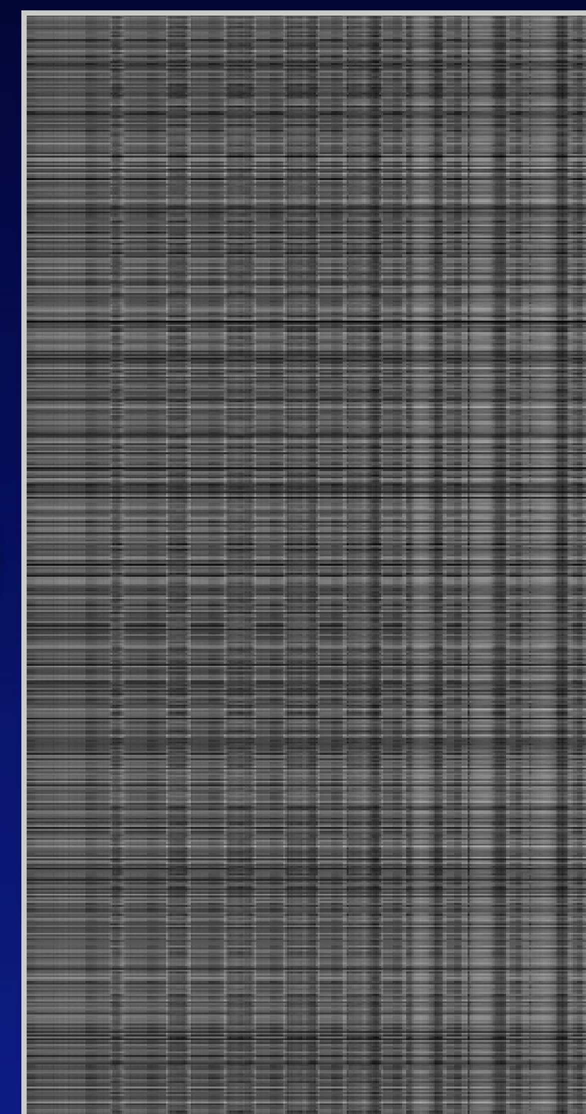




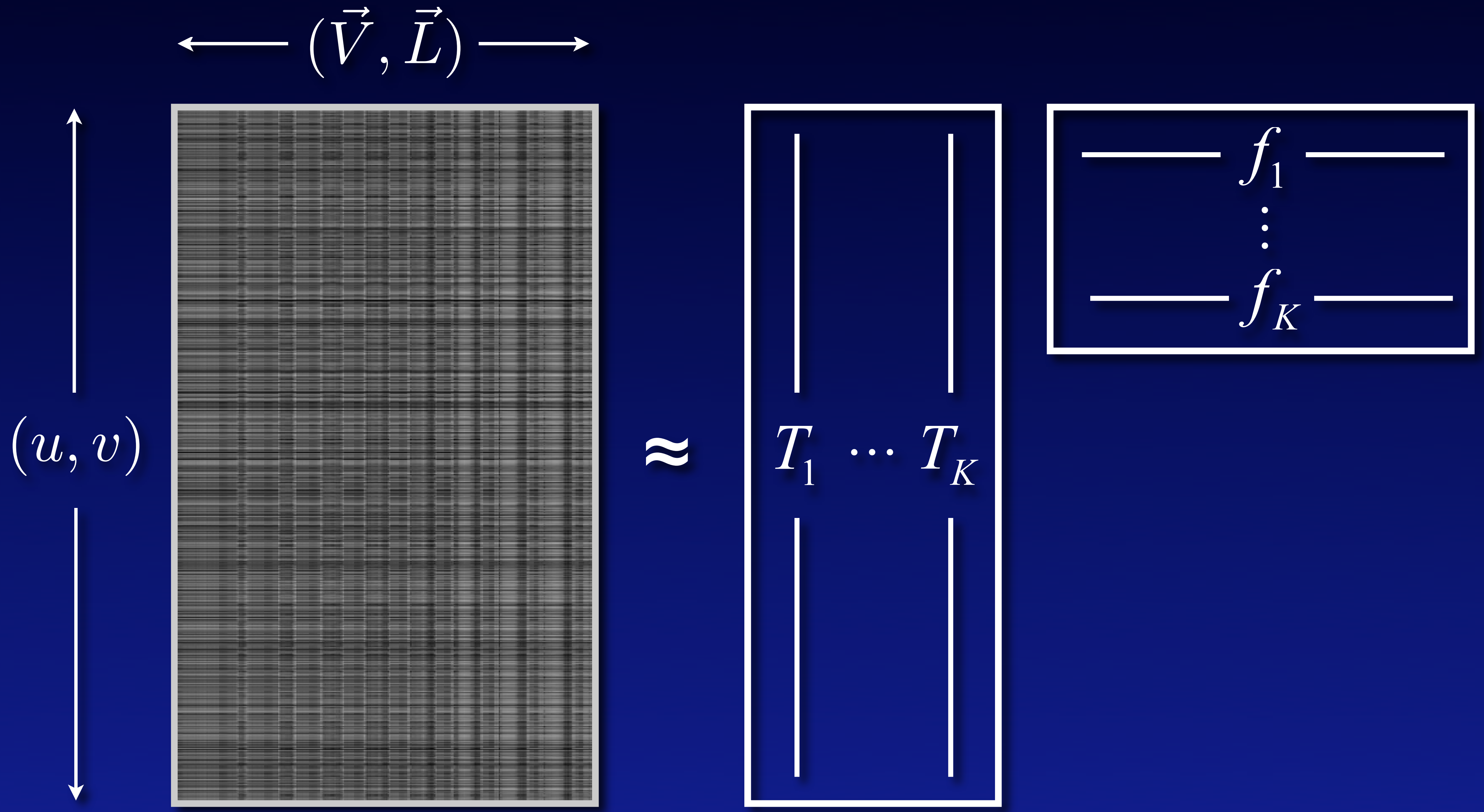
$\vdots$

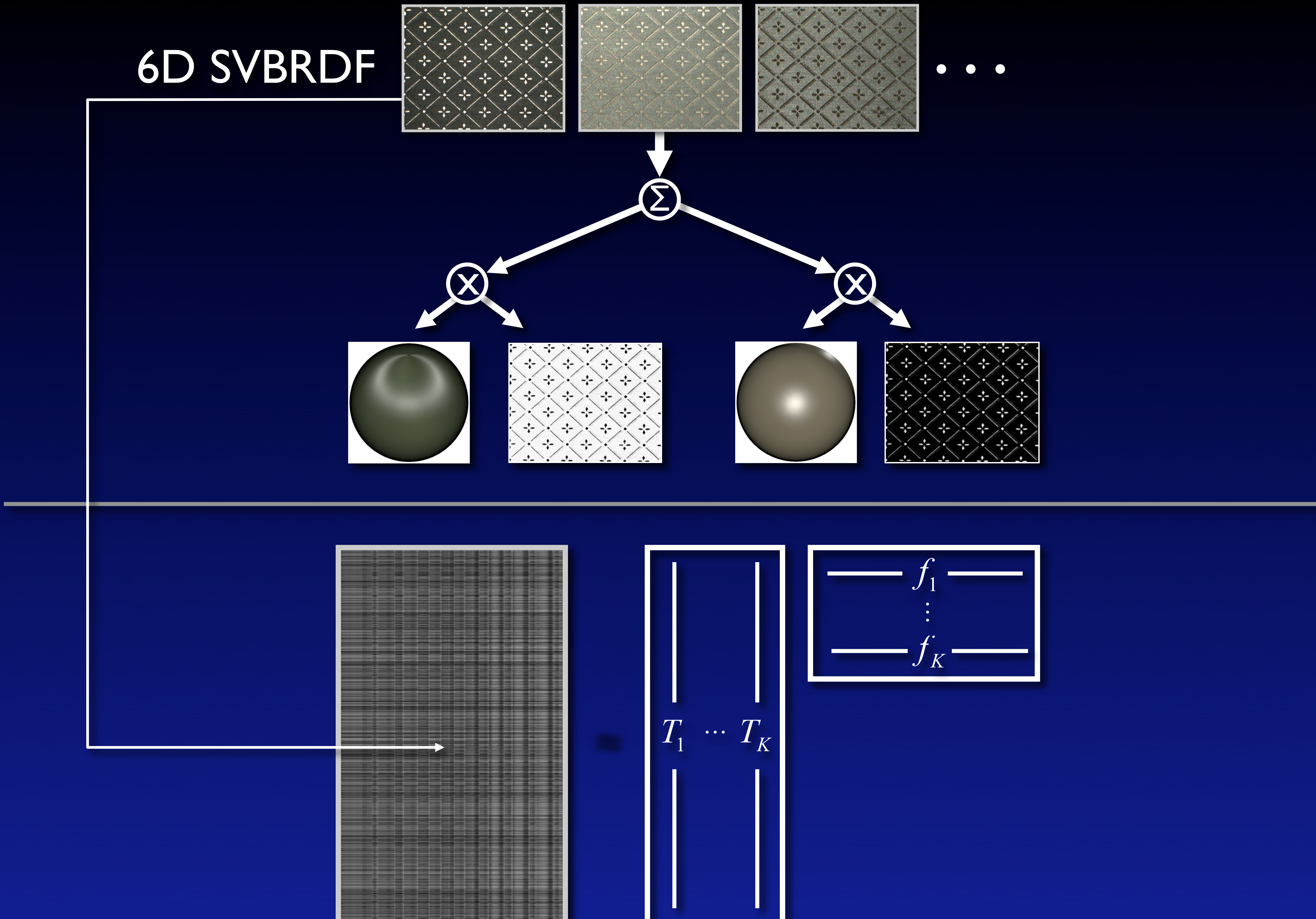
(u, v)

