Digital Photography with Flash and No-Flash Image Pairs

[Petschnigg 2004]

COS 526: Advanced Computer Graphics

Slide credits: Hugues Hoppe, Tom Funkhouser

You want to take a picture in a scene with low light. What do you do?

Solution	**Side effects**
Long exposure time	Motion blur
Open the aperture	Reduced depth of field
Increase gain	Increase in noise
Use flash	Unnatural lighting

You want to take a picture in a scene with low light. What do you do?

Solution	Side effects
Long exposure time	Motion blur
Open the aperture	Reduced depth of field
Increase gain	Increase in noise
Use flash	Unnatural lighting


Motion Blur

You want to take a picture in a scene with low light. What do you do?

Solution	**Side effects**
Long exposure time	Motion blur
Open the aperture	Reduced depth of field
Increase gain	Increase in noise
Use flash	Unnatural lighting


Noise


A Lot of Noise

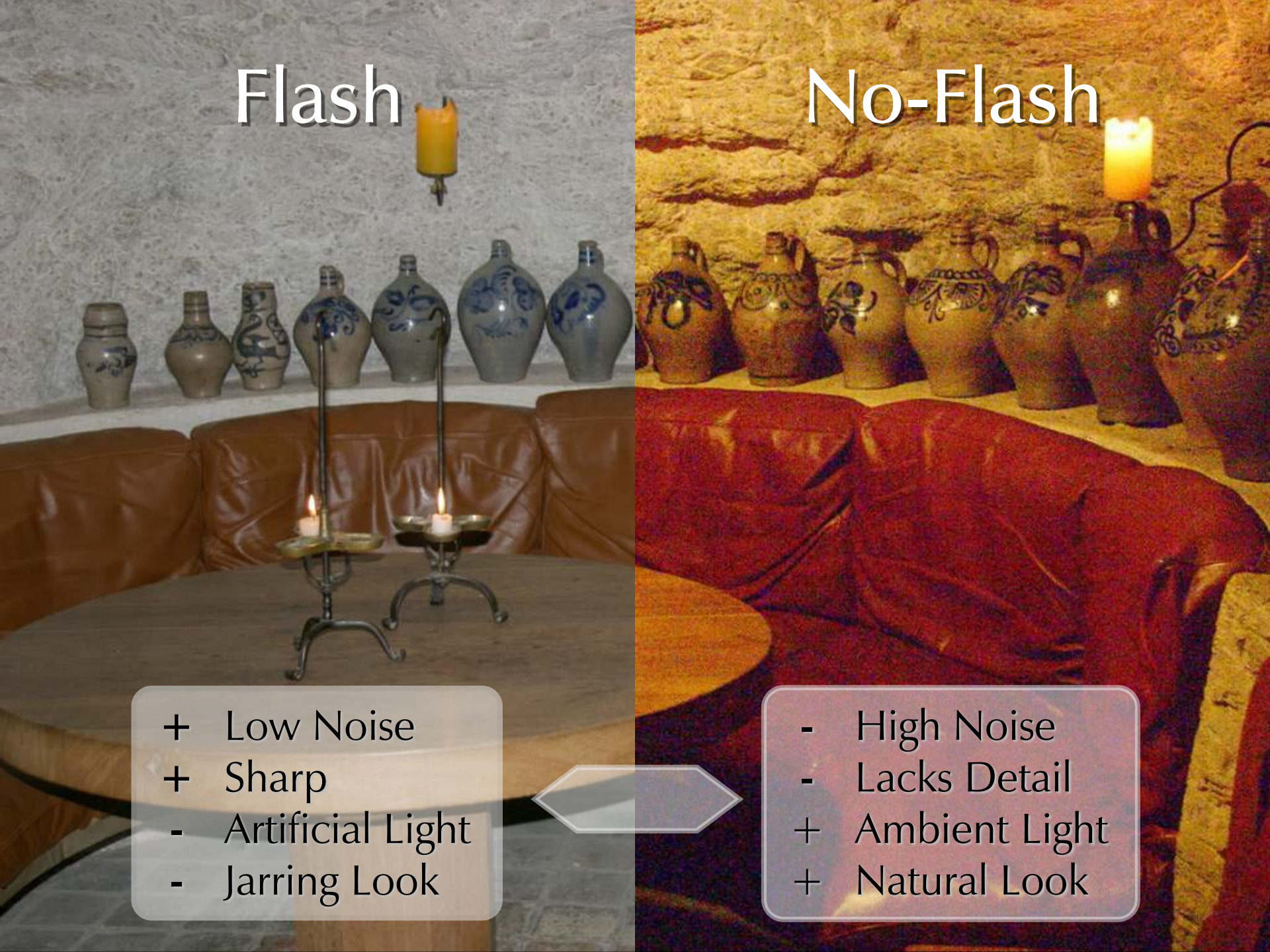
You want to take a picture in a scene with low light. What do you do?

Solution	**Side effects**
Long exposure time	Motion blur
Open the aperture	Reduced depth of field
Increase gain	Increase in noise
Use flash	Unnatural lighting


Ruined Ambiance


Unflattering Lighting


Red Eye


Flash
No-Flash
+ Low Noise
+ Sharp
- Artificial Light
- Jarring Look
- High Noise
- Lacks Detail
+ Ambient Light
+ Natural Look

Combining the Strengths of Both Images

- Ambient image denoising
- Flash to ambient detail transfer
- White balancing
- Red-eye correction
- Continuous flash adjustment


Result


No-Flash


Result

Acquisition

1. Focus on the subject, then lock the focal length and aperture.
2. Set exposure time Δt and ISO for a good exposure.
3. Take the ambient image A.
4. Turn on the flash.
5. Adjust the exposure time Δt and ISO to the smallest settings that still expose the image well.
6. Take the flash image F.

No-Flash

Flash

Denoising

- Bilateral filter
  - Removes noise while still maintaining edges
  - Gaussian weights in both domain and range
  - Just applied to noisy ambient image A
    (no use of flash image yet!)

$$A_p^{Base} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(A_p - A_{p'})\, A_{p'}$$

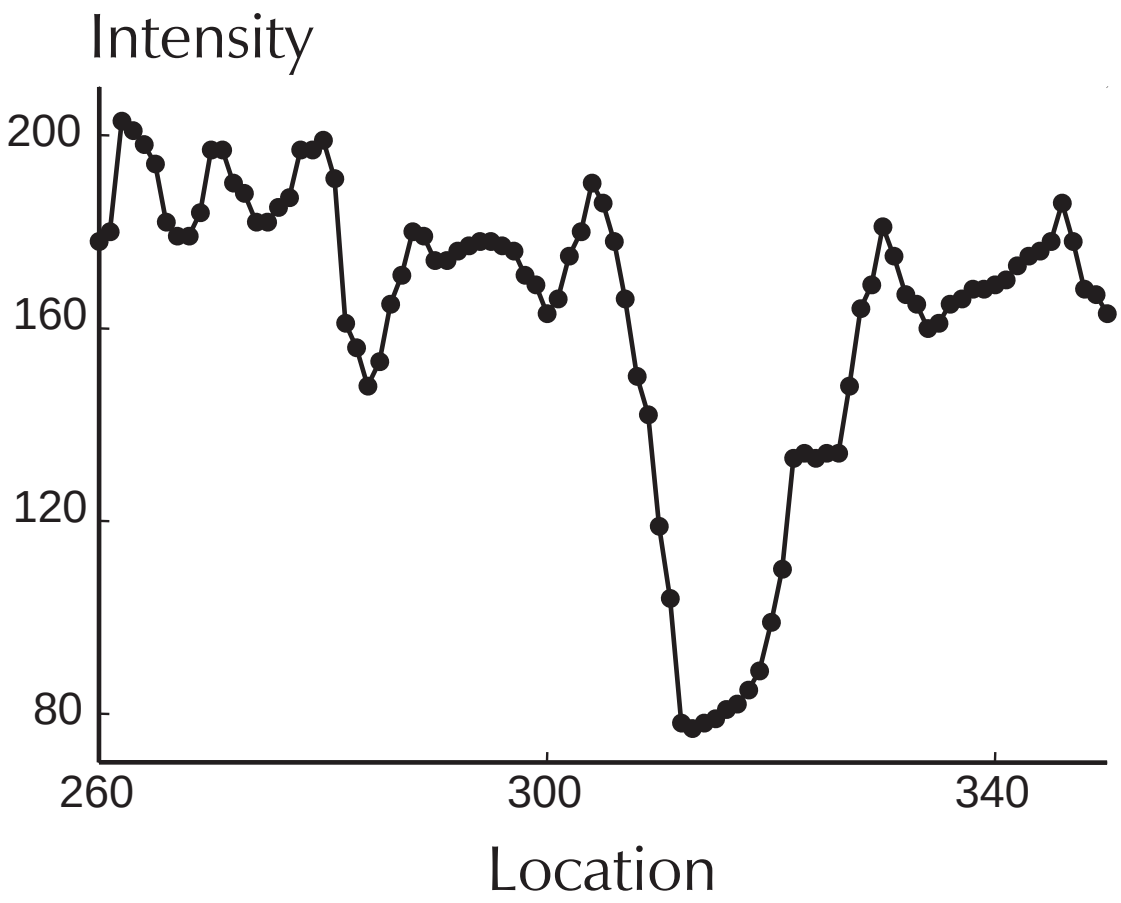
normalization

weight based on spatial distance between pixels

weight based on intensity difference (edge-stopping)

