Shadows and Flash

15-463: Rendering and Image Processing
Alexei Efros

Problem Description

- Shadow Matting and Compositing
  - Extracting and Compositing the shadow in image space
- Estimating Shadow Deformations
  - Needs to account for the context differences in 3D

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Shadow Compositing Equation

$$C = \beta L + (1-\beta)S$$

- C: observed color
- S: shadow color
- L: color of a pixel when not in shadow
- β: shadow matte

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Defining the set Σ

- Let Σ be a set of pixels in the source image, that covers the shadow of our interest

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Shadow Matte Extraction

- Obtain an image sequence so that, by selecting appropriate frames, each pixel in Σ has both shadowed and unshadowed versions. Then, exclude the foreground object (using the video matting algorithm).
- For each pixel in Σ, find min and max over frames

$$S = \min_f C_f \quad \text{and} \quad L = \max_f C_f$$

  - S=shadow color, L=unshadow color of the pixel
- Find the shadow map β by $\beta = \frac{(C-S)\cdot(L-S)}{\|L-S\|^2}$
  - β is the essential part we are looking for

Shadow Matte Extraction

(a) Source frame (b) Source lit image (c) Source shadow image (d) Recovered β

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Shadow Compositing

- Extract S’ and L’ from the lit and shadowed versions of the novel background scene.

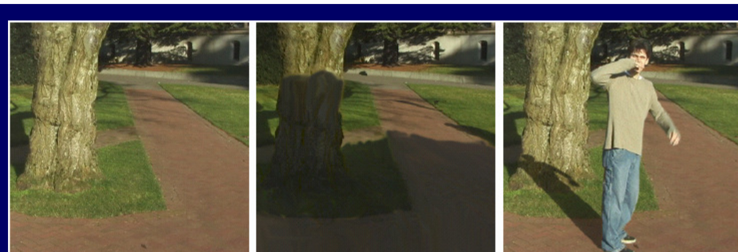
$$S^{'} = \min_{f} C_{f} \quad \text{and} \quad L^{'} = \max_{f} C_{f}$$

- Use β obtained from the shadow matte extraction step, and use the following equation to composite.

$$C = \beta L^{'} + (1 - \beta) S^{'}$$

Shadow Computation

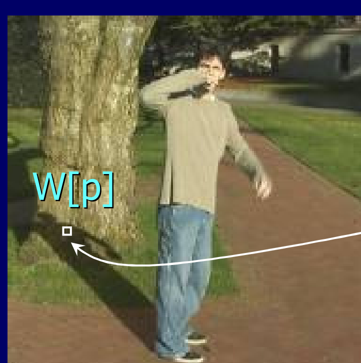
(a) Source frame (b) Source lit image (c) Source shadow image (d) Recovered β



(a) Target lit image (b) Target shadow image (c) Composite without displacement

Estimating Shadow Deformations

The Problem Reduces to Finding the Displacement Map W[p]



Source planar surface version

Target version with 3D geometry

- Once we obtain the map W, then just use
  - $\beta' = \beta[W[p]]$

An Assumption

Source and target images share a common reference plane π

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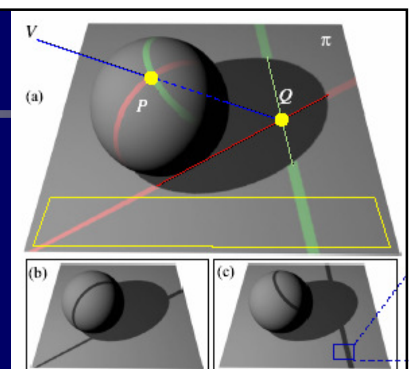
How to Find W[p]?



- In 3D, W[P] = Q
- In 2D image space, W[p] = q
  - p = the pixel representing P
  - q = the pixel representing Q

An Observation

- If projections of two 3D lines happened to intersect at P
  - Q is the intersection of two lines, formed by…

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Preparation for Finding W[p]

"Directional Scan"

See the Video

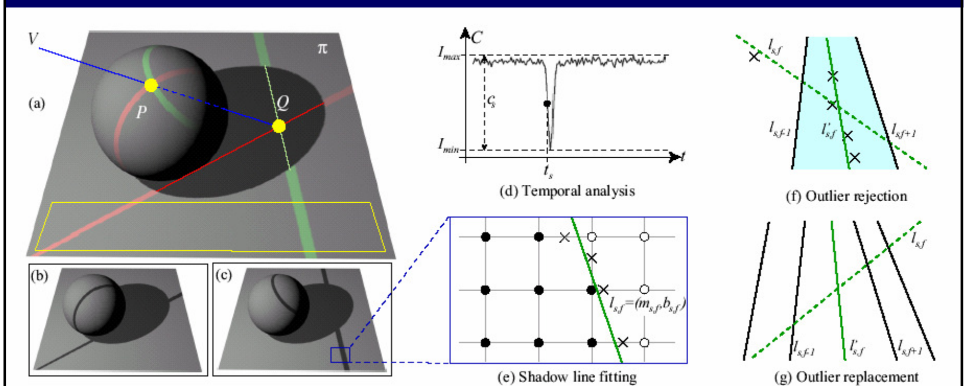
Part 1: For each directional scan s do

A. Label each pixel location p with the continuous time $t_s[p]$ at which it is first crossed by the shadow edge using temporal analysis

B. For each frame f, fit a shadow line equation $x=m_{s,f}y+b_{s,f}$ to the points r in the reference plane region labeled with time $t_s[r]=f$.

C. Perform outliner rejection and replacement on the line equation parameters $(m_{s,f}, b_{s,f})$ to reduce noise.

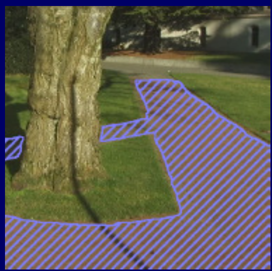
Illustraions

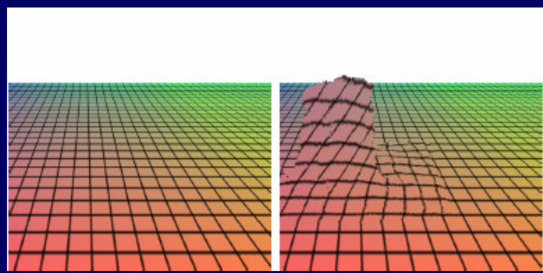


Part 2: For each pixel location p do

A. For each scan s, interpolate the line equation parameters $(m_{s,\lfloor ts[p] \rfloor}, b_{s,\lfloor ts[p] \rfloor})$ and $(m_{s,\lceil ts[p] \rceil}, b_{s,\lceil ts[p] \rceil})$ from the nearest integer frames of the scan sequences to obtain the line equation parameters $(m_{s,ts[p]}, b_{s,ts[p]})$ for this pixel
B. Compute the intersection q of lines for all scans
C. Store q as the value of the displacement map for pixel p: i.e. $W[p] \leftarrow q$.

Visualization of Displacement Map





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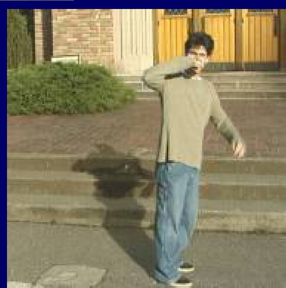
Results



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Other Graphics-related Courses

15-505: Animation Art and Technology, Hodgins/Duesing
15-463: Rendering and Image Processing, Efros
15-493: Computer Game Programming, Hodgins/???

