Intrinsic Relighting

- *Flash Photography Enhancement via Intrinsic Relighting*
  - Eisemann and Durand

based on Eisemann's slides

- *Dark Flash Photography*
  - Krishnan amd Fergus
  - SIGGRAPH 2009

No-Flash

- Nice lighting

- Noisy or blurry
- Wrong color?

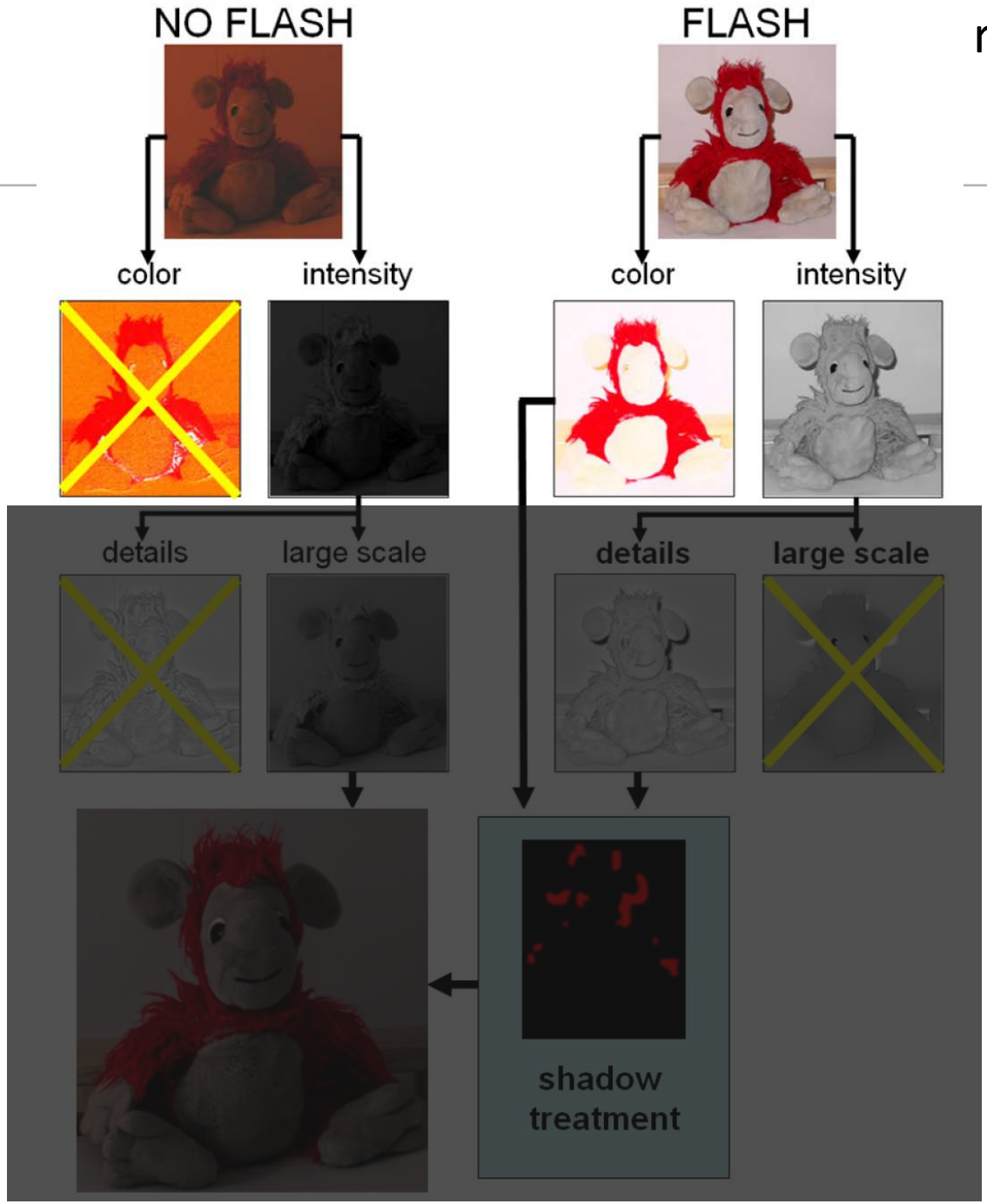
Flash

- Visible details
- Correct color

- Flat/artificial
- Flash shadows
- Red-eye

Use No-Flash Image to Relight Flash Image

registered


NO FLASH
FLASH
color
intensity
color
intensity
details
large scale
details
large scale
shadow
treatment