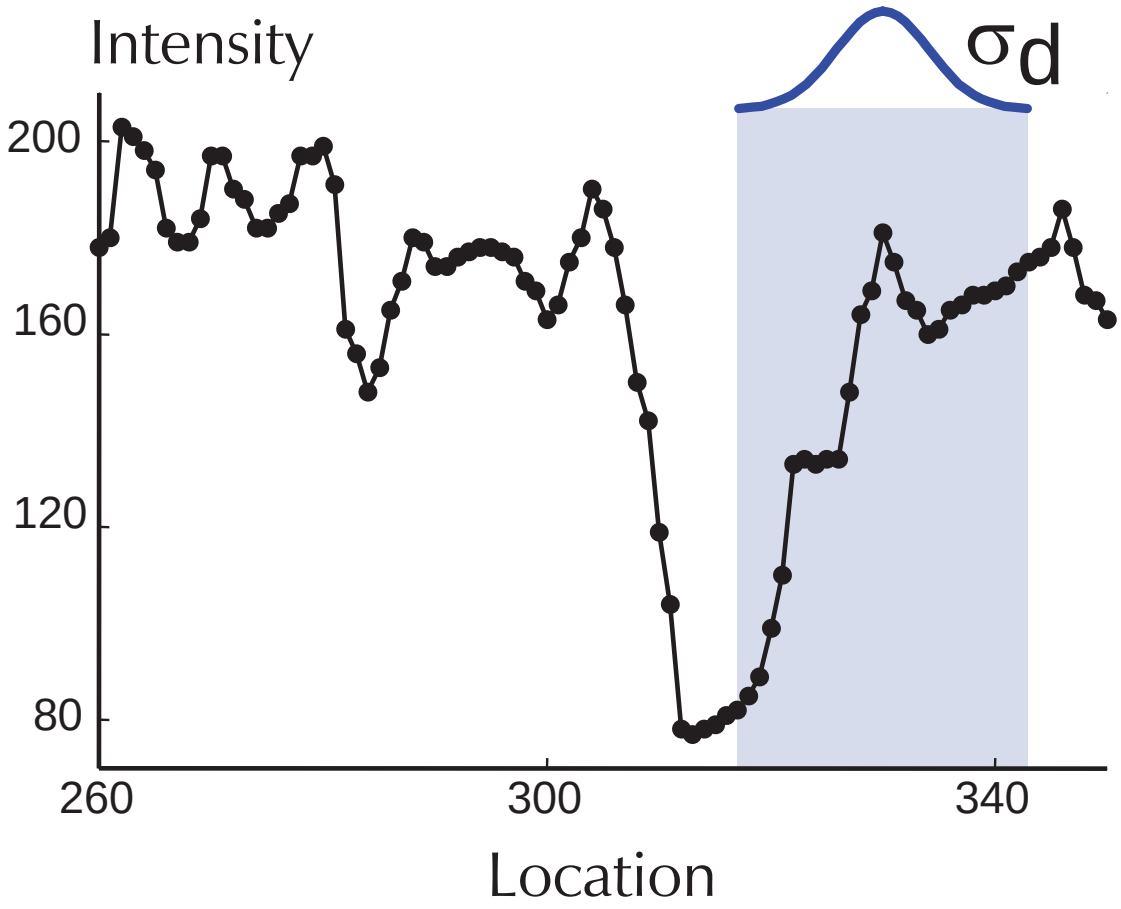
No-Flash

No-Flash

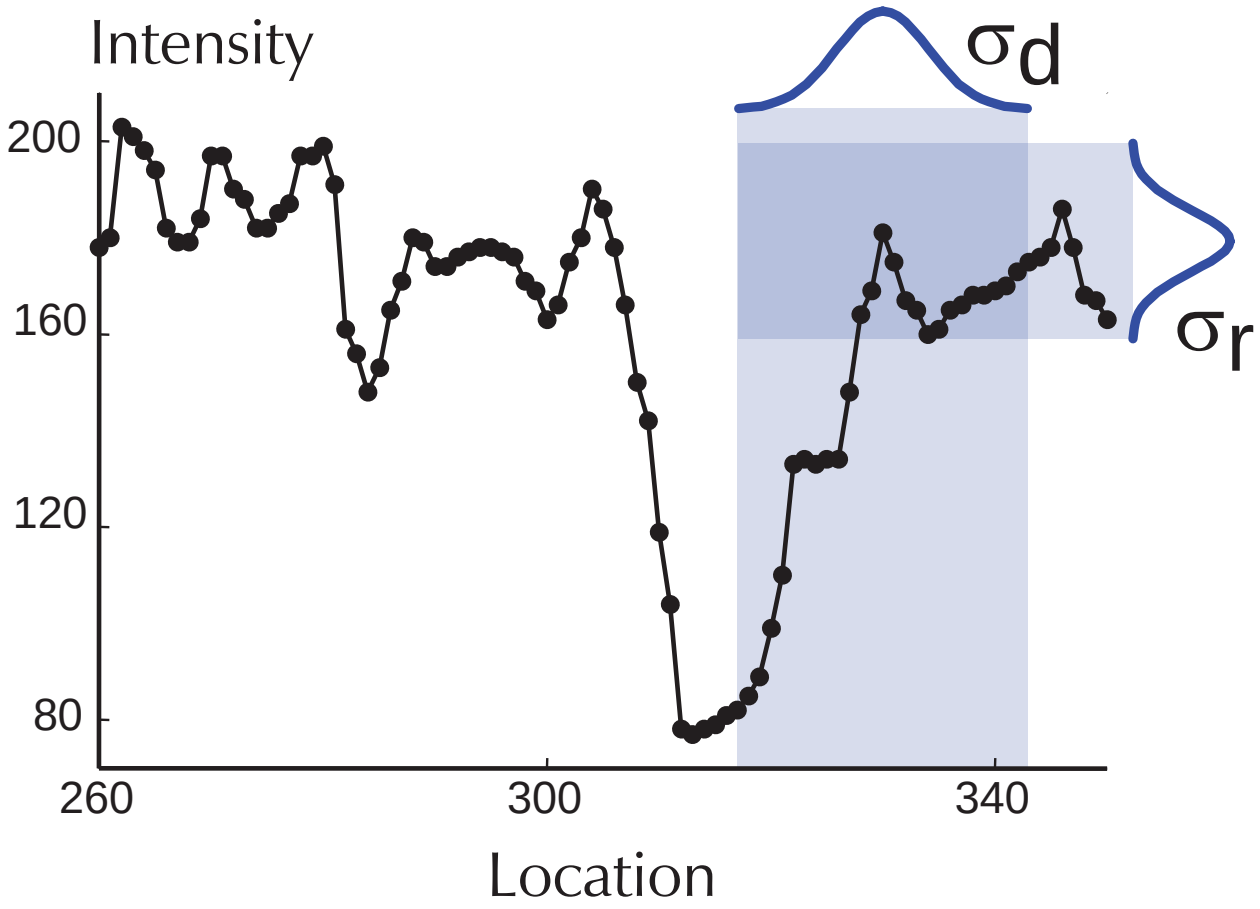


[Tomasi98]

