Light transport probing
conventional photography

photo \quad transport\text{ matrix} \quad [\text{Ng et al. 03}]

degrees of freedom = m
primal-dual coding photography

\[ p = \Pi \cdot T \]

“probing matrix”

degrees of freedom = \( m \times n \)
primal-dual coding photography

\[ p = \Pi \cdot T \]

"probing matrix"

degrees of freedom = \( m \times n \)
primal-dual coding photography

\[ p = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot T \]

“probing matrix”

degrees of freedom = \( m \times n \)
primal-dual coding photography

degrees of freedom = $m \times n$
\[ p = \Pi \cdot T \]
\[ \mathbf{p} = \Pi \circ \mathbf{T} \]

\[ \Pi = \sum_{i=1}^{K} m_i l_i \]
\[ p = \sum_{i=1}^{K} m_i \cdot T \]

\[ \Pi = \sum_{i=1}^{K} m_i \cdot l_i \]
experimental setup

scene

beamsplitter

SLR camera

LCD mask

projector
\[
p = \sum_{i=1}^{K} m_i \cdot T \cdot l_i
\]

**Step 1**: Open shutter

**Step 2**: Illuminate scene with vector \(l_i\) (primal code)

**Step 3**: Attenuate image with vector \(m_i\) (dual code)

**Step 4**: Repeat \(K\) times

**Step 5**: Close shutter
\[ p = \sum_{i=1}^{K} m_i \odot T \]

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\[
p = \sum_{i=1}^{K} m_i \cdot T_i
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\[ p = \sum_{i=1}^{K} m_i \cdot T \]

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Step 2: Illuminate scene with vector \( l_i \) (primal code)
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\[ p = \sum_{i=1}^{K} m_i \odot T \]

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**Step 3:** Attenuate image with vector \( m_i \) (dual code)

**Step 4:** Repeat \( K \) times

**Step 5:** Close shutter
step 1: open shutter
step 2: illuminate scene with vector $\mathbf{l}_i$ (primal code)
step 3: attenuate image with vector $\mathbf{m}_i$ (dual code)
step 4: repeat $K$ times
step 5: close shutter
step 1
open shutter

step 2
illuminate scene with vector $1_i$ (primal code)

step 3
attenuate image with vector $m_i$ (dual code)

step 4
repeat $K$ times

step 5
close shutter
step 1
open shutter

step 2
illuminate scene with vector $l_i$ (primal code)

step 3
attenuate image with vector $m_i$ (dual code)

step 4
repeat $K$ times

step 5
close shutter
$$\sum_{i=1}^{K}$$

**step 1**
open shutter

**step 2**
illuminate scene with vector $\mathbf{l}_i$ (primal code)

**step 3**
attenuate image with vector $\mathbf{m}_i$ (dual code)

**step 4**
repeat $K$ times

**step 5**
close shutter
**step 1**  
open shutter

**step 2**  
illuminate scene with vector $\mathbf{1}_i$ (primal code)

**step 3**  
attenuate image with vector $\mathbf{m}_i$ (dual code)

**step 4**  
repeat $K$ times

**step 5**  
close shutter
stochastic diagonal estimator \[ \text{[Bekas et al. 07]} \]

primal codes are Rademacher random vectors: \( l_i \) = random vector in \( \{ -1, +1 \}^m \)

dual codes derive from primal code: \( m_i = l_i \)

codes converge to identity probing matrix: \( (I \ominus T)1 \approx \frac{1}{K} \sum_{i=1}^{K} m_i \ominus T l_i \)

variance of pixel \( n \) for \( K \) primal-dual codes \( = \frac{1}{K} \sum_{i=1, n \neq m}^{M} T_{nm}^2 \)

aperture correlation (microscopy) is a diagonal estimator \[ \text{[Wilson et al. 96, Levoy et al. 04]} \]

stochastic estimator for general probing

dual codes for general probing matrix \( \Pi \): \( m_i = \Pi l_i \)
Direct-global separation using diagonal probing (co-axial case)
designing probing matrices

transport matrix
Coaxial configuration: use a beamsplitter to make projector and camera effectively collocated
Coaxial configuration: use a beamsplitter to make projector and camera effectively collocated.

Designing probing matrices
coaxial example: contrast-enhancing direct light

conventional photo

all light paths
coaxial example: contrast-enhancing direct light

conventional photo  direct + ½ indirect

direct + 1/2 indirect light paths
coaxial example: contrast-enhancing direct light

- conventional photo
- direct + ½ indirect
- direct + ¼ indirect
- direct + 1/16 indirect

light paths
coaxial example: capturing short to long range paths

conventional

all light paths
coaxial example: capturing short to long range paths

conventional

indirect

indirect light paths
coaxial example: capturing short to long range paths

conventional

indirect

mid-range indirect

medium to long range indirect light paths
coaxial example: capturing short to long range paths

conventional

long-range indirect

indirect

mid-range indirect

long range indirect light paths
coaxial example: separating light transport effects
coaxial example: separating light transport effects

conventional

indirect

indirect light paths
coaxial example: separating light transport effects

conventional

indirect

direct + backscatter

direct + back-scatter light paths
coaxial example: separating light transport effects

indirect [Nayar et al. 06]

direct [Nayar et al. 06]

indirect

direct + backscatter
coaxial example: separating light transport effects

low-freq. indirect  +  high-freq. indirect

indirect  +  direct + backscatter
What if my camera and projector are not co-axial?