Intensity–Color Decomposition

O_f = **I_f** x **C_f**

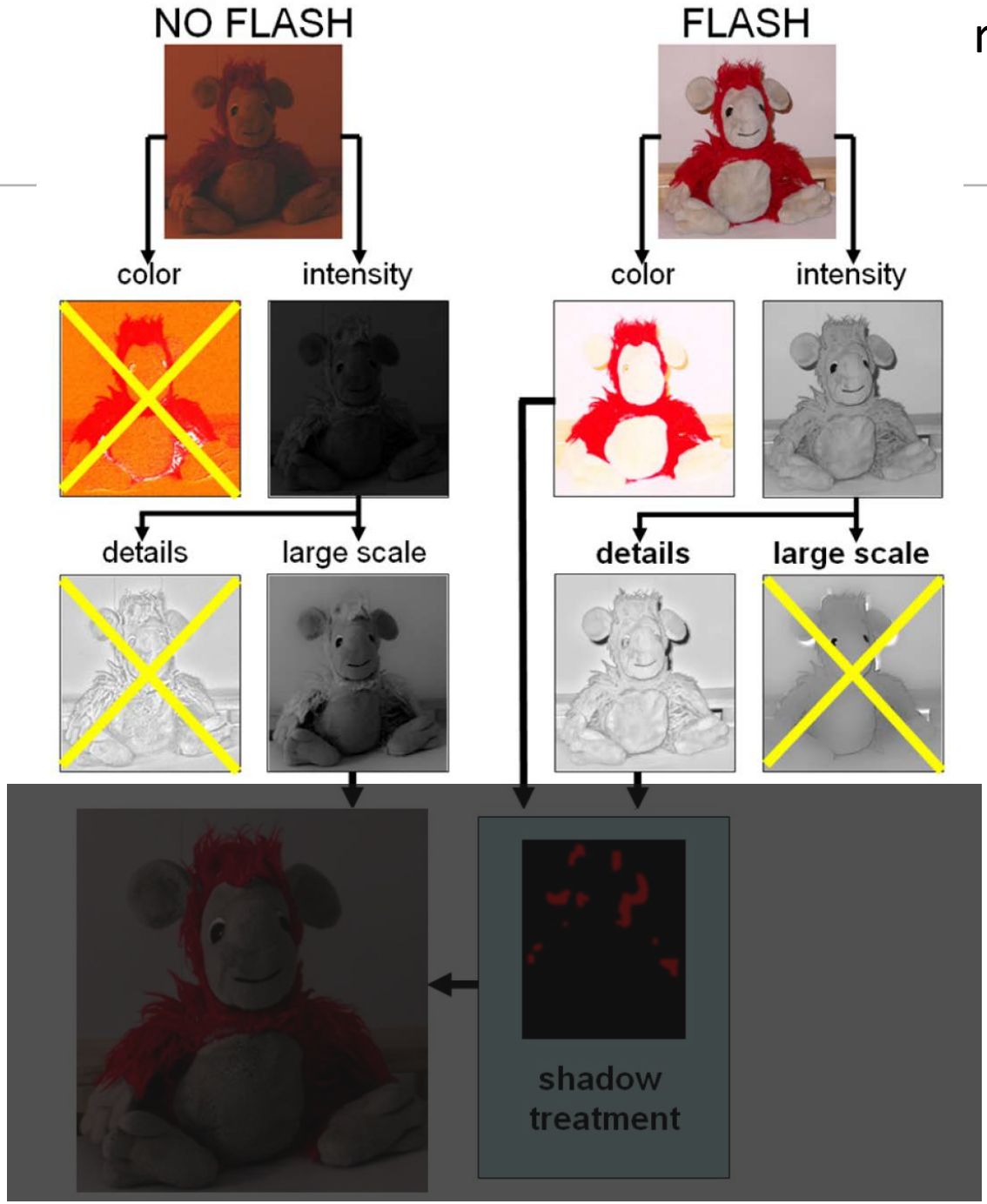
original = intensity x color

```
C_f(:,:,1) = O_f(:,:,1) ./ I_f(:,:); % R
C_f(:,:,2) = O_f(:,:,2) ./ I_f(:,:); % G
C_f(:,:,3) = O_f(:,:,3) ./ I_f(:,:); % B
```

better decoupling $I = \frac{R}{R+G+B}R + \frac{G}{R+G+B}G + \frac{B}{R+G+B}B$

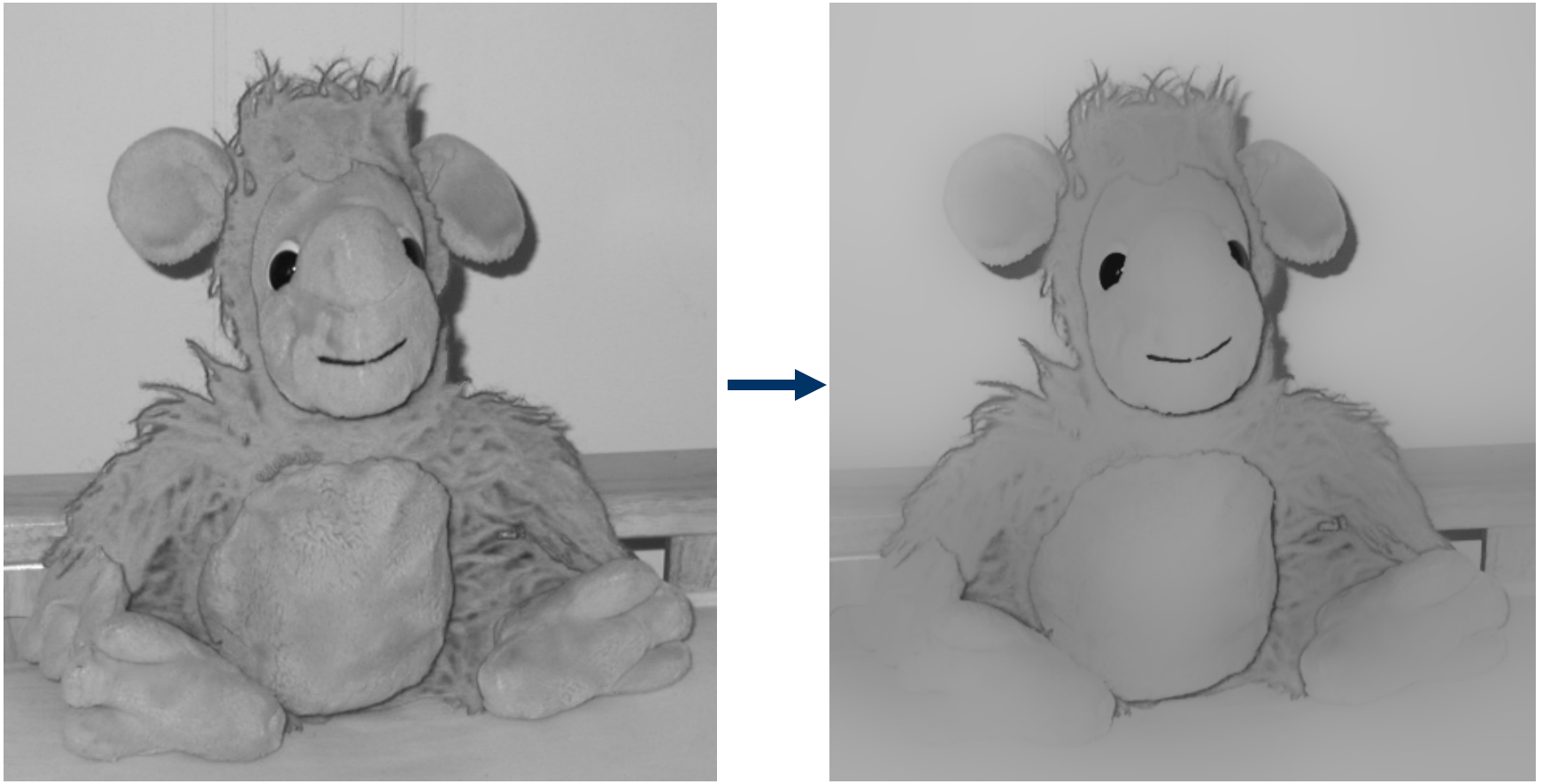
use the channels of the flash image as weight for both pictures