$\longleftarrow (\vec{V}, \vec{L}) \longrightarrow$

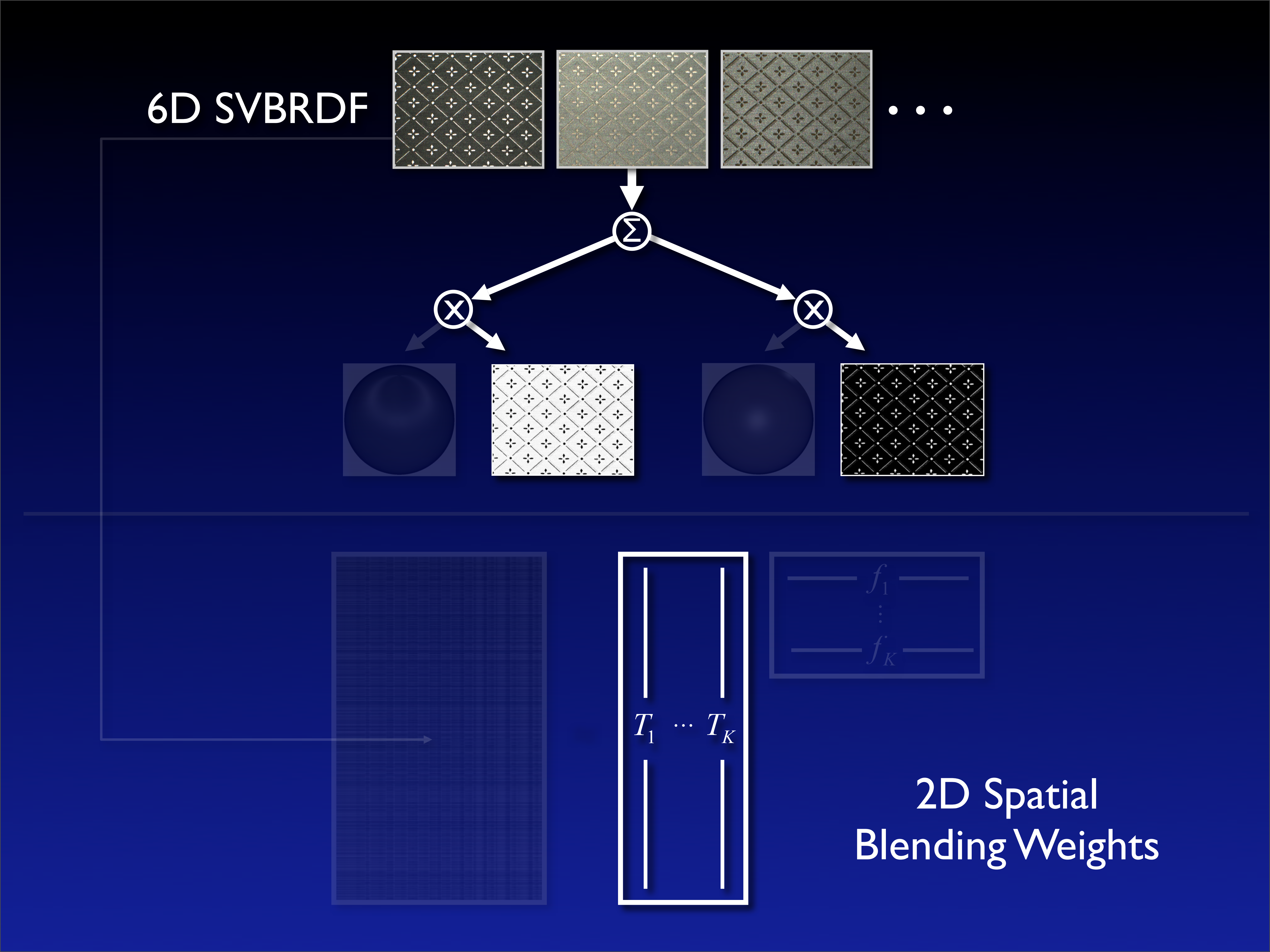


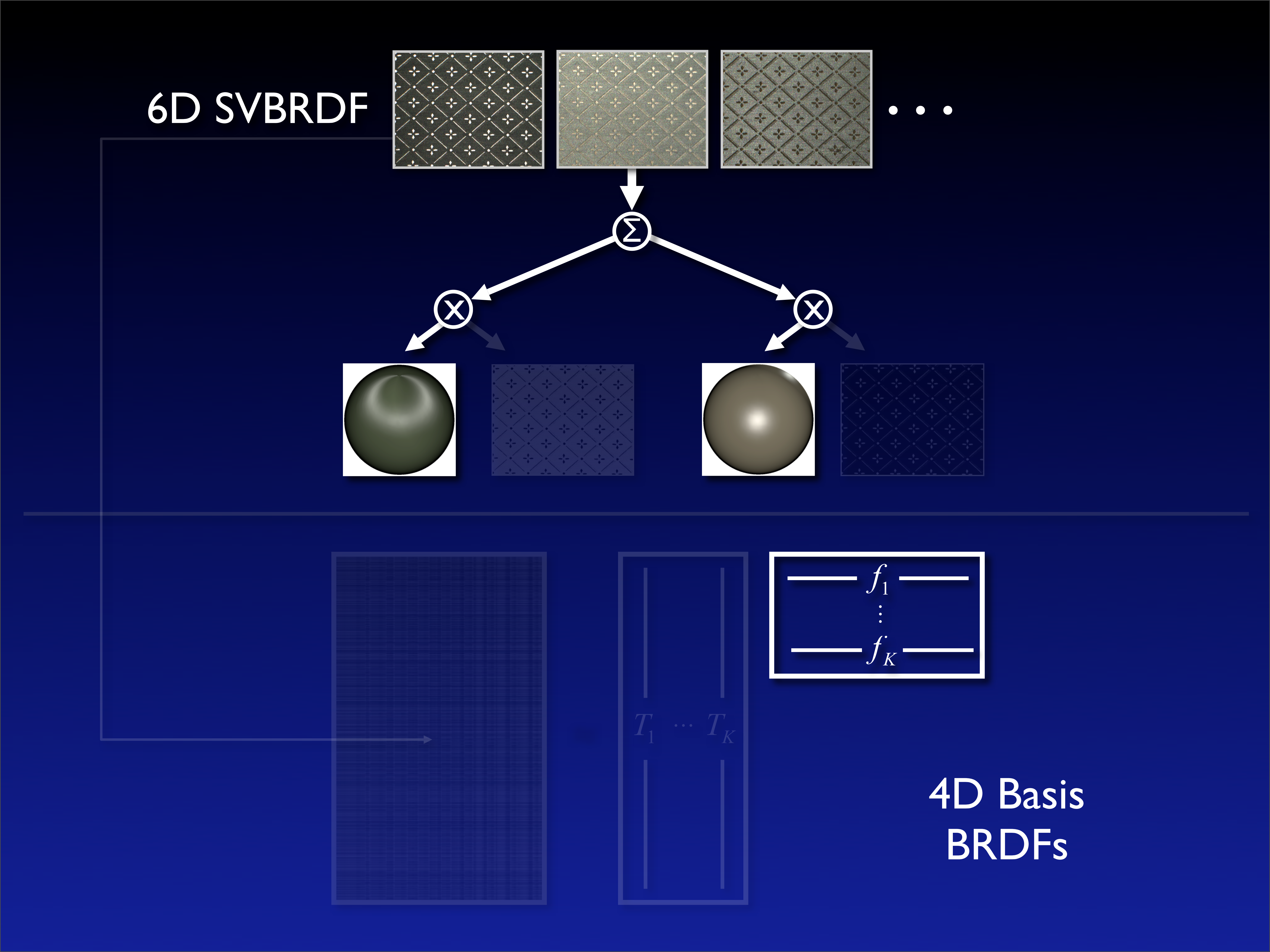
Factorization of SVBRDF





6D SVBRDF
. . .
Σ
x
x
$T_1 \cdots T_K$
f_1
f_K

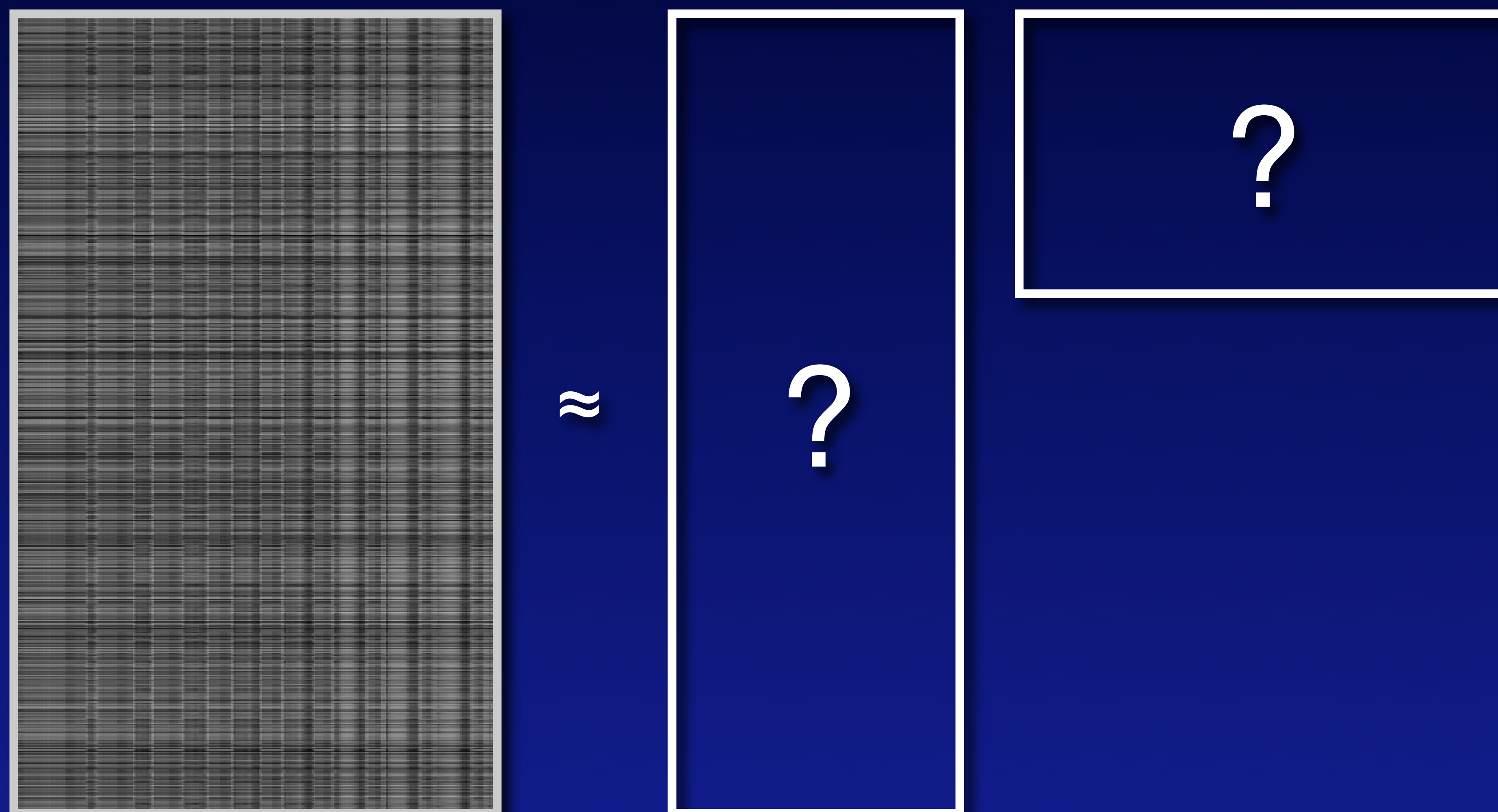

6D SVBRDF
. . .
T1 ··· TK
f1
fK
2D Spatial
Blending Weights



6D SVBRDF
. . .
f_1
f_K
$T_1 \cdots T_K$
4D Basis
BRDFs

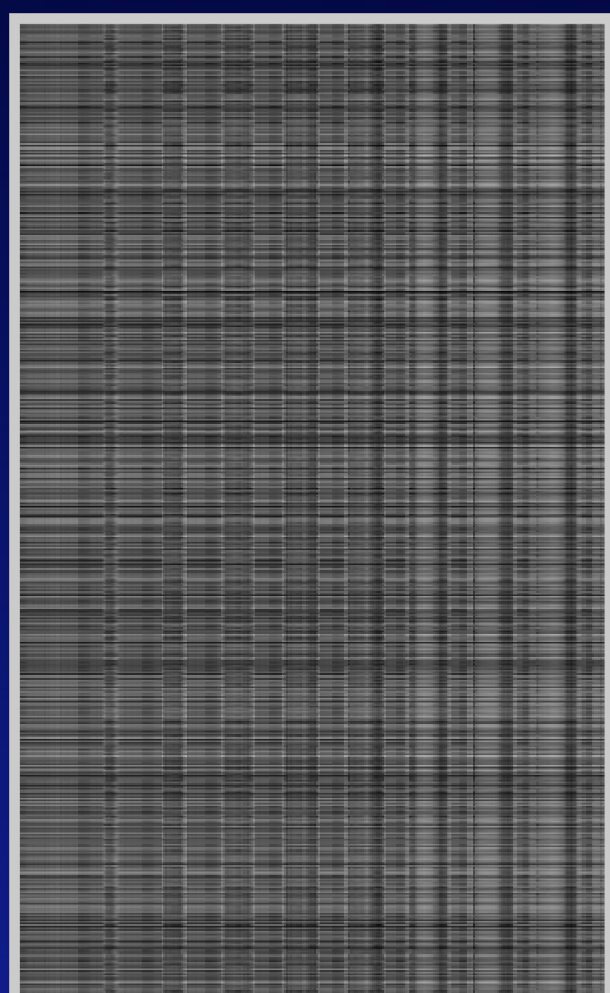
Research Challenge

Providing an intuitive factorization:



Key Idea

Incorporate domain-specific knowledge as constraints of factorization:



$\approx$

Plausible blending weights.