05-331: Building Virtual Worlds, Pausch
15-863: Simulation for Animation, James
15-864: Advanced Computer Graphics, James
15-869: Physically Based Character Animation, Pollard
15-???: Other specialized graduate courses in graphics

15-385: Computer Vision
60-415: 3-D Animation, Duesing

Flash Photography Enhancement via Intrinsic Relighting

Elmar Eisemann
MIT/Artis-INRIA

Frédo Durand
MIT

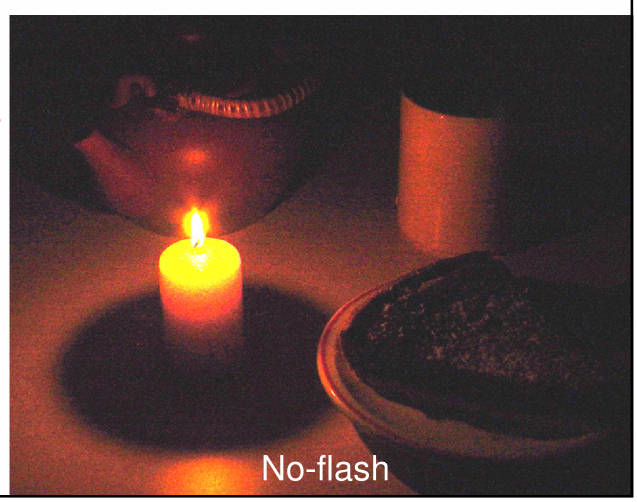
Introduction

- Satisfactory photos in dark
- environments are challenging!

Introduction

- Available light:
- + nice lighting

- noise/blurriness
- color



Introduction

SIGGRAPH2004

- **Flash:**
- + details
- + color

- flat/artificial
- flash shadows
- red eyes

Introduction

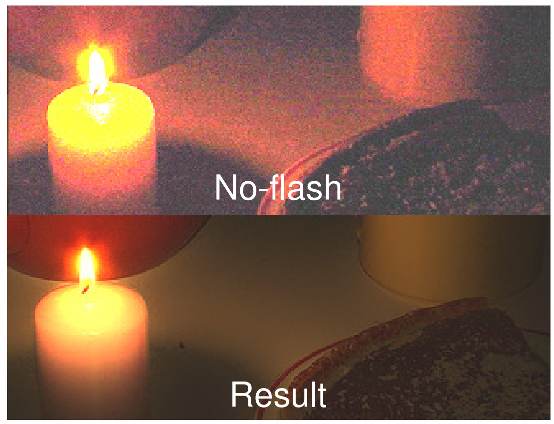
SIGGRAPH2004

- **Our approach:**
- Use no-flash image relight flash image

Introduction

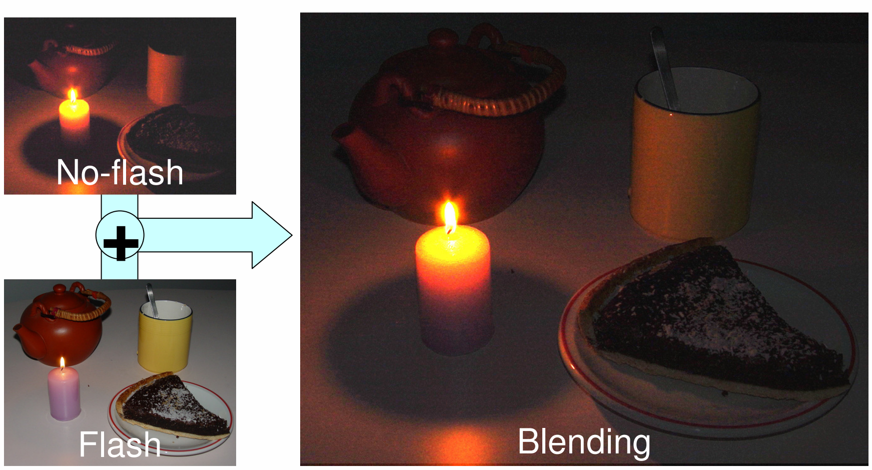
- **Our approach:**
- Use no-flash image relight flash image