registered


NO FLASH
FLASH
color
intensity
color
intensity
details
large scale
details
large scale
shadow
treatment

Large-Scale Layer

- Bilateral filter



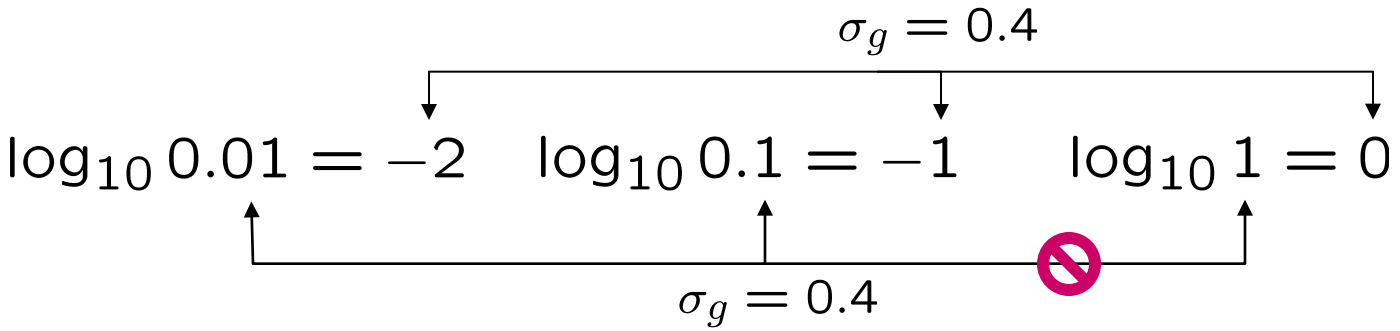
Bilateral Decoupling

$$J_s = \frac{1}{k(s)} \sum_{p \in \Omega} f(p - s) \; g(I_p - I_s) \; I_p$$

$$k(s) = \sum_{p \in \Omega} f(p - s) \; g(I_p - I_s)$$

- Computation is performed in the $\log_{10}$ domain to respect intensity ratios

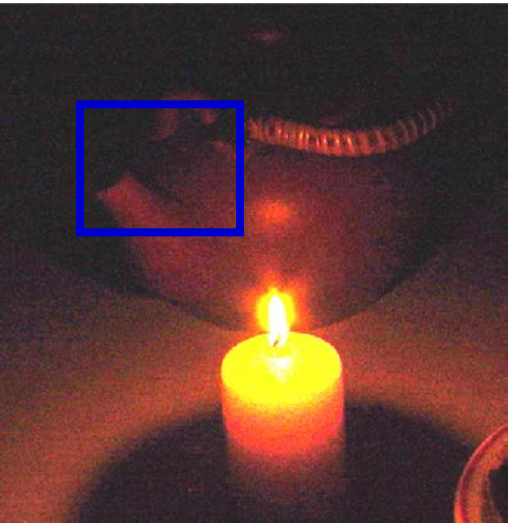
  i) spatial variance σ_f of 1.5% of the images diagonal
  ii) intensity variance $\sigma_g = 0.4$



Use *Cross* Bilateral Filter to Compute the Large-Scale Layer of No-Flash Image

- When the no-flash image is too noisy
- Borrow similarity from flash image
  - Preserve edges not present in the no-flash image

$$J_s^{nf} = \frac{1}{k(s)} \sum_{p \in \Omega} f(p-s)\ g(I_p^f - I_s^f)\ I_p^{nf}$$



bilateral

cross bilateral

Detail Layer of the Flash Image

intensity

/

large-scale

=

detail

Reconstruction

large-scale
no-flash

contrast can be enhanced

x

detail
flash

=

intensity
result

Reconstruction: Large scale x Detail = Intensity

Reconstruction

intensity
result

x

color
flash

≈

result

Reconstuction: Intensity x Color = Color Output

```
Res(:,:,1) = I_r(:,:) .* C_f(:,:,1);
Res(:,:,2) = I_r(:,:) .* C_f(:,:,2);
Res(;,:,3) = I_r(:,:) .* C_f(:,:,3);
```

