Illumination Decomposition for Material Editing with Consistent Interreflections

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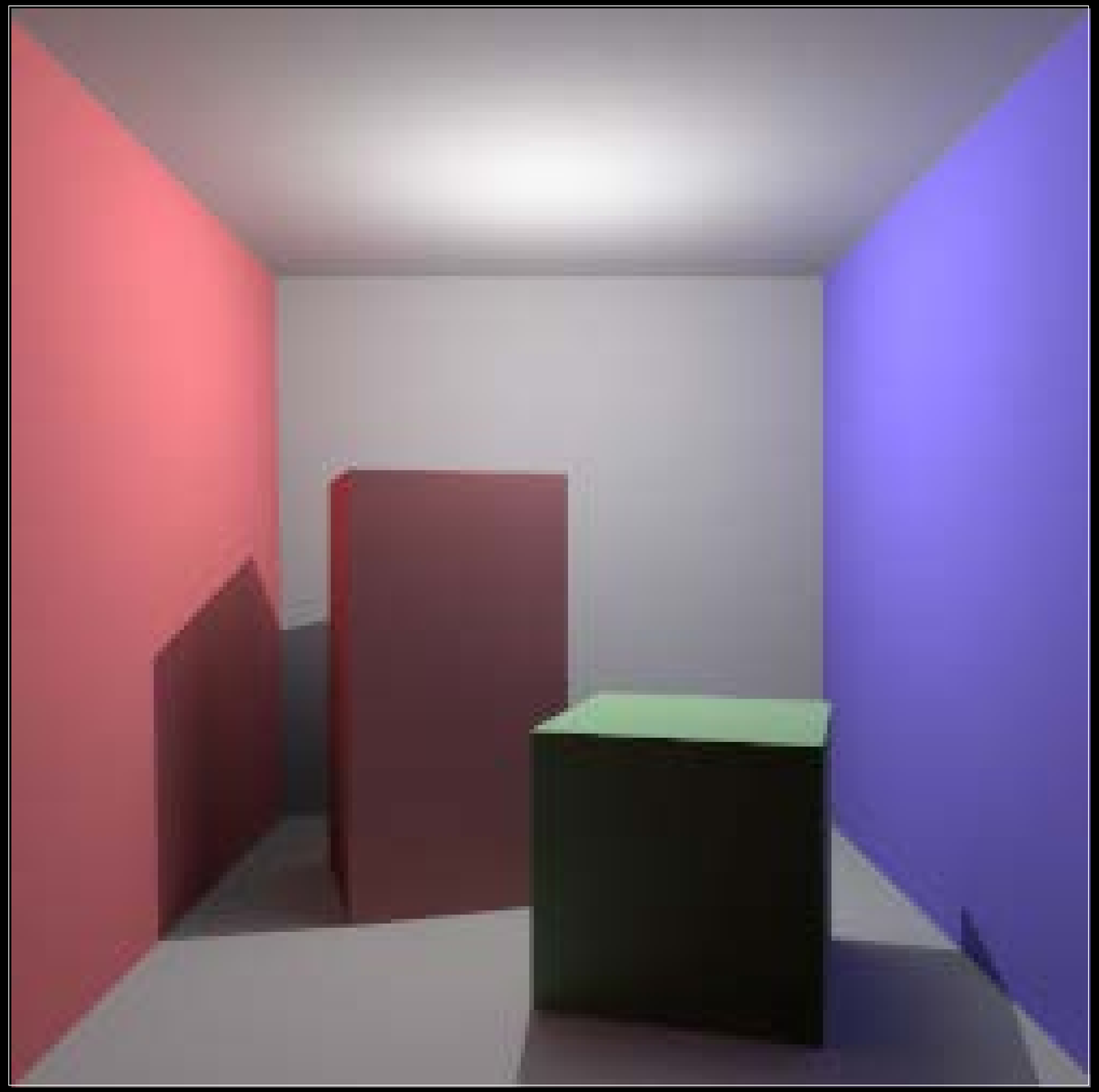
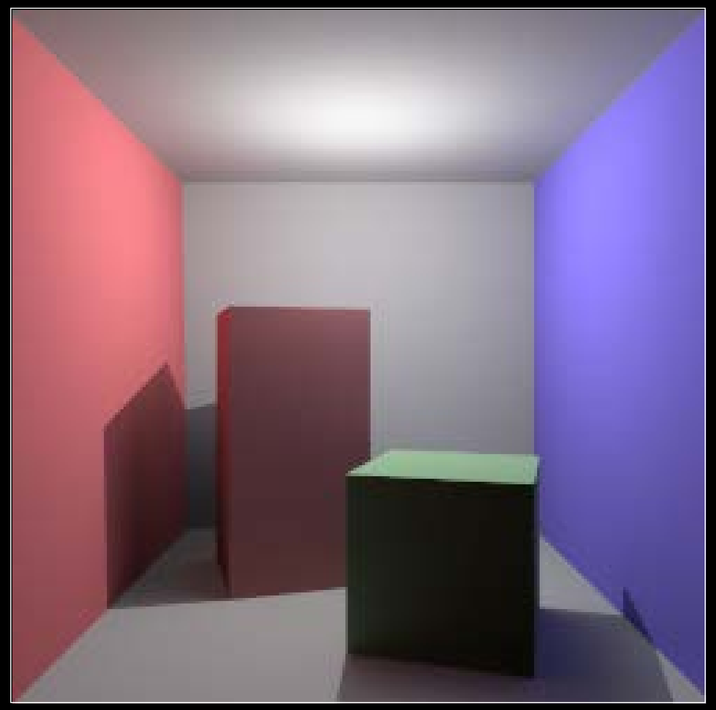
University of California, Berkeley

Presented by Wesley Willett
Computational Photography & Image Manipulation
(UCB CS294-69) 16 Nov 2011

Editing Material Colors Today



Intrinsic Images

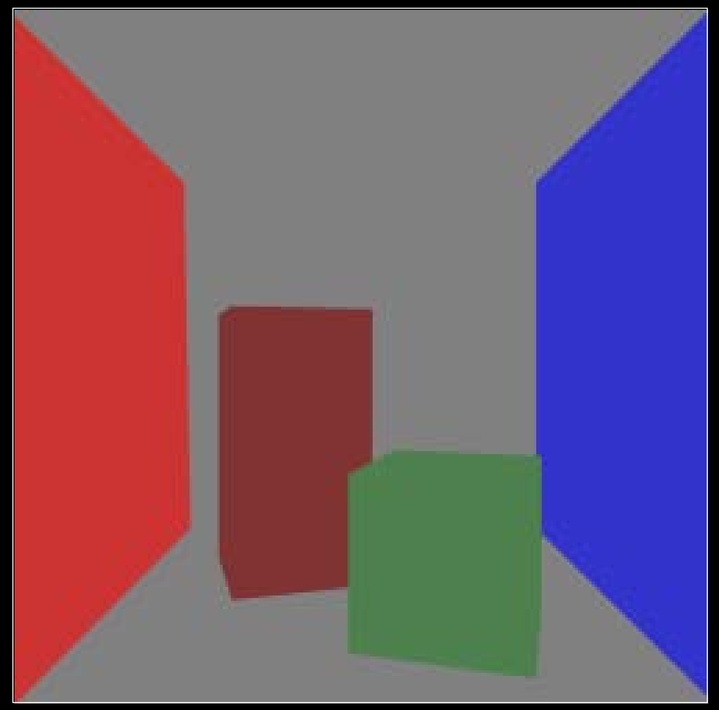


Observed Image

=

Illumination

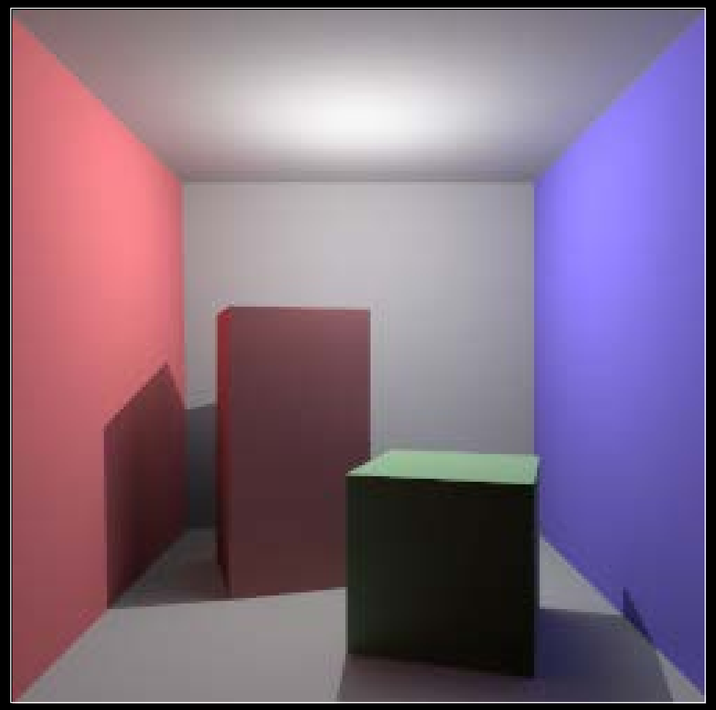
×



Reflectance

[Barrow78, Horn86, Tappen05, Shen08, Weiss01, Rousseau09]

Intrinsic Images

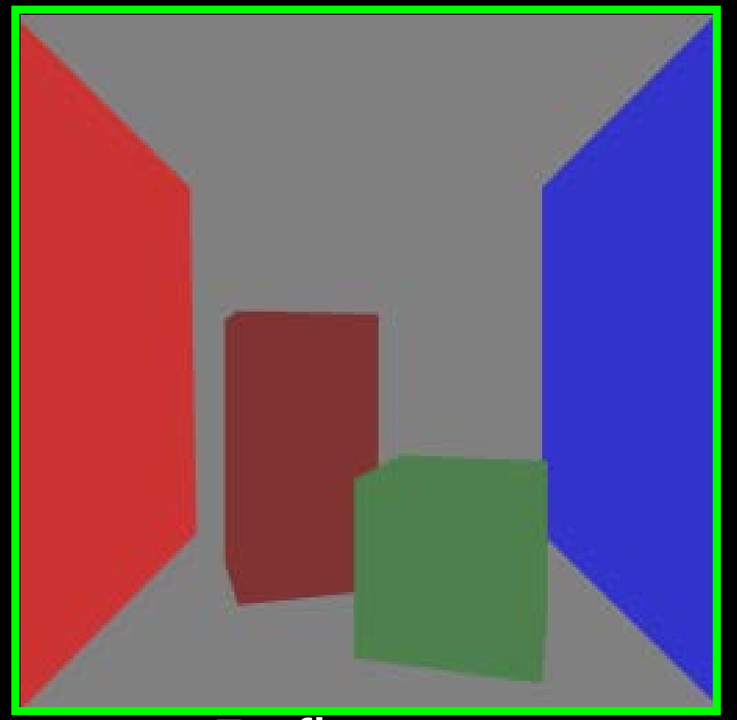


Observed Image

=

Illumination

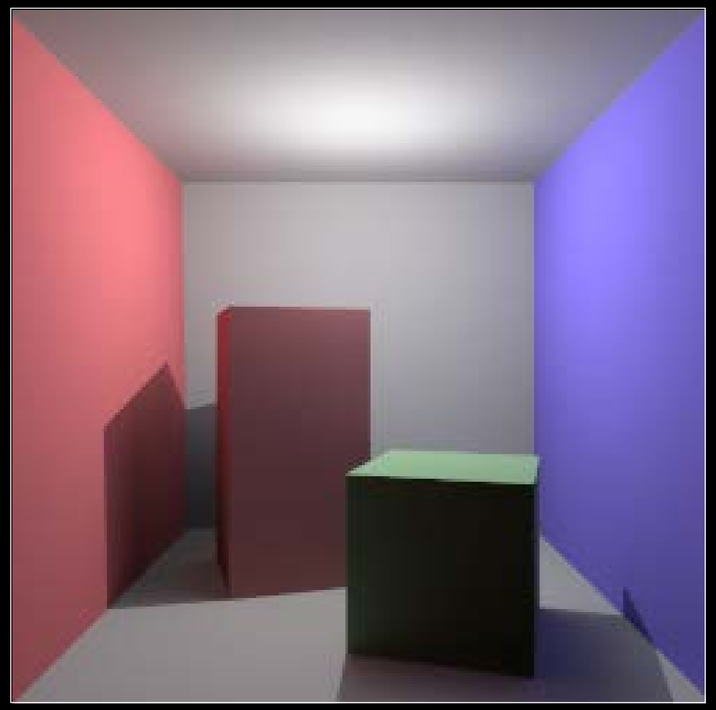
×



Reflectance

[Barrow78, Horn86, Tappen05, Shen08, Weiss01, Rousseau09]