Plausible BRDFs

Factorization Constraints

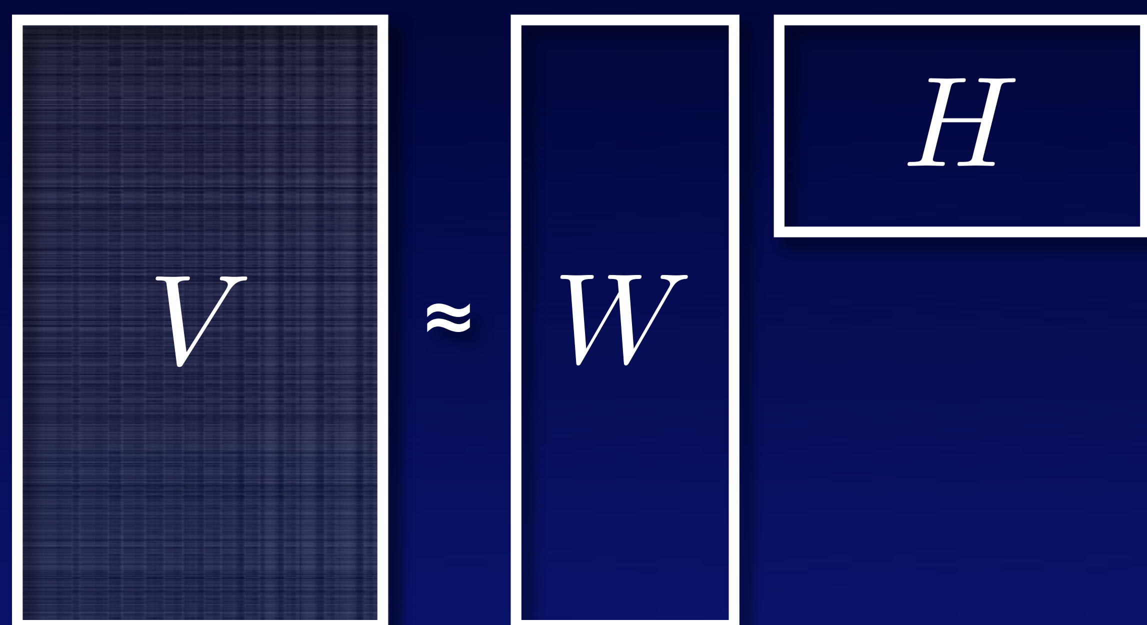
- Non-negativity:
  Reflectance functions are non-negative
- Sparsity:
  Few BRDFs at each position
- Domain-specific:
  Energy-conservation, monotonicity, etc.

Factorization Algorithms

Algorithm Groups	**Properties**			
	Linear	Positive	Sparse	Domain
PCA	✓	✗	✗	✗
Clustering	✗	✓	✓	✗
NMF	✓	✓	✗	✗
Our Method	✓	✓	✓	✓

Our Method

Alternating Constrained Least Squares (ACLS)



1. Initialize W and H
2. Update W
3. Update H
4. Iterate until convergence

Our Method

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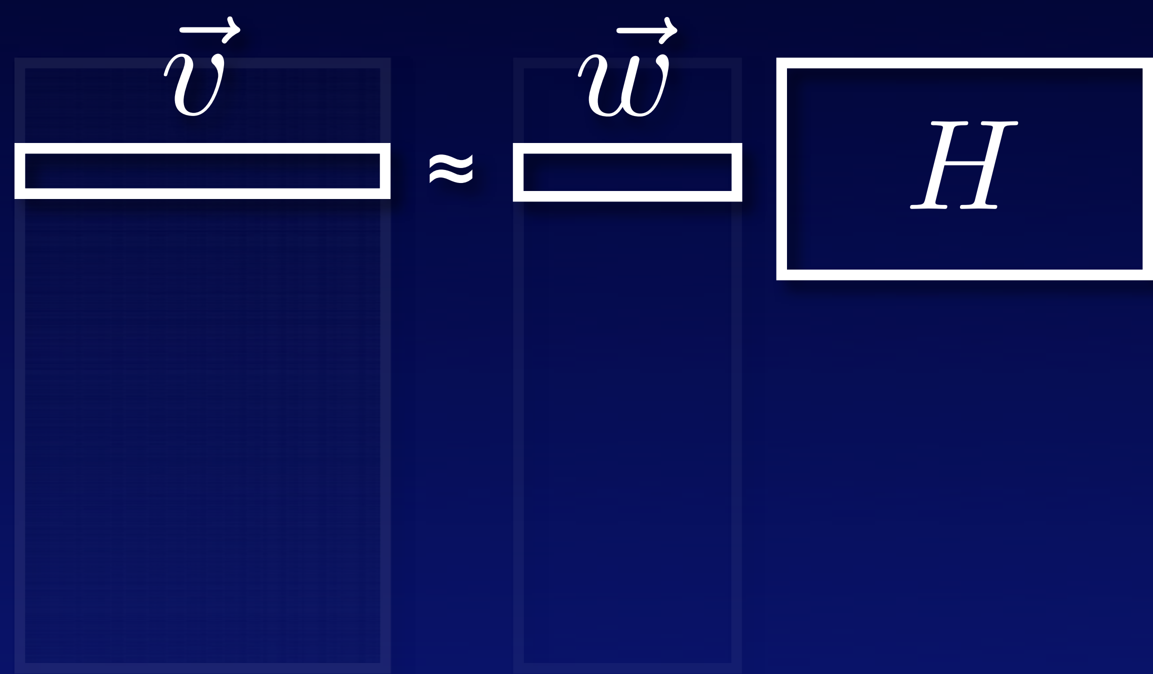

1. Initialize W and H
2. **Update W**
3. Update H
4. Iterate until convergence

Convex QP Problem

$$\min_{\vec{w}} \|\vec{v} - \vec{w}H\|^2$$

$$\vec{l} \leq \left\{ \begin{array}{c} \vec{w}^T \\ A\vec{w}^T \end{array} \right\} \leq \vec{u}$$

Appearance Constraints

- Non-negativity
  - Value constraint
- Energy conservation
  - Constraint on sum
- Monotonicity
  - Constraint on derivative

$$\vec{l} \leq \left\{ \begin{array}{c} \vec{w}^T \\ A\vec{w}^T \end{array} \right\} \leq \vec{u}$$

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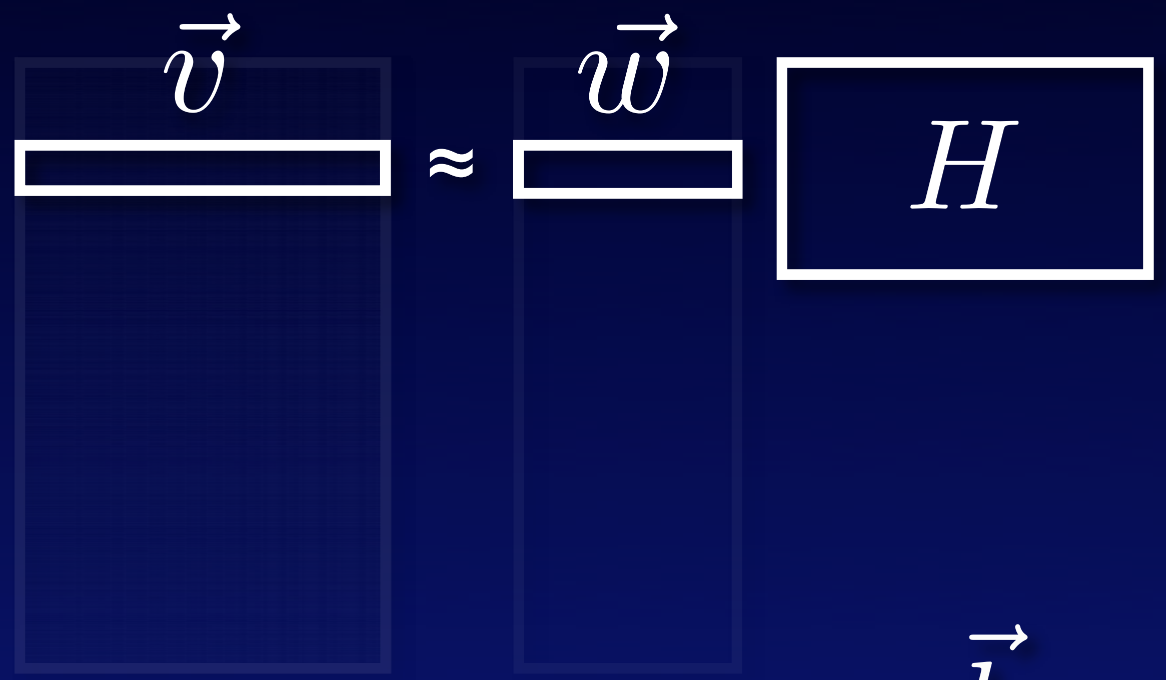
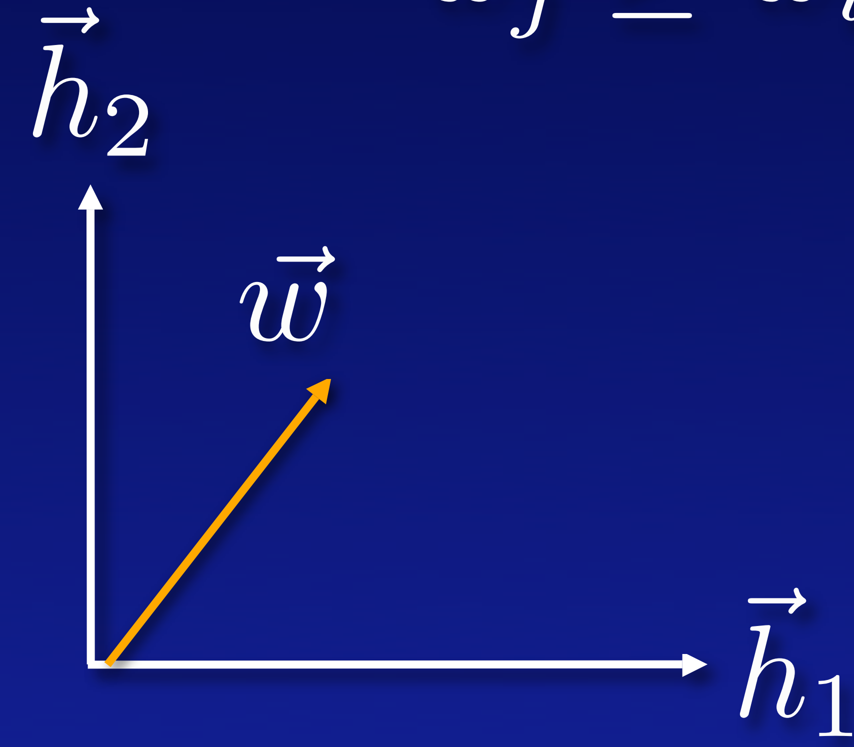
Measure of Sparsity