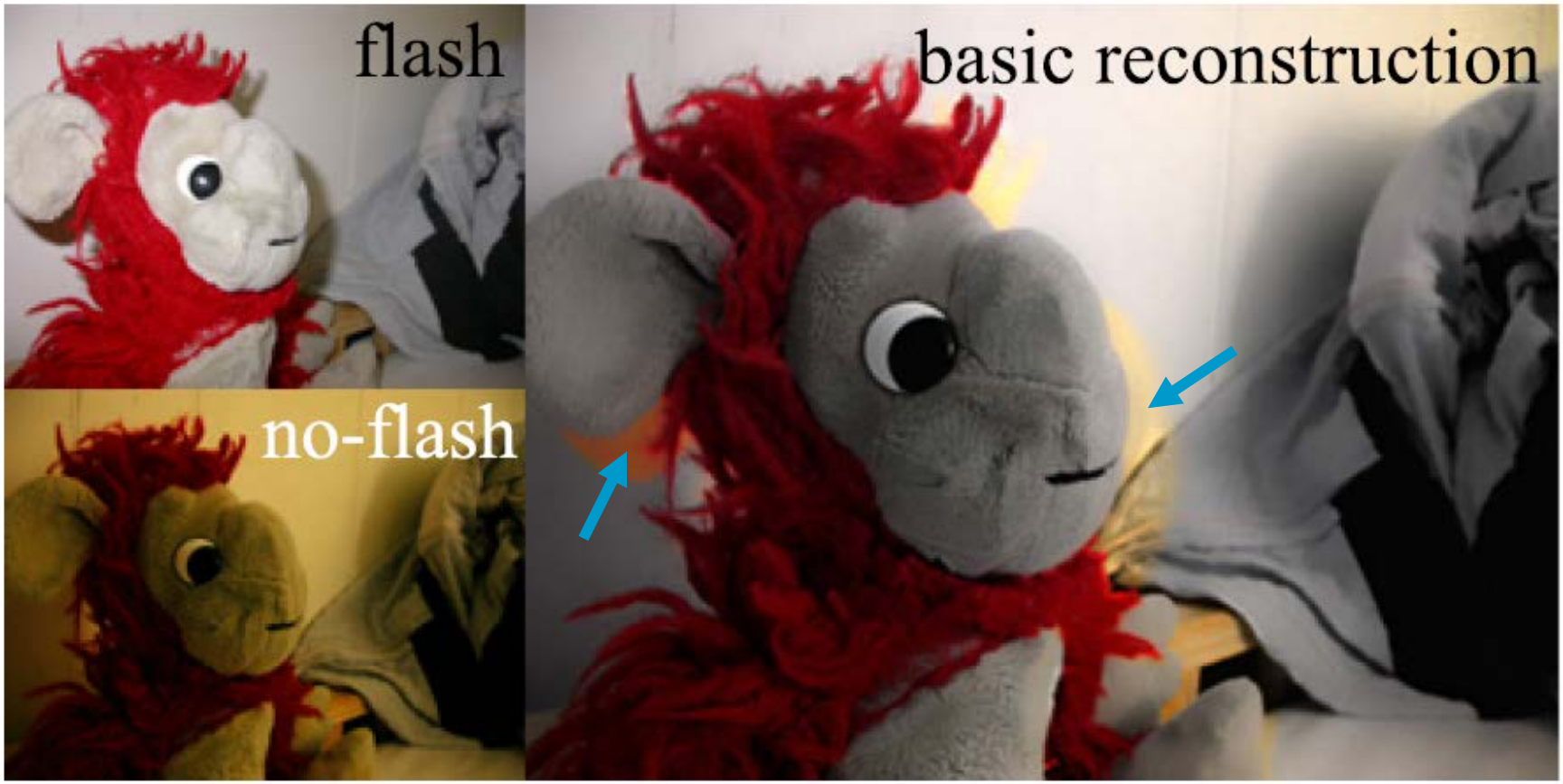
White Balance (for Later Use)

```
W_r = mean(A.*O_f(:,:,1)) / mean(A.*O_nf(:,:,1));
W_g = mean(A.*O_f(:,:,2)) / mean(A.*O_nf(:,:,2));
W_b = mean(A.*O_f(:,:,3)) / mean(A.*O_nf(:,:,3));
```

The matrix **A** gives stronger weights for bright pixels with a white color in the flash image

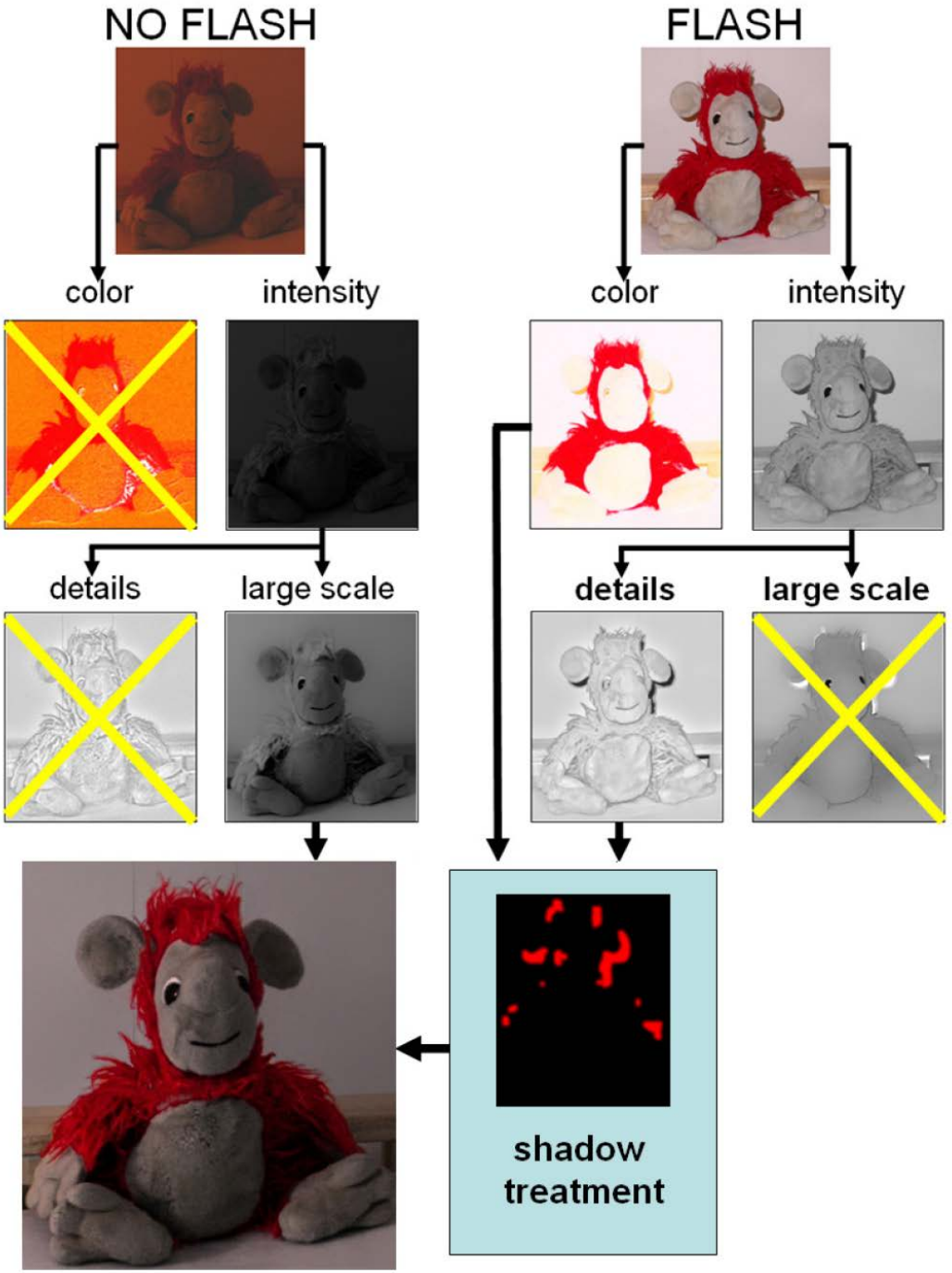
```
O_nf(:,:,1) = (W_r^0.2)*O_nf(:,:,1);
O_nf(:,:,2) = (W_g^0.2)*O_nf(:,:,2);
O_nf(:,:,3) = (W_b^0.2)*O_nf(:,:,3);
```