Intrinsic Images

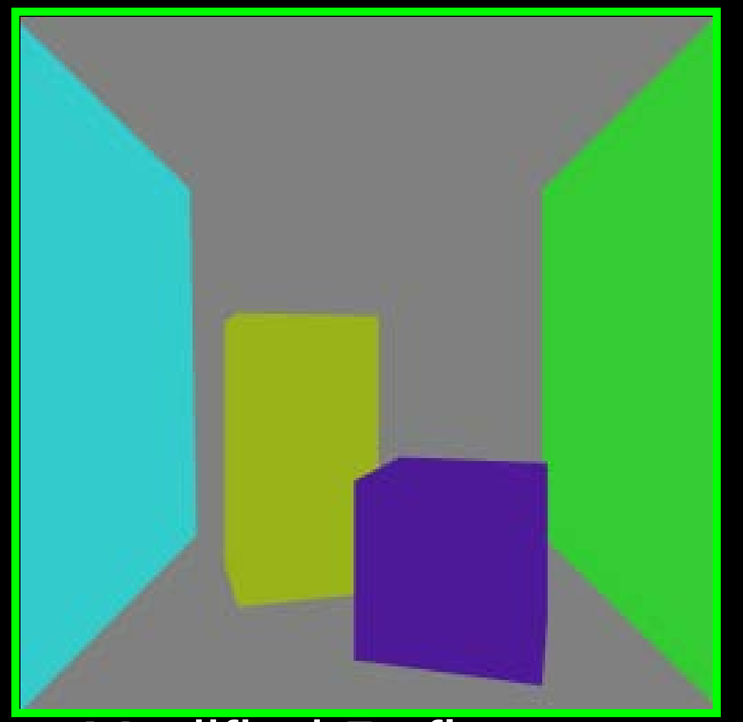


Observed Image

=

Illumination

×



Modified Reflectance

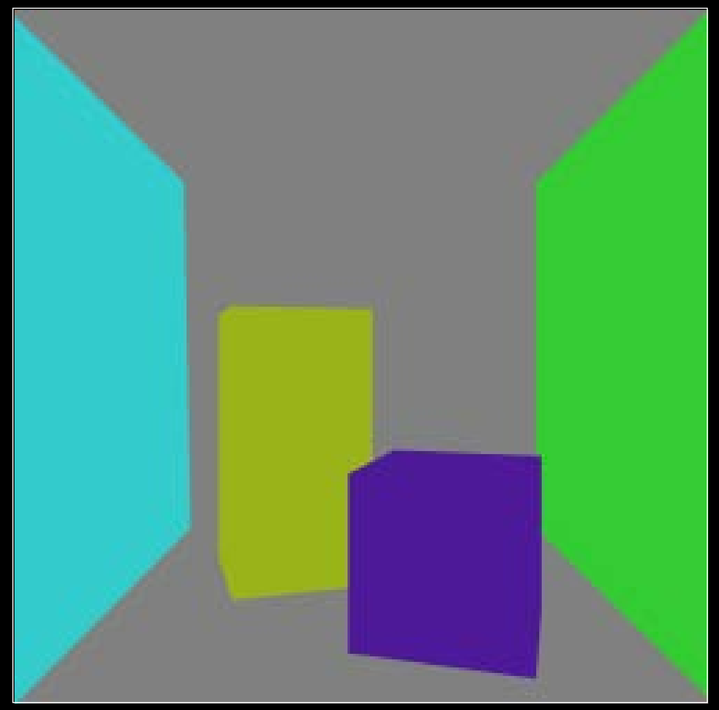
Intrinsic Images

Observed Image

=

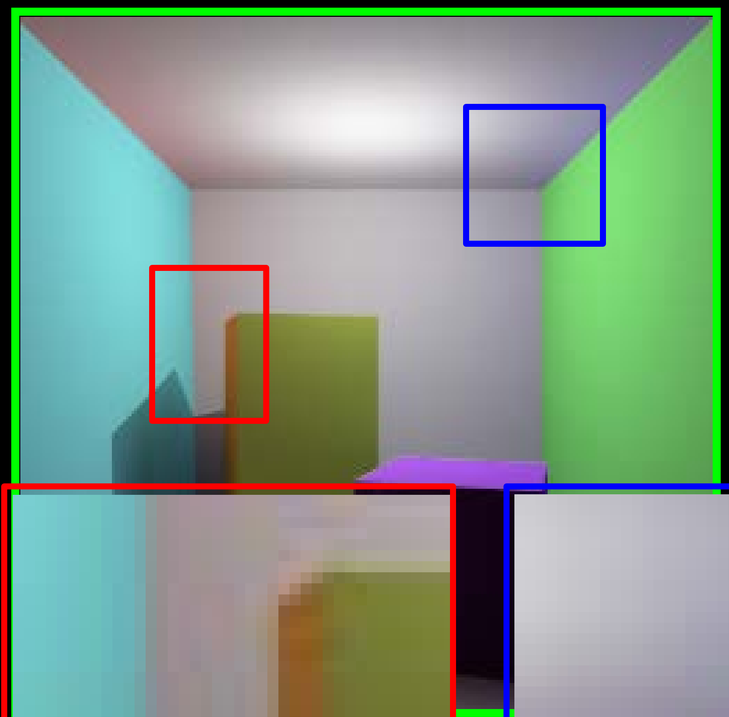
Illumination

×



Modified Reflectance

Intrinsic Images



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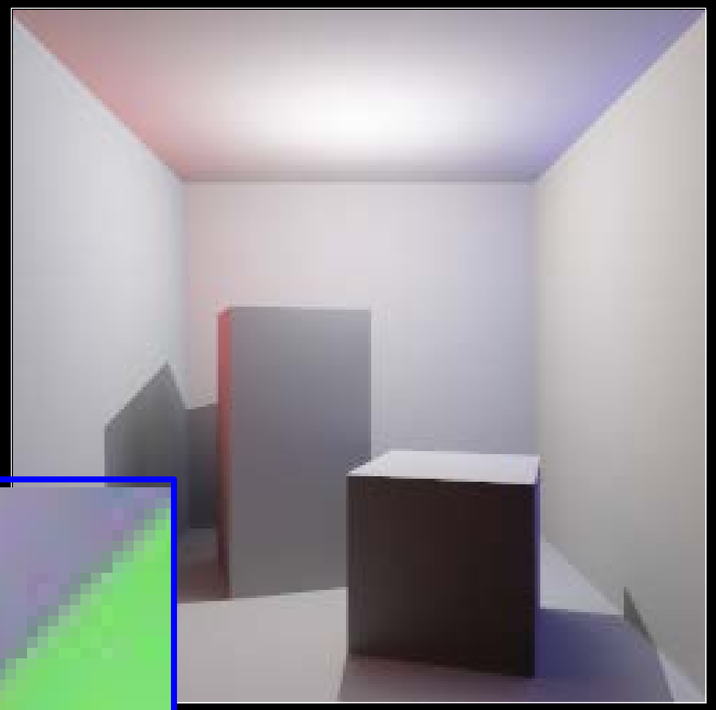

Illumination

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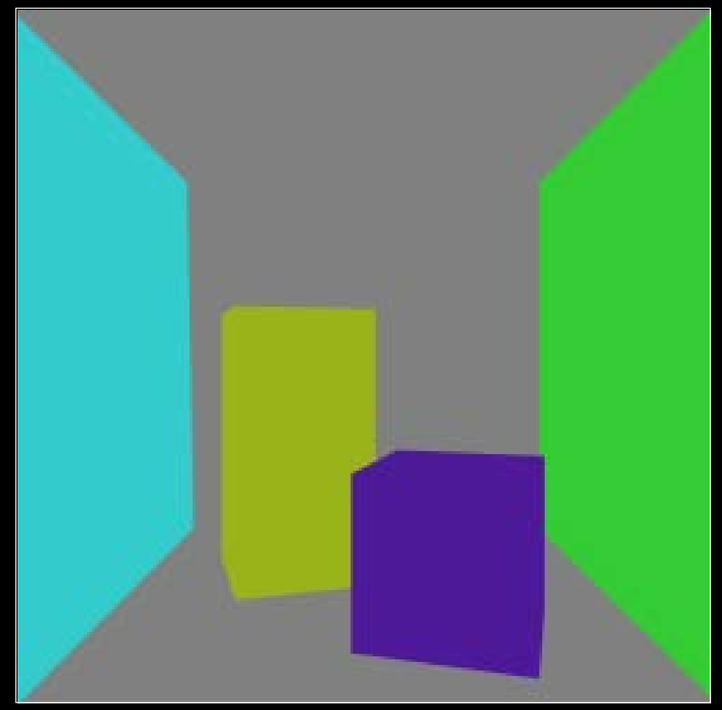
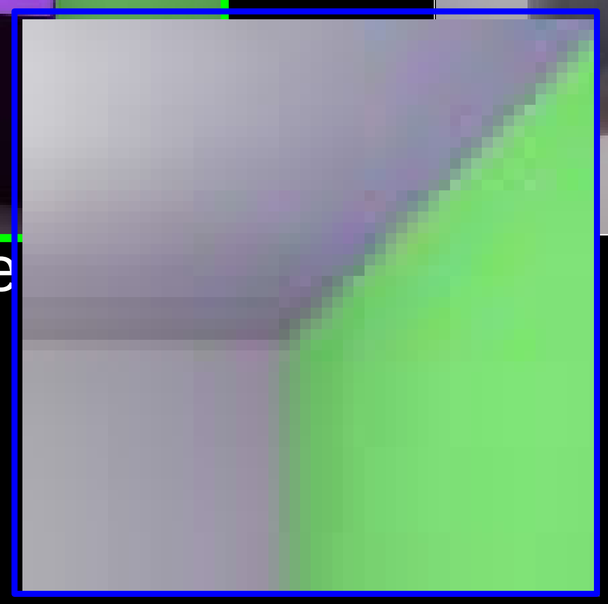
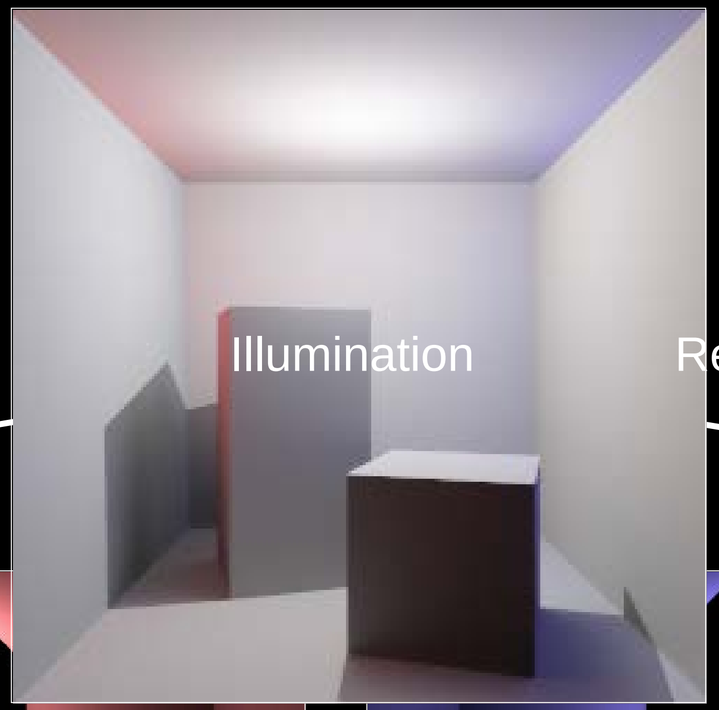