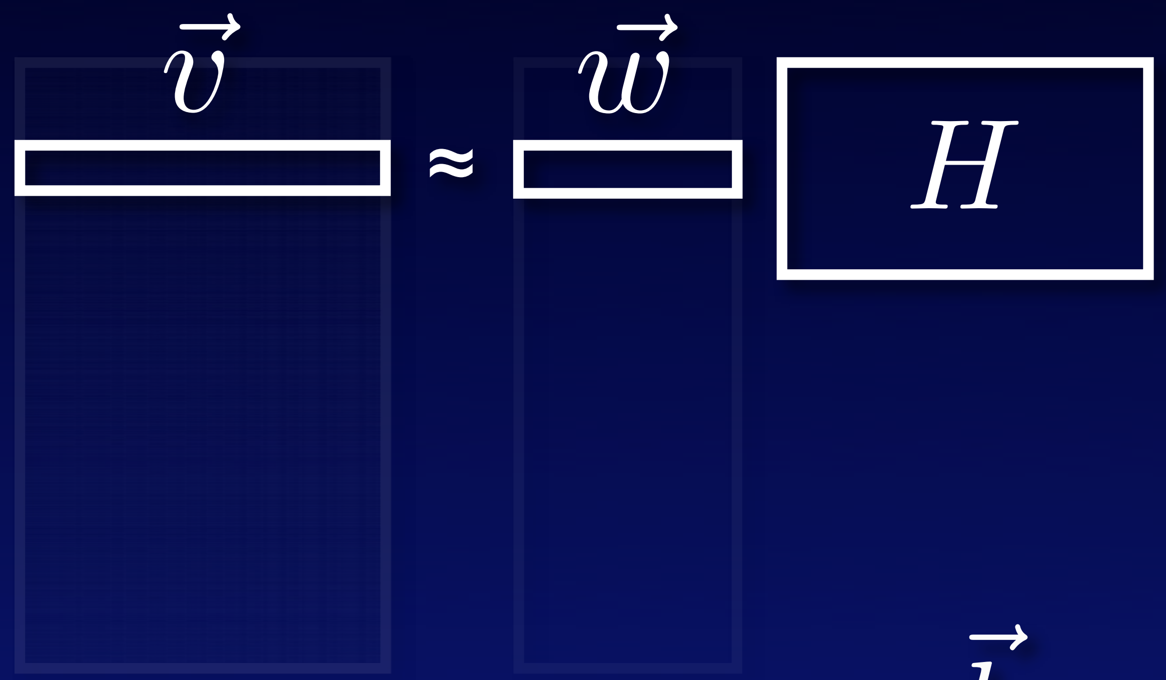


$$E_{sparse} = \sum_{i \neq j} w_i$$

$$w_j \geq w_i, i = 1...\mathrm{K}$$



Measure of Sparsity



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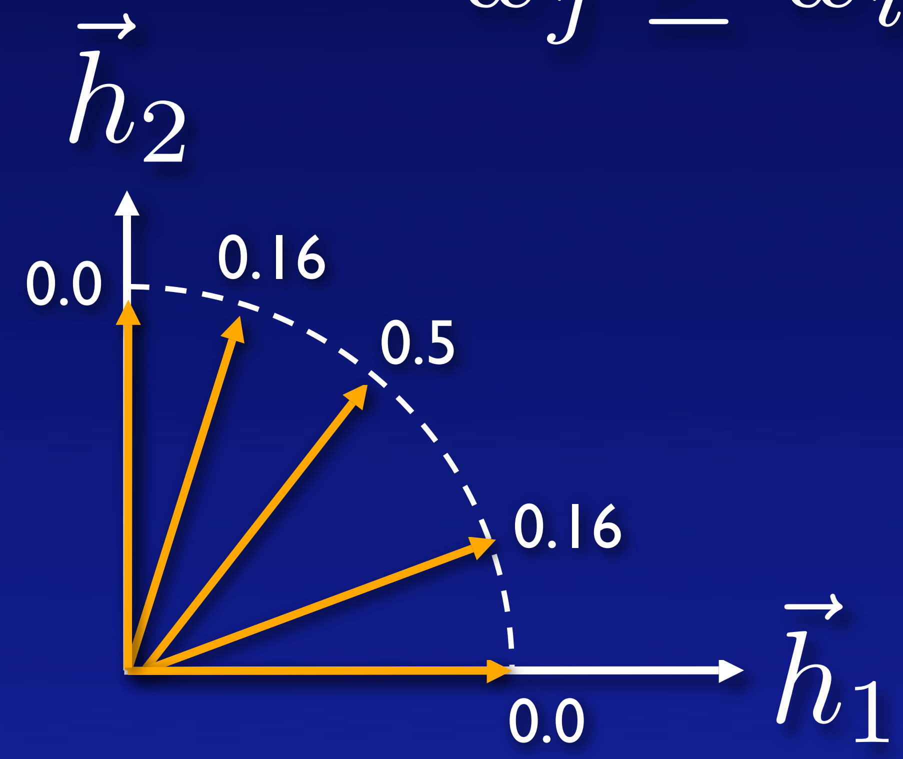


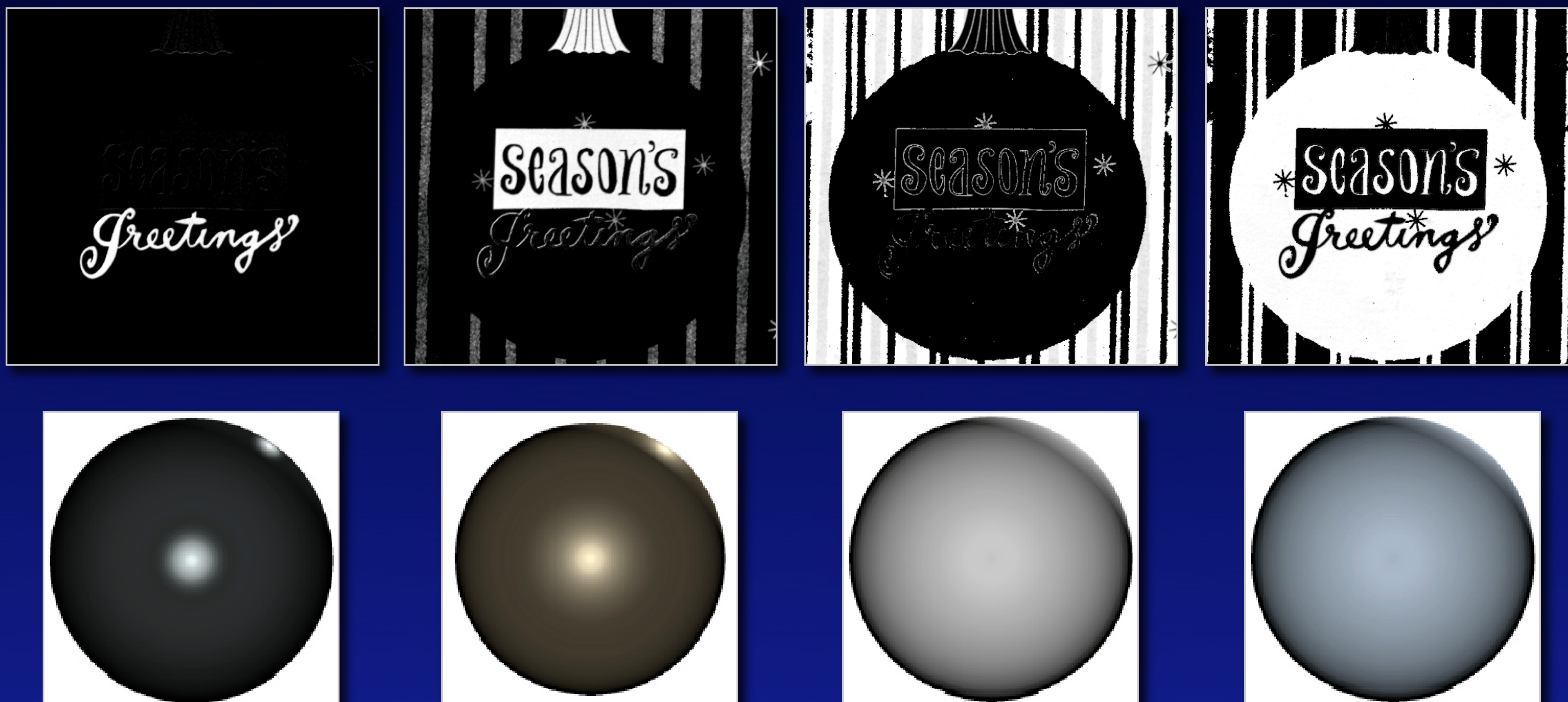
Season's Greetings Dataset

5 Camera Positio… …tions ~ 1,750 Images

Gold Foil Silver Foil White Paper Blue Paper

Season's Greetings Dataset

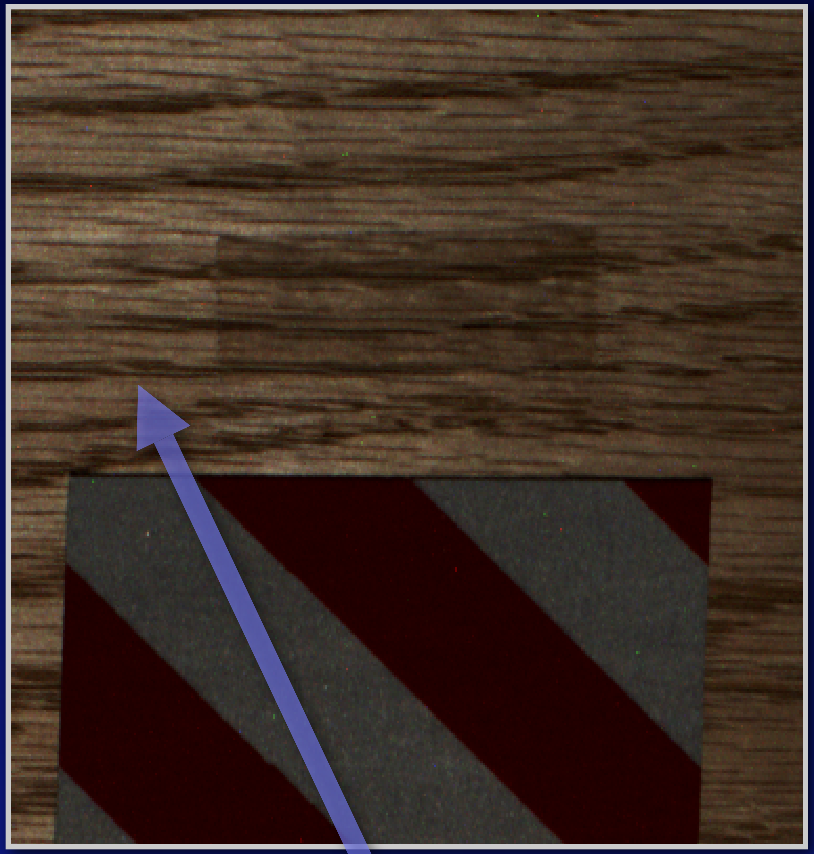
Factorization Computed with ACLS (4 Terms)