Basic Reconstruction



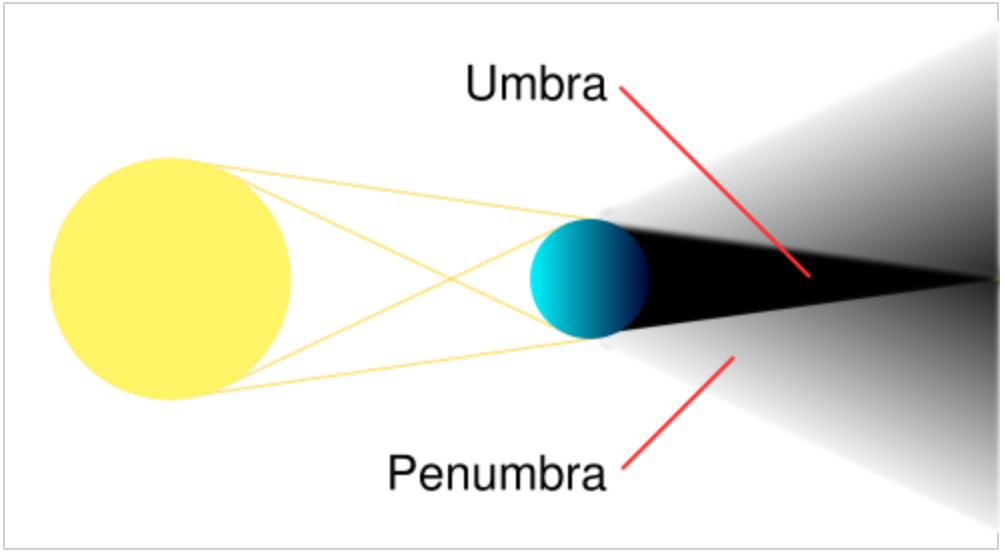
some areas did not receive light from the flash

registered

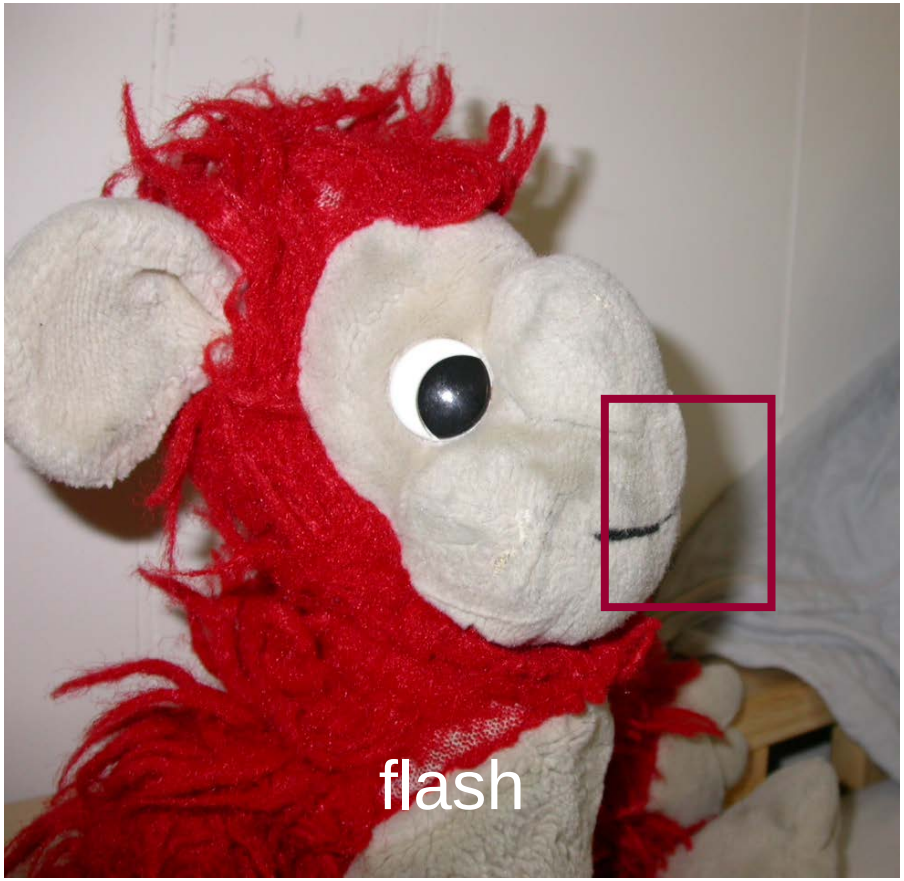

NO FLASH
FLASH
color
intensity
color
intensity
details
large scale
details
large scale
shadow
treatment