+ original lighting
+ details/sharpness
+ color



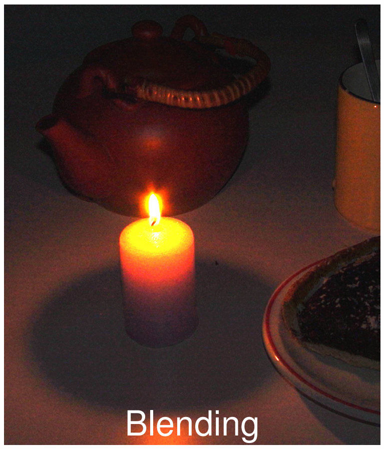
Introduction

- One approach: Blend the two photos



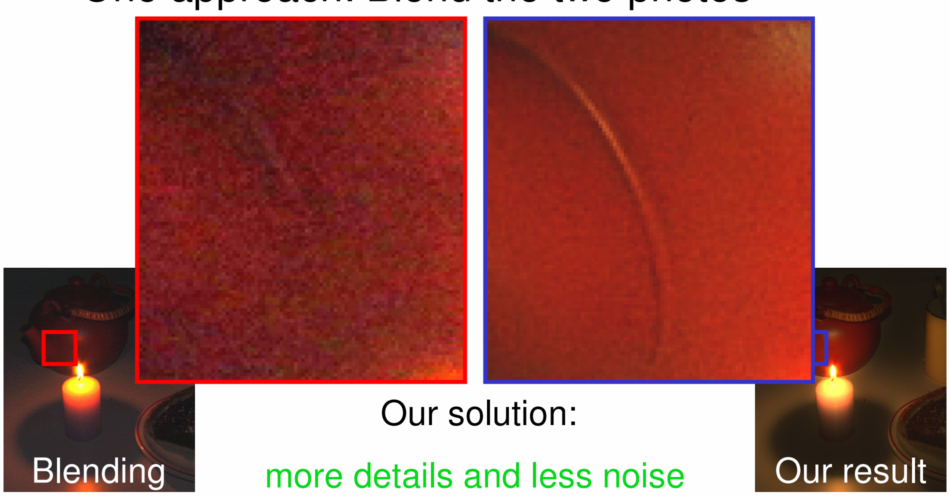
Introduction

- One approach: Blend the two photos



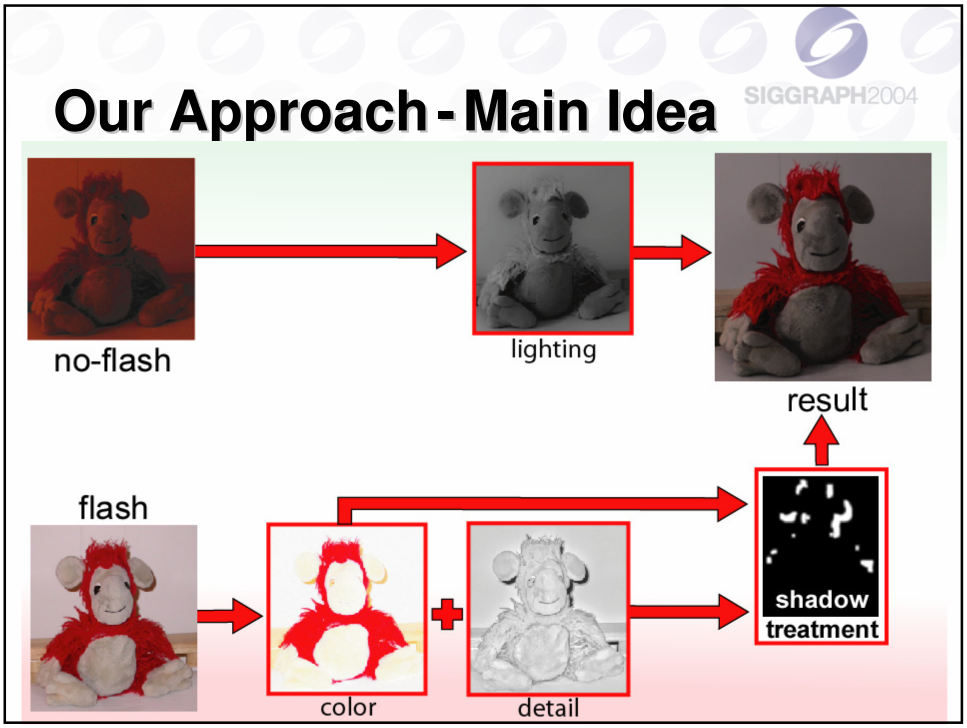
Introduction

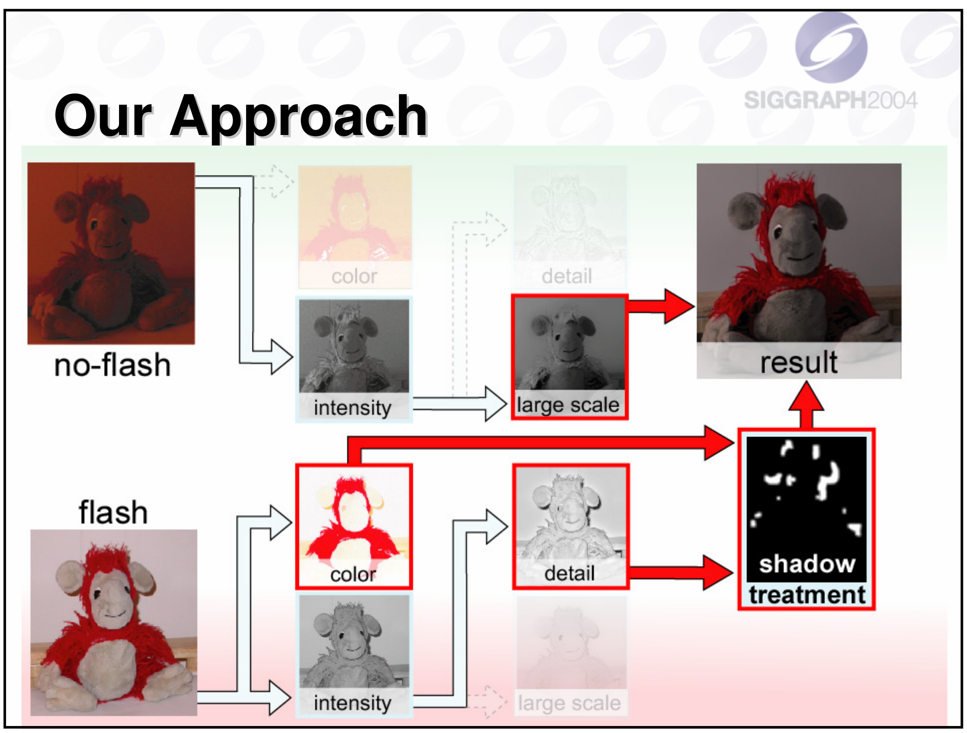
- One approach: Blend the two photos



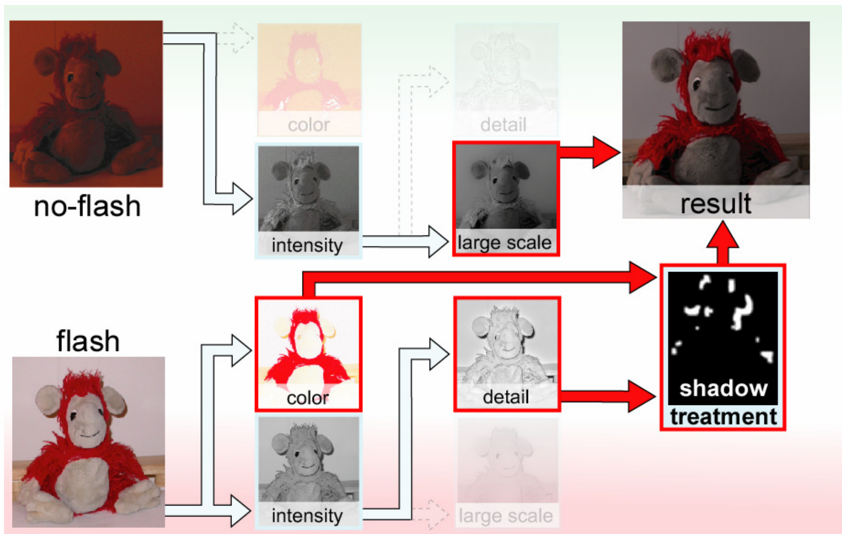
Our solution:

more details and less noise


SIGGRAPH2004
Our Approach - Main Idea
no-flash
lighting
result
flash
shadow
treatment
color
detail

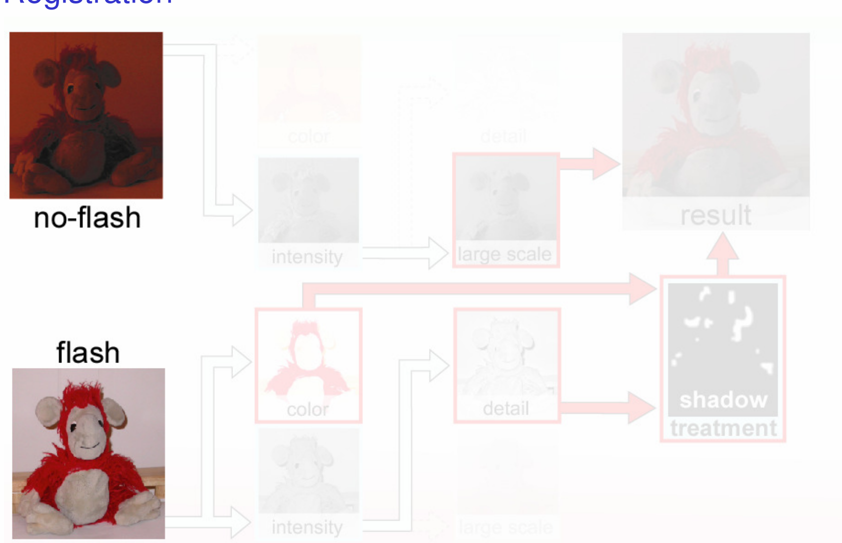

SIGGRAPH2004
Our Approach
color
detail
no-flash
intensity
large scale
result
flash
color
detail
shadow
treatment
intensity
large scale

Our Approach



Our Approach

Registration

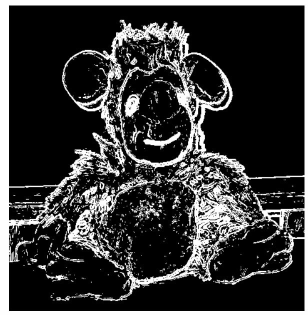


Registration

SIGGRAPH2004

- Compensate for camera motion (image translation)
- Difficult because lighting changes
- Edge detection


No-flash

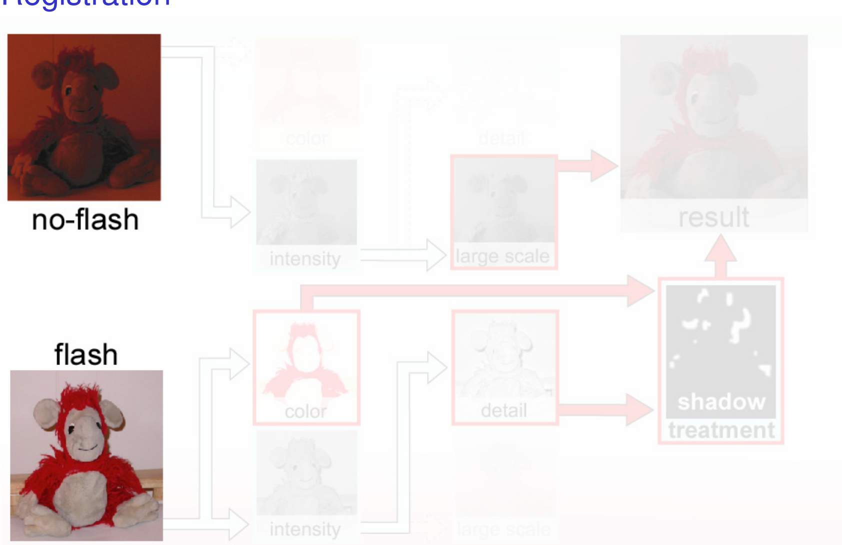

Flash

- See also Ward[2004], Kang[2003]