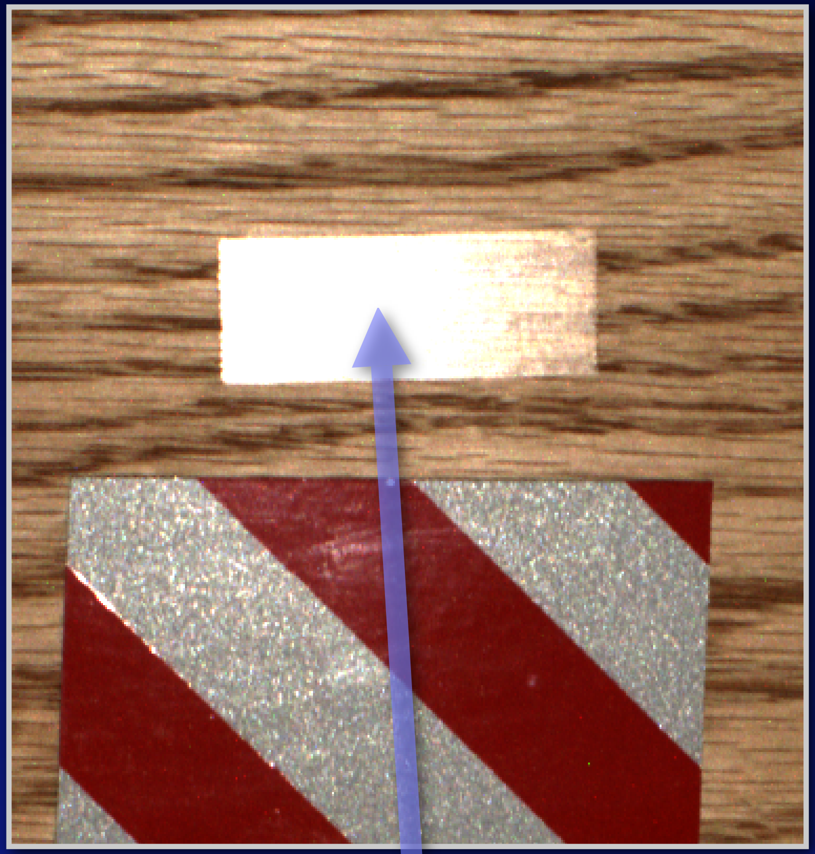
Silver Foil | Gold Foil | White Paper | Blue Paper

Wood+Tape Dataset

12 Camera Positions x 480 Light Positions = 6,000 Images



Oak Wood (Anisotropic)

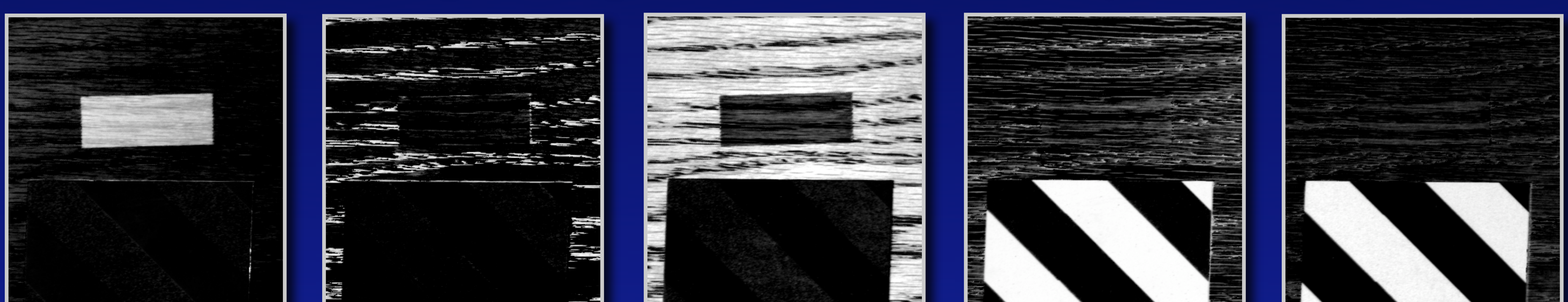


Semi-Transparent Tape

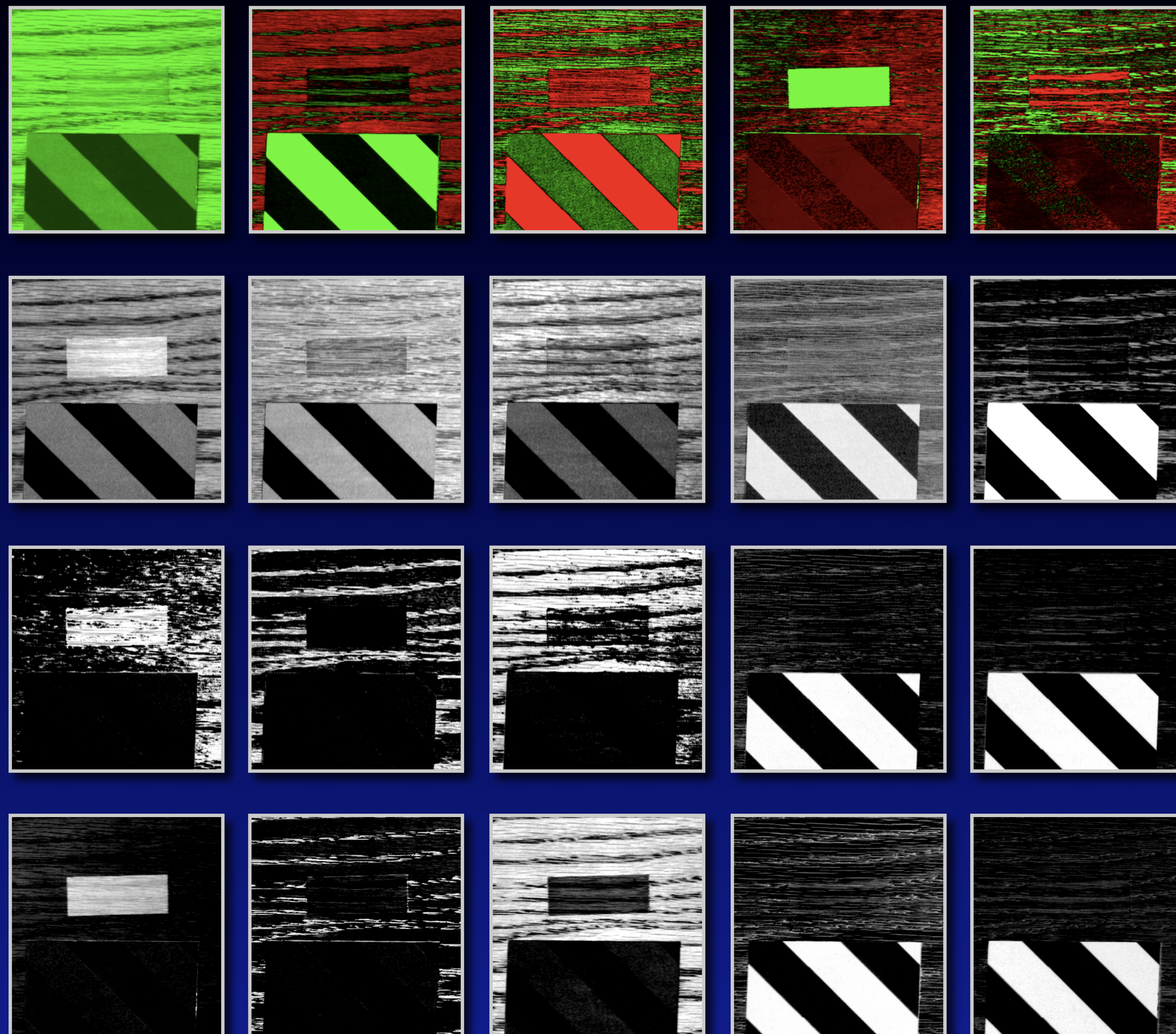
Retroreflective Bicycle Tape

Wood+Tape Dataset

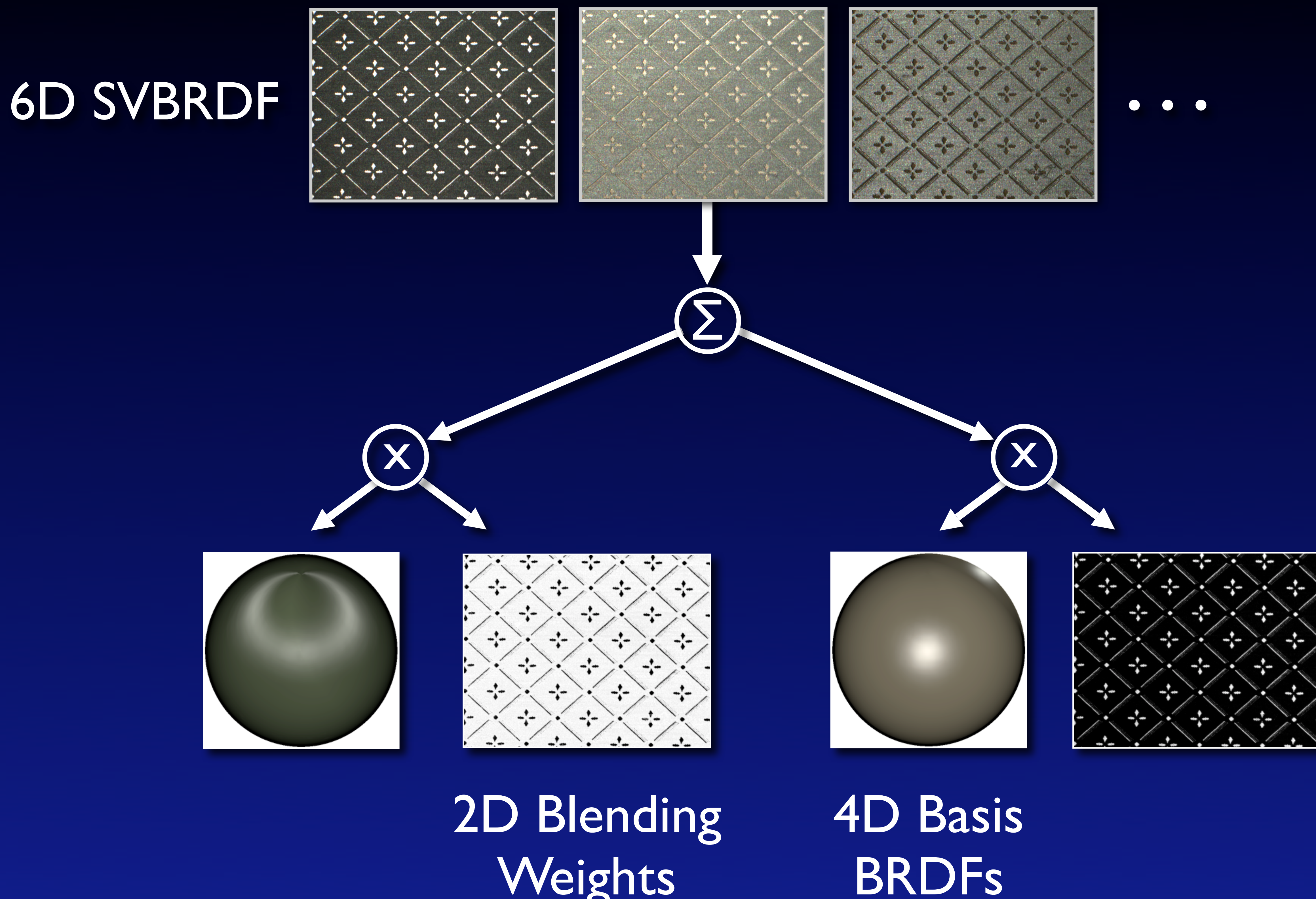
Blending Weights from ACLS (5 Terms)