Modified Reflectance



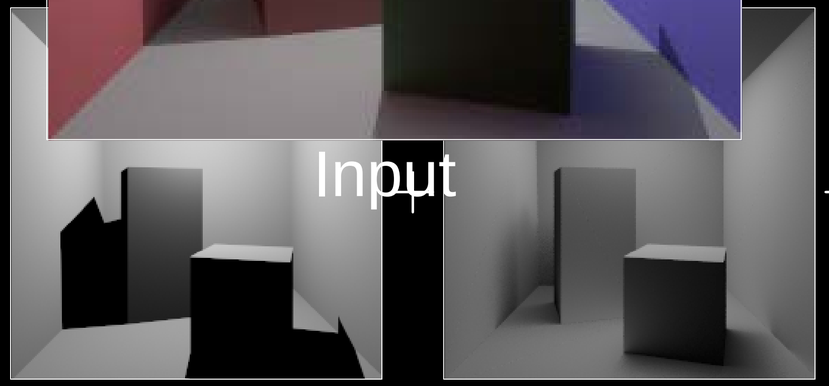
Illumination Decomposition

Input



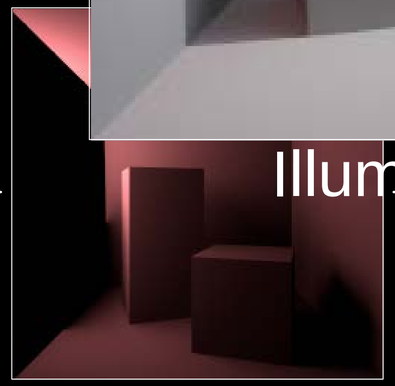
Illumination

Reflectance



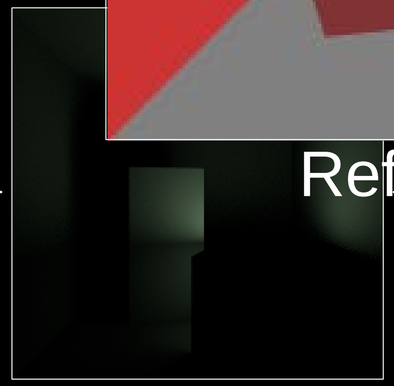
Direct

White Walls

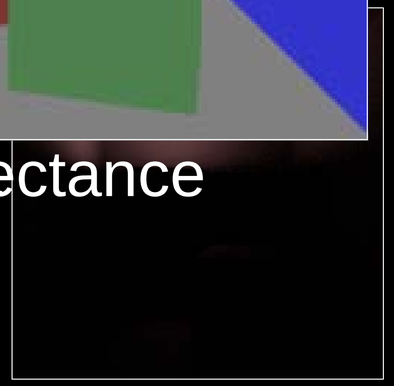


Left Wall

Right Wall

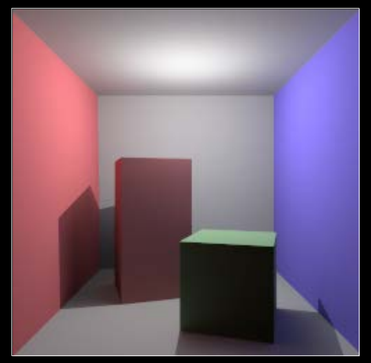


Short Box



Tall Box

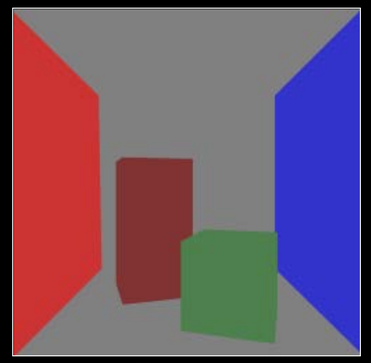
Illumination Decomposition

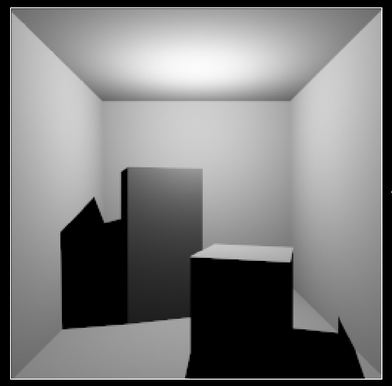

Input

=

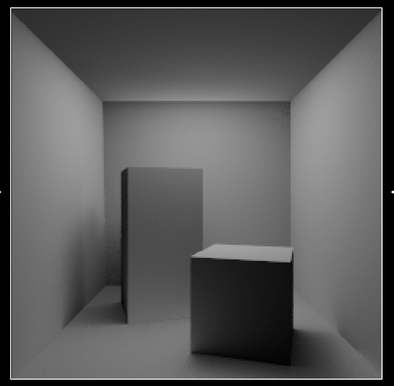
Illumination

×

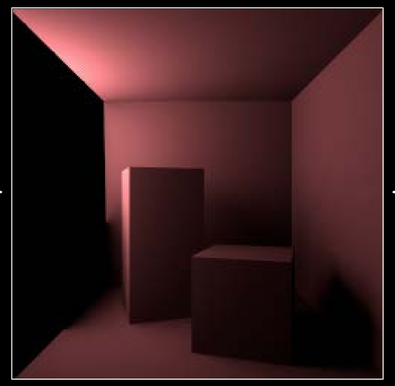

Reflectance


Direct

+


White Walls

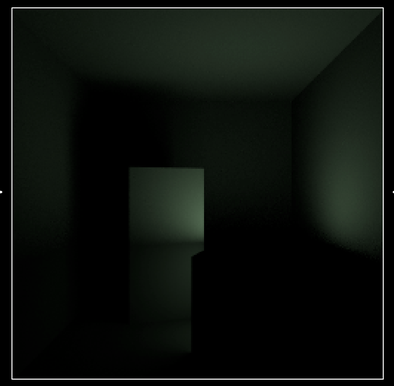
+


Left Wall

+

Right Wall

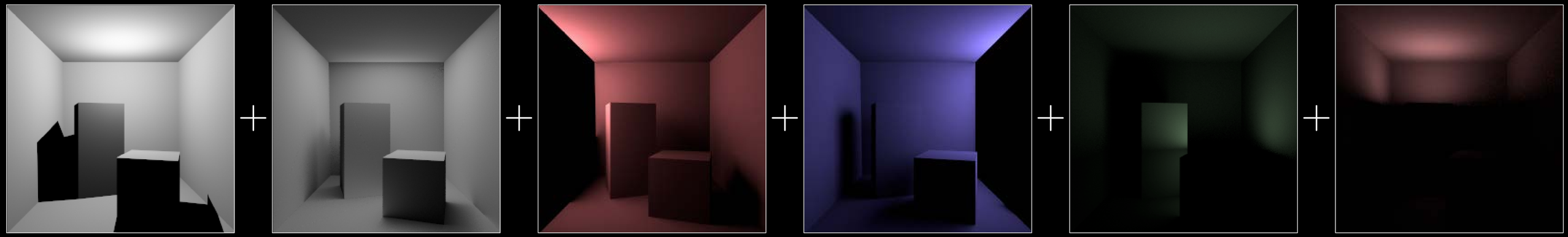
+


Short Box

+

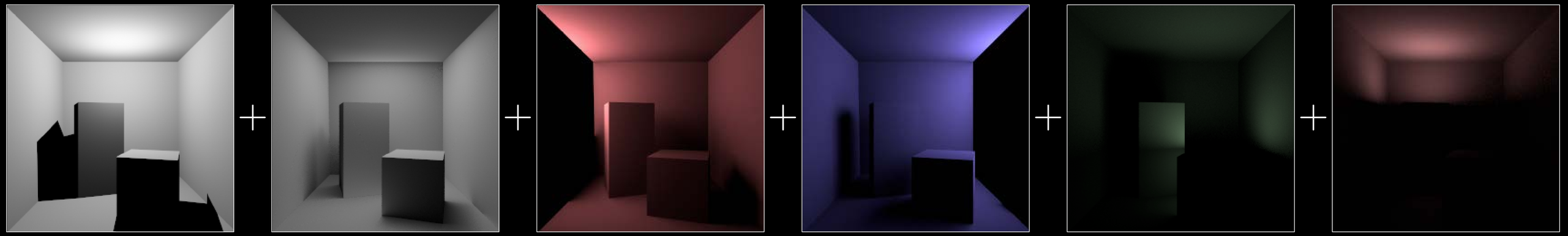
Tall Box

Illumination Decomposition



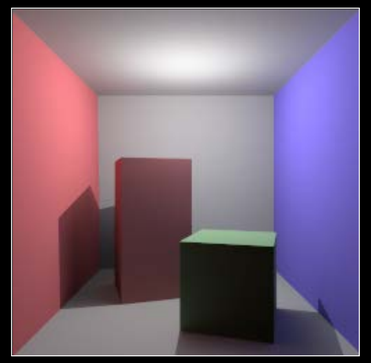
Illumination Decomposition

Input Illumination Modified Reflectance



Direct White Walls Left Wall Right Wall Short Box Tall Box

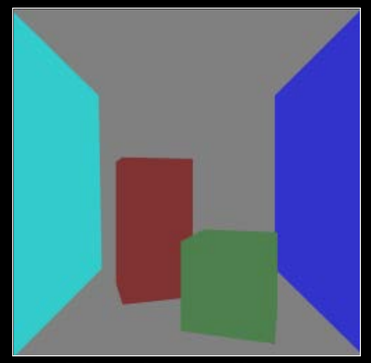
Illumination Decomposition

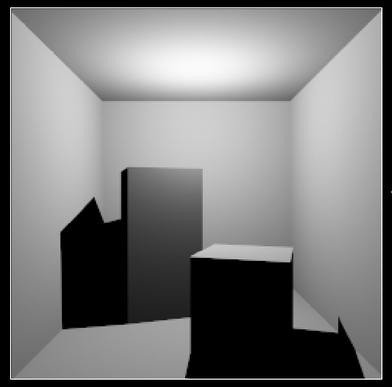

Input

=

Illumination

×


Modified Reflectance


Direct

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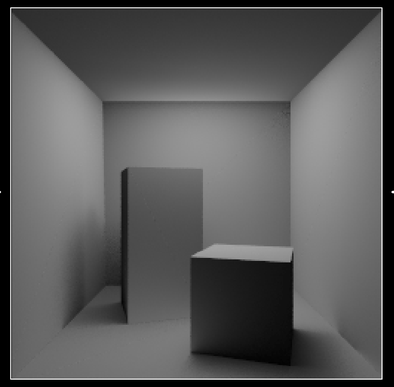
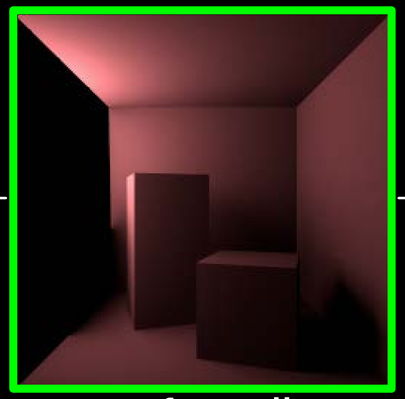

White Walls

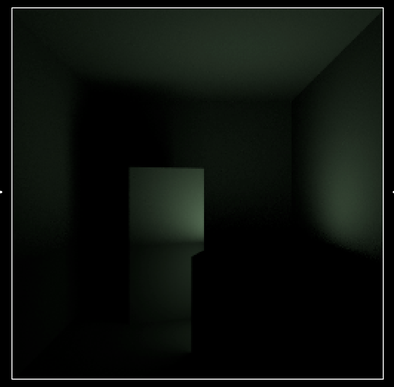
+


Left Wall

+

Right Wall

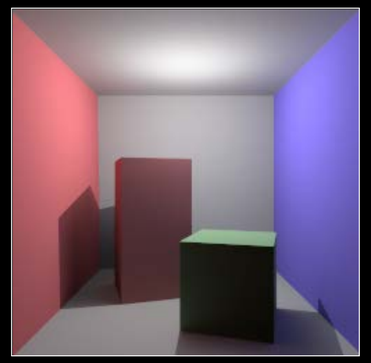
+


Short Box

+

Tall Box

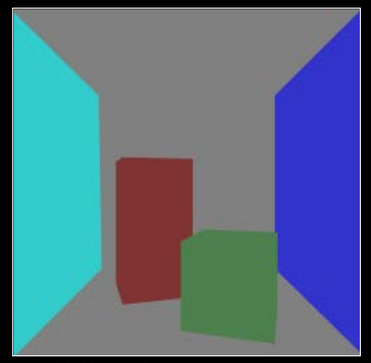
Illumination Decomposition

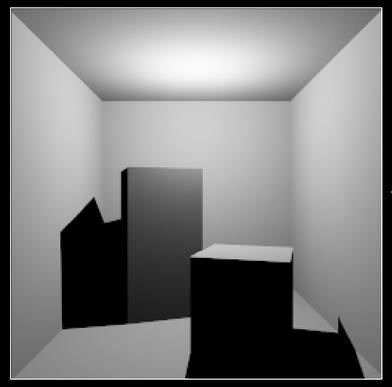

Input

=

Illumination

×


Modified Reflectance


Direct

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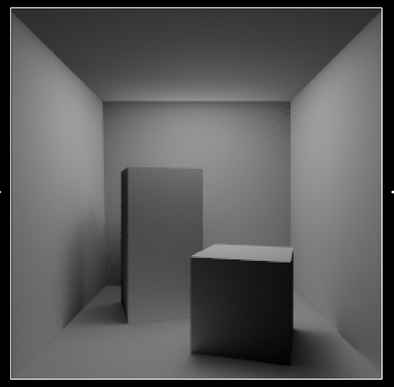
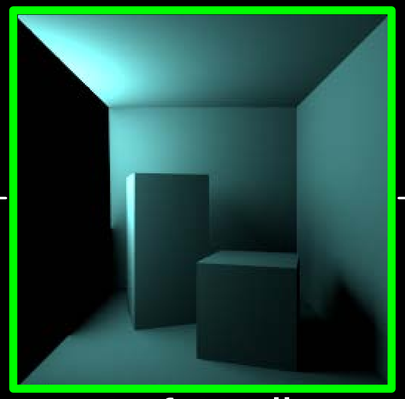