Our Approach

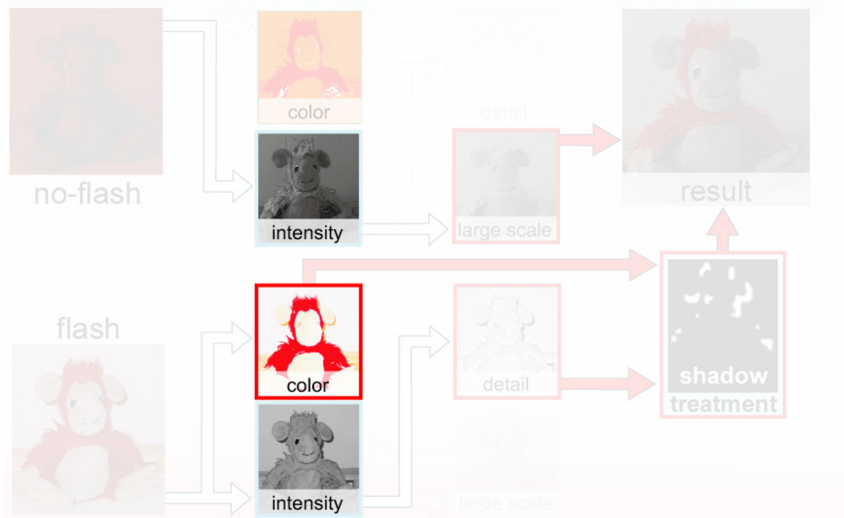
SIGGRAPH2004

Registration



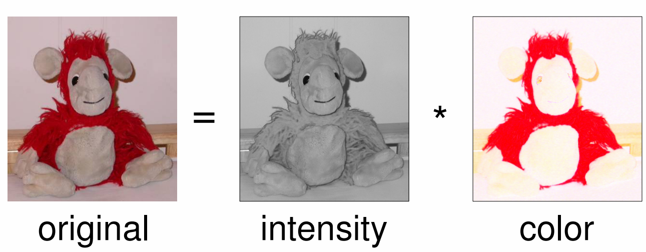
Our Approach

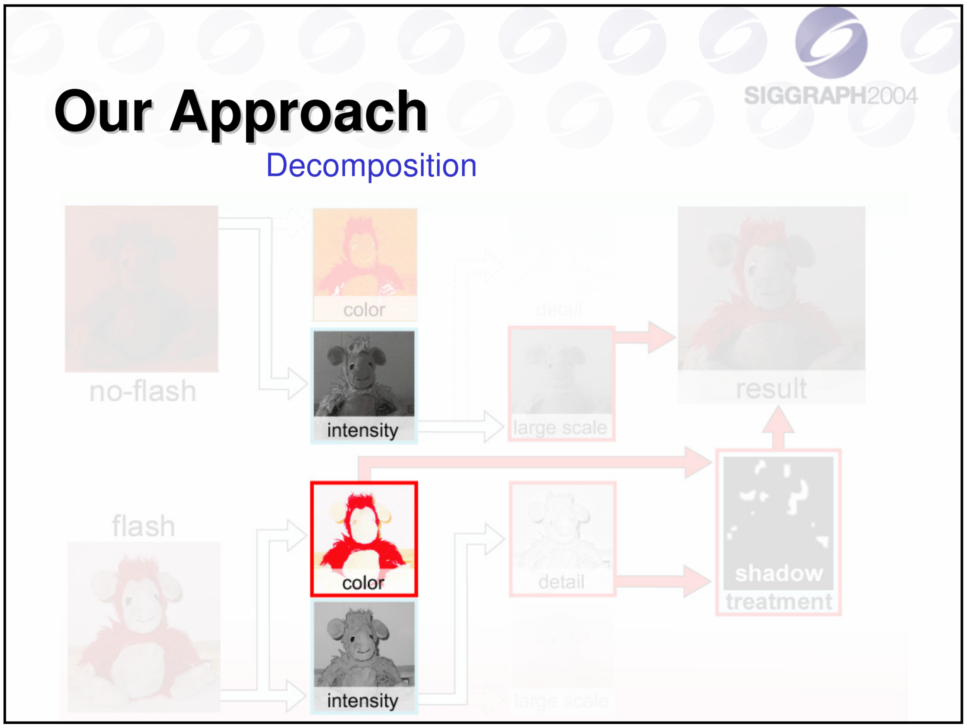
Decomposition

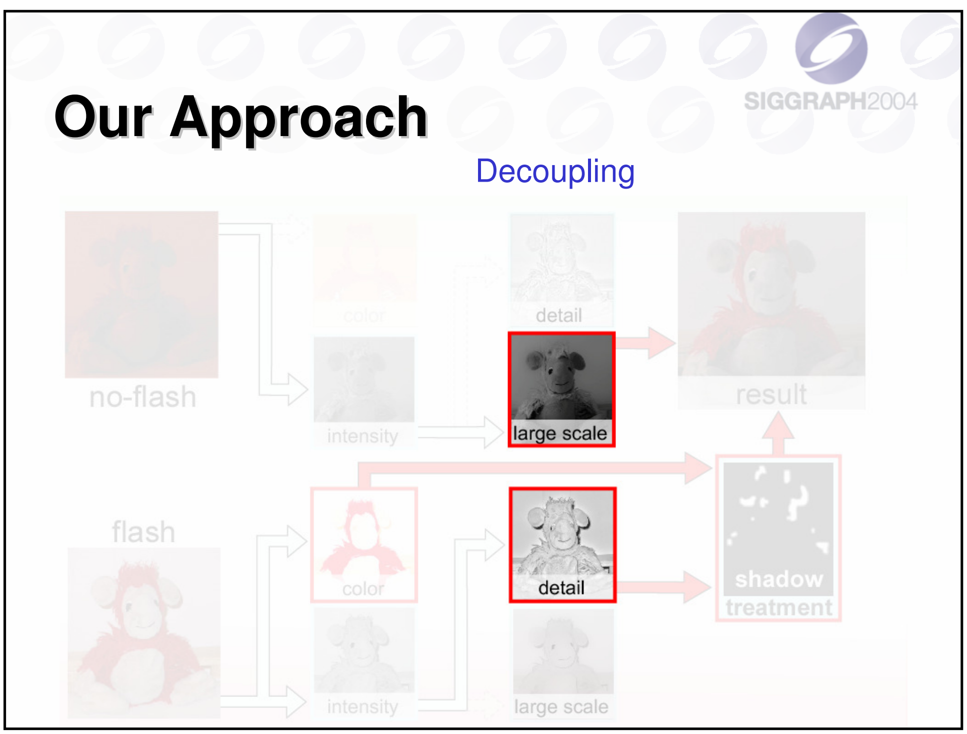


Decomposition

- Color / Intensity:




Our Approach
Decomposition
SIGGRAPH2004
no-flash
flash
color
intensity
large scale
detail
result
shadow
treatment


Our Approach
Decoupling
SIGGRAPH2004
no-flash
flash
color
intensity
detail
large scale
result
shadow
treatment