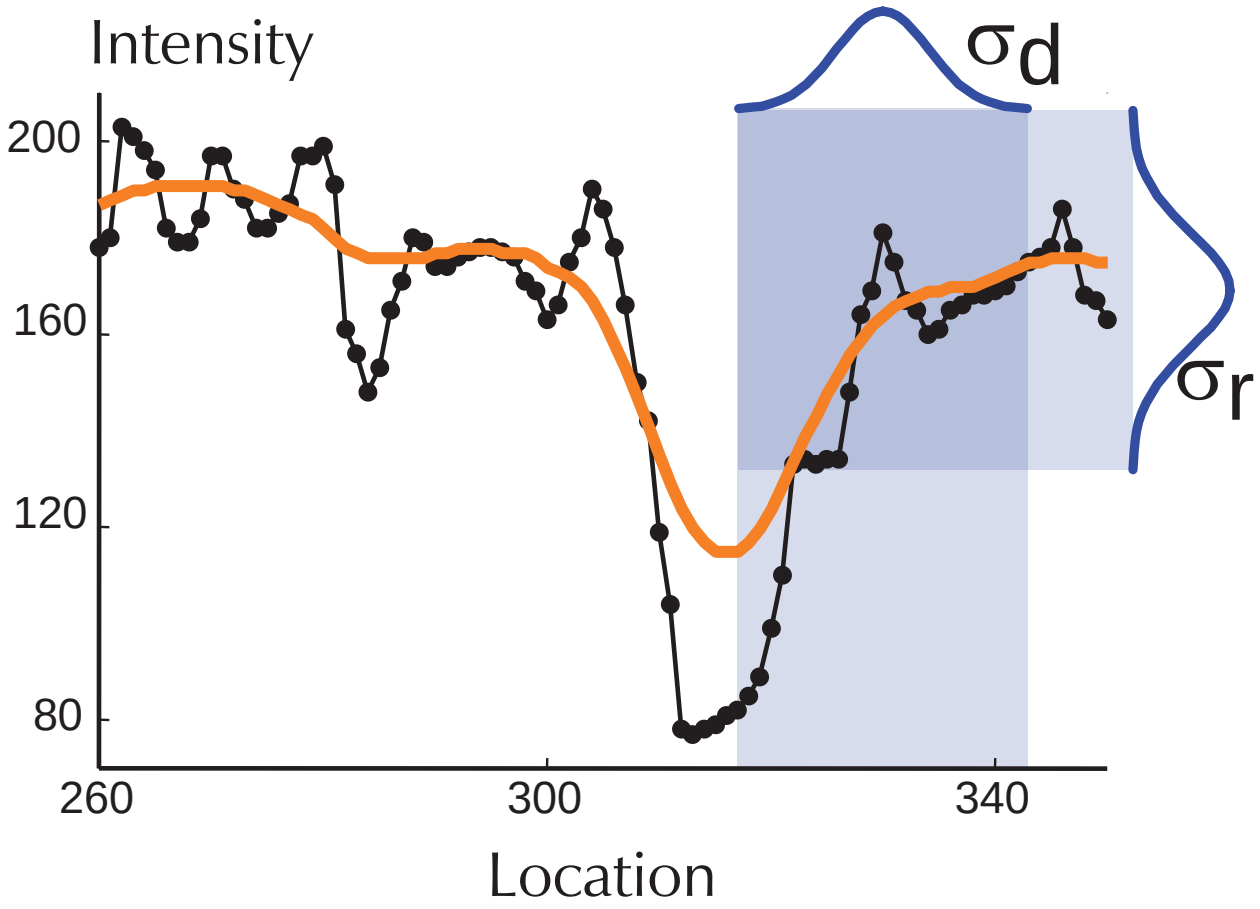
No-Flash



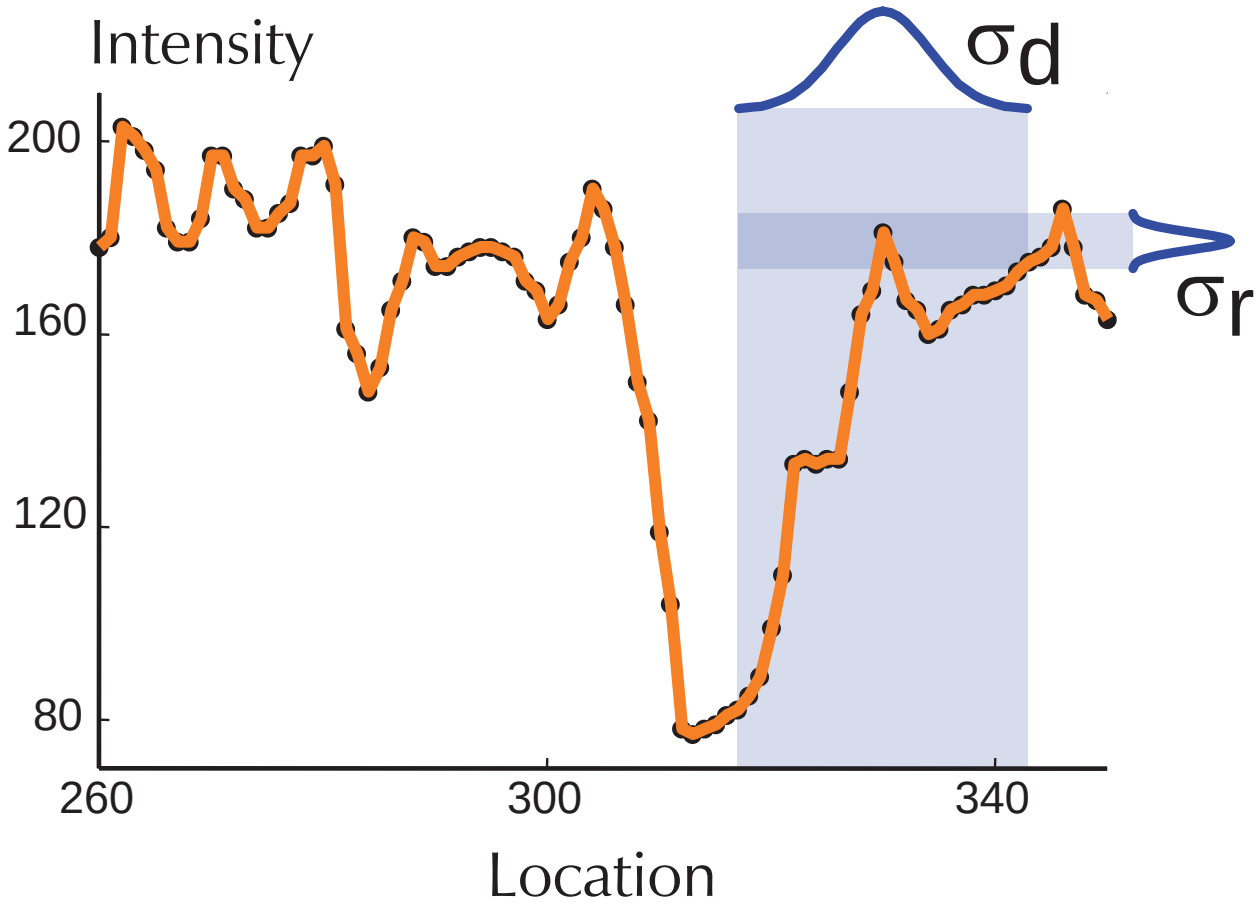
No-Flash



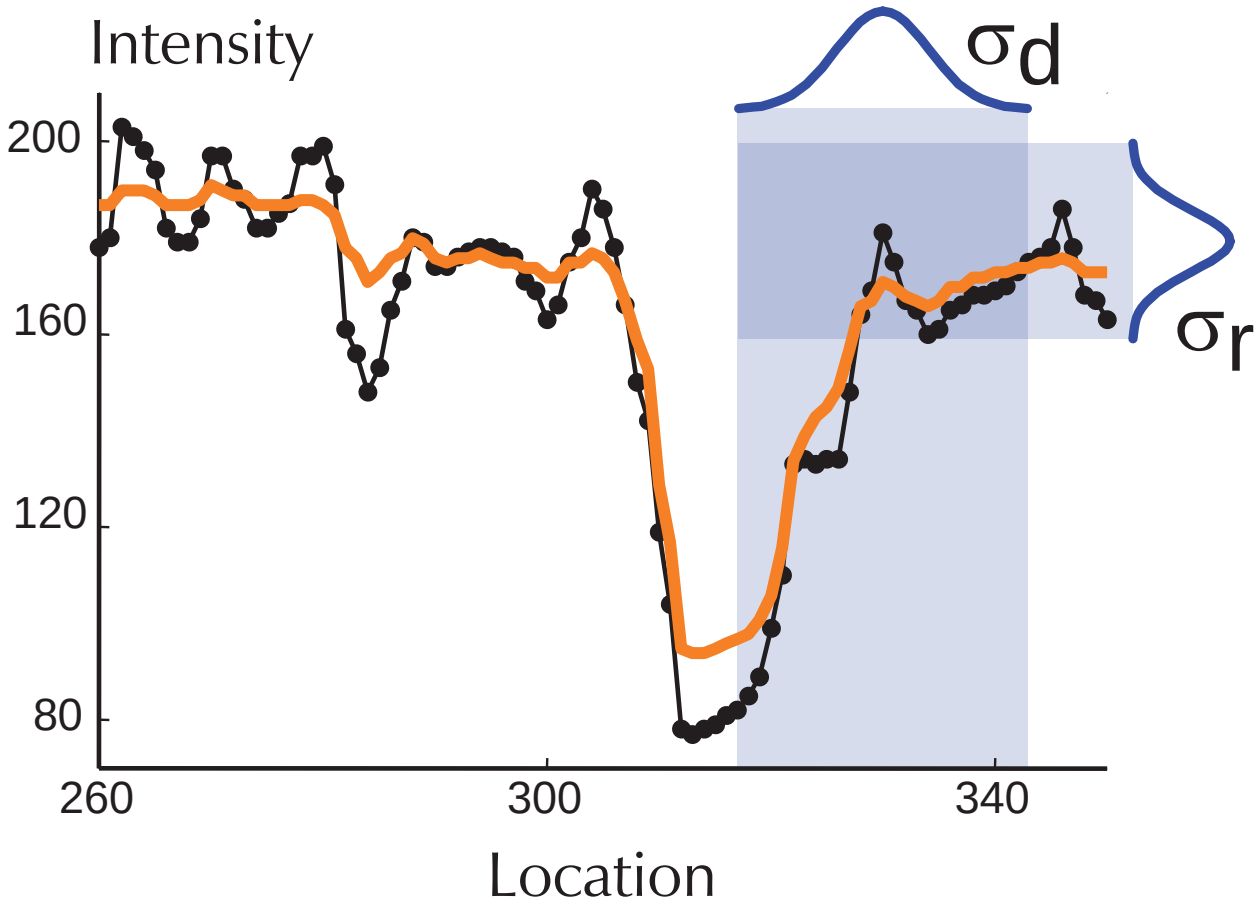
No-Flash



No-Flash

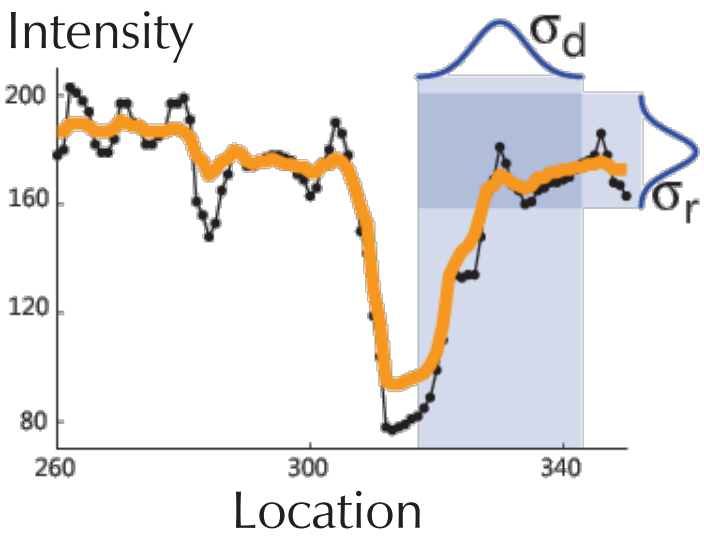


No-Flash



No-Flash

Bilateral Filter



No-Flash

Bilateral Filter

Denoising

- Problem: noise in A makes it hard to set range sigma
  - Too low: preserve edges due to noise
  - Too high: too much blurring (like plain Gaussian)
- Solution: joint bilateral filter
  - Edge-stopping function based on flash image F instead of A

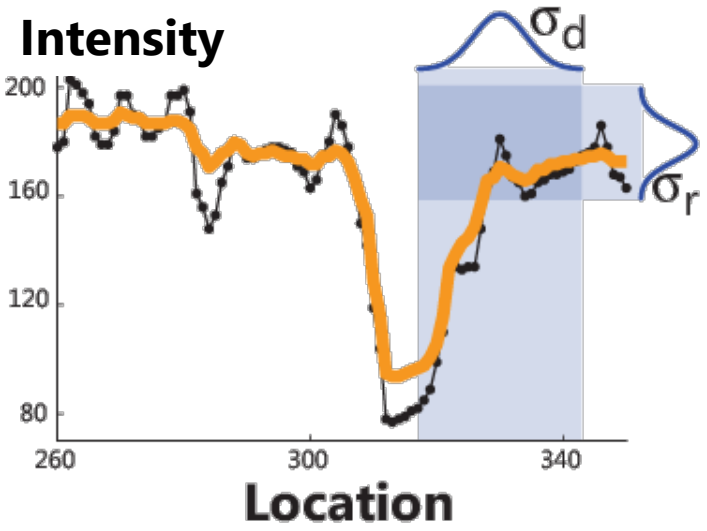
$$A_p^{NR} = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(F_p - F_{p'})\, A_{p'}$$

