HDR, Demosaicing and Flash/No-flash imaging

Projects

List available now

Project proposal (2 pages): 1st of June

Project idea presentation: 8th of June

Final Project presentation: 20th of July

Project report

Persons to contact:

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Persons to contact

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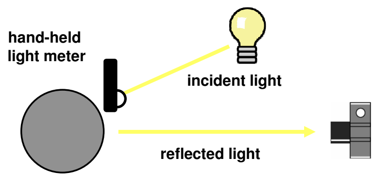
Metering

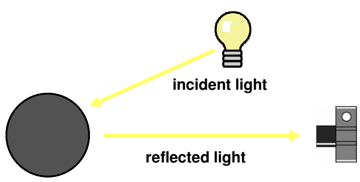
- determine exposure time and aperture
- referenced to a standard 18% grey reflector



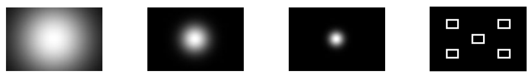
In Camera Metering

inherent problem:

- camera measures reflected light
- depends on object's reflectance



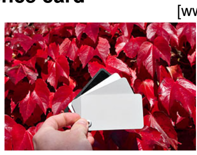
In Camera Metering



center weighted | partial metering | spot metering | matrix evaluation

- still dependent on scene reflectance
- use of reference card

[www.cambridgeincolour.com]



Exposure Bracketing

- capture additional over and underexposed images

Exposure Bracketing

- capture additional over and underexposed images

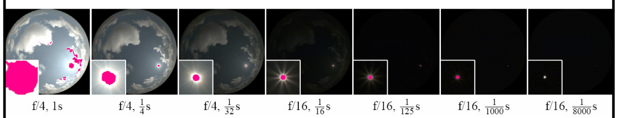
Exposure Bracketing

- capture additional over and underexposed images
- how much variation?
- how to combine?

Dynamic Range in Real World Images

- natural scenes: 18 stops (2^18)
- human: 17stops (after adaptation 30stops ~ 1:1,000,000,000)
- camera: 10-16stops

[Stumpfel et al. 00]



Dynamic Range of Cameras

example: photographic camera with standard CCD sensor

- dynamic range of sensor — 1:1000
- exposure variation (handheld camera/non-static scene): 1/60th s – 1/6000th s exposure time — 1:100
- varying aperture f/2.0 – f/22.0 — ~1:100
- exposure bias/varying "sensitivity" — 1:10

- total (sequential) — 1:100,000,000

simultaneous dynamic range still only 1:1000

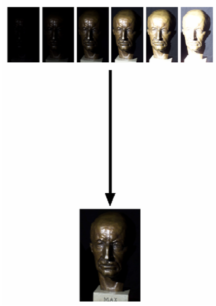
similar situation for analog cameras

High Dynamic Range (HDR) Imaging

basic idea of multi-exposure techniques:

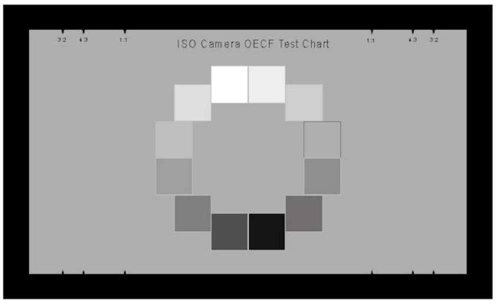
- combine multiple images with different exposure settings
- makes use of available sequential dynamic range

other techniques available (e.g. HDR video)



OECF Test Chart

absolute calibration



High Dynamic Range Imaging

- limited dynamic range of cameras is a problem
  - shadows are underexposed
  - bright areas are overexposed
  - sampling density is not sufficient
- some modern CMOS imagers have a higher and often sufficient dynamic range than most CCD imagers

High Dynamic Range (HDR) Imaging

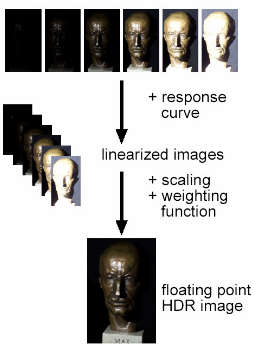
- analog film with several emulsions of different sensitivity levels by Wyckoff in the 1960s
  - dynamic range of about 10^8
- commonly used method for digital photography by Debevec and Malik (1997)
  - selects a small number of pixels from the images
  - performs an optimization of the response curve with a smoothness constraint
- newer method by Robertson et al. (1999)
  - optimization over all pixels in all images

High Dynamic Range Imaging

general idea of High Dynamic Range (HDR) imaging:

- combine multiple images with different exposure times
  - pick for each pixel a well exposed image
  - response curve needs to be known
  - don't change aperture due to different depth-of-field

High Dynamic Range Imaging



HDR Imaging [Robertson et al.99]

Principle of this approach:

- calculate a HDR image using the response curve
- find a better response curve using the HDR image

(to be iterated until convergence)

HDR Imaging [Robertson et al.99]

input:

- series of i images with exposure times t_i and pixel values y_{ij}

$$y_{ij} = f(t_i x_j)$$

task:

- find irradiance (luminance) x_j
- recover response curve $I(y_{ij})$

$$f^{-1}(y_{ij}) = t_i x_j = I_{y_{ij}}$$

HDR Imaging [Robertson et al.99]

input:

- series of i images with exposure times t_i and pixel values y_{ij}
- a weighting function $w_{ij} = w_{ij}(y_{ij})$ (bell shaped curve)
- a camera response curve $I(y_{ij})$
  - initial assumption: linear response