White Walls

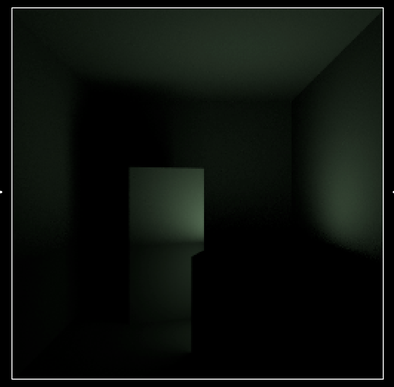
+


Left Wall

+

Right Wall

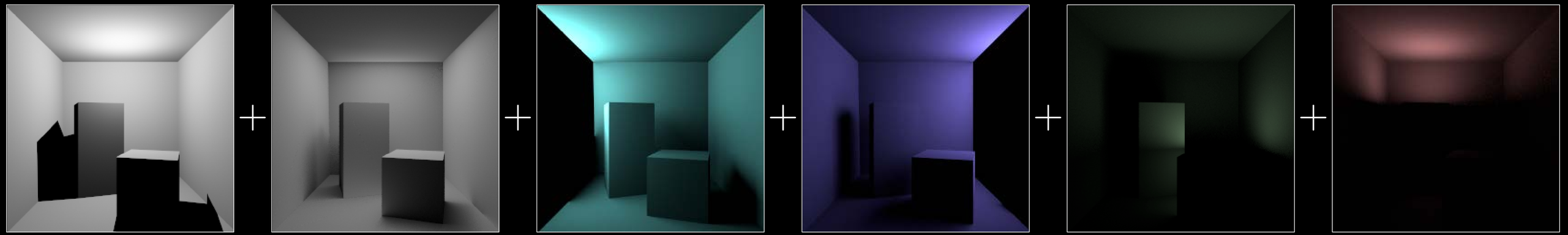
+


Short Box

+

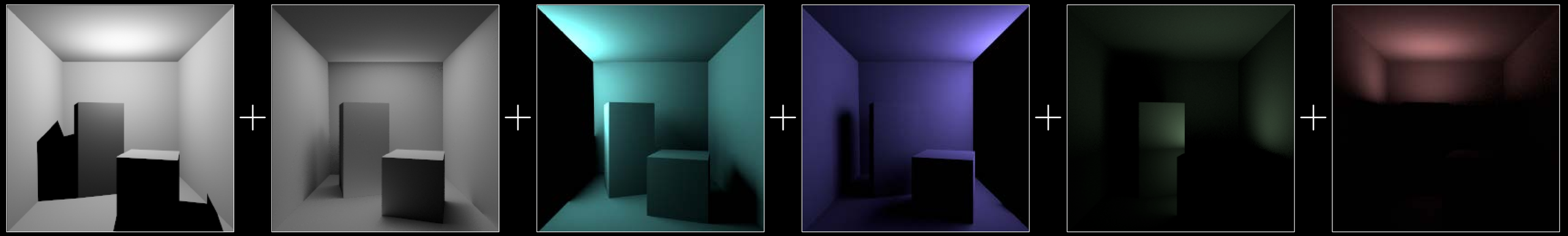
Tall Box

Illumination Decomposition



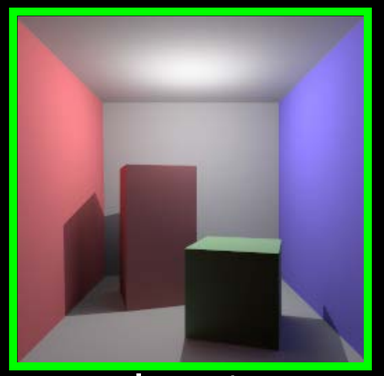
Illumination Decomposition

Input = Modified Illumination × Modified Reflectance



Direct + White Walls + Left Wall + Right Wall + Short Box + Tall Box

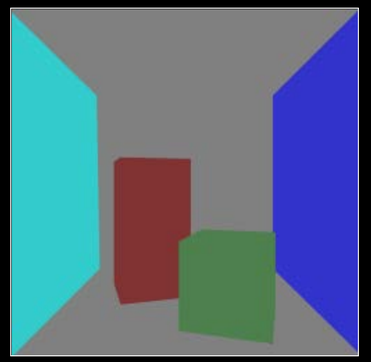
Illumination Decomposition

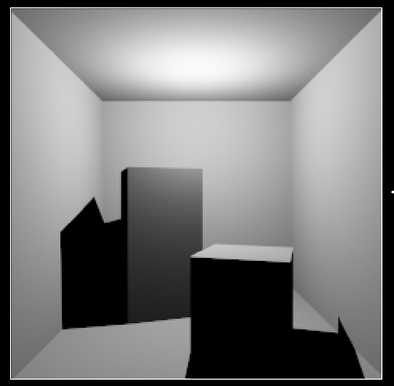

Input

=

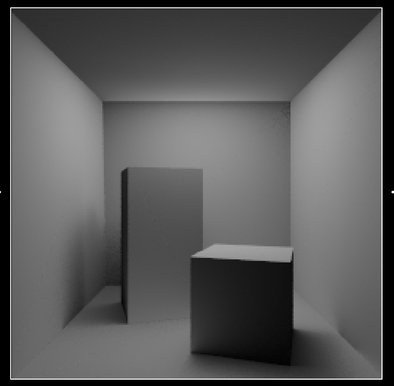
Modified Illumination

×

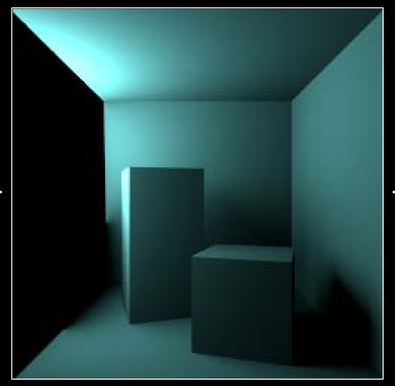

Modified Reflectance


Direct

+


White Walls

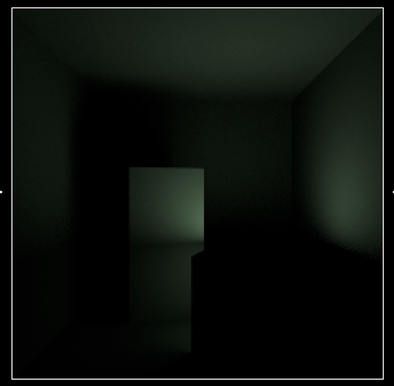
+


Left Wall

+

Right Wall

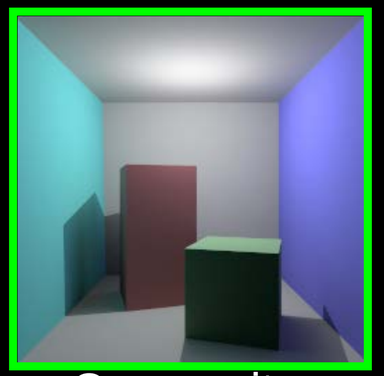
+


Short Box

+

Tall Box

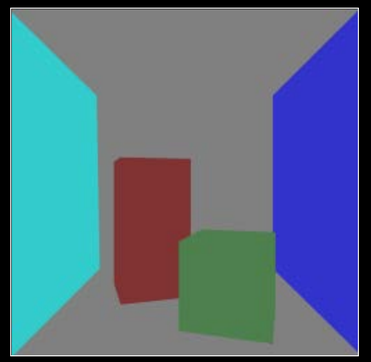
Illumination Decomposition

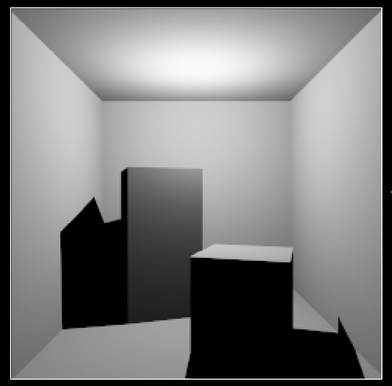

Composite

=

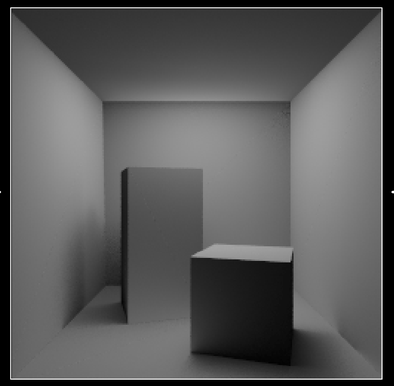
Modified Illumination

×

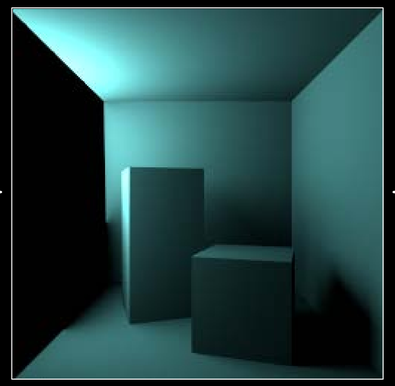

Modified Reflectance


Direct

+


White Walls

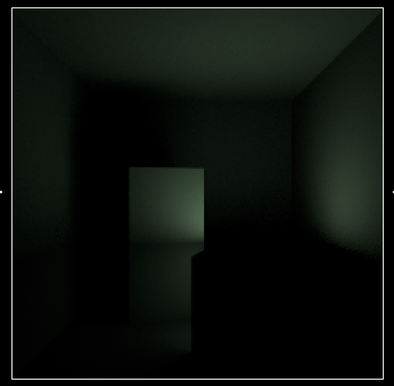
+


Left Wall

+

Right Wall

+

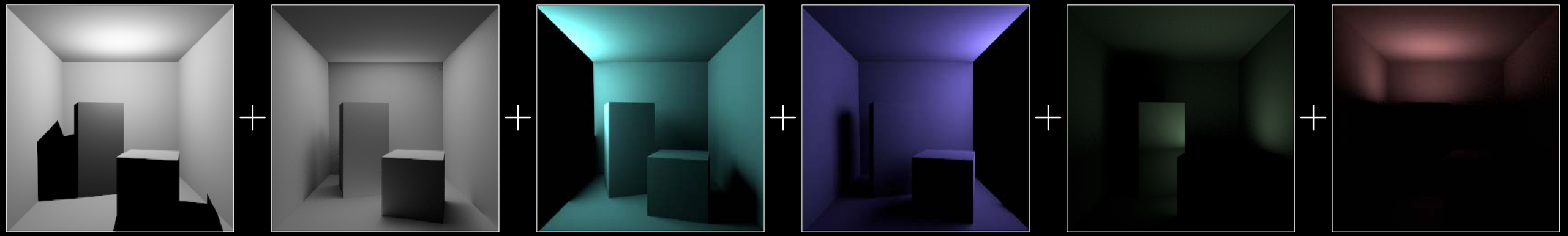

Short Box

+

Tall Box

Illumination Decomposition

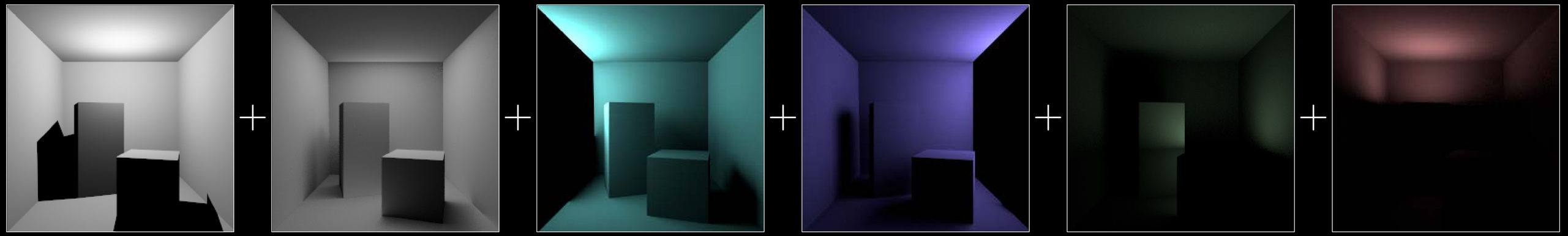
Composite | Modified Illumination | Modified Reflectance