Flash

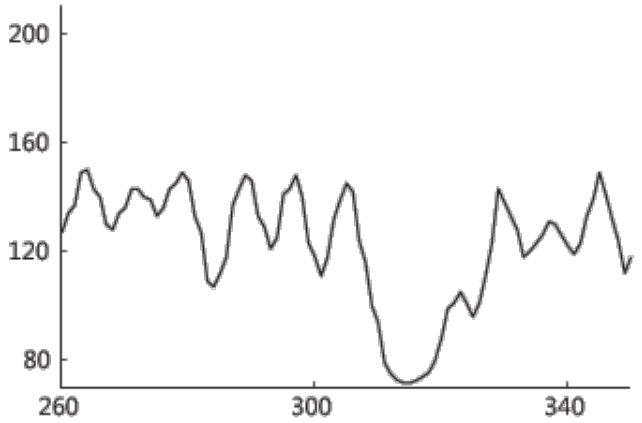
Bilateral Filter

No-Flash

Bilateral Filter

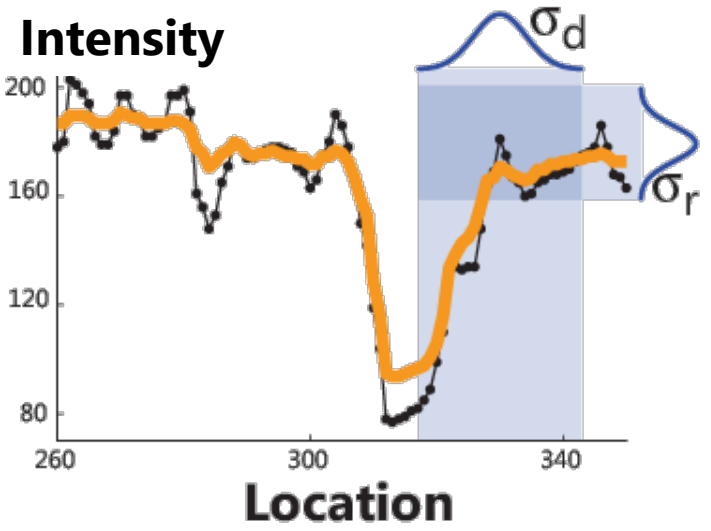


Flash

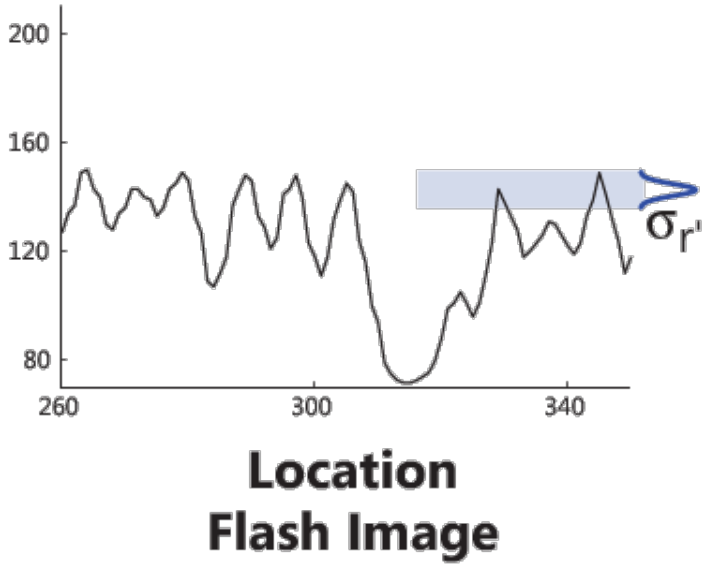


No-Flash

Bilateral Filter

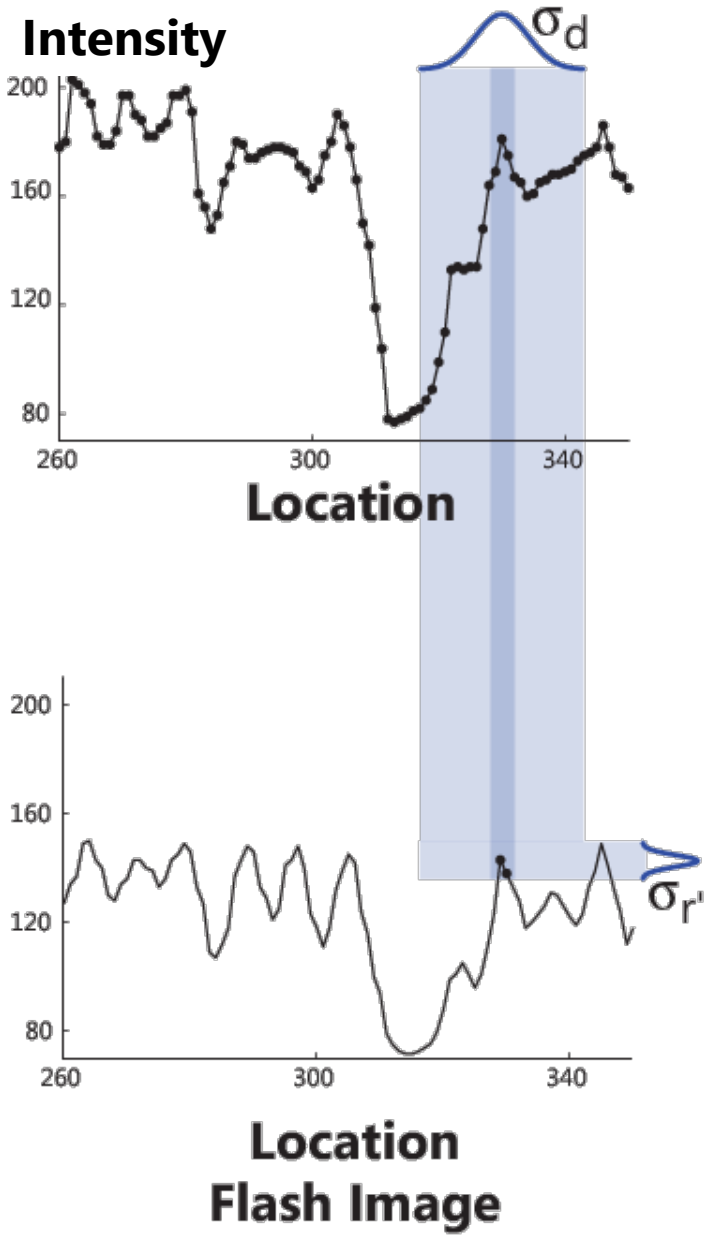


Flash



No-Flash

Bilateral Filter

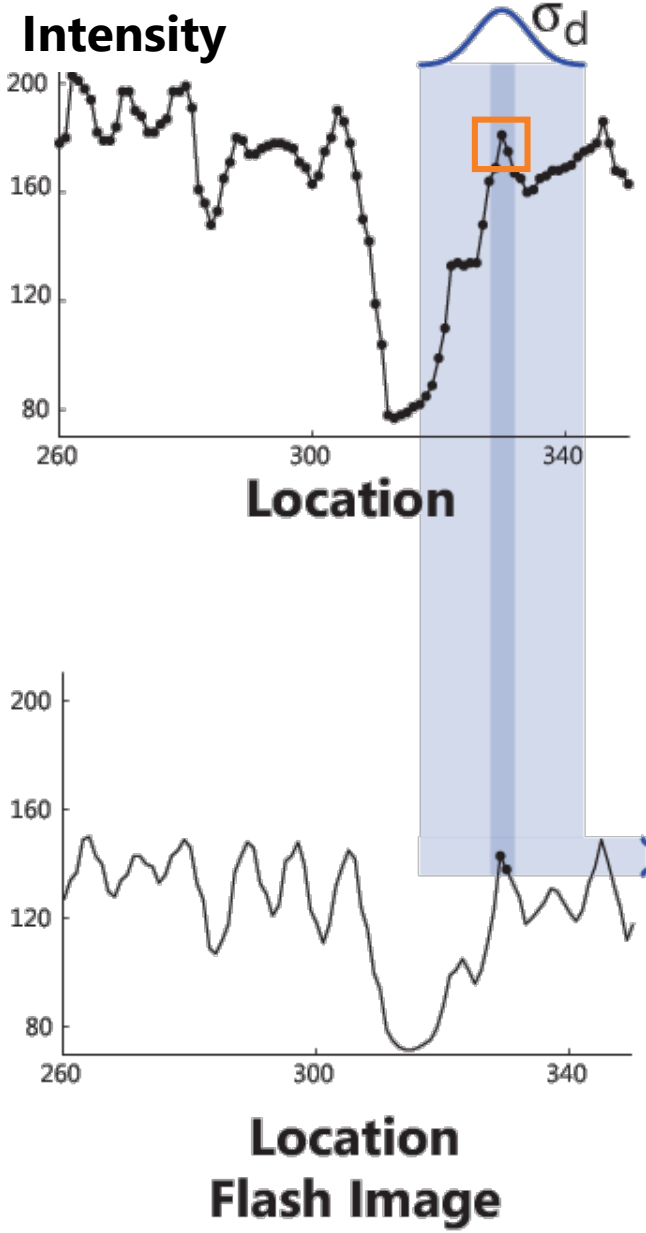


Flash

No-Flash

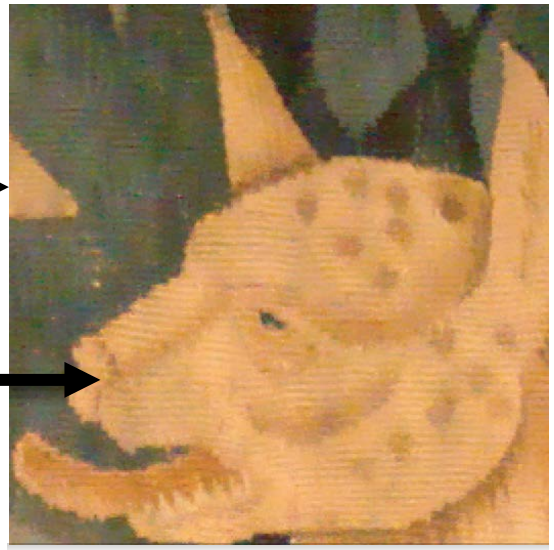
Bilateral Filter

Flash

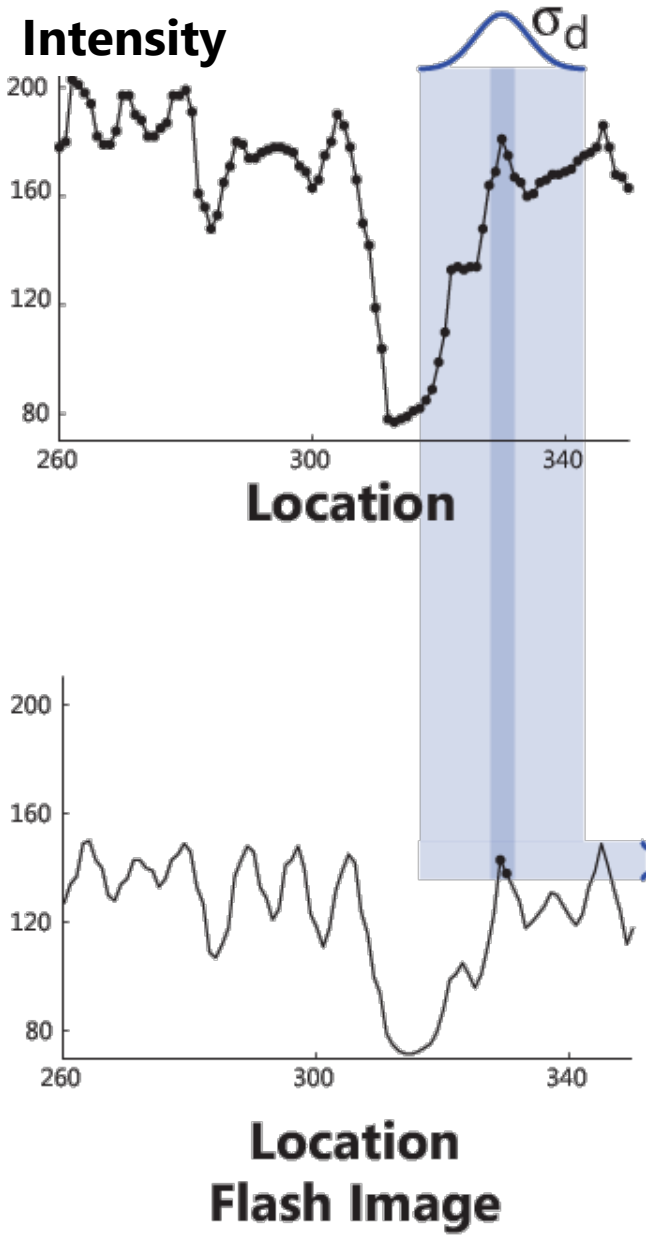


No-Flash

Joint Bilateral Filter



Flash



Bilateral Filter

Joint Bilateral Filter

[Eisemann04]

Flash

Joint Bilateral Filter

Flash-To-Ambient Detail Transfer

- Joint bilateral filter can reduce noise, but cannot add detail present only in the flash image