⇒ calculate HDR values x_j from images using

$$x_j = \frac{\sum_i w_{ij} t_i I_{y_{ij}}}{\sum_i w_{ij} t_i^2}$$

Computational Photography Hendrik Lensch, Summer 2007

HDR Imaging [Robertson et al.99]

optimizing the response curve $I(y_{ij})$ resp. $I(m)$:

- minimization of objective function O

$$O = \sum_{i,j} w_{ij} (I_{y_{ij}} - t_i x_j)^2$$

using Gauss-Seidel relaxation yields

$$I_m = \frac{1}{\mathrm{Card}(E_m)} \sum_{i,j \in E_m} t_i x_j$$

$$E_m = \{(i,j) : y_{ij} = m\}$$

- normalization of I so that I_{128}=1.0

Computational Photography Hendrik Lensch, Summer 2007

HDR Imaging [Robertson et al.99]

both steps

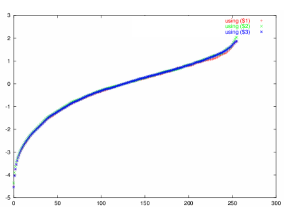
- calculation of a HDR image using I
- optimization of I using the HDR image

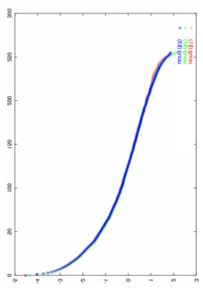
are now iterated until convergence

- criterion: decrease of O below some threshold
- usually about 5 iterations

Computational Photography Hendrik Lensch, Summer 2007

HDR Imaging [Robertson et al.99]

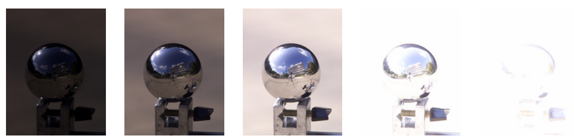




$\log(I(y_{ij}))$

Computational Photography Hendrik Lensch, Summer 2007

Example: Capturing Environment Maps



1/2000s 1/500s 1/125s 1/30s 1/8s

series of input images

Computational Photography Hendrik Lensch, Summer 2007

Example: Capturing Environment Maps

Weighting Function [Robertson et al.99]

choice of weighting function *w(y*$_{ij}$*)* for response recovery

- for 8 bit images $w_{ij} = \exp\left(-4\frac{(y_{ij}-127.5)^2}{127.5^2}\right)$
- possible correction at both ends (over/underexposure)
- motivated by general noise model

Weighting function [Robertson et al.03]

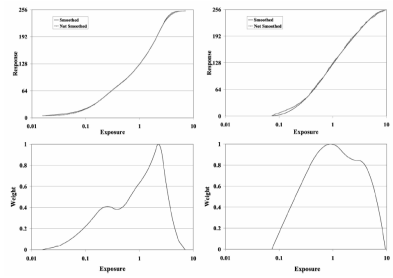
choice of weighting function *w(y*$_{ij}$*)* for HDR reconstruction

- introduce certainty function *c* as derivative of the response curve with logarithmic exposure axis
- approximation of response function by cubic spline to compute derivative

$$w_{ij} = w(y_{ij}) = c(I_{y_{ij}})$$

Algorithm of Robertson et al.

- consider response curve gradient
- what would be the best curve based on noise?



[Robertson et al. 2003]

Algorithm of Robertson et al.

discussion

- method very easy
- doesn’t make assumptions about response curve shape
- converges fast
- takes all available input data into account
- can be extended to >8 bit color depth
- 16bit should be followed by smoothing

Input Images for Response Recovery

my favorite:

- grey card, out of focus, smooth illumination gradient

advantages

- uniform histogram of values
- no color processing or sharpening interfering with the result

Input Images for HDR Generation

how many images are necessary to get good results?

- depends on scene dynamic range and on quality requirements
- most often a difference of two stops (factor of 4) between exposures is sufficient
- [Grossberg & Nayar 2003]

HDR-Video

- LDR [Bennett & McMillan 2005]
- HDR image formats [OpenExr, HDR JPEG]
- HDR MPEG Encoding [Mantiuk et al. 2004]
- HDR + motion compensation [Kang et al. 2003]

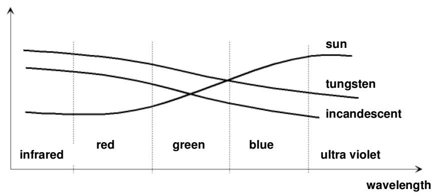
White Balance

capture the spectral characteristics of the light source to assure correct color reproduction

White Balance

build-in function

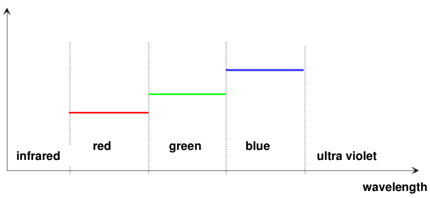
derive scale from white point



White Balance

build-in function

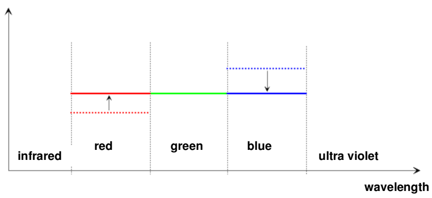
derive scale from white point



White Balance

build-in function

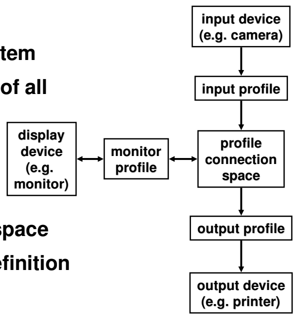
derive scale from white point



ICC Profiles

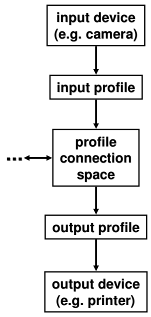
(ICC –international color consortium)