Direct | White Walls | Left Wall | Right Wall | Short Box | Tall Box

Illumination Decomposition

Composite | Modified Illumination | Modified Reflectance



Direct | White Walls | Left Wall | Right Wall | Short Box | Tall Box

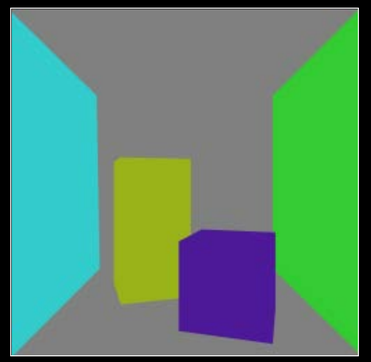
Illumination Decomposition

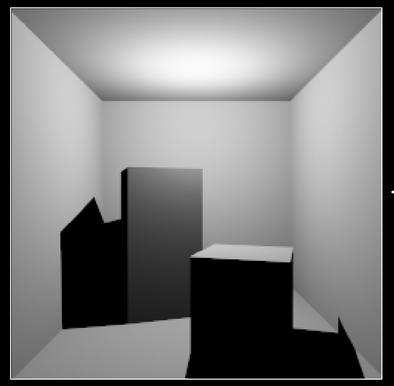
Composite

=

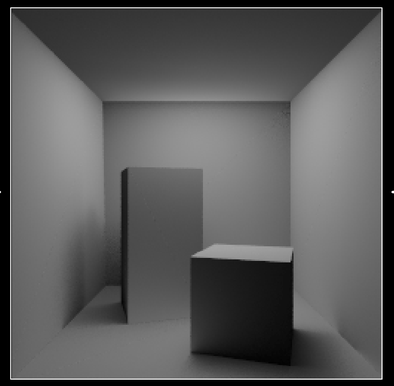
Modified Illumination

×

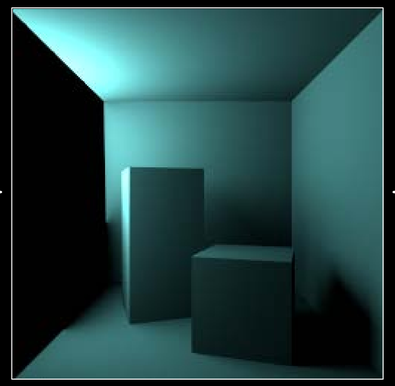

Modified Reflectance


Direct

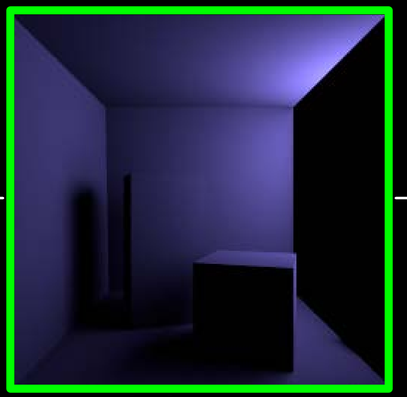
+


White Walls

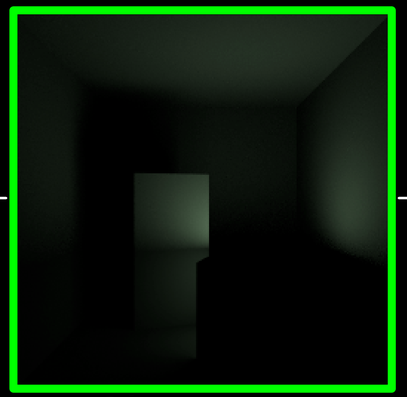
+


Left Wall

+


Right Wall

+

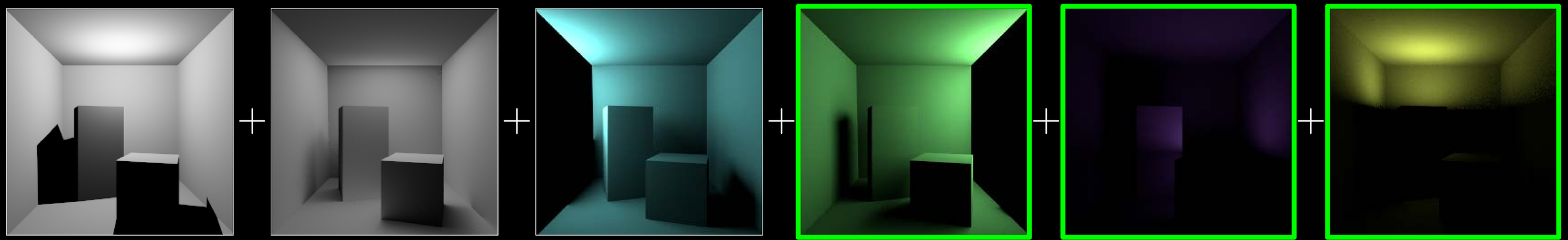

Short Box

+

Tall Box

Illumination Decomposition

Composite = Modified Illumination × Modified Reflectance



Direct + White Walls + Left Wall + Right Wall + Short Box + Tall Box

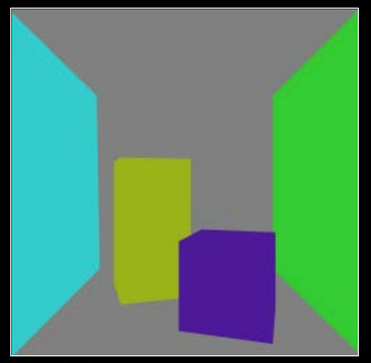
Illumination Decomposition

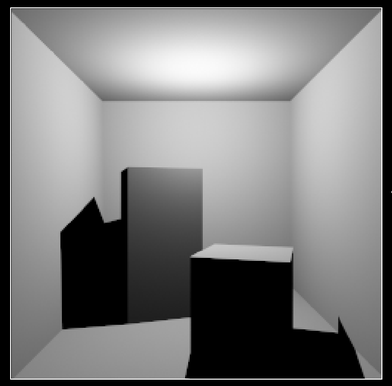
Composite

=

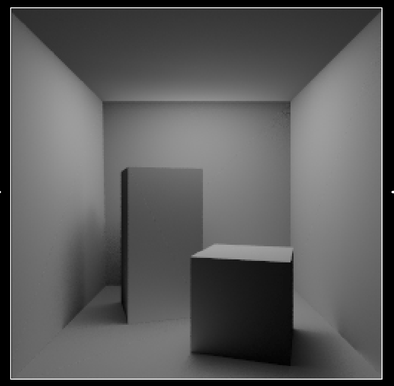
Modified Illumination

×

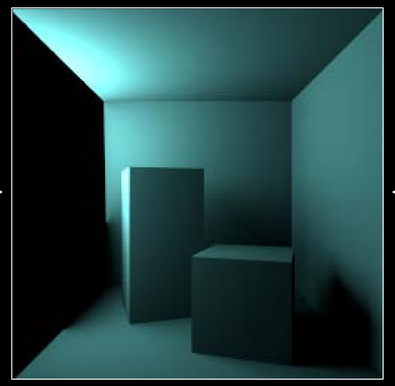

Modified Reflectance


Direct

+


White Walls

+


Left Wall

+

Right Wall

+

Short Box

+

Tall Box

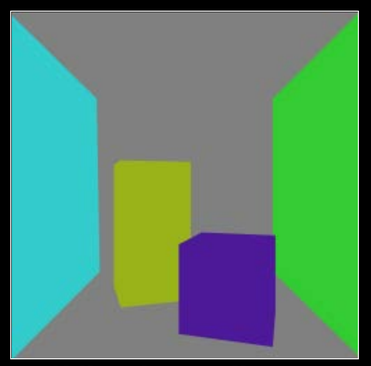
Illumination Decomposition

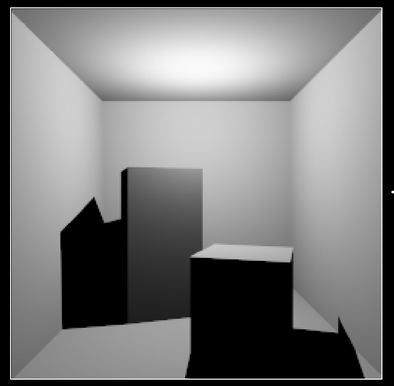
Composite

=

Modified Illumination

×


Modified Reflectance


Direct

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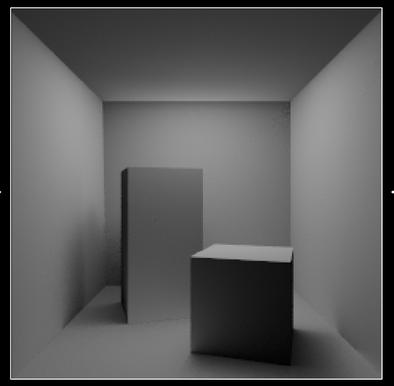
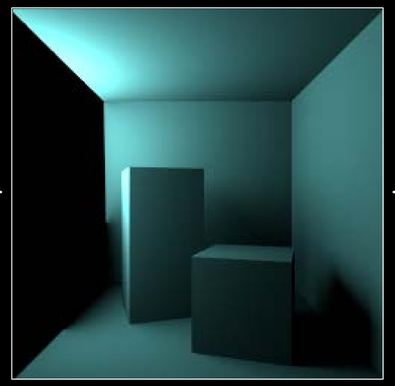