Scotch Tape | Dark Grain | Light Grain | Red Bicycle | White Bicycle



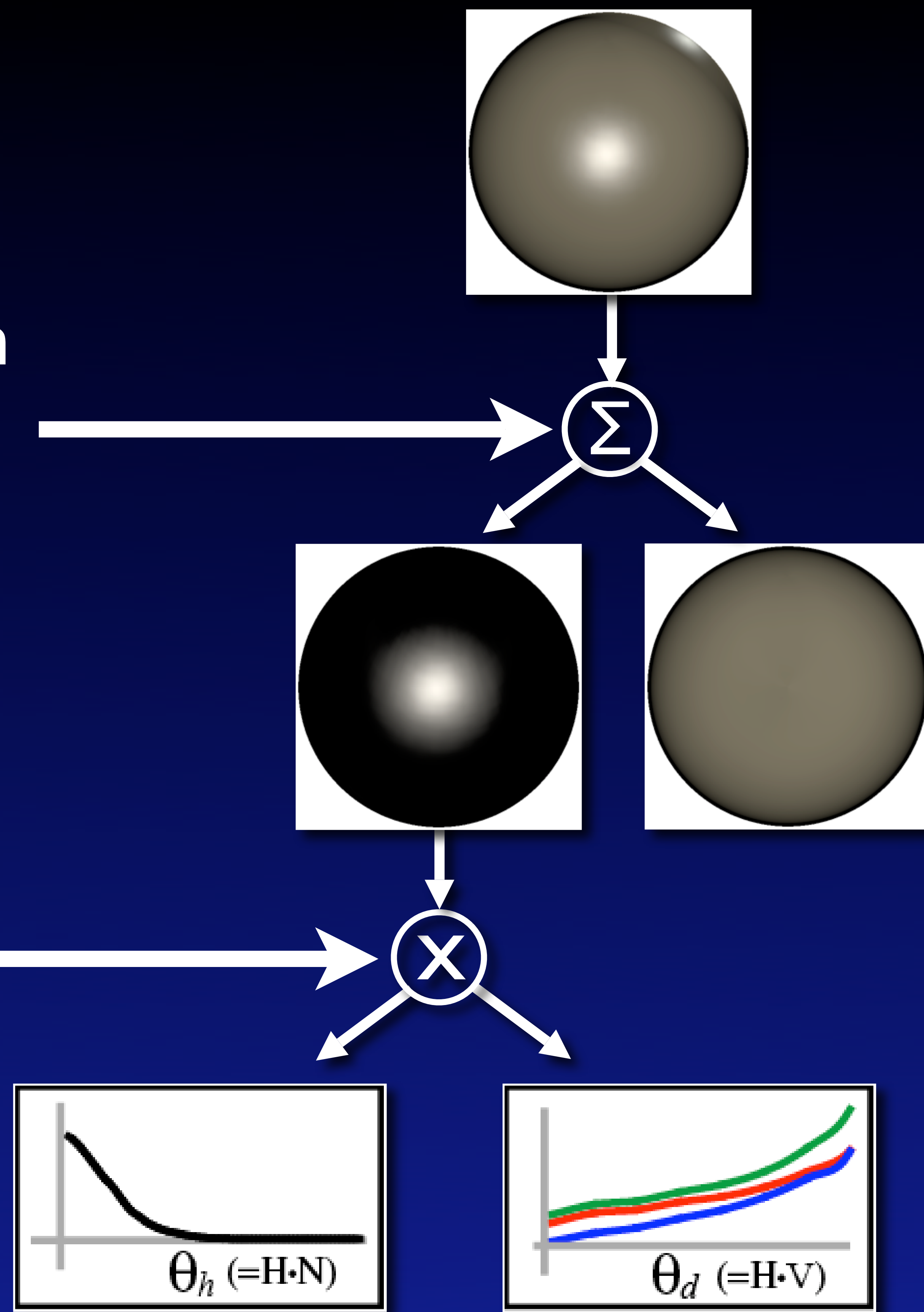
SVD	0.014 (RMS)
NMF	0.015
k-means	0.029
ACLS	0.022


6D SVBRDF
. . .
Σ
x
x
2D Blending Weights
4D Basis BRDFs

6D SVBRDF
. . .
x
x
2D Blending
Weights
4D Basis
BRDFs

BRDF
4D

Reparamaterization
and Constrained
Factorization



"Lobes"

Single Term
Factorization

Curves
1D

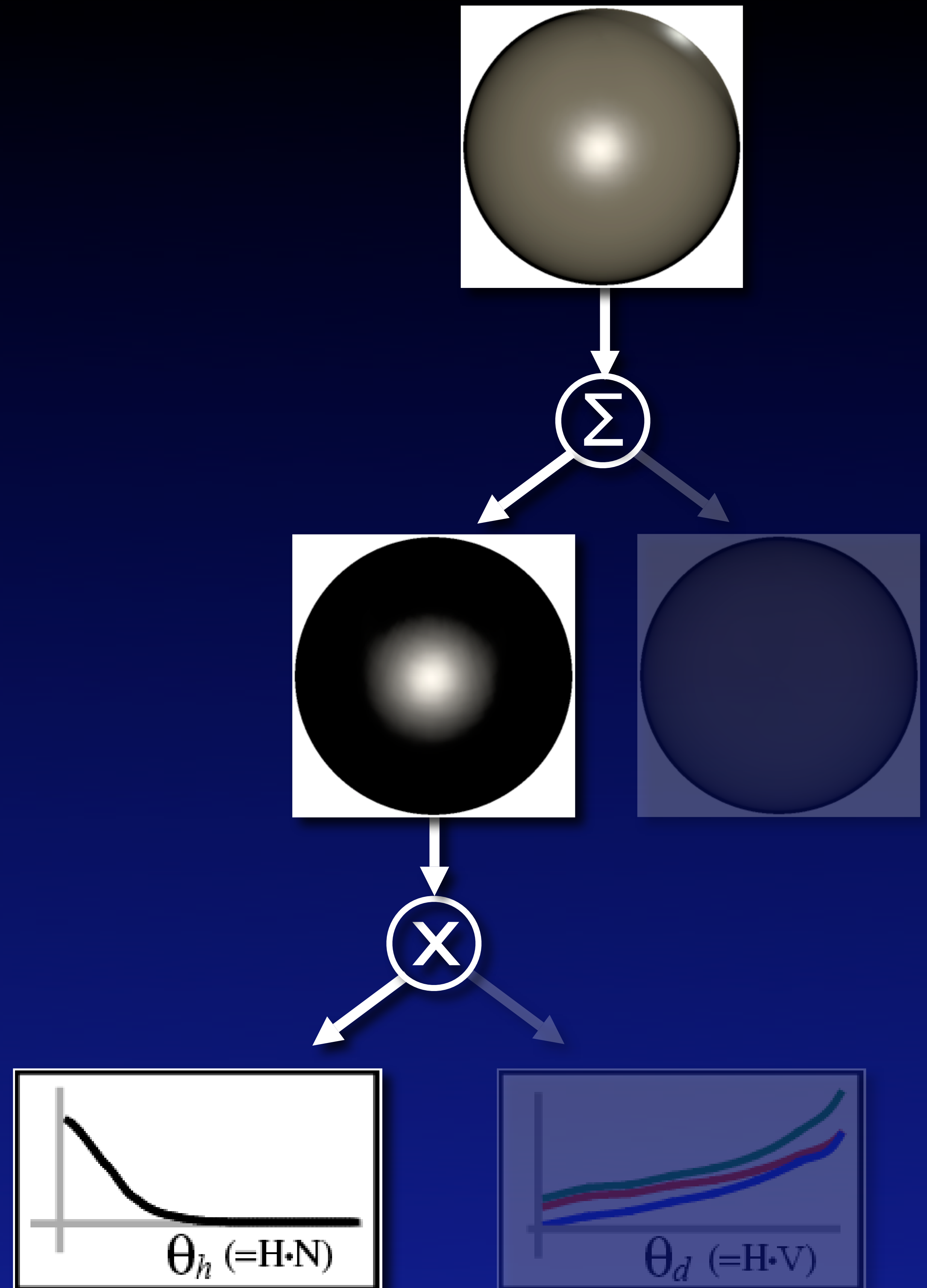
Specular Highlight

Grazing Effects

BRDF
4D

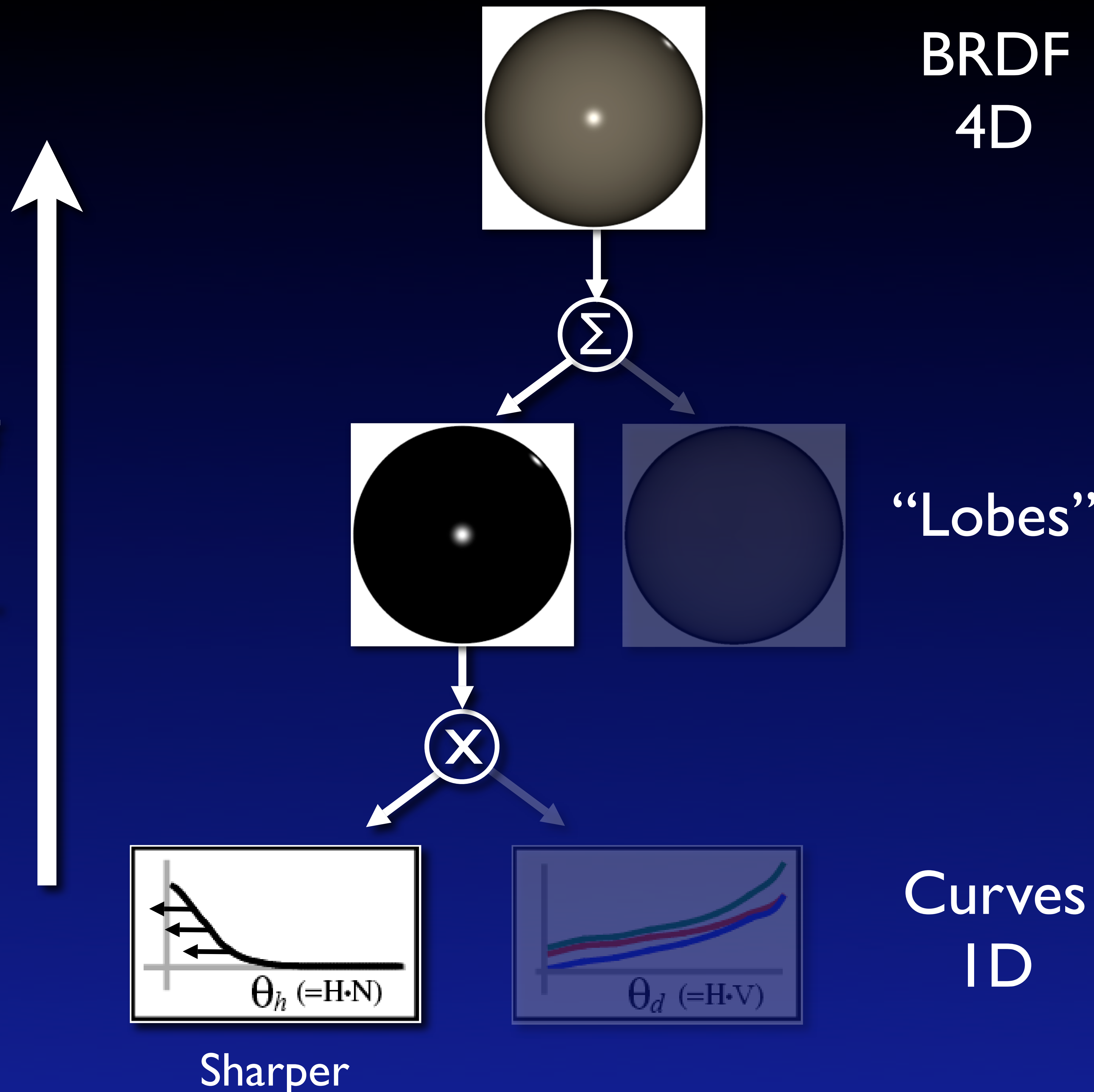
“Lobes”

Curves
1D



Original

Edits at leaf propagate up the tree.