- color management system
- capture the properties of all devices
  - camera and lighting
  - monitor settings
  - output properties
- common interchange space
- sRGB standard as a definition of RGB



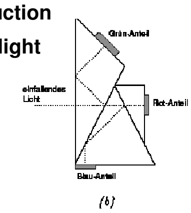
ICC Profiles and HDR Image Generation

- profile connection spaces
  - CIELAB (perceptual linear)
  - linear CIEXYZ color space
- can be used to create an high dynamic range image in the profile connection space
- allows for a color calibrated workflow



3-Chip CCD

- a prism splits up the incoming image into RGB images
- each color channel is captured by a different sensor
- registration during production
- problems with polarized light

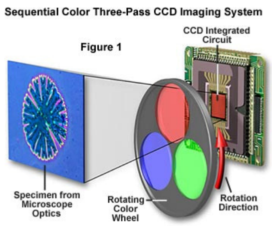


Color Wheel

one color channel is captured at one shot

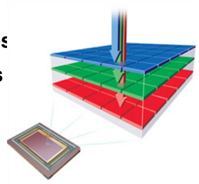
3 times the acquisition time

static images only



Foveon Technology

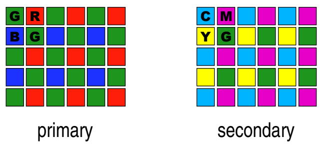
- 3 layers capture RGB at the same location
- takes advantage of silicon's wavelength selectivity
- light decays at different rates for different wavelengths
- multilayer CMOS sensor gets 3 different spectral sensitivities
- don't get to choose the curves



Ways to sense color

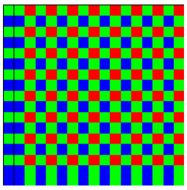
Color filter array

- paint each sensor with an individual filter
- requires just one chip but loses some spatial resolution
- "demosaicing" requires tricky image processing



Multi-Shot

- take four images, moving the sensor by one pixel
- (use fourth image for noise reduction)



- can be used for supersampling (move by ½, ¼ pixel)

Demosaicing

mosaic image

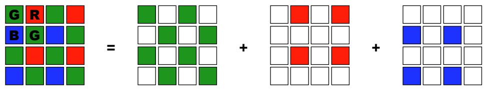
Bilinear interpolation

[Alleysson & Suesstrunk05]

Demosaicing

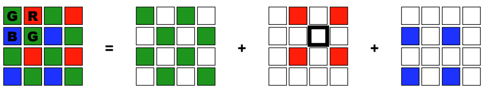
- bilinear interpolation
- sampling theory
- edge-directed/pattern-based interpolation
- correlation-based

Bilinear Interpolation



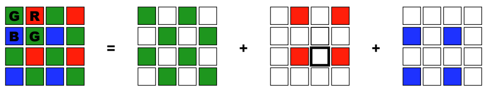
perform interpolation for each color channel separately

Bilinear Interpolation



$$R_{23} = \frac{R_{12} + R_{14} + R_{32} + R_{34}}{4}$$

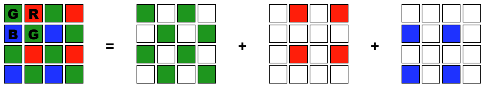
Bilinear Interpolation



$$R_{23} = \frac{R_{12} + R_{14} + R_{32} + R_{34}}{4}$$

$$R_{33} = \frac{R_{32} + R_{34}}{2}$$

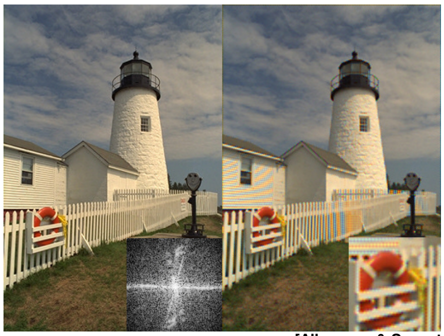
Bilinear Interpolation



set all non-measured values to zero then convolve

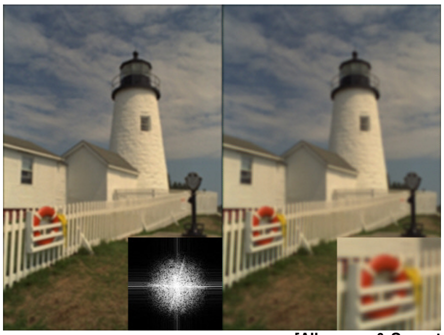
$$F_{R,B} = \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} / 4 \qquad F_G = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 0 \end{bmatrix} / 4$$

Problem: Aliasing



[Alleysson & Suesstrunk05]

Problem: Aliasing



[Alleysson & Suesstrunk05]

Luminance and Chrominance

[Alleysson & Suesstrunk05]

Luminance is sampled at every pixel

Chrominance (opponent colors) only available on a sparser grid (zero mean)

$$I = \{C_i(x,y)\} = \Phi(x,y) + \{\Psi_i(x,y)\}$$

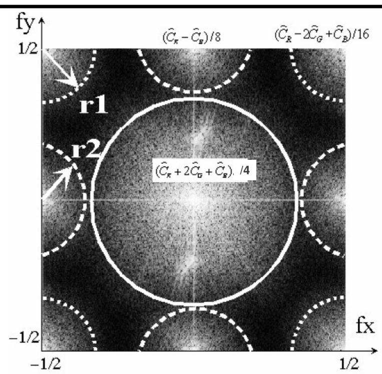
$$\Phi(x,y) = \sum_{i \in \{R,G,B\}} p_i C_i(x,y) \qquad \text{low-pass}$$

$$\Psi_i(x,y) = (1-p_i)C_i(x,y) - \sum_{j \neq i} p_j C_j(x,y) \qquad \text{high-pass}$$