- Compute a detail layer:

$$F^{Detail} = \frac{F + \varepsilon}{F^{Base} + \varepsilon},$$

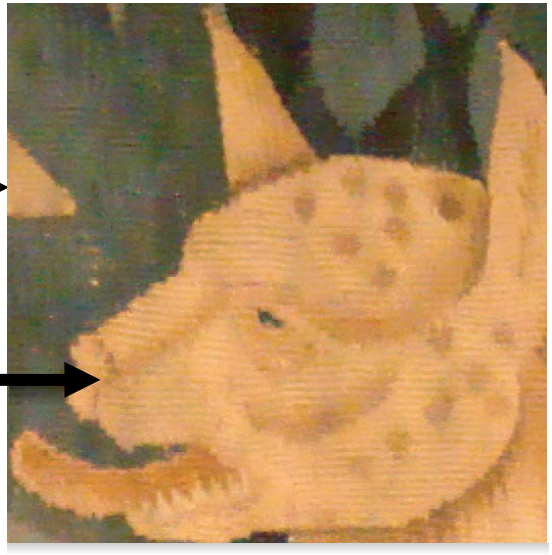
F^{Base} is computed using the basic bilateral filter on F.

- … and apply it to the denoised ambient image:

$$A^{Final} = (1 - M) A^{NR} F^{Detail} + M A^{Base}$$

No-Flash

Joint Bilateral Filter



Flash

No-Flash

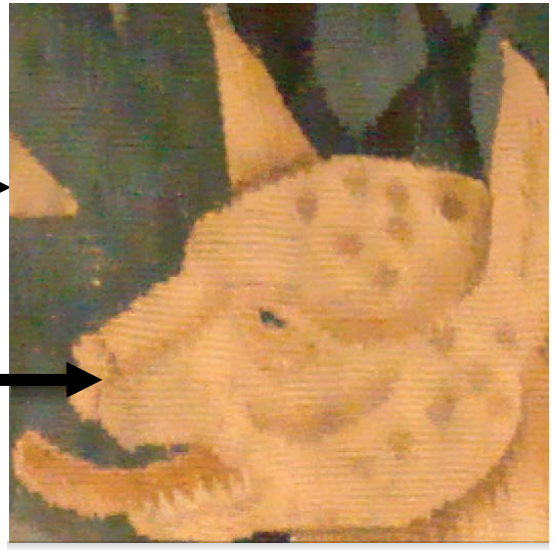
Joint Bilateral Filter

Flash

Bilateral Filter

No-Flash

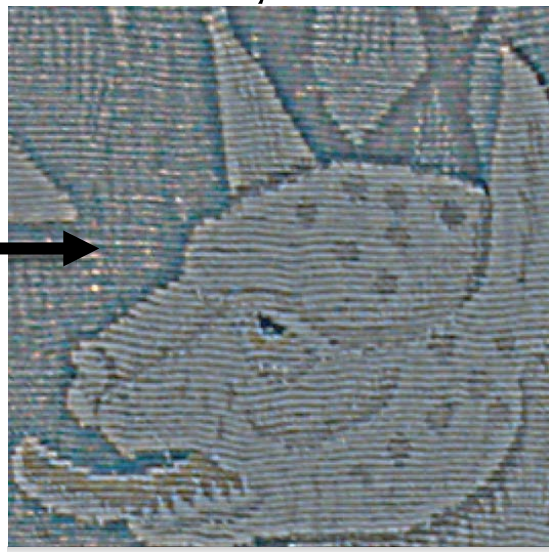
Joint Bilateral Filter

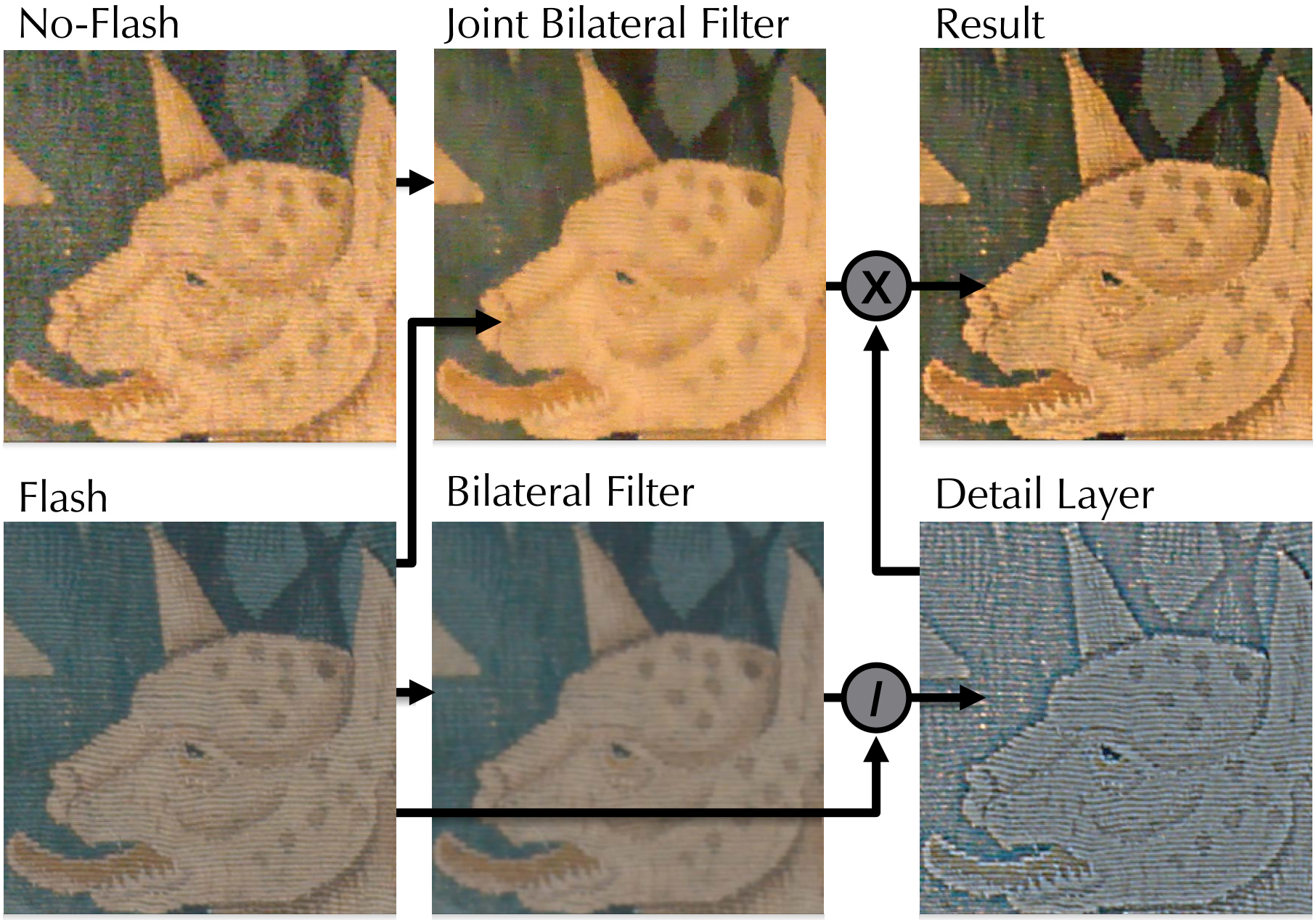


Flash

Bilateral Filter

Detail Layer




No-Flash
Joint Bilateral Filter
Result
X
Flash
Bilateral Filter
Detail Layer
/

[Durand02]