Shadow Treatment

- Umbra detection
- Penumbra detection



Shadow Detection

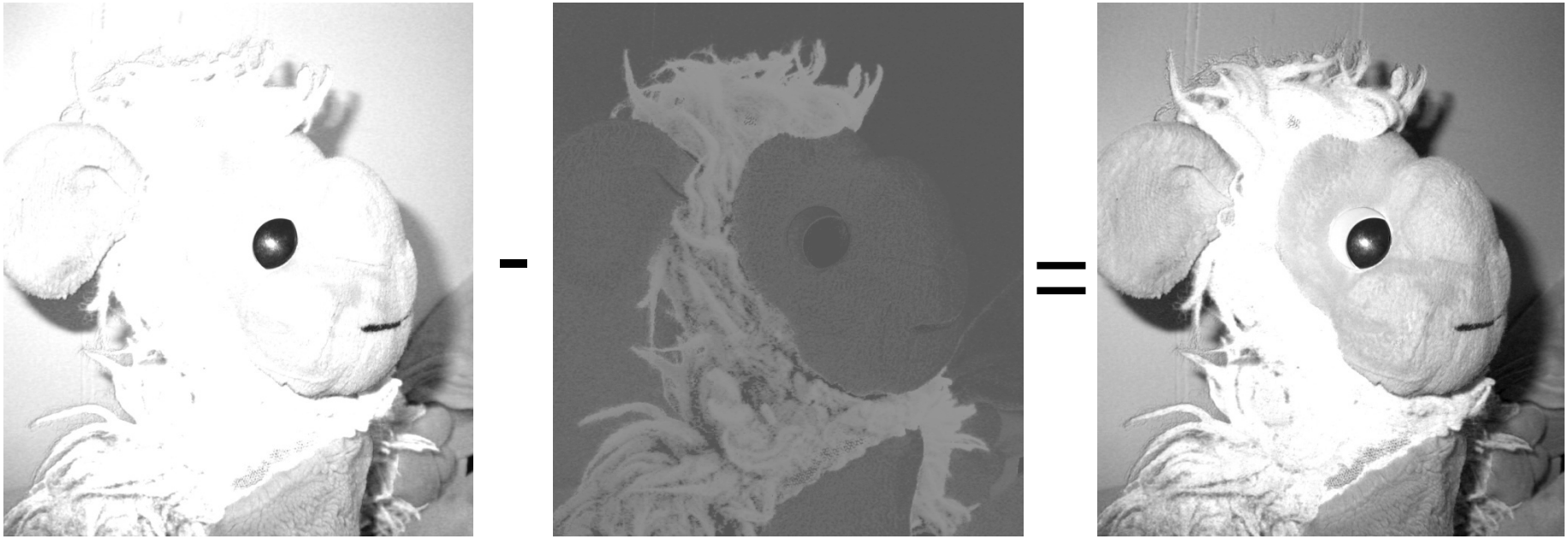


Umbra

Penumbra

Umbra Detection

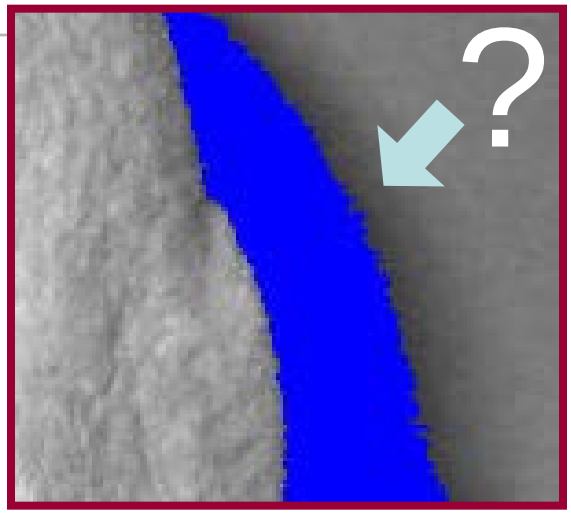
- No direct light from flash
- Difference of the two photos ΔI reveals these regions
  - However, shadows do not always correspond to $\Delta I=0$