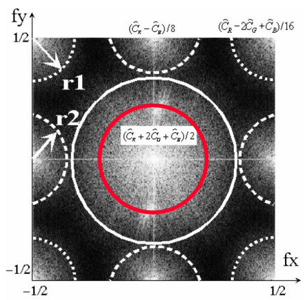
one possible set for Bayer patterns:

$$\{p_R = \frac{1}{4}, p_G = \frac{1}{2}, p_B = \frac{1}{4}\}$$

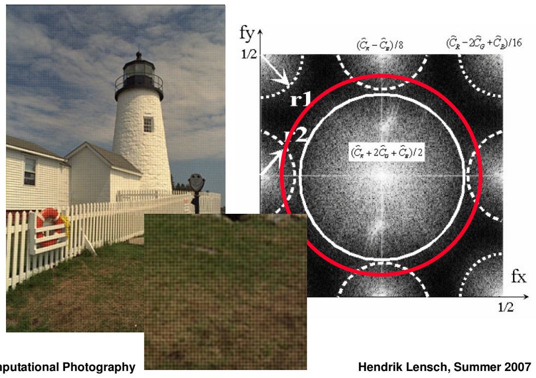
Fourier Space



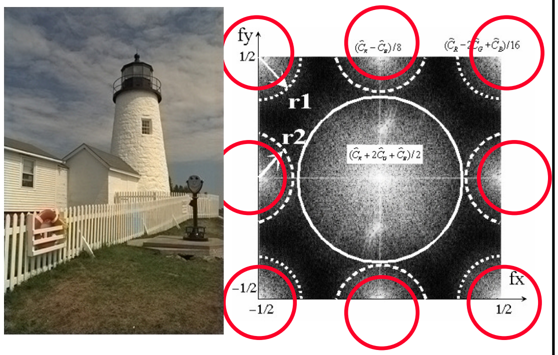
Excessive Blurring



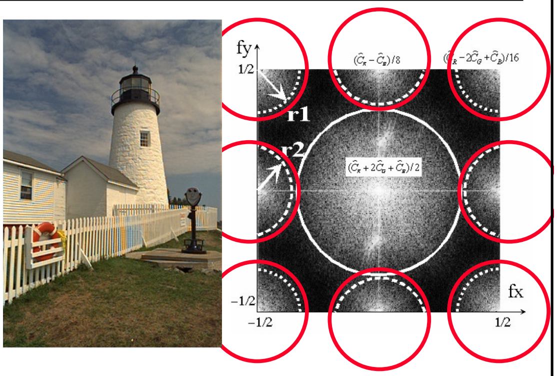
Grid Effect



Watercolors



False Color



[Alleysson & Suesstrunk05]

optimize r1 and r2 to gain best separation

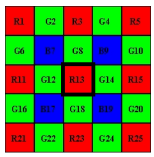
- Low-pass filter luminance
- High-pass filter chrominance (orthogonal filter)
- Demultiplex chrominance
- Interpolate opponent colors
- Add luminance and interpolated colors

Gradient-based (dcraw)

[Chuang et al. 99]

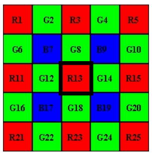
1. Calculate gradients in 5x5 region
2. Select subset of gradients (below threshold)
3. Average color differences in the determined regions

Gradients



Gradient S = $|G18-G8|+|R23-R13|+$
$|B19-B9|/2+|B17-B7|/2+$
$|G24-G14|/2+|G22-G12|/2$

Regions



selection: gradient < 1.5*Min+0.5*(Max-Min)

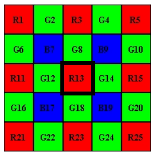
e.g. {S,W,NE,SE}

S: R = (R13+R23)/2, G = G18, B = (B17+B19)/2

NE: R = (R13+R5)/2, G = (G4+G8+G10+G14)/4, B = B9

…

Average



Rsum = (Rs + Rw + Rne + Rse)/4

Gsum = (Gs + Gw + Gne + Gse)/4

Bsum = (Bs + Bw + Bne + Bse)/4

average of color differences!

G13 = R13 + (Gsum-Rsum); B13 = R13 + (Bsum-Rsum)

Correlation-Based Demosaicing

[Gunturk et al 02]

Subband decomposition of full RGB-image using

$$h_0 = [1 \quad 2 \quad 1]/4$$
$$h_1 = [1 \quad -2 \quad 1]/4$$

results in (LL, LH, HL, HH).

Observation: inter channel correlation of red/green and blue/green is larger than 0.9.

(discontinuities present in all channels at once!)