White Walls

+


Left Wall

+

Right Wall

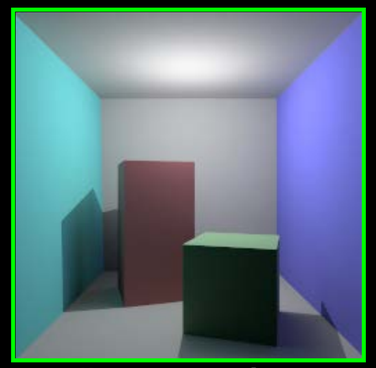
+

Short Box

+

Tall Box

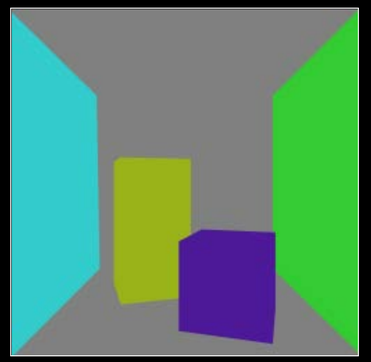
Illumination Decomposition

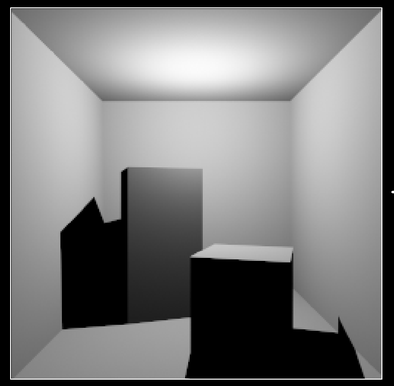

Composite

=

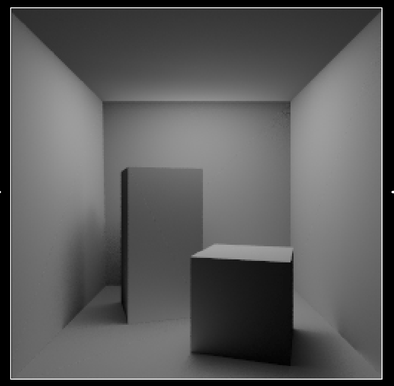
Modified Illumination

×

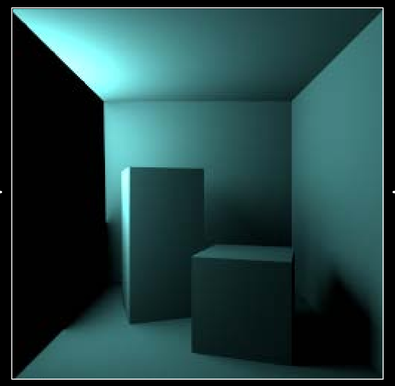

Modified Reflectance


Direct

+


White Walls

+


Left Wall

+

Right Wall

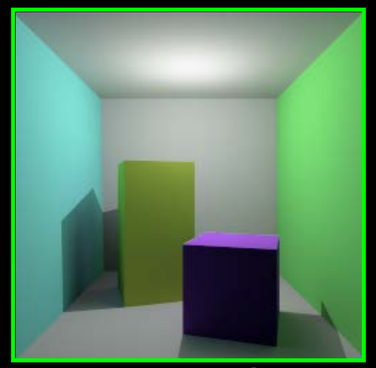
+

Short Box

+

Tall Box

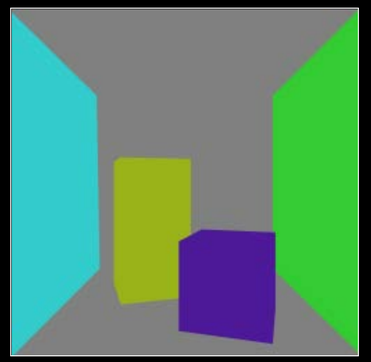
Illumination Decomposition

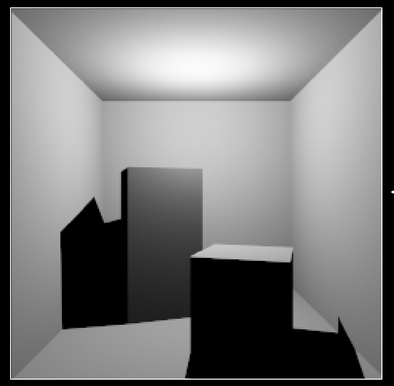

Composite

=

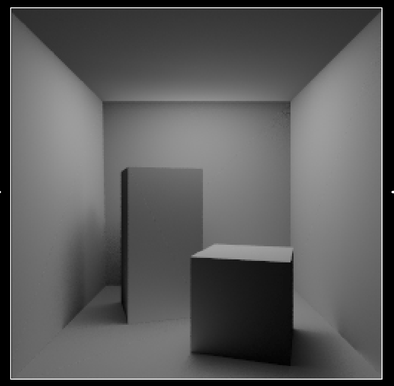
Modified Illumination

×

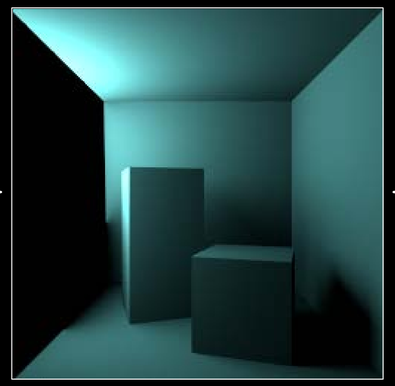

Modified Reflectance


Direct

+


White Walls

+


Left Wall

+

Right Wall

+

Short Box

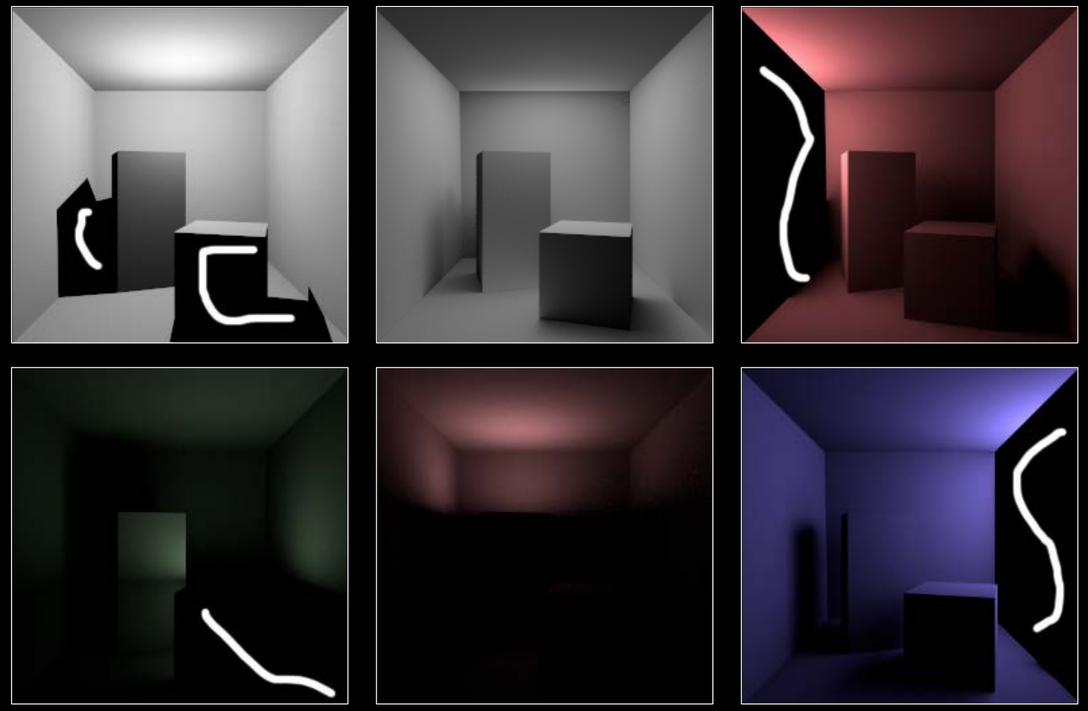
+

Tall Box

Many possible decompositions

Plausible Illumination

User Guidance



Assumptions

Illumination colors are locally independent

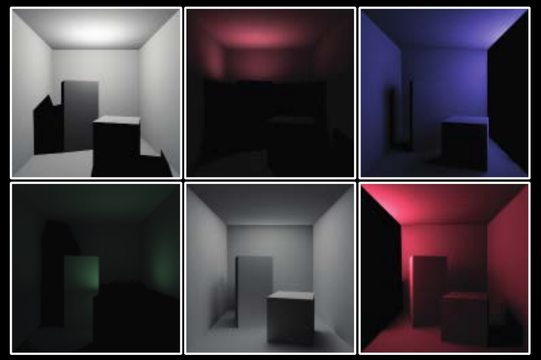
Single bounce of indirect illumination

Lambertian reflectance

Workflow

Sources

Stage 1: Setup

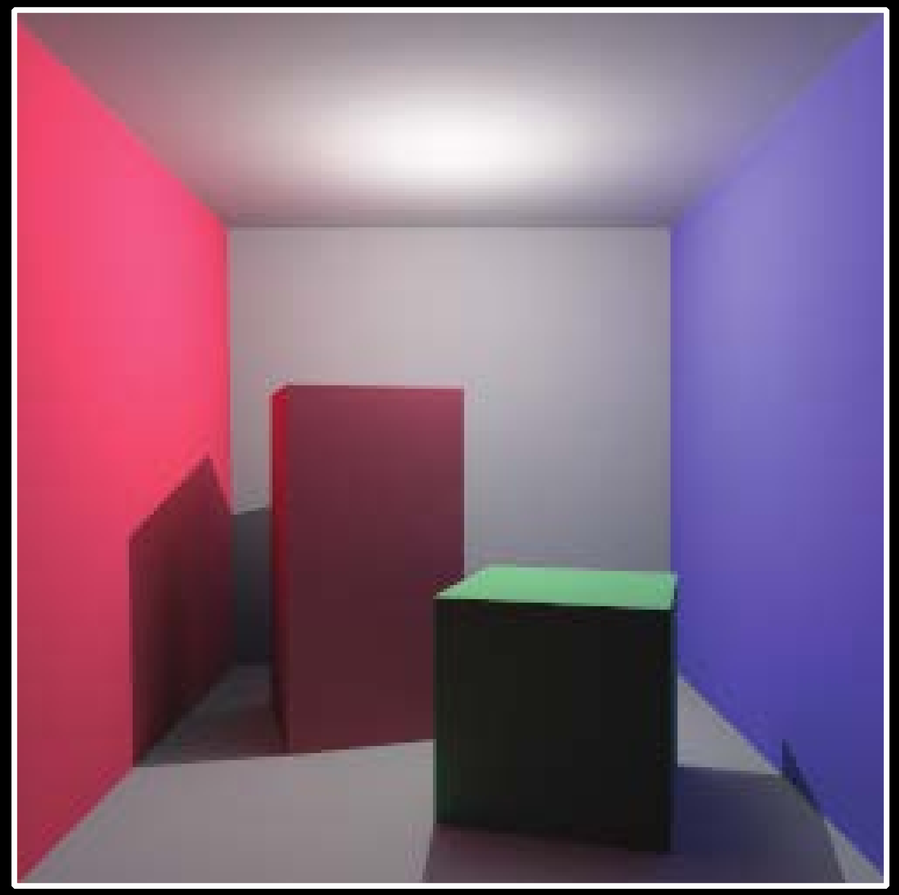


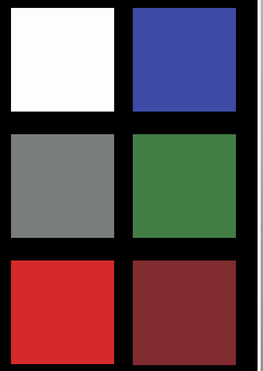
Stage 2: Illumination Decomposition

Basis Sources

Stage 3: Compositing

Workflow

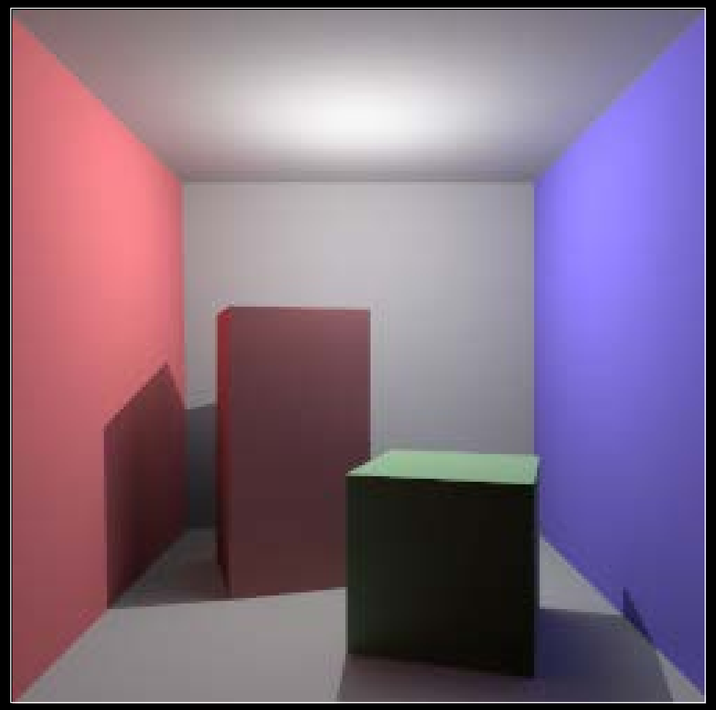




Sources

Stage 1: Setup

Image Formation Model

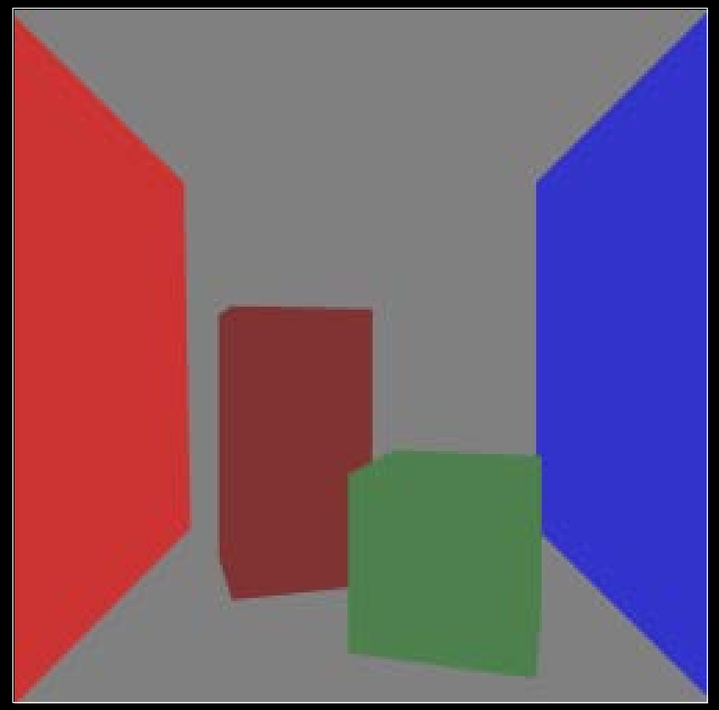


Input

=

Illumination

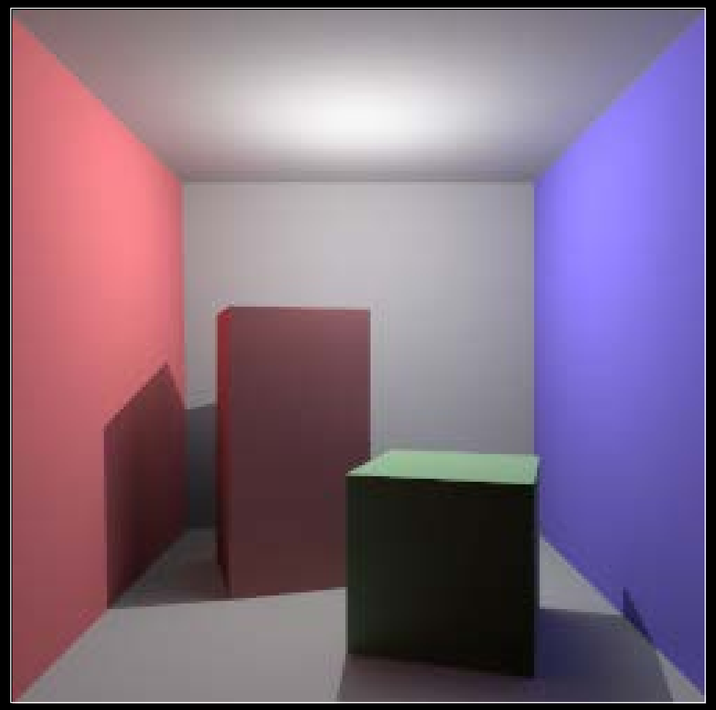
×



Reflectance

$$\mathbf{I}(x, y) = \mathbf{S}(x, y)\mathbf{R}(x, y)$$

Image Formation Model



=

×

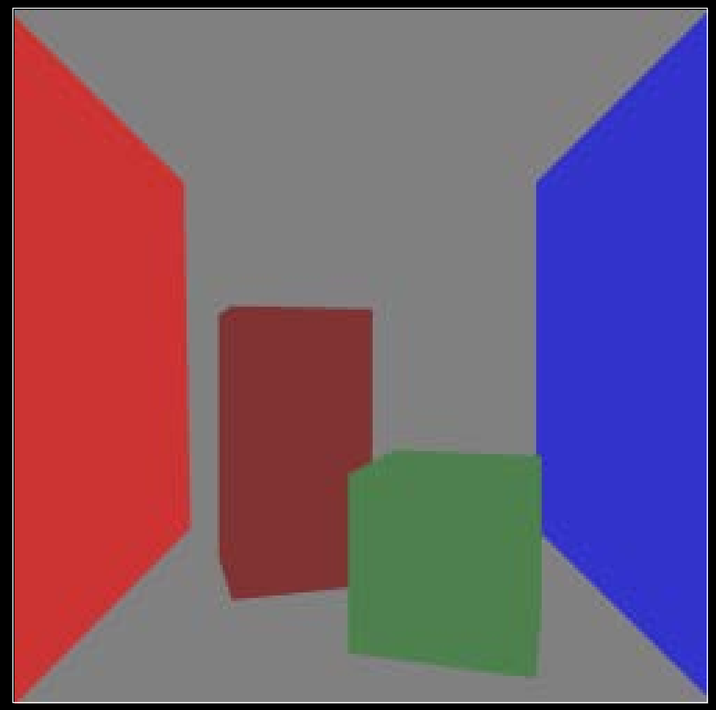
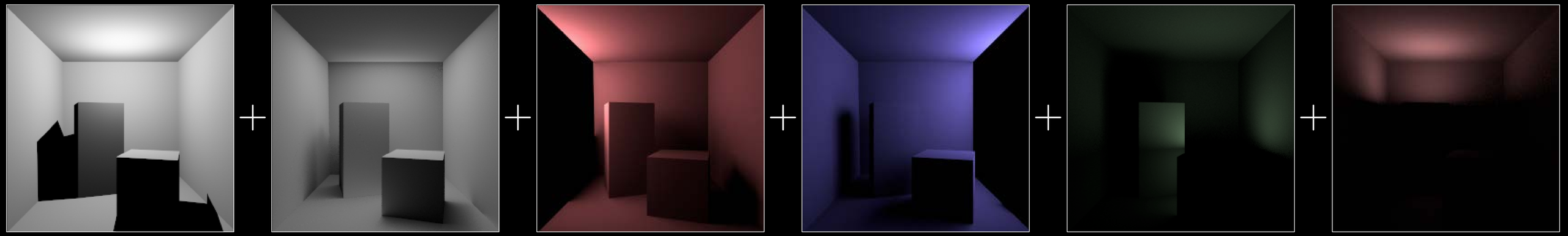