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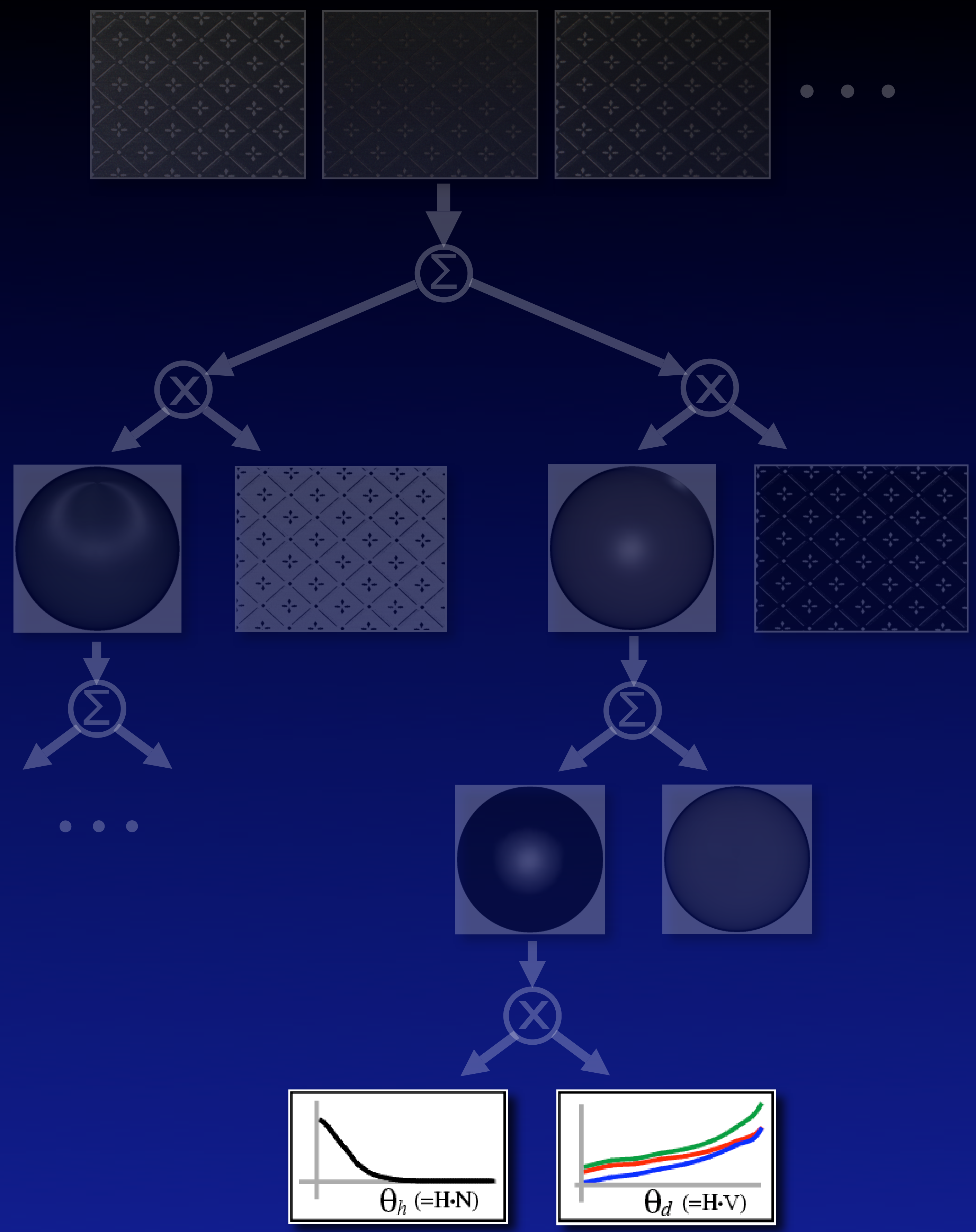
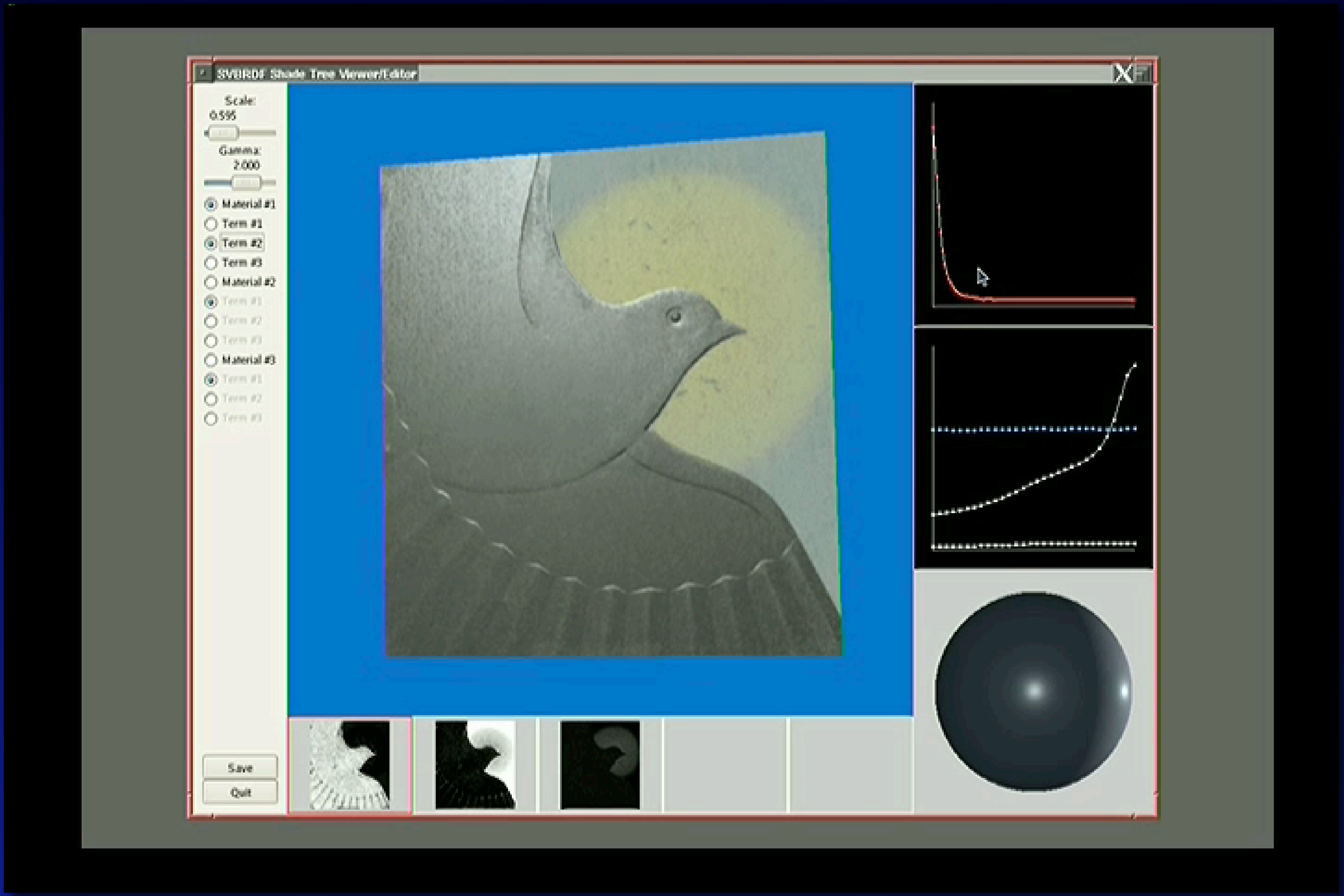
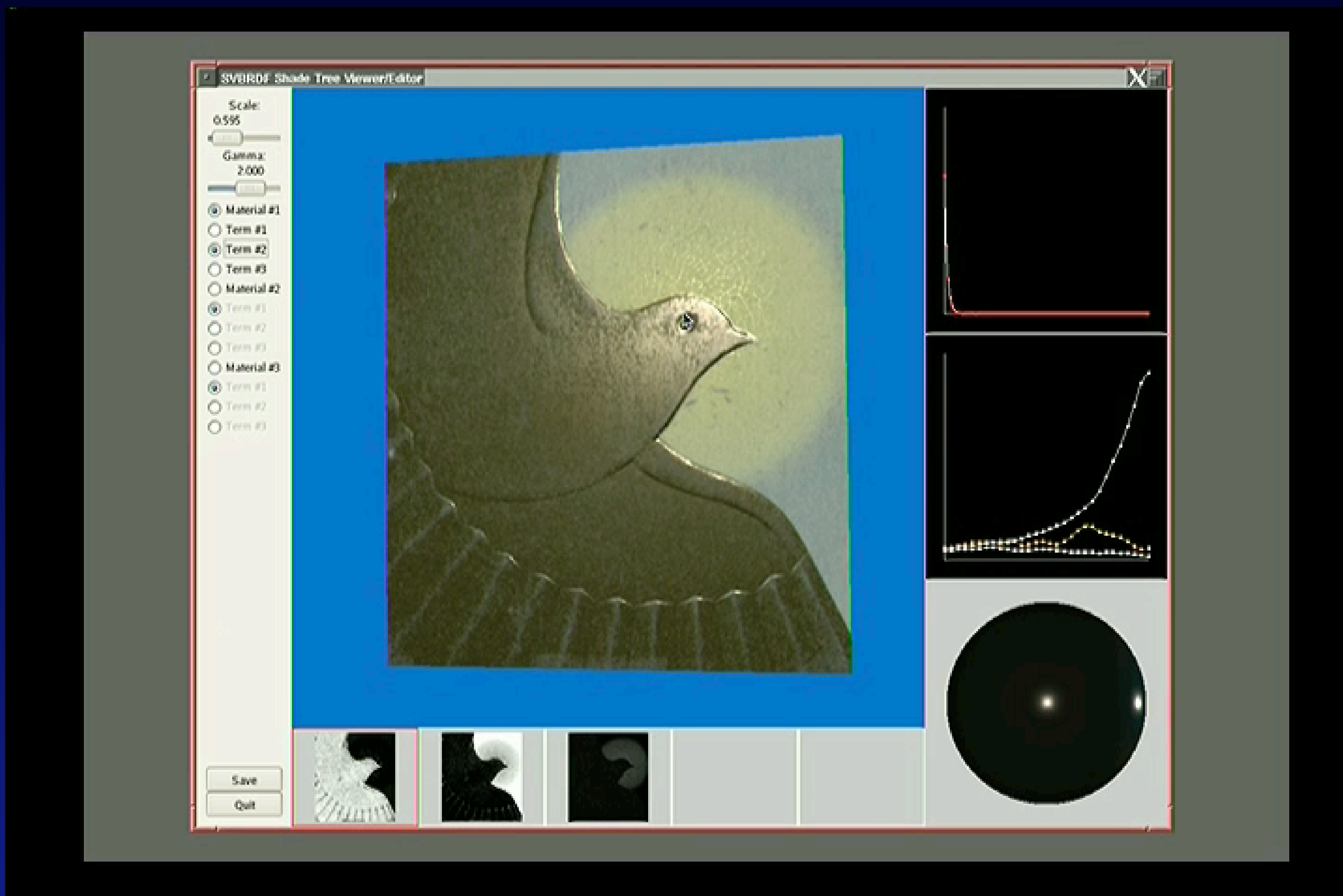
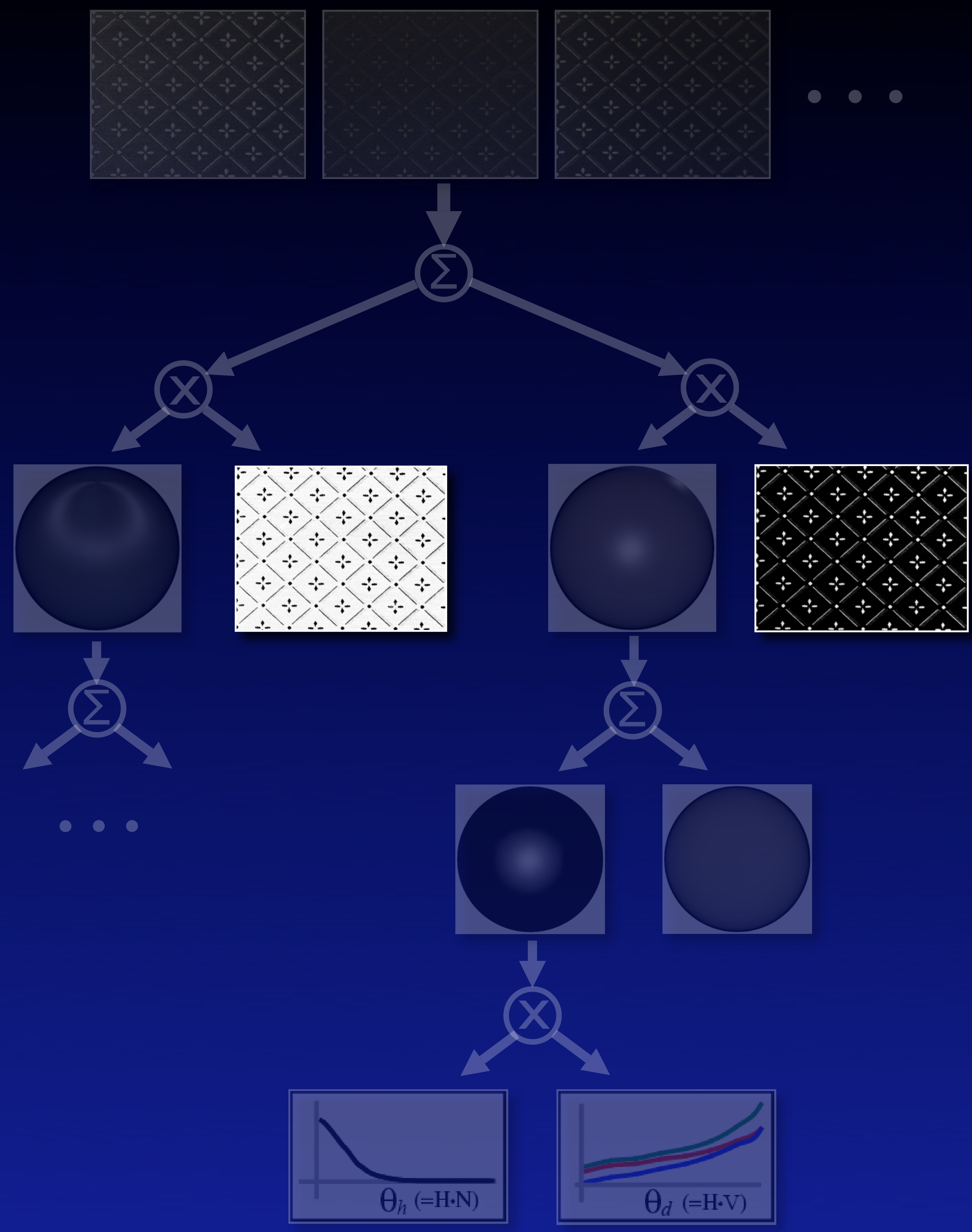