=> reconstruct (LH,HL,HH) for red and blue according to green

Alternating Projections

1. **Interpolate red, green, and blue**
2. **Decompose all three channels (LL,HL,LH,HH)**
3. **Update red and blue high frequencies i=(HL,LH,HH) according to green:**

$$r_i = red_i - green_i \qquad red_i = \begin{cases} green_i + T; r_i > T \\ red_i; |r_i| \le T \\ green_i - T; r < -T \end{cases}$$

4. **Reset observed data**
5. **Iterate: goto 2 until stopping criterion achieved.**
6. **Reconstruct image**

Comparison

correlation-based

gradient-selection

Comparison

correlation-based

gradient-selection

Demosaicing – Take-home-points

- **2/3 of your image are just made up!**
- **avg. 5% error, much larger for individual pixels**
- **color resolution is less than image resolution**
- **be careful with spiky BRDFs**
- **combining multiple video frames might help**

Flash-No-Flash [Eisenmann&Durand04]

[the following slides are from Eisenmann's SIGGRAPH talk]

Available light:

+ nice lighting

- noise/blurriness

- color

Flash

Flash:

+ details

+ color

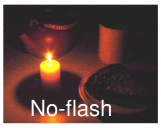
- flat/artificial

- flash shadows

- red eyes

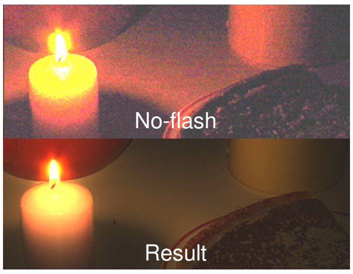
Combined