Decoupling

SIGGRAPH2004

- Lighting : Large-scale variation
- Texture : Small-scale variation

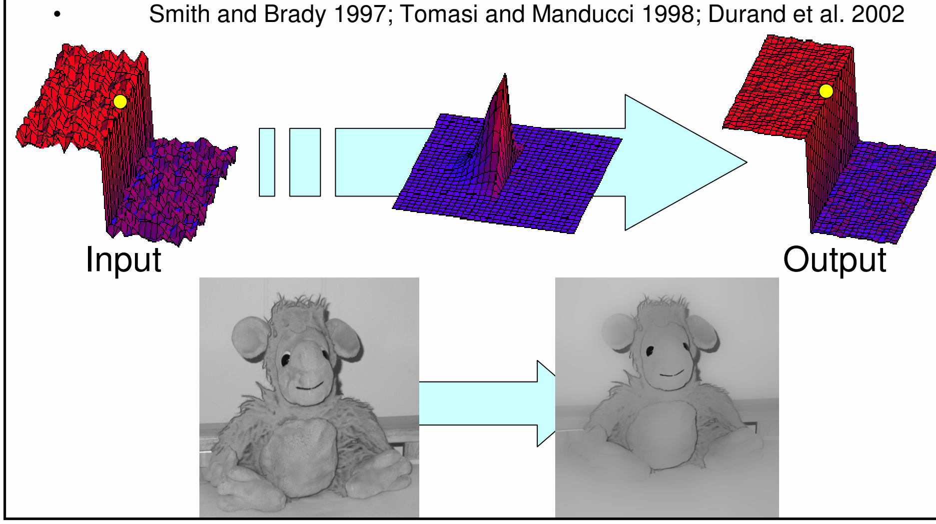
Lighting

Texture

Large-scale Layer

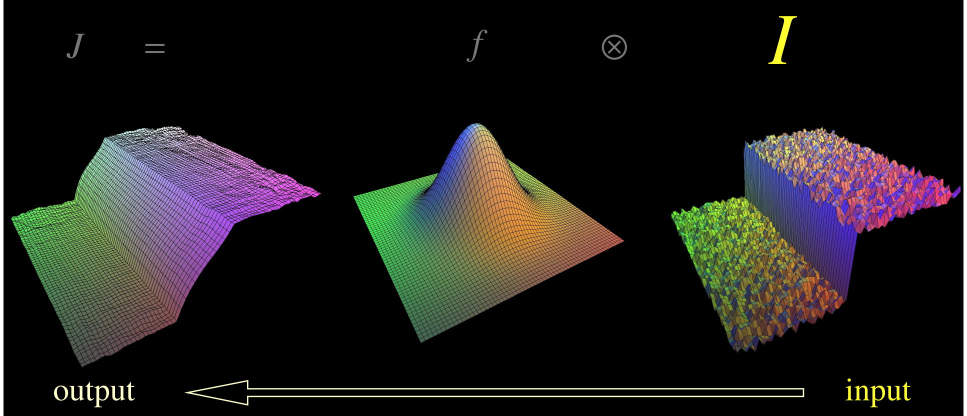
SIGGRAPH2004

- Bilateral filter – edge preserving filter
- Smith and Brady 1997; Tomasi and Manducci 1998; Durand et al. 2002



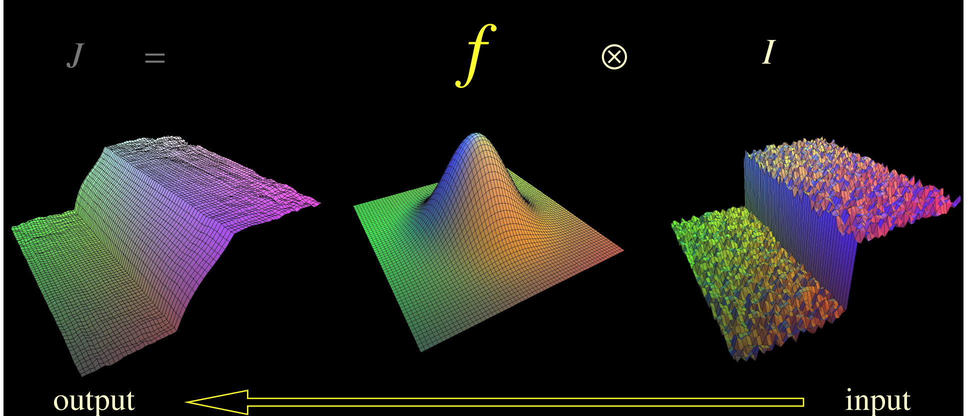
Start with Gaussian filtering

- Here, input is a step function + noise



Start with Gaussian filtering

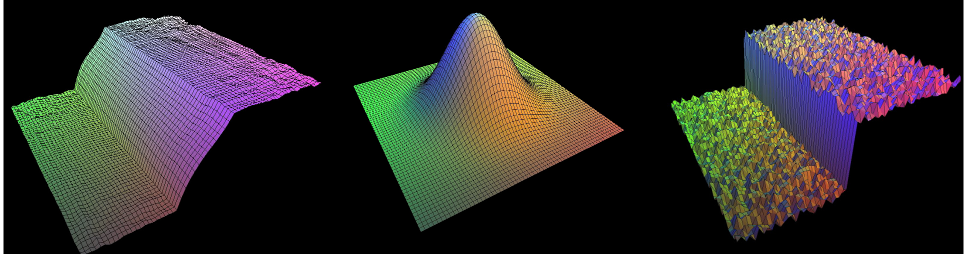
- Spatial Gaussian f



Start with Gaussian filtering

- Output is blurred

$$J \quad = \quad f \quad \otimes \quad I$$

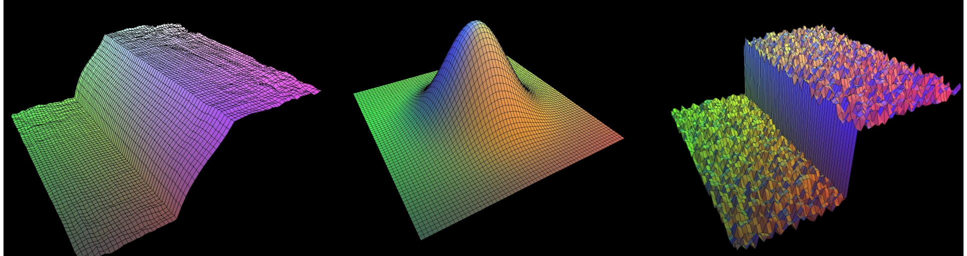


output $\longleftarrow$ input

Gaussian filter as weighted average

- Weight of ξ depends on distance to x

$$J(x) = \sum_{\xi} \quad f(x,\xi) \quad I(\xi)$$

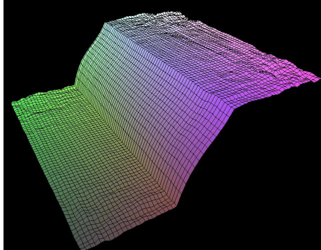


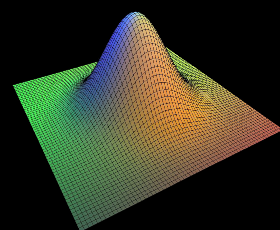
output $\longleftarrow$ input

The problem of edges

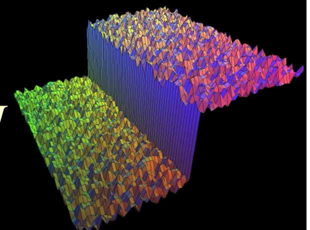
- Here, $I(\xi)$ "pollutes" our estimate J(x)
- It is too different

$$J(x) = \sum_{\xi} \quad f(x,\xi) \quad I(\xi)$$





I

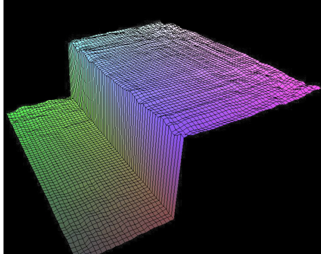


output ⟵ input

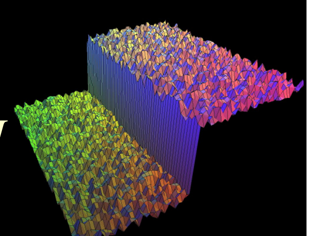
Principle of Bilateral filtering

- [Tomasi and Manduchi 1998]
- Penalty g on the intensity difference

$$J(x) = \frac{1}{k(x)} \sum_{\xi} \quad f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$



I

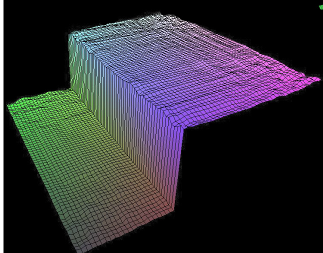
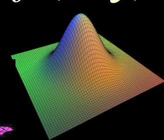
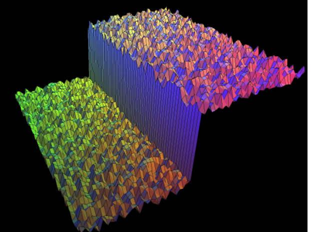


output ⟵ input

Bilateral filtering

- [Tomasi and Manduchi 1998]
- Spatial Gaussian f

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$

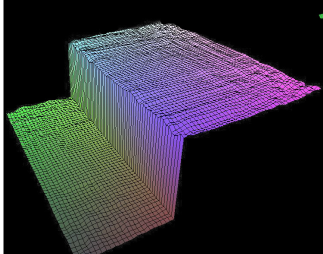
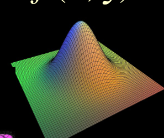
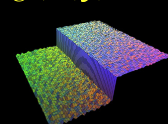
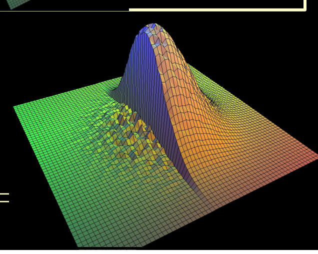
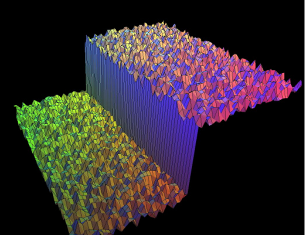




output ⟸ input

Bilateral filtering

- [Tomasi and Manduchi 1998]
- Spatial Gaussian f
- Gaussian g on the intensity difference