θh (=H•N)
θd (=H•V)

Specular Highlight Edit



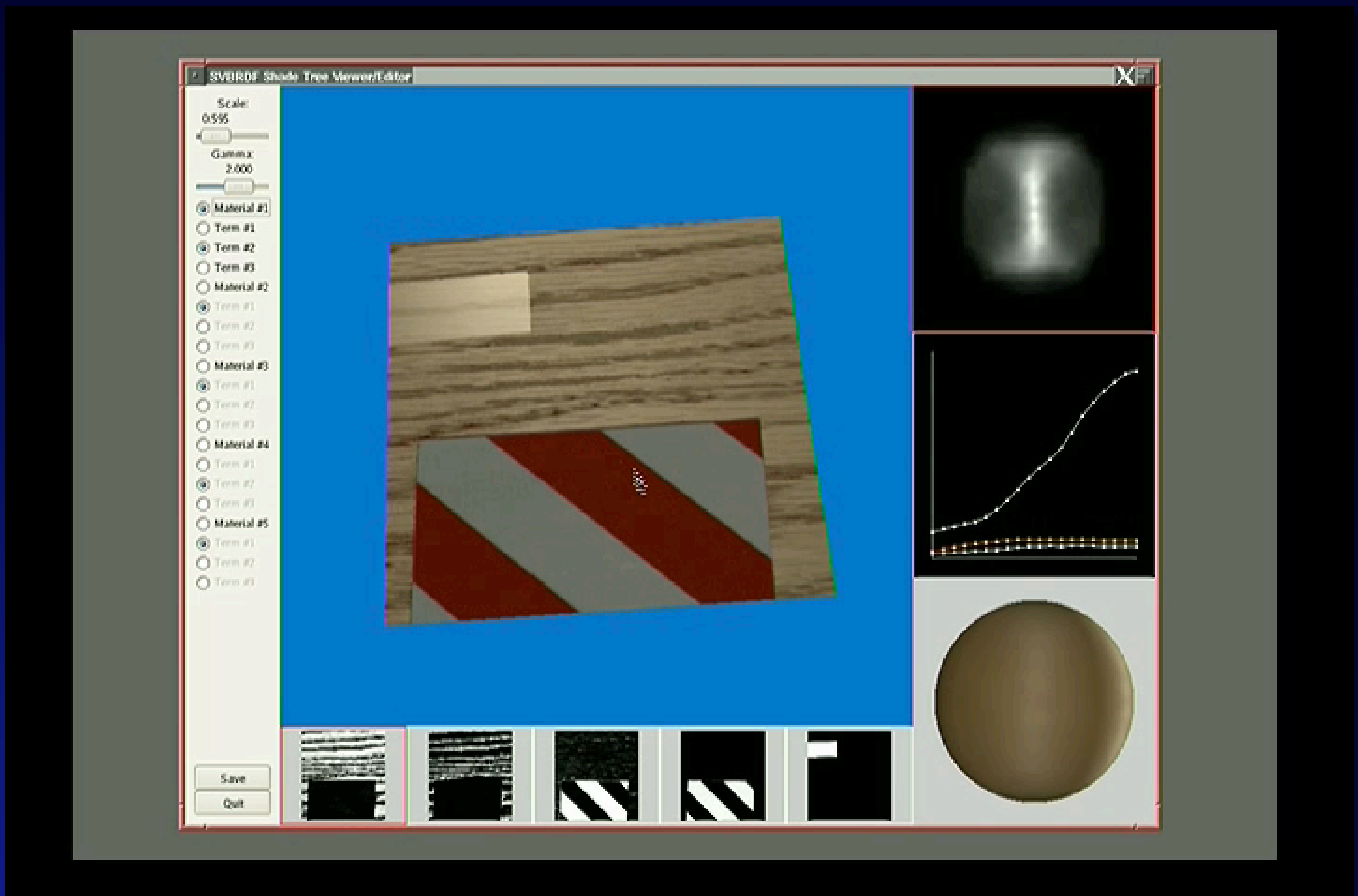
Material Replacement





θ_h (=H·N)
θ_d (=H·V)

Blending Weights Edit



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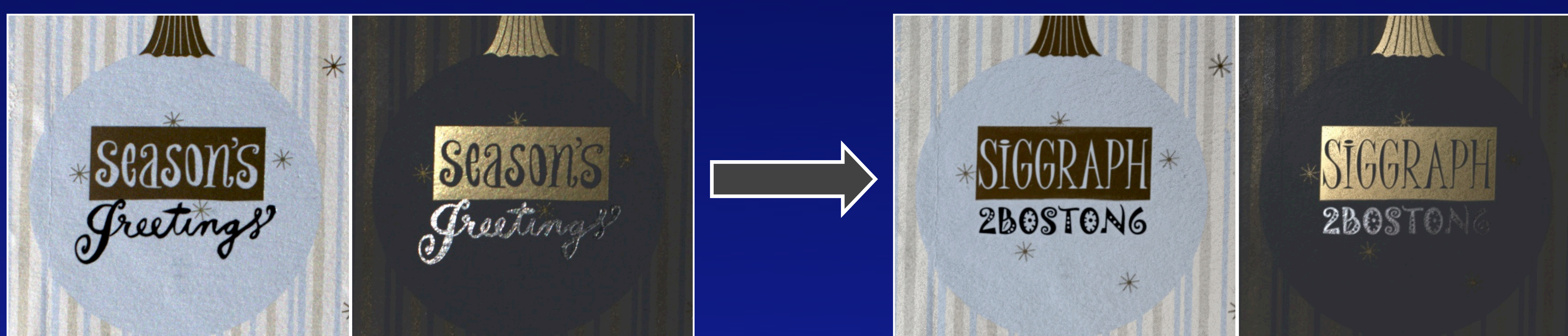
Conclusion

Inverse Shade Trees enable applications with measured appearance data:

- Compression for interactive rendering
- Editing of texture and reflectance



Concurrent Work

Translucent
[Peers et al. 06]

Time-Varying
[Gu et al. 06]

Future Work

- Automatic selection of tree topology
- Additional composition nodes:
  (e.g. over operators, masks, etc.)
- Higher-dimensional light transport functions
- Other linear decomposition problems

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  Marc Levoy
  Steve Marschner
  SIGGRAPH reviewers
  TIGGRAPH reviewers

Thank You

http://ist.cs.princeton.edu