Use no-flash image relight flash image



Introduction

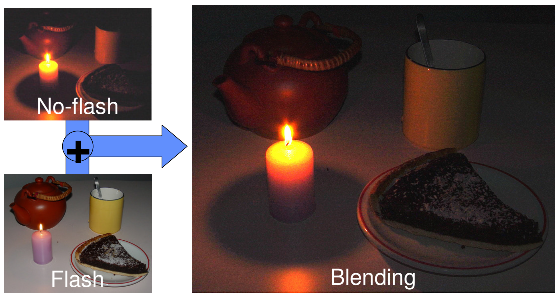
Use no-flash image relight flash image



+ original lighting
+ details/sharpness
+ color

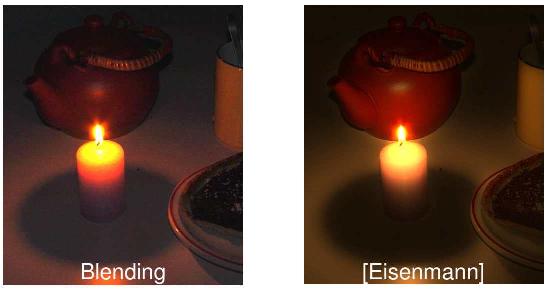
Introduction

One approach: Blend the two photos



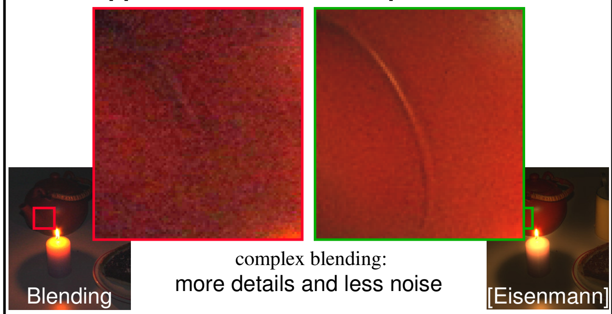
Introduction

One approach: Blend the two photos

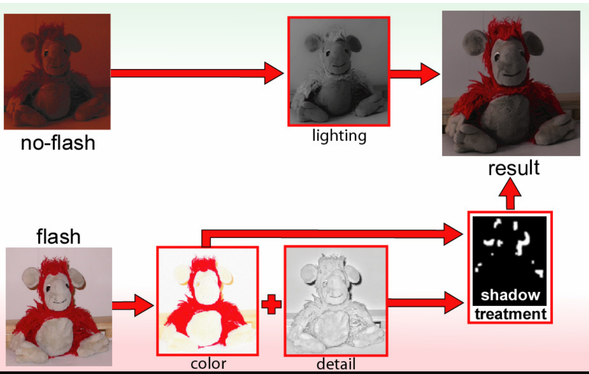


Introduction

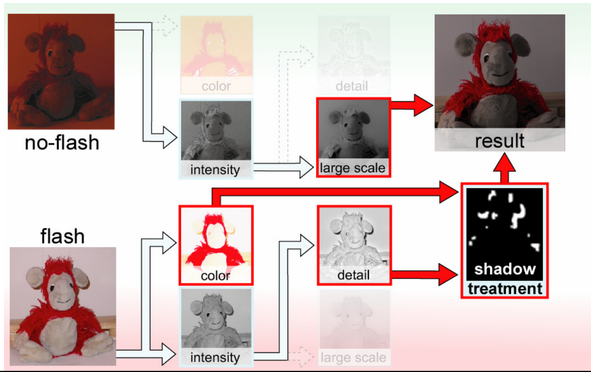
One approach: Blend the two photos



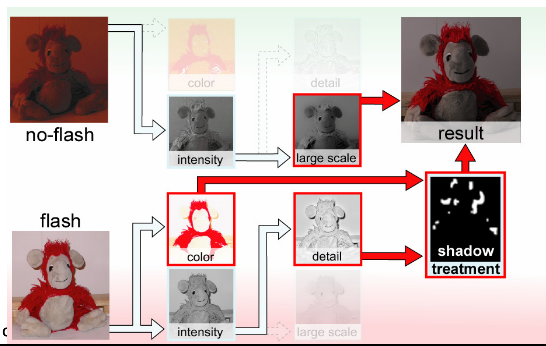
Main Idea



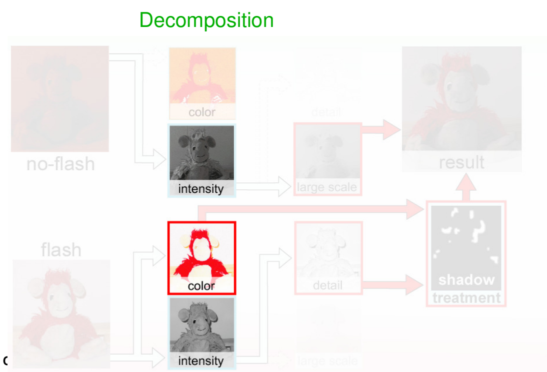
Structure



Structure

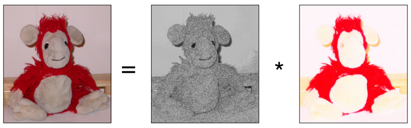


Intensity-Color Decomposition



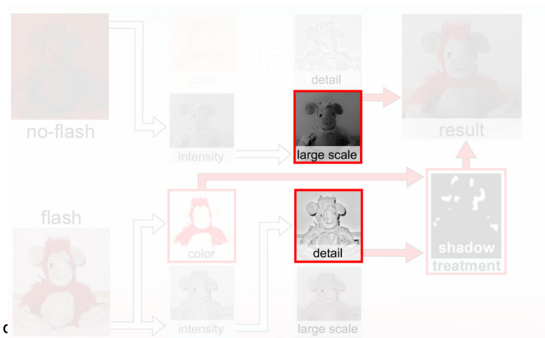
Decomposition

Color / Intensity:



original = intensity * color

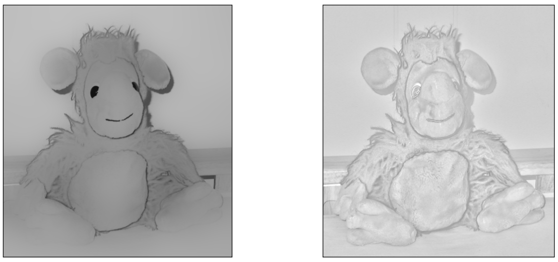
Frequency Decoupling



Decoupling

Lighting : Large-scale variation

Texture : Small-scale variation



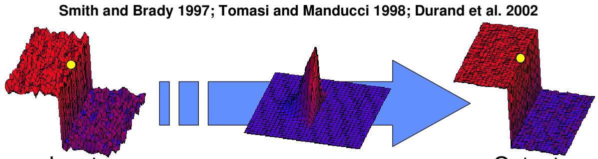
Lighting

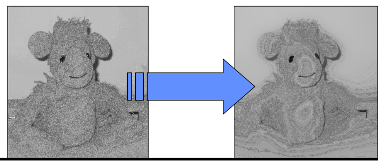
Texture

Large-scale Layer

Bilateral filter – edge preserving filter

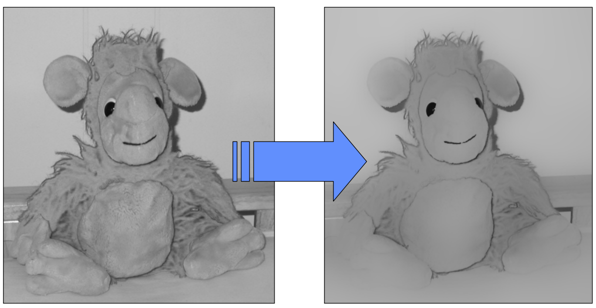
Smith and Brady 1997; Tomasi and Manducci 1998; Durand et al. 2002