No-Flash

JBF & Detail Transfer


Flash


No-Flash


No-Flash


Result


Flash


No-Flash


No-Flash


Result


Flash


No-Flash

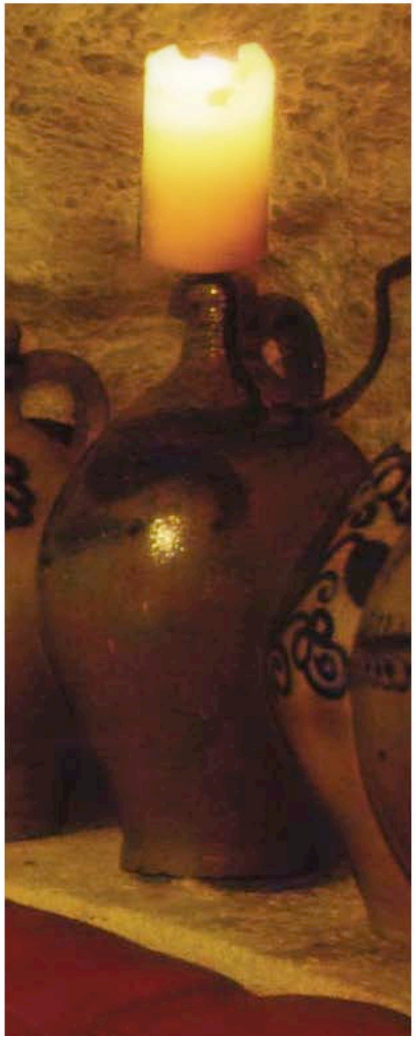

Flash


No-Flash

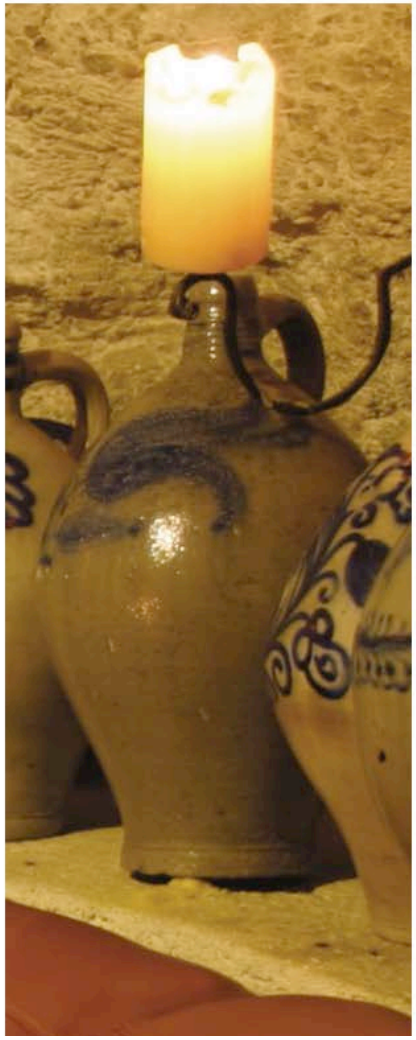

Result

Flash-To-Ambient Detail Transfer

No-Flash



Detail Transfer
with Denoising



Long Exposure
Reference

Flash Shadows and Specularities

Orig. (top) Detail Transfer (bottom) Detail Transfer without Mask

Flash Shadows and Specularities

- To avoid these artifacts, compute *mask* of locations where detail transfer is suppressed
  - For shadows, threshold on *linearized* intensity difference:

$$M^{Shad} = \begin{cases} 1 \text{ when } F^{Lin} - A^{Lin} \leq \tau_{Shad} \\ 0 \text{ else} \end{cases}$$

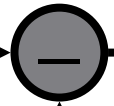
  - For specularities, luminance above 95%
  - Masks are merged and feathered

Flash

No-Flash

Flash

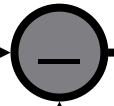
Difference



No-Flash

Flash

Difference



No-Flash

Flash

No-Flash

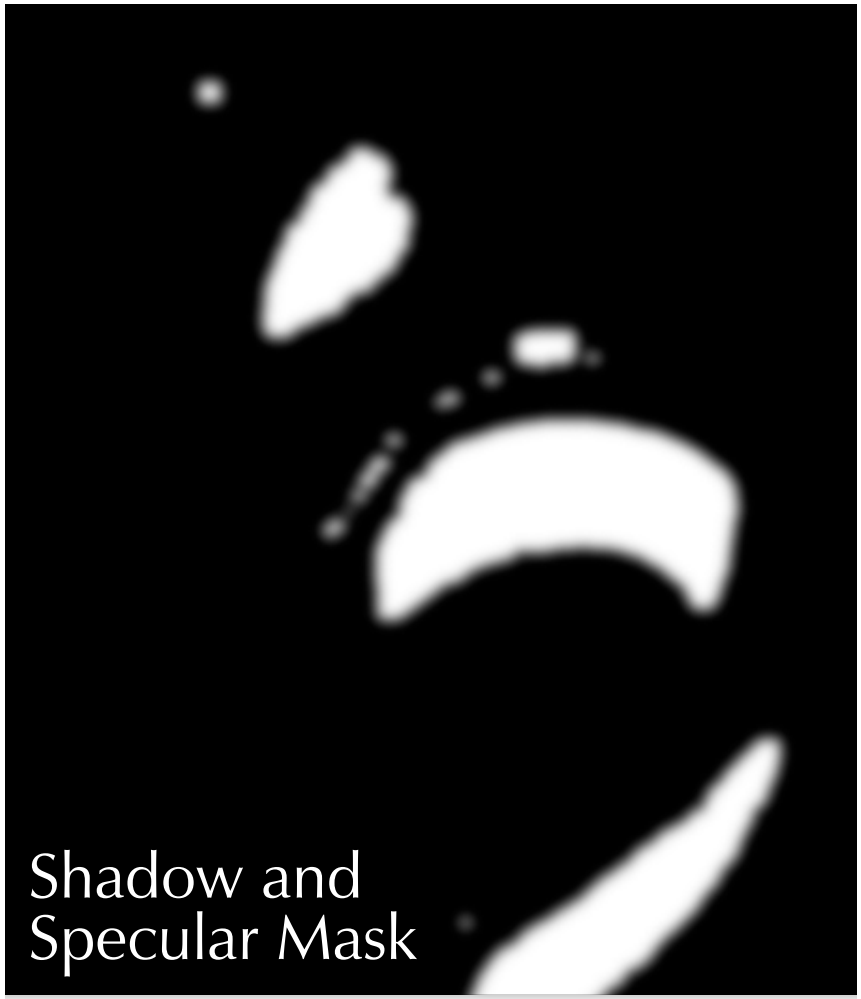
Difference

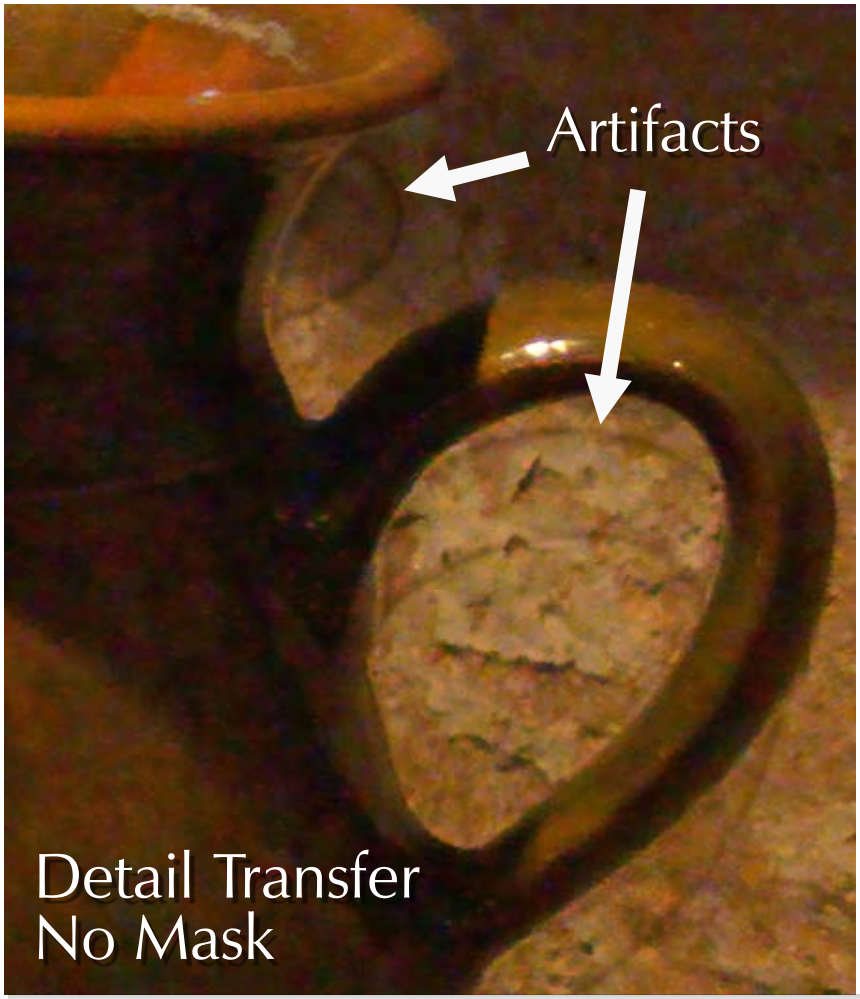
Threshold & Feather

Shadow & Specular Mask

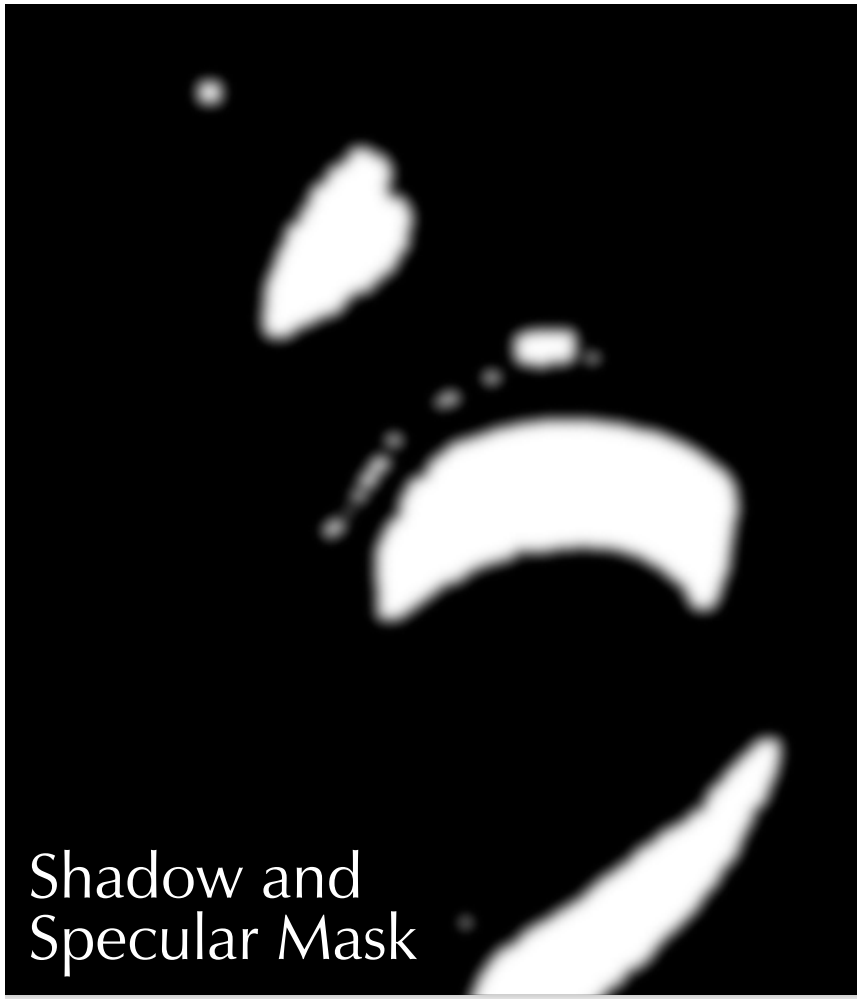
[Eisemann04]