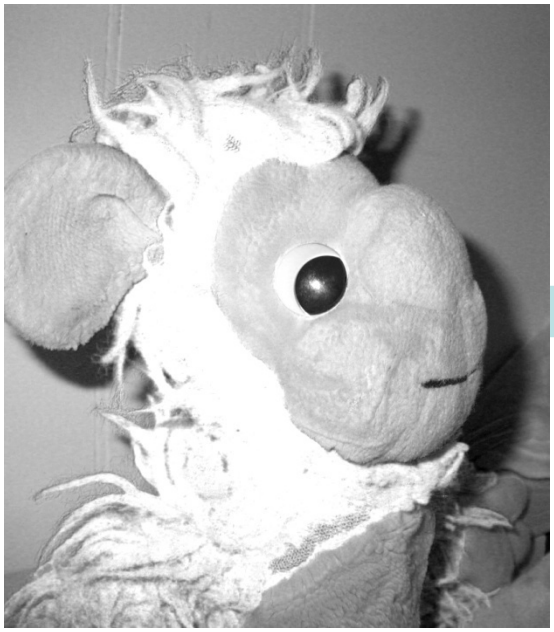


flash - no-flash = ΔI

Umbra Detection

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

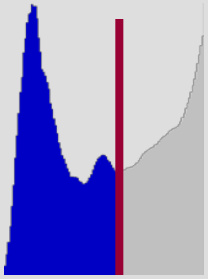




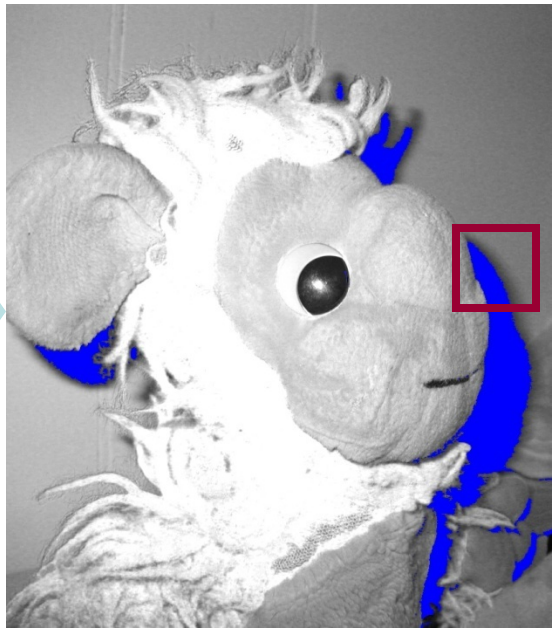
ΔI

128-bin blurred histogram

find local minimum

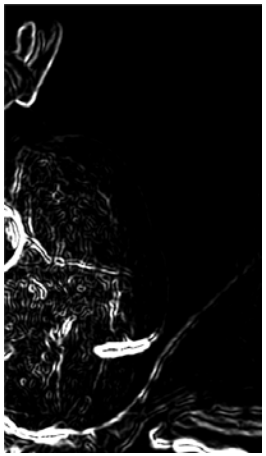


ΔI



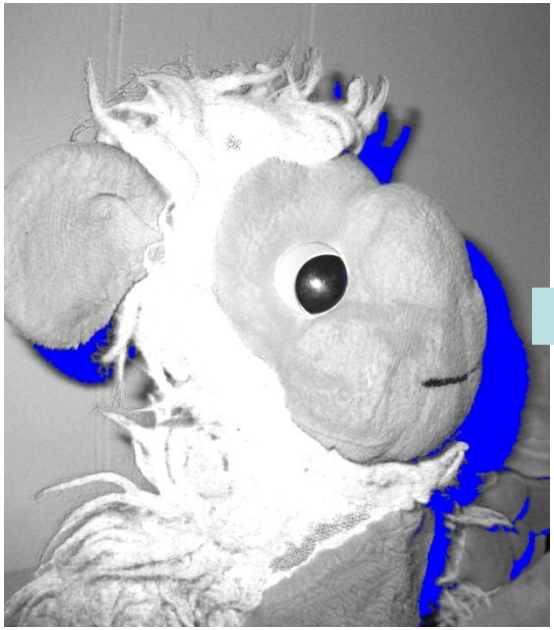
Penumbra Detection

1. Shadow boundaries create strong gradients in the flash image that do not correspond to gradients in the no-flash image
2. Keep only pixels that are connected to umbra

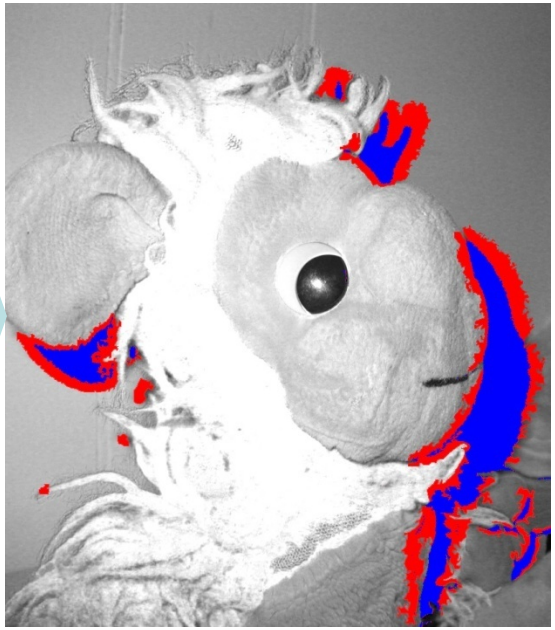


no-flash

flash



umbra



penumbra

Shadow Correction

- Correct color and detail

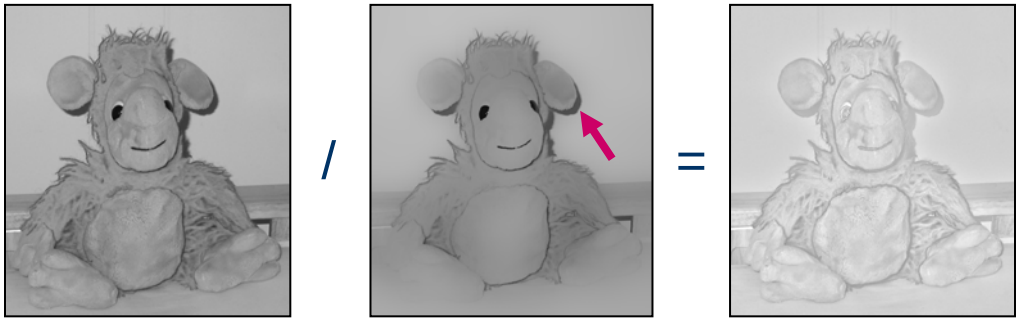
- Shadow areas receive different amounts of indirect light from the flash