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$

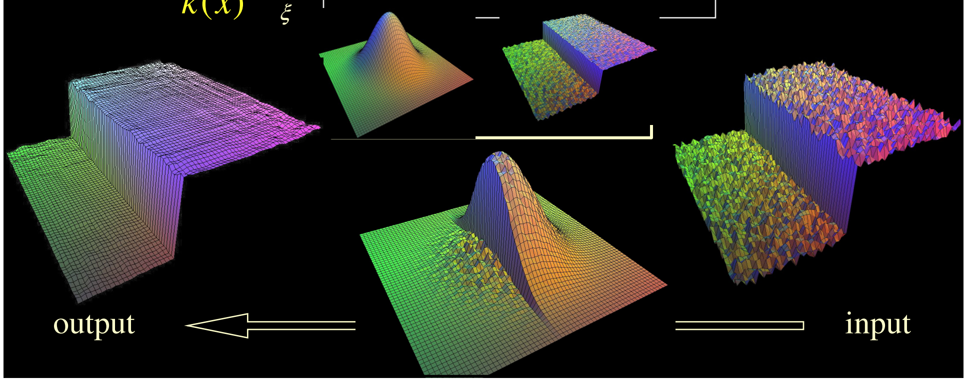






output ⟸ input

Normalization factor

- [Tomasi and Manduchi 1998]
- k(x)= $\sum_{\xi} \boxed{f(x,\xi) \quad g(I(\xi)-I(x))}$

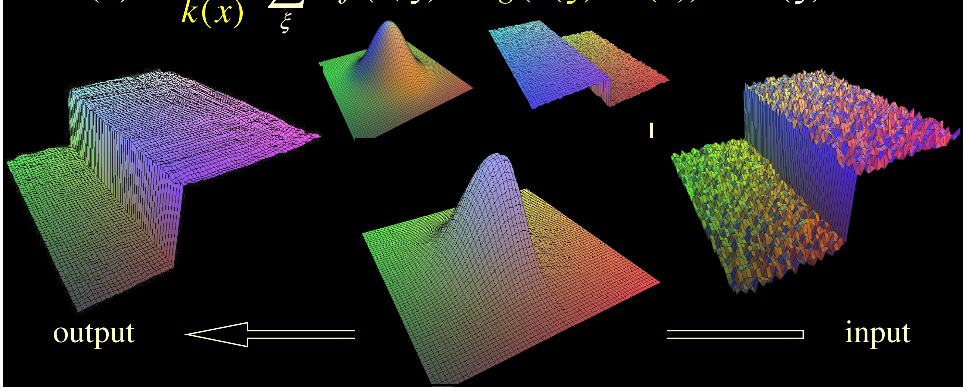
$$J(x) = \frac{1}{k(x)} \sum_{\xi} \boxed{f(x,\xi) \quad g(I(\xi)-I(x))} \quad I(\xi)$$



Bilateral filtering is non-linear

- [Tomasi and Manduchi 1998]
- The weights are different for each output pixel

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi)-I(x)) \quad I(\xi)$$



Halos: Bilateral vs. Gaussian

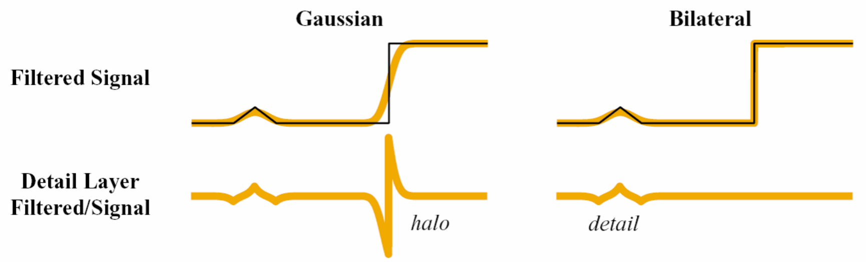


Figure 5: (left) A Gaussian low-pass filter blurs across all edges and will therefore create strong peaks and valleys in the detail image that cause halos. (right) The bilateral filter does not smooth across strong edges and thereby reduces halos, while still capturing detail.

Large-scale Layer

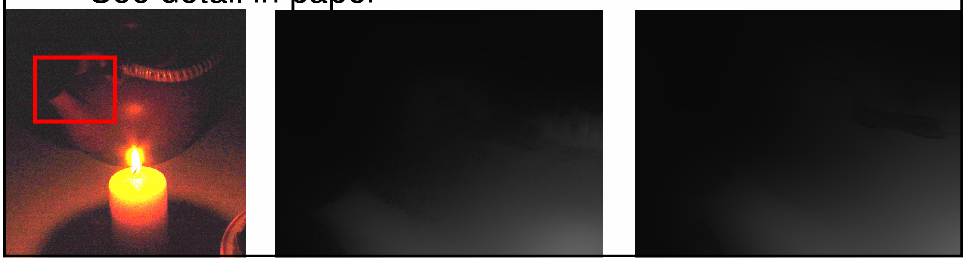
SIGGRAPH2004

- Bilateral filter

Cross Bilateral Filter

SIGGRAPH2004

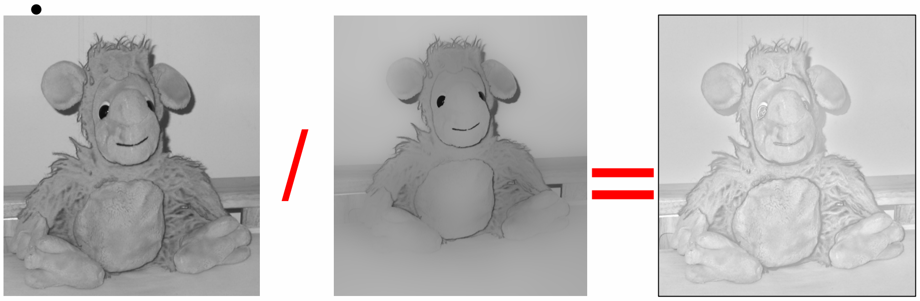
- Similar to joint bilateral filter by Petschnigg et al.
- When no-flash image is too noisy
- Borrow similarity from flash image
  - ➢ edge stopping from flash image
- See detail in paper