Image Formation Model

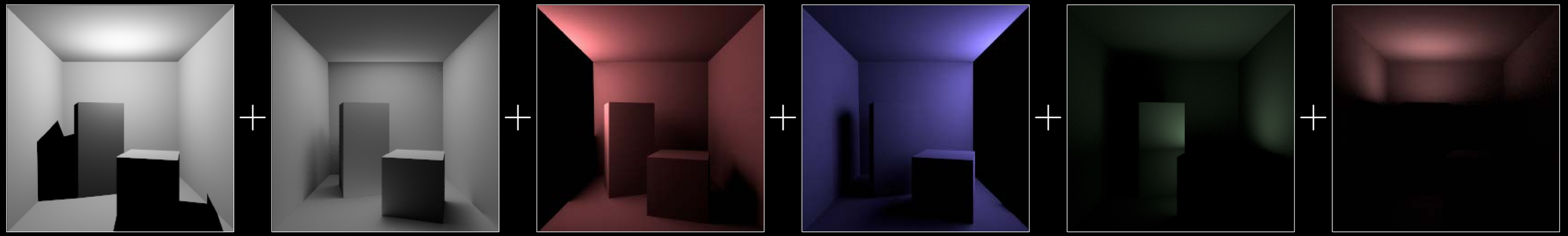
Input Illumination Reflectance



Direct White Walls Left Wall Right Wall Short Box Tall Box

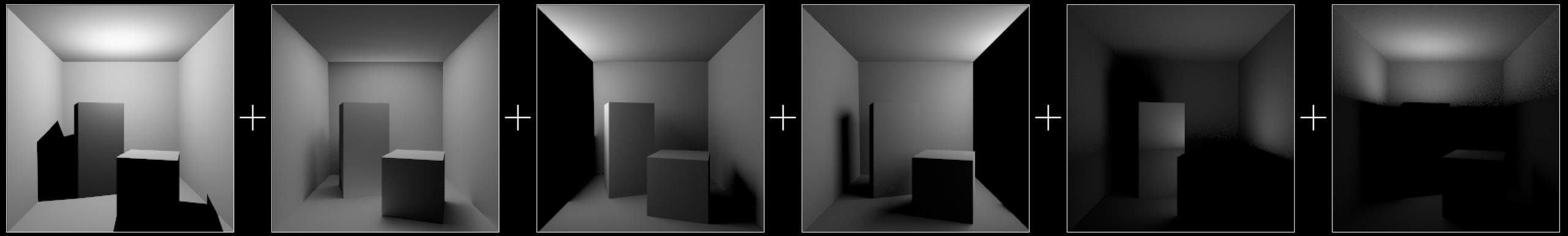
Image Formation Model

Input Illumination Reflectance



Direct White Walls Left Wall Right Wall Short Box Tall Box

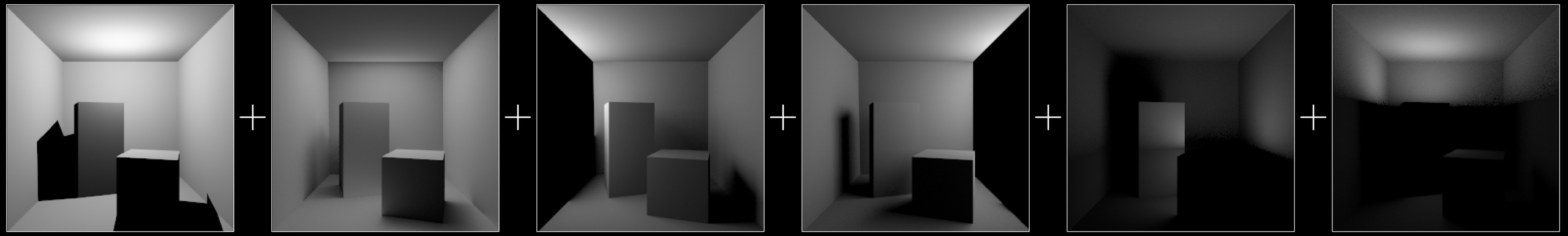
Illumination Model



$T_1\mathbf{b}_1$ $T_2\mathbf{b}_2$ $T_3\mathbf{b}_3$ $T_4\mathbf{b}_4$ $T_5\mathbf{b}_5$ $T_6\mathbf{b}_6$

$$\mathbf{S}(x,y) = \sum_{i=1}^{n} T_i(x,y)\mathbf{b}_i$$

Inverting the Illumination Model



$T_1\mathbf{b}_1$ $T_2\mathbf{b}_2$ $T_3\mathbf{b}_3$ $T_4\mathbf{b}_4$ $T_5\mathbf{b}_5$ $T_6\mathbf{b}_6$

$$\underbrace{\mathbf{S}(x,y)}_{\text{Known}} = \sum_{i=1}^{n} \underbrace{T_i(x,y)}_{\text{Unknown}} \underbrace{\mathbf{b}_i}_{\text{Known}}$$

Underdetermined system – 3 equations and n unknowns per pixel

Energy Minimization

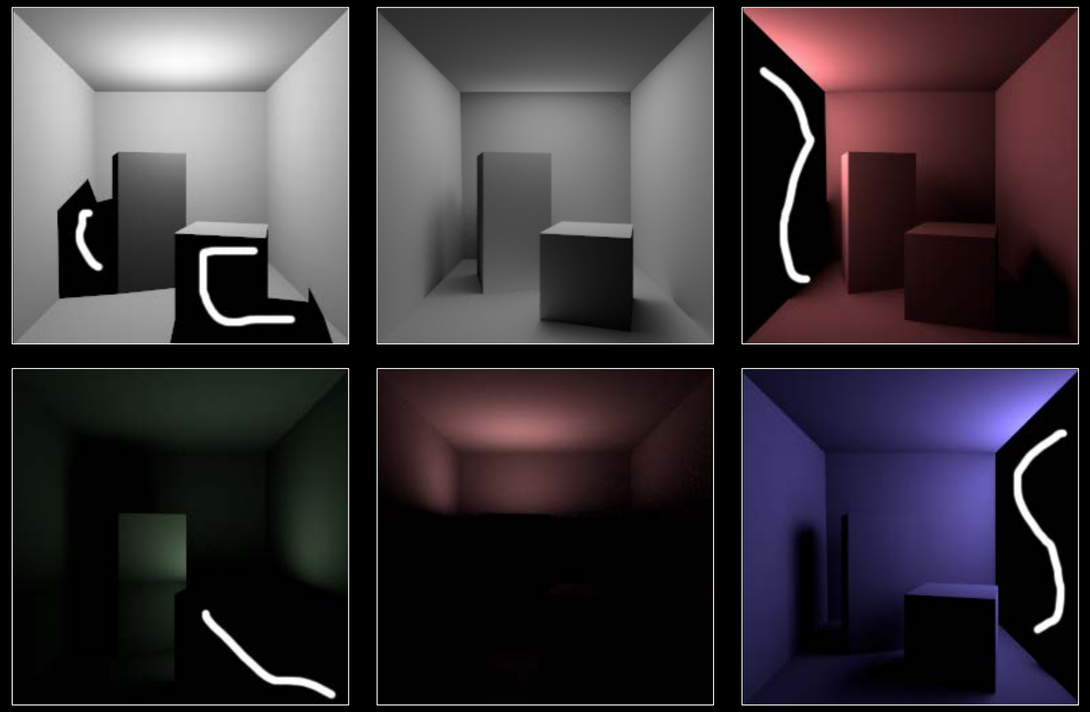
Data Fidelity: $$E_{df} = \left\| \mathbf{S} - \sum_i T_i \mathbf{b}_i \right\|^2$$

Non-Negativity: $$E_{nn} = \sum_i \|\min(T_i, \mathbf{0})\|_1$$

Smoothness : $$E_{sm} = \sum_i \|T_i\|_{TV} = \sum_i \sum_{x,y} \|\nabla T_i(x,y)\|$$

Sparsity : $$E_{sp} = \sum_i \|W_i T_i\|_1 = \sum_i \sum_{x,y} w_i(x,y)|T_i(x,y)|$$

User Interaction



Strokes constrain contribution to zero

Set $w_i(x, y)$ very large in

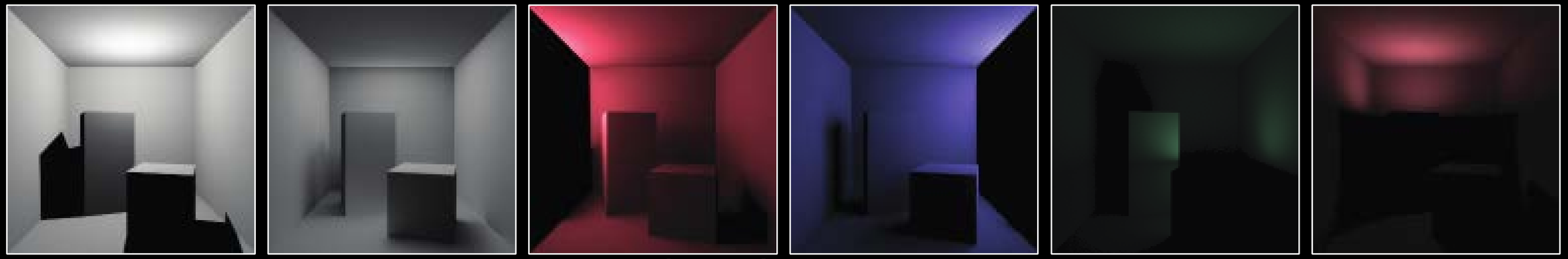
$$E_{sp} = \sum_i \sum_{x,y} w_i(x, y)|T_i(x, y)|$$

Optimization

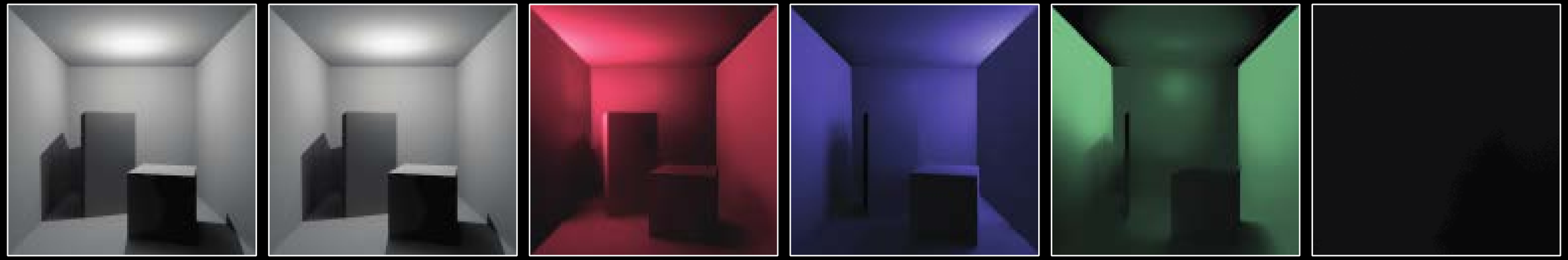
$$E = \underbrace{E_{df}}_{\text{least-squares}} + \lambda_{nn}\underbrace{E_{nn}}_{\text{one-sided penalty}} + \lambda_{sm}\underbrace{E_{sm}}_{\text{least-absolute-value}} + \lambda_{sp}E_{sp}$$

- Optimize with IRLS (Iteratively Reweighted Least Squares)
- Matlab implementation: 3 min for 250x250 image with 6 components