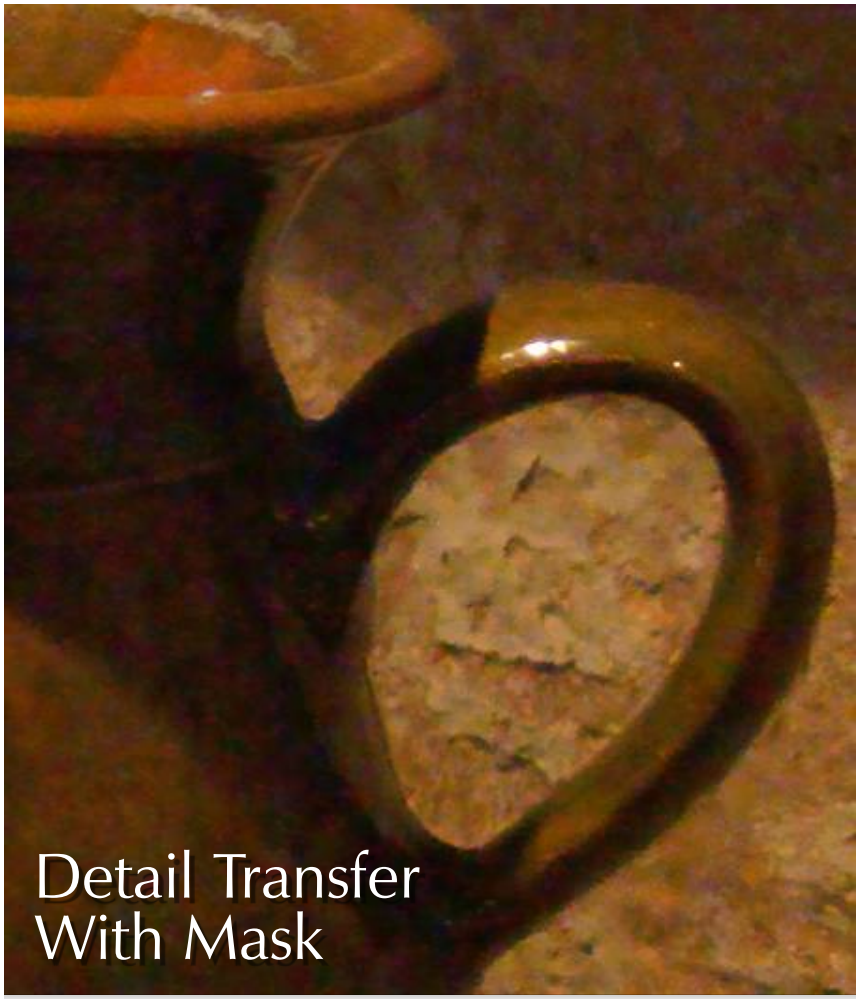
Flash Shadows and Specularities





Flash Shadows and Specularities





White Balancing

- Flash adds light source of known color to the scene
- Illumination due to the flash only: $\Delta = F^{Lin} - A^{Lin}$
- Estimate ambient illumination at the surface:

$$C_p = \frac{A_p}{\Delta_p}$$

Note typo in paper…

- Take mean over sufficiently-bright pixels in image to infer ambient illumination color *c*
- White balance by dividing each pixel by *c*

Flash

No Flash

Assumptions

- Single ambient illuminant
- Flash is white
- Lambertian reflectance

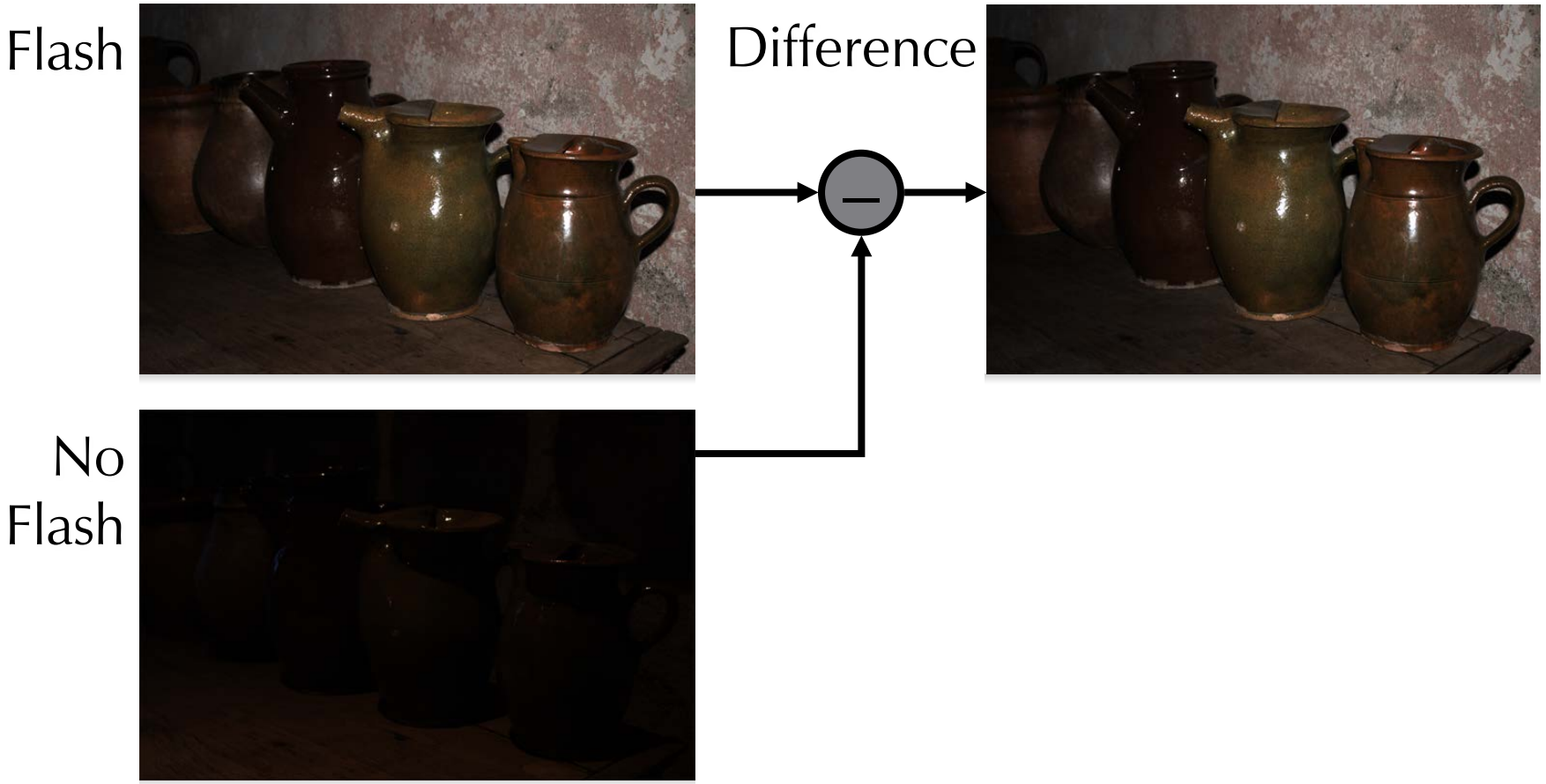
[DiCarlo01]