Detail Layer

SIGGRAPH2004

•



Intensity / Large-scale = Detail

Recombination: Large scale * Detail = Intensity

Recombination

SIGGRAPH2004

Large-scale
No-flash

*

Detail
Flash

=

Intensity
Result

Recombination: Large scale * Detail = Intensity

Recombination

SIGGRAPH2004

shadows

Intensity
Result

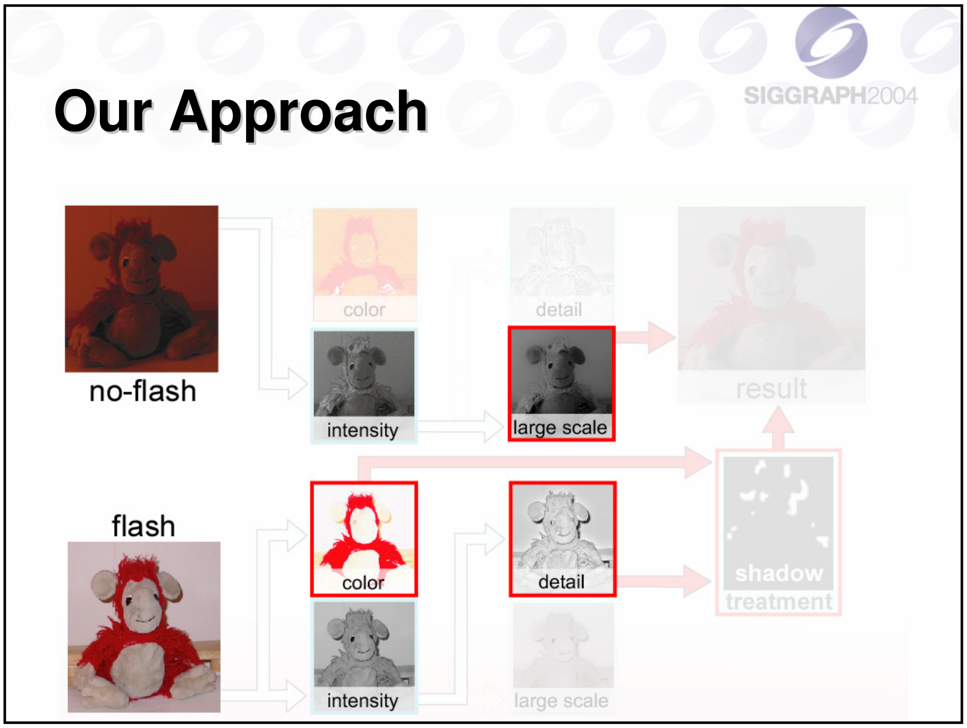
*

Color
Flash

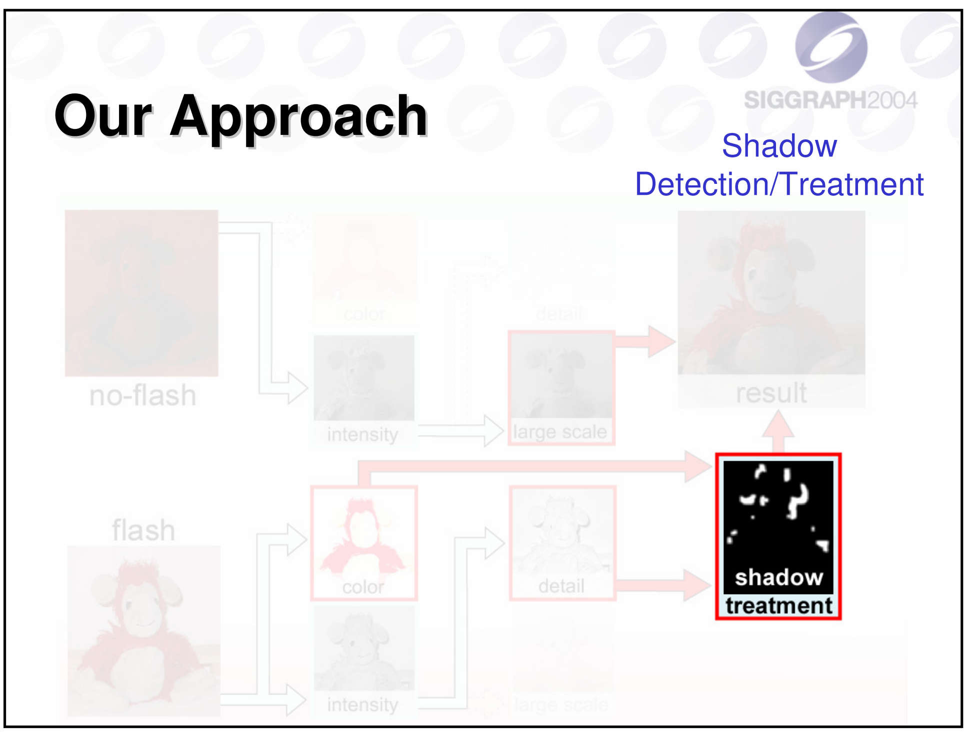
≈

Result

Recombination: Intensity * Color = Original



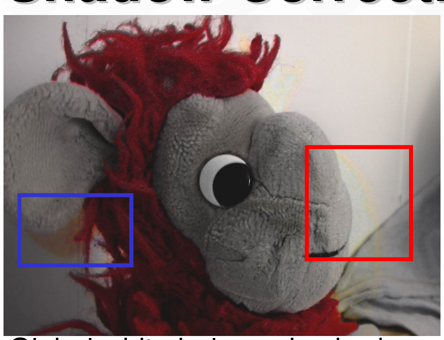
Our Approach
SIGGRAPH2004
no-flash
color
intensity
detail
large scale
result
flash
color
intensity
detail
large scale
shadow
treatment



Our Approach
SIGGRAPH2004
Shadow
Detection/Treatment
no-flash
color
intensity
detail
large scale
result
flash
color
intensity
detail
large scale
shadow
treatment

Shadow Correction – Why?

Shadow Correction – Why?



Global white balance in shadows

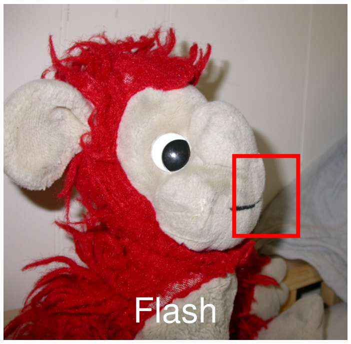
Several artifacts:

- at shadow boundary
- inside shadows (color bleeding)

➢ shadows need to be corrected !

... and detected

Shadow Detection



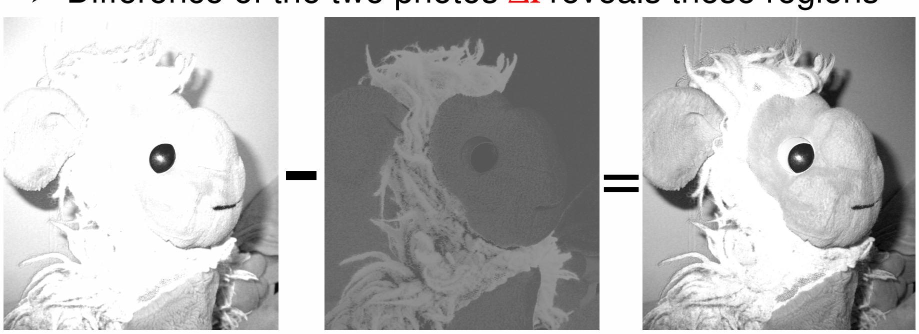
- Umbra
- Penumbra

➢ Detection in two steps

Shadow Detection

- Umbra detection
- No direct light from flash

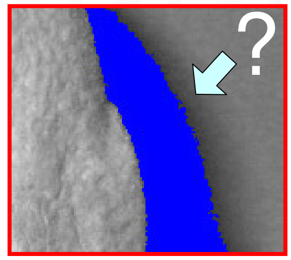
➢ Difference of the two photos ΔI reveals these regions



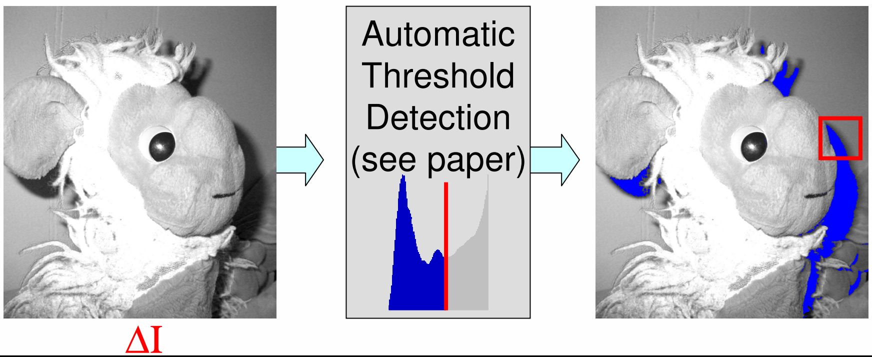
Flash   No-flash ΔI

Shadow Detection

SIGGRAPH2004



- Umbra detection
- Difference ΔI = light from the flash
- Goal: Find a threshold for ΔI