Ground Truth Comparison

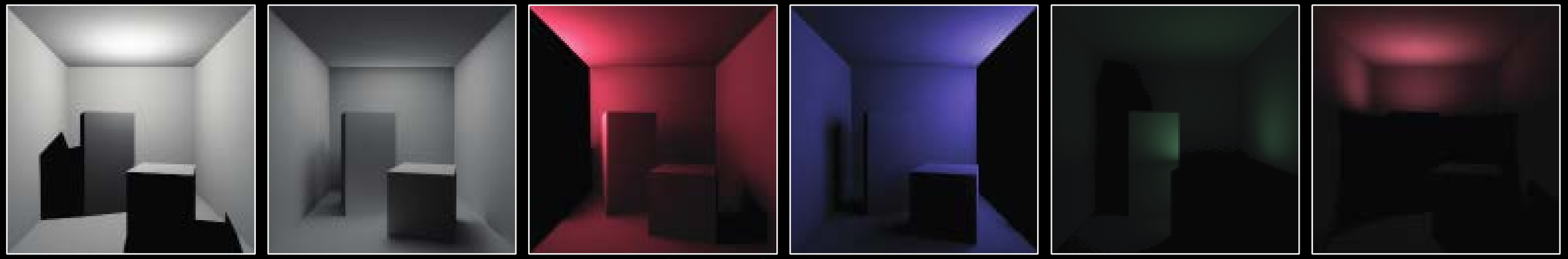


Ground Truth Components

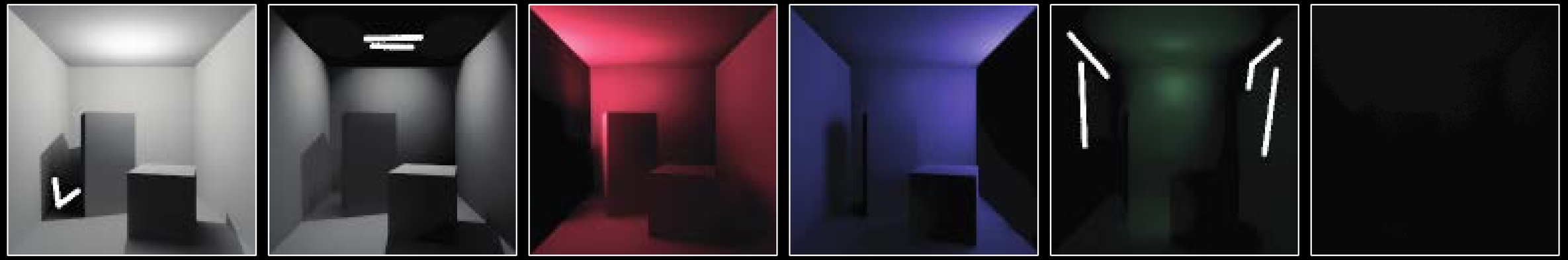


Our Decomposition (before user guidance)

Ground Truth Comparison

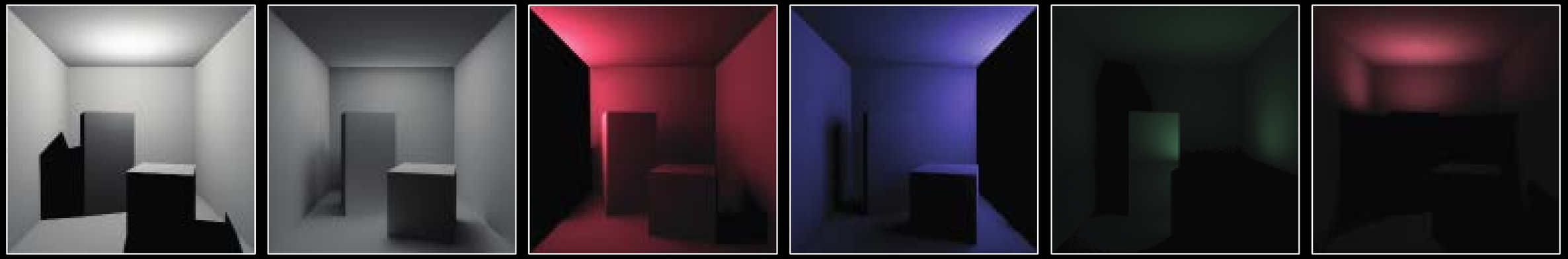


Ground Truth Components

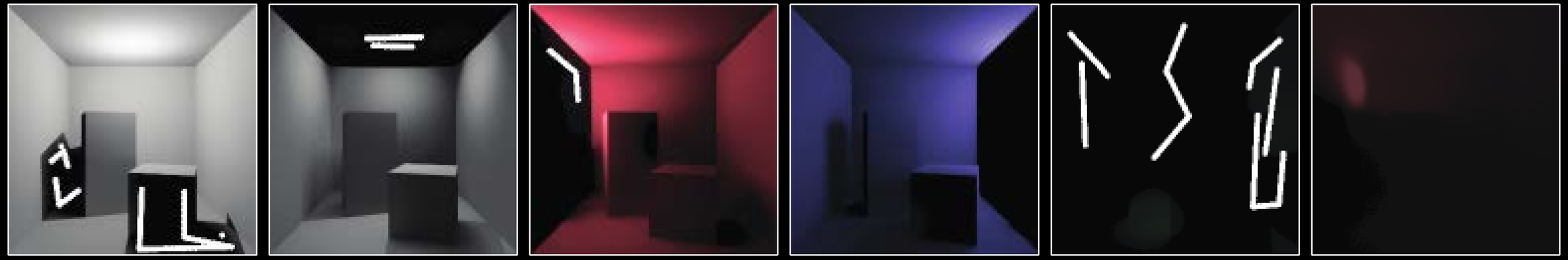


Our Decomposition after 7 strokes

Ground Truth Comparison



Ground Truth Components

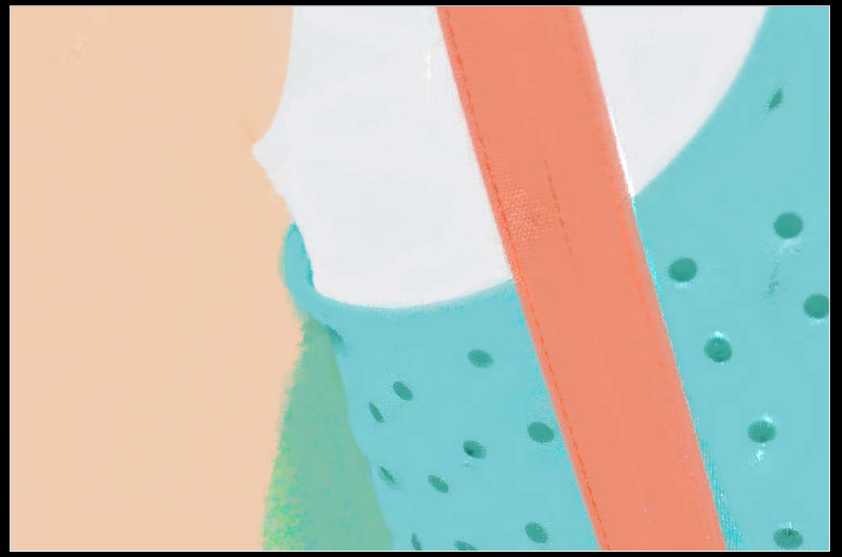


Our Decomposition after 12 strokes

Input

Input

Illumination



Reflectance

Direct

Shirt

Skin

Strap

Illumination Components

Our Result

Input

Modified Reflectance Only

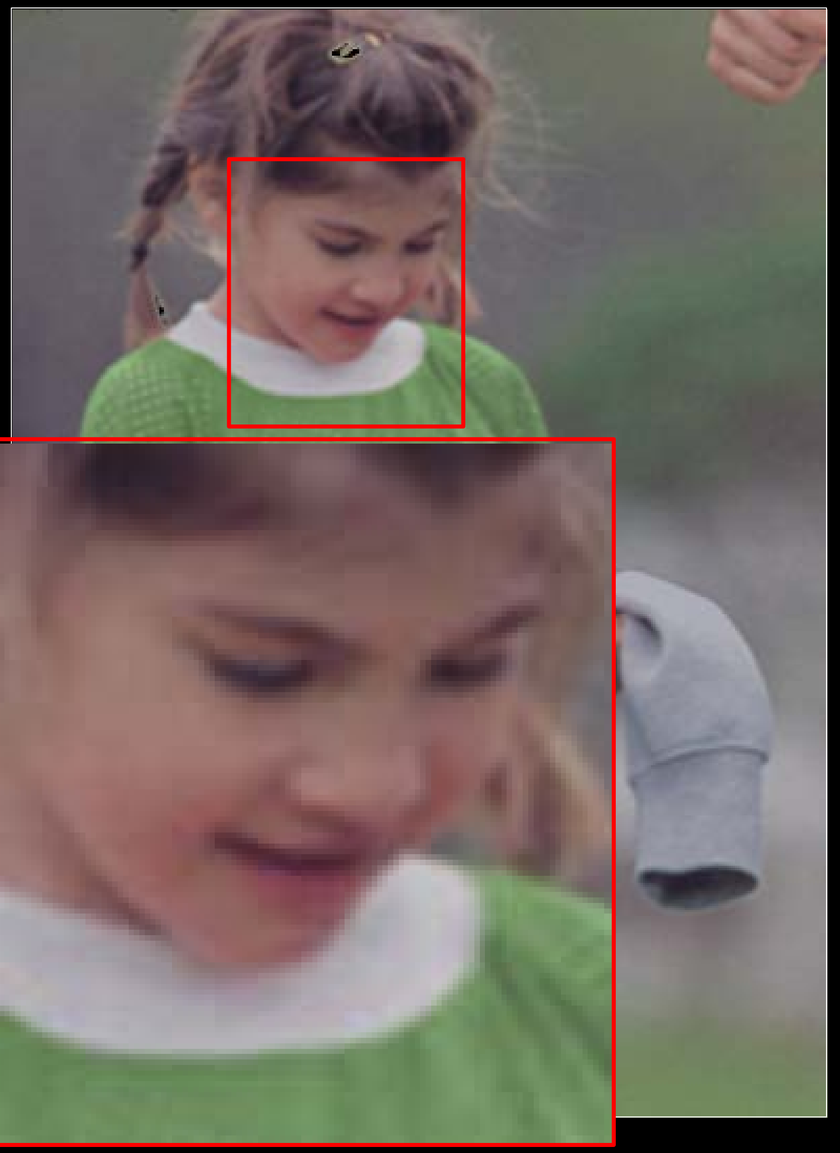
Our Result

Input

Modified Reflectance Only

Our Result

Input



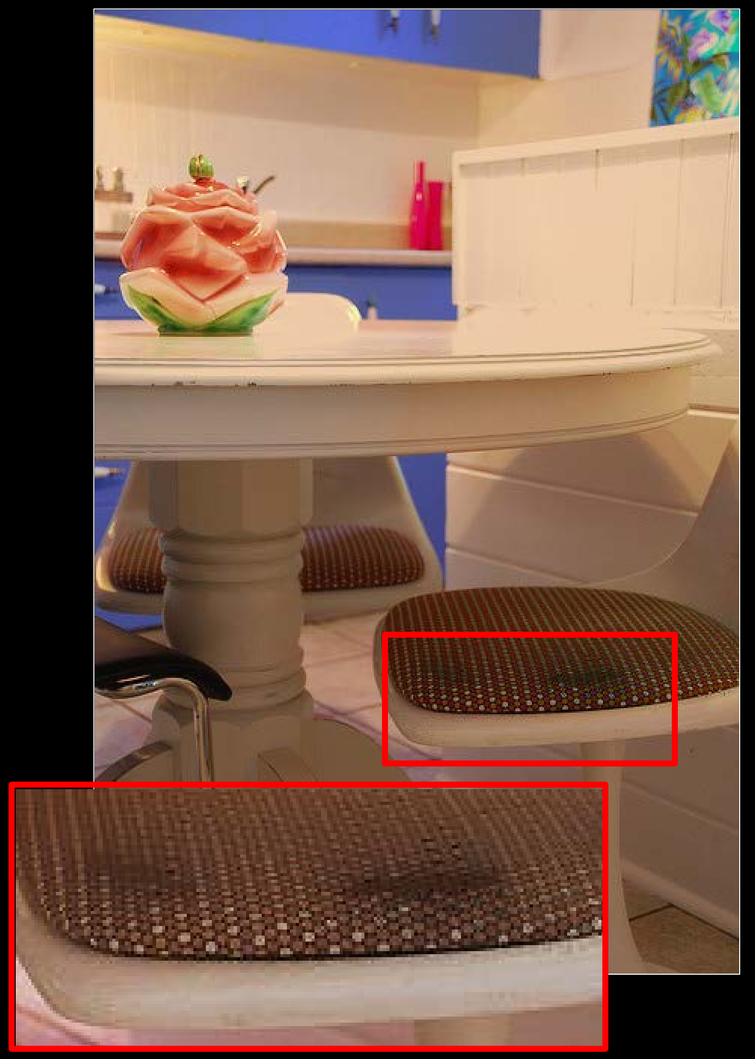
Modified Reflectance Only

Our Result

Limitations and Future Work

- Intrinsic Image Quality
- More flexible user interaction
- Reliance on dissimilar colors

Illumination Intrinsic Image



Our Result

Discussion

- Real world applications?