Flash

No Flash

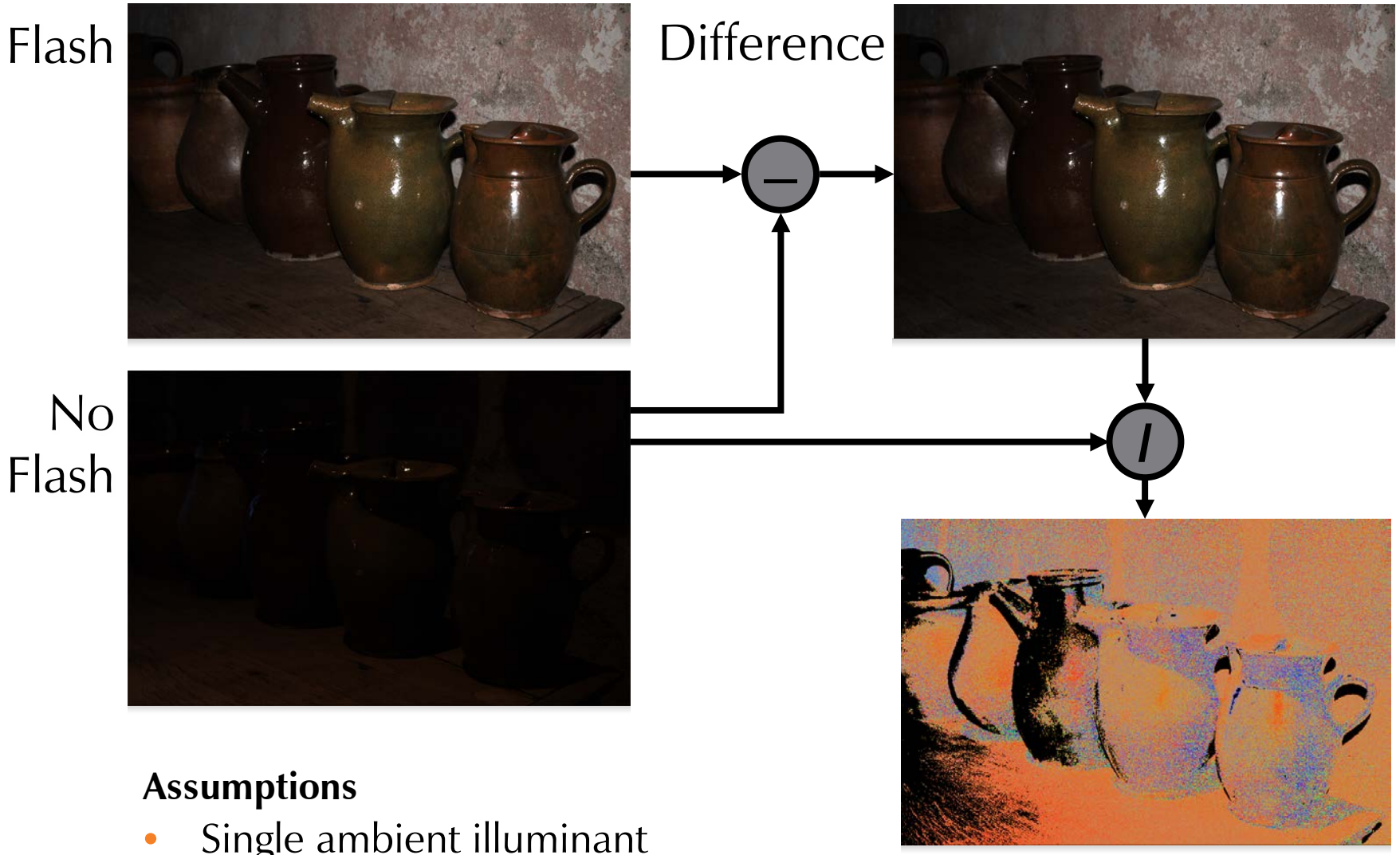
Assumptions

- Single ambient illuminant
- Flash is white
- Lambertian reflectance



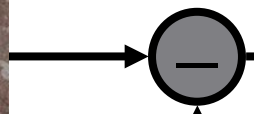
Assumptions

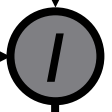
- Single ambient illuminant
- Flash is white
- Lambertian reflectance

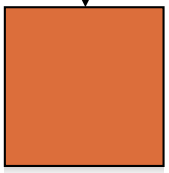


Assumptions

- Single ambient illuminant
- Flash is white
- Lambertian reflectance



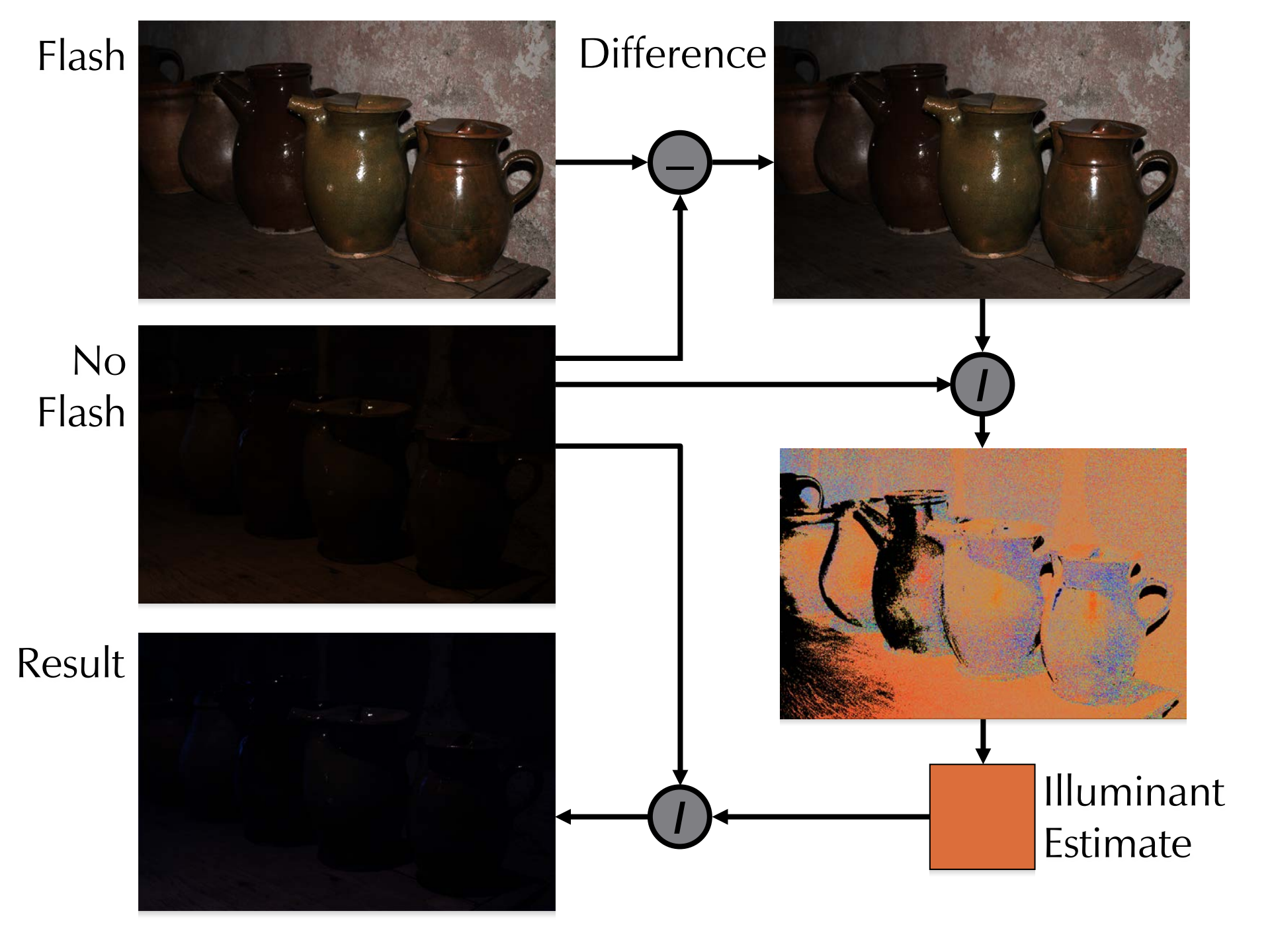




Illuminant
Estimate

Assumptions

- Single ambient illuminant
- Flash is white
- Lambertian reflectance


Flash
Difference
No Flash
Result
Illuminant Estimate

No-Flash

Result

Illuminant
Estimate

Red-Eye Correction

- Convert the pair to YCbCr space (decorrelates luminance from chrominance)
- Compute a relative redness measure:

$$R = F_{Cr} - A_{Cr}$$

- Segment the image into regions where $R > \tau_{Eye}$
- Select regions containing seed pixels where

$$R > \max[0.6, \mu_R + 3\sigma_R] \text{ and } A_Y < \tau_{Dark}$$

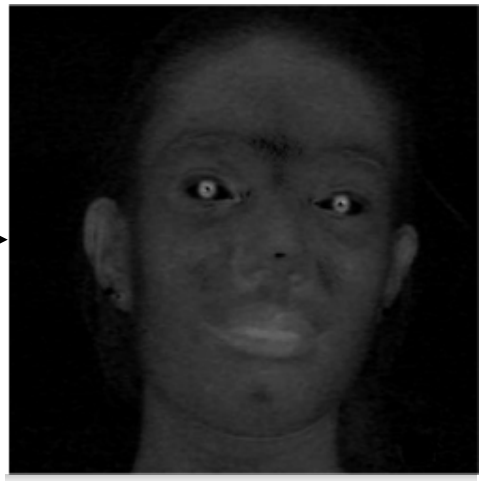
and check that region is circular and not too big

Flash

No-Flash

Flash

Cr Channel



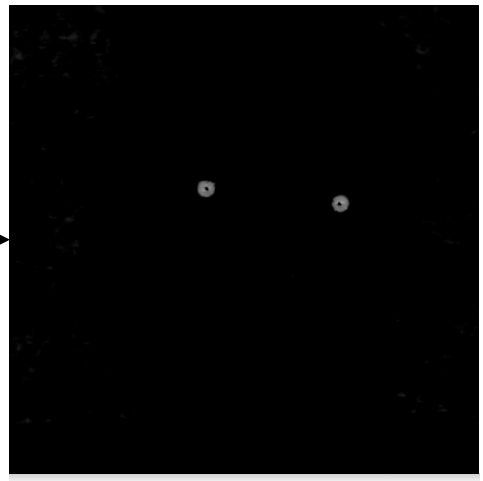
No-Flash

Cr Channel

Flash

Cr Channel

Cr Difference



No-Flash

Cr Channel

Flash

Cr Channel

Cr Difference

No-Flash

Cr Channel

Red Eye Detection And Correction

Result

[Patti98]

Red-Eye Correction

No-Flash

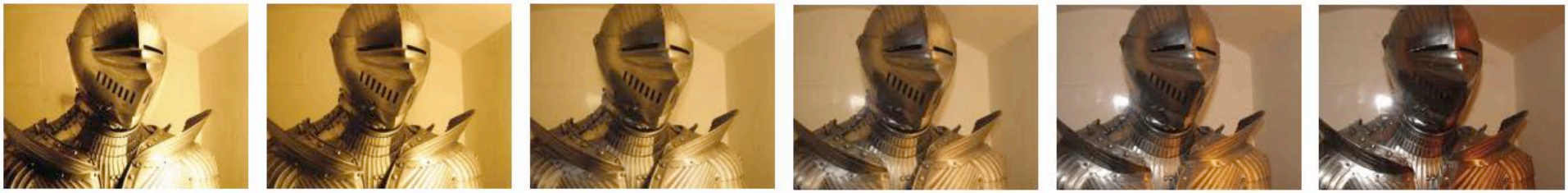
Flash

Red-Eye Corrected

Continuous Flash Adjustment

- Convert Flash and Ambient images to YCbCr space and interpolate linearly:

$$F^{Adjusted} = (1-\alpha)A + (\alpha)F$$



-0.5 0.0 (No-Flash) 0.33 0.66 1.0 (Flash) 1.5

Figure 10: An example of continuous flash adjustment. We can extrapolate beyond the original flash/no-flash pair.

Summary

- Multiple methods used to combine strengths of both flash and no-flash images
  - ambient image denoising
  - flash to ambient detail transfer
  - white balancing
  - red-eye correction
  - continuous flash adjustment
- Techniques that generalize to other applications:
  - (joint) bilateral filter, multi-scale decomposition, reflectance/illumination separation