- The no-flash image often lacks information in the blue channel due to yellowish lighting and poor sensitivity of sensors in the small wavelengths

shadow mask
with feathering at boundaries

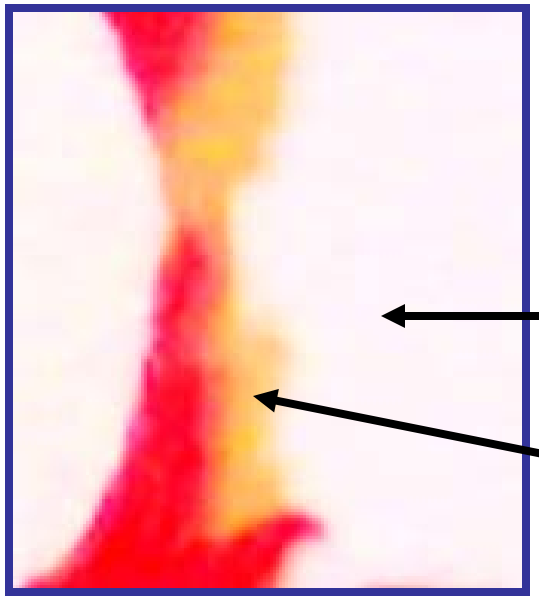
Flash Detail Correction

- Exploit the shadow mask to exclude shadow pixels from the bilateral filtering
- This results in a higher-quality detail layer for the flash image

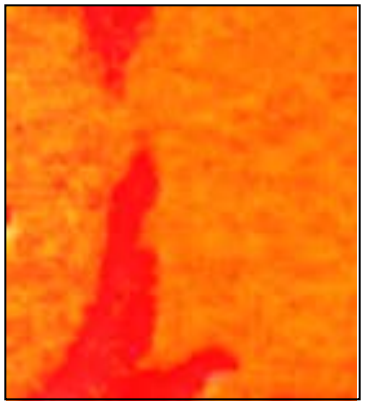


intensity large-scale detail

Shadow Color Correction



fill in shadow from similar surrounding

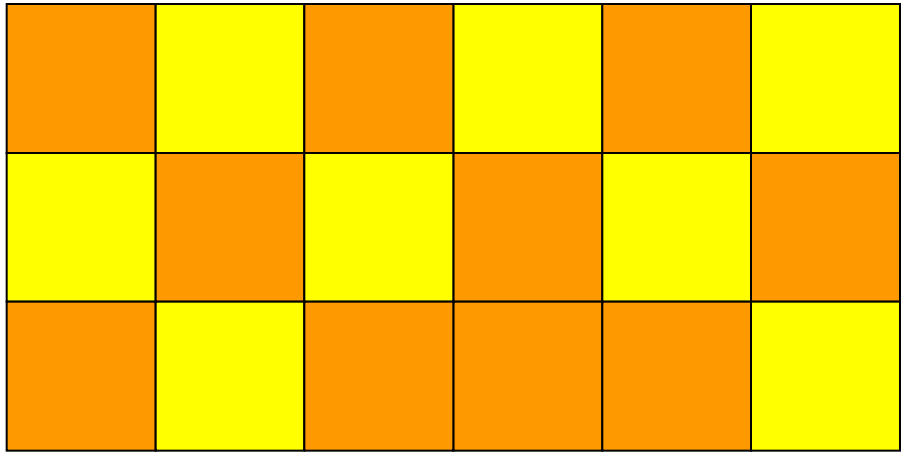


no-flash colors

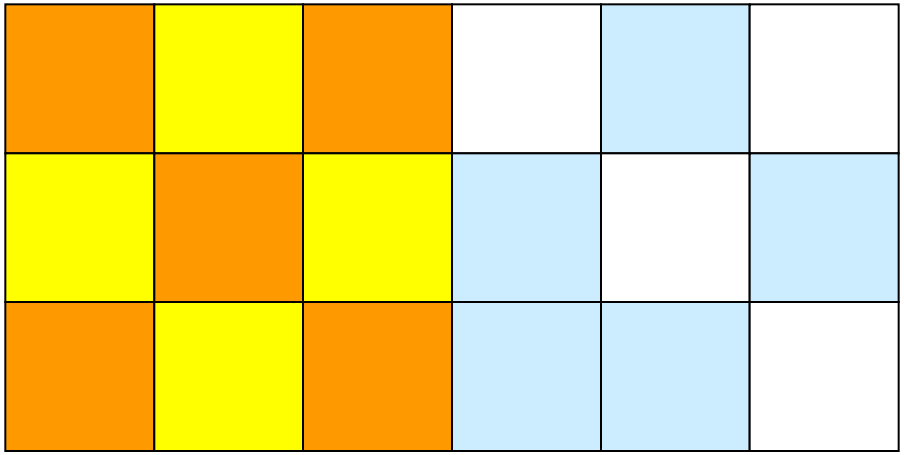
Eisemann's slides

Shadow Color Correction

no-flash



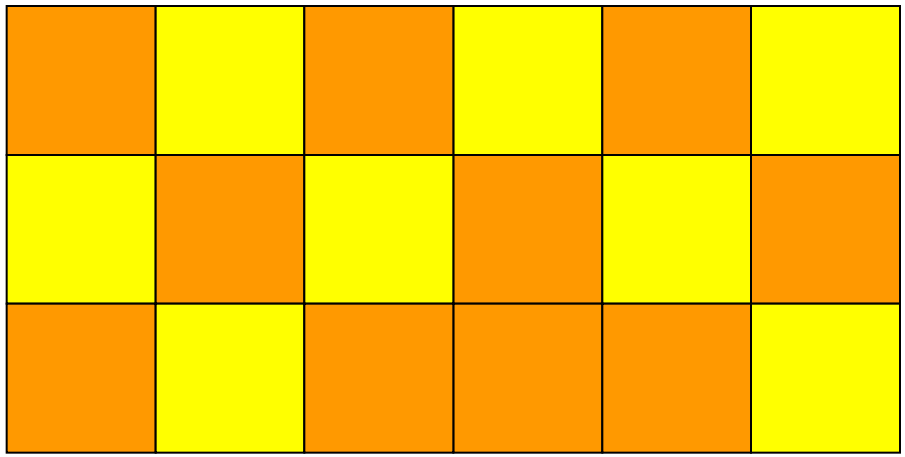
flash