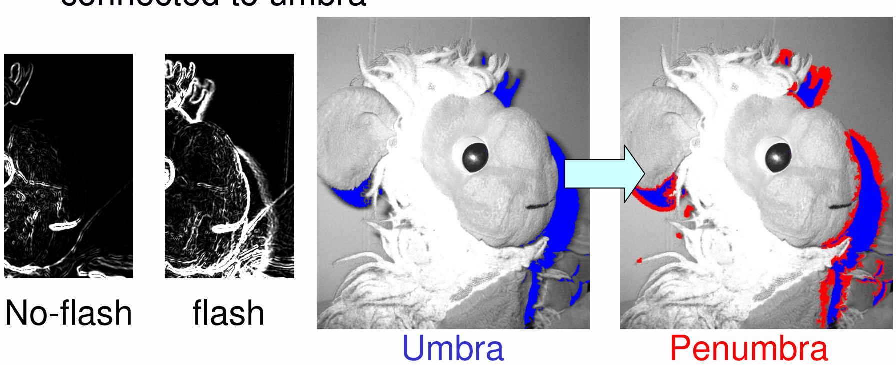


Shadow Detection

SIGGRAPH2004

Penumbra detection

- strong gradient at boundary
- no strong gradient in no-flash image
- connected to umbra

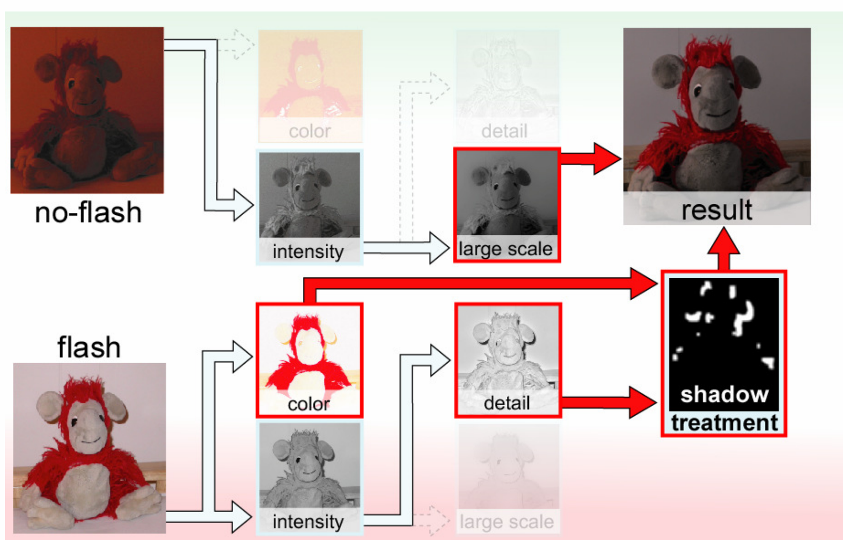


Shadow Correction

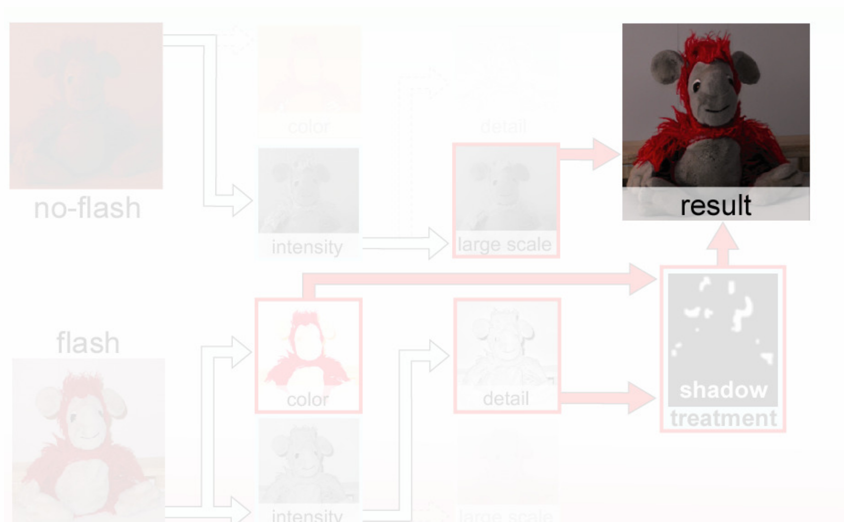
- Correct color and detail

Shadow mask

Our Approach



Our Approach



Results


No-flash


Flash

Results

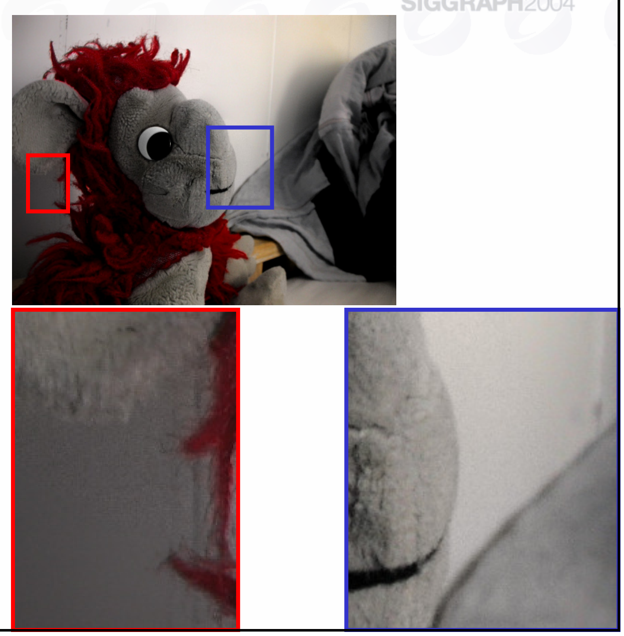
SIGGRAPH2004

Results

SIGGRAPH2004

No-flash

Flash



Results

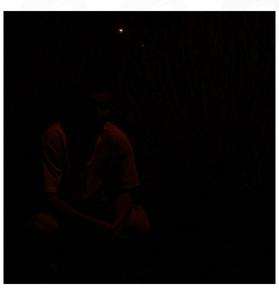
SIGGRAPH2004

No-flash

Flash

Results

SIGGRAPH2004



Our result

Results

Results

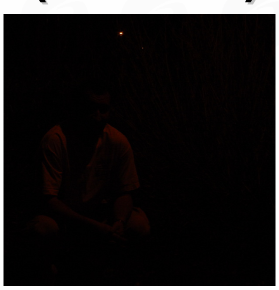
Emphasize Foreground

Deduce "distance" to camera

Exploit $1/r^2$ flash intensity falloff

(see paper)

(Inverse) White Balance



Retain warm tones from available lighting (see paper)

Results

No-flash

Flash

SIGGRAPH2004

Don't Transfer Color

SIGGRAPH2004

Digital Photography with Flash and No-Flash Image Pairs

Georg Petschnigg, Richard Szeliski, Maneesh Agrawala, Michael Cohen, Hugues Hoppe, Kentaro Toyama

Microsoft Corporation

Orig. (top) Detail Transfer (bottom) | Flash | No-Flash | Detail Transfer with Denoising

Figure 1: This candlelit setting from the wine cave of a castle is difficult to photograph due to its low light nature. A flash image captures the high-frequency texture and detail, but changes the overall scene appearance to cold and gray. The no-flash image captures the overall appearance of the warm candlelight, but is very noisy. We use the detail information from the flash image to both reduce noise in the no-flash image and sharpen its detail. Note the smooth appearance of the brown leather sofa and crisp detail of the bottles. For full-sized images, please see the supplemental DVD or the project website http://research.microsoft.com/projects/FlashNoFlash.

Don’t Transfer Color…

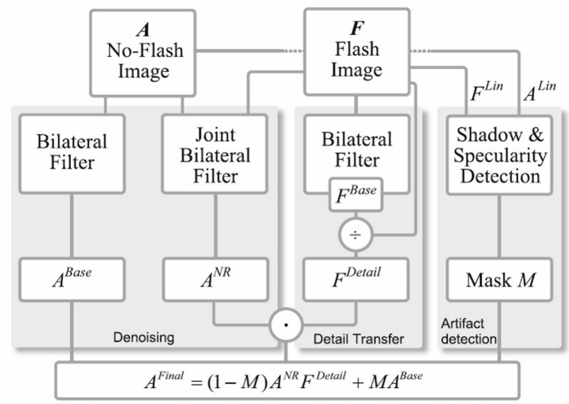


Figure 3: Overview of our algorithms for denoising, detail transfer, and flash artifact detection.