Large-scale Layer

Bilateral filter

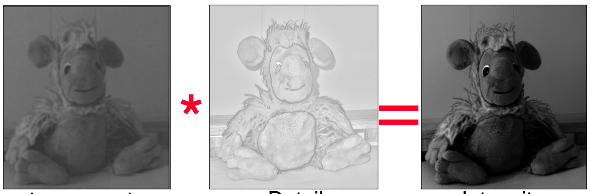


Detail Layer

Intensity / Large-scale = Detail

Recombination: Large scale * Detail = Intensity

Recombination



Large-scale
No-flash

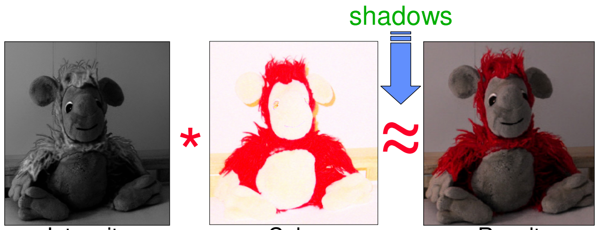
Detail
Flash

Intensity
Result

Recombination: Large scale * Detail = Intensity

Computational Photography Hendrik Lensch, Summer 2007

Recombination



Intensity
Result

Color
Flash

Result

Recombination: Intensity * Color = Original

Computational Photography Hendrik Lensch, Summer 2007

Results

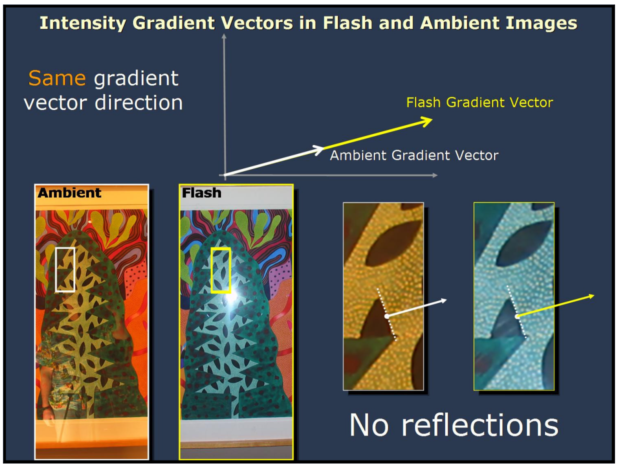
Hendrik Lensch, Summer 2007

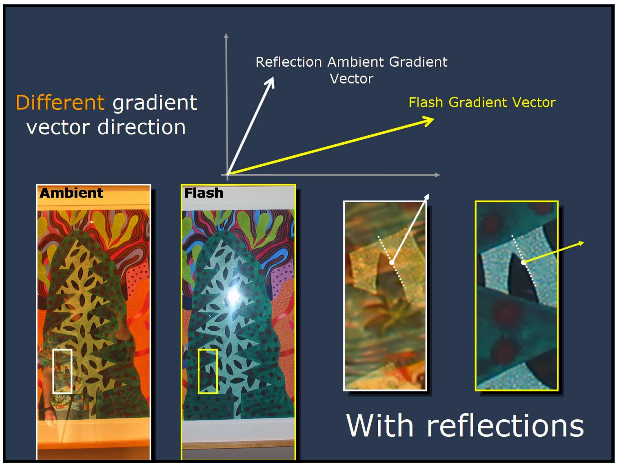
More Flash-noflash Algorithms

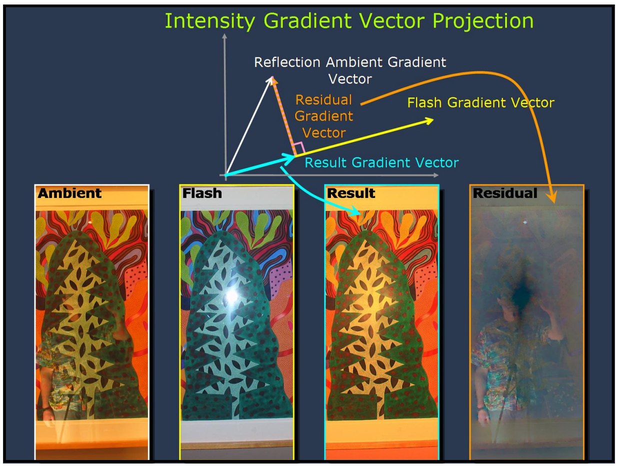
[following slides from Agrawal SIGGRAPH 2005]

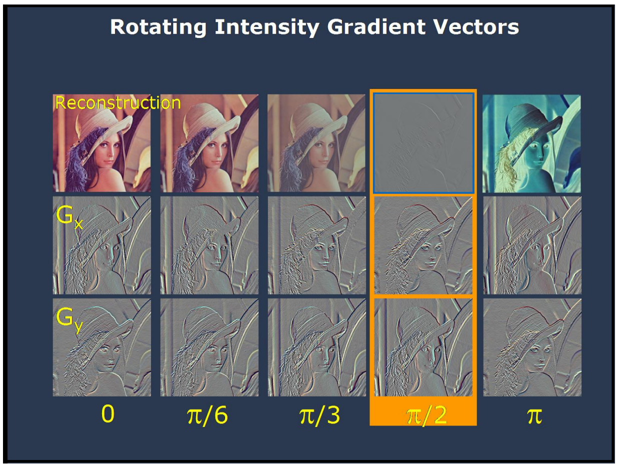
remove features that don't appear in both
(as determined from image gradients)

Computational Photography Hendrik Lensch, Summer 2007



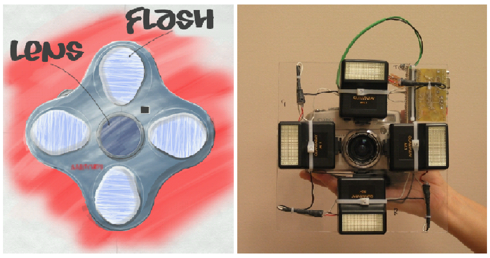




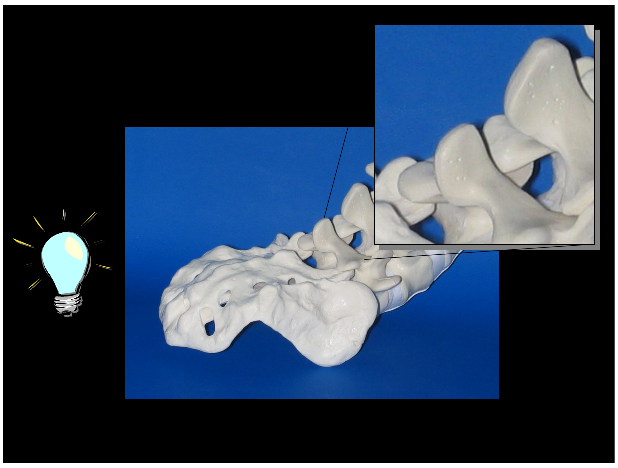


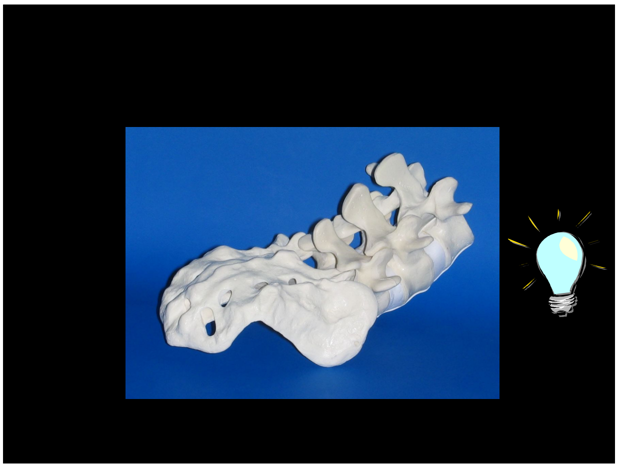
Multi-Flash Images

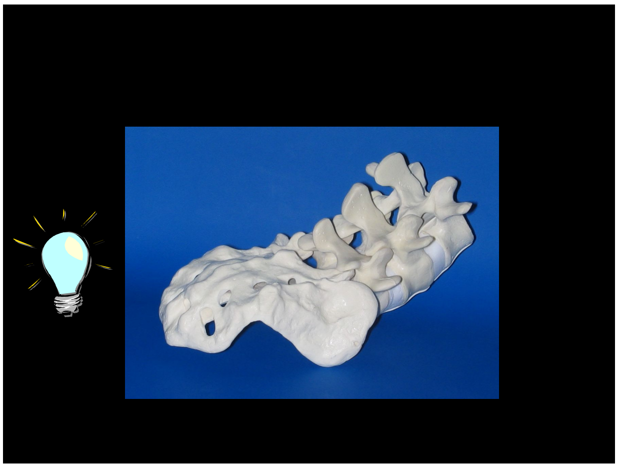
- extract edge information

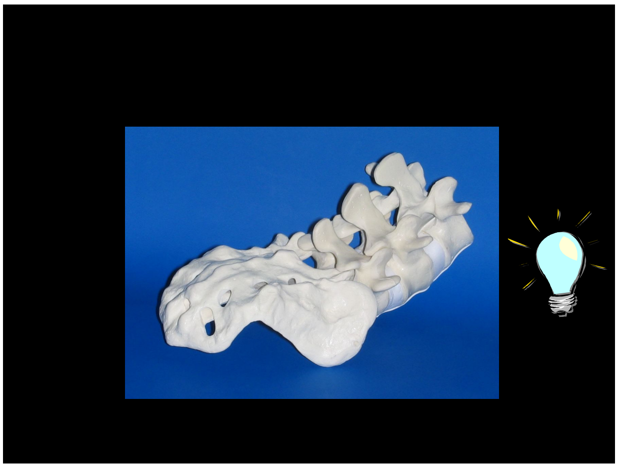


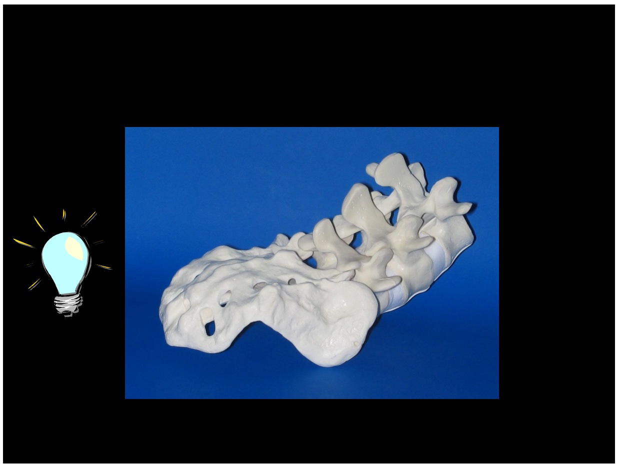
[following slides from Raskar 2004]



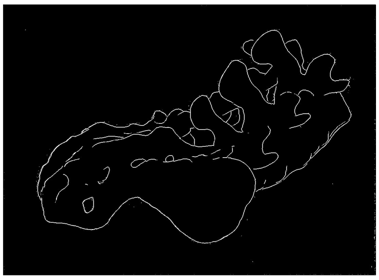




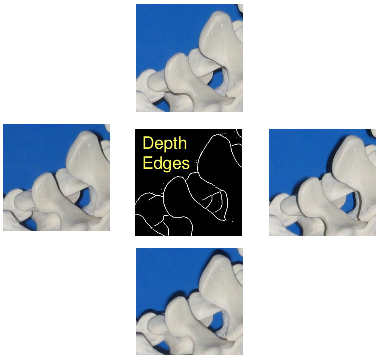


Depth Discontinuities

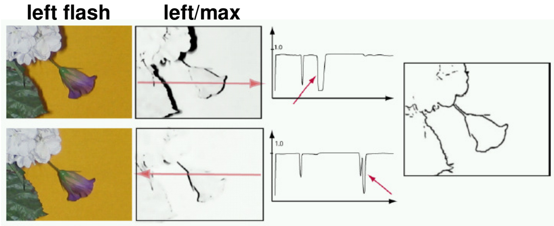


Internal and external
Shape boundaries, Occluding contour, Silhouettes

Depth Discontinuities



Finding the Correct Edge

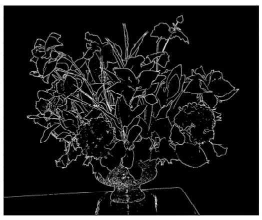



```
% Max composite
maximg = max( left, right, top, bottom);

% Normalize by computing ratio images
r1 = left./ maximg;              r2 = top ./ maximg;
r3 = right ./ maximg; r4 = bottom ./ maximg;

% Compute confidence map
v = fspecial( 'sobel' ); h = v';
d1 = imfilter( r1, v ); d3 = imfilter( r3, v );  % vertical sobel
d2 = imfilter( r2, h ); d4 = imfilter( r4, h ); % horizontal sobel

%Keep only negative transitions
silhouette1  = d1 .* (d1>0);
silhouette2 = abs( d2 .* (d2<0) );
silhouette3 = abs( d3 .* (d3<0) );
silhouette4  = d4 .* (d4>0);

%Pick max confidence in each
confidence = max(silhouette1,  silhouette2, silhouette3,
     silhouette4);
imwrite( confidence, 'confidence.bmp');
```

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

Multi-Flash Images

- extract edge information



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  Amit Agrawal, Ramesh Raskar, Shree K. Nayar, Yuanzhen Li.
  ACM Transactions on Graphics. *24(3)*, pp. 828-835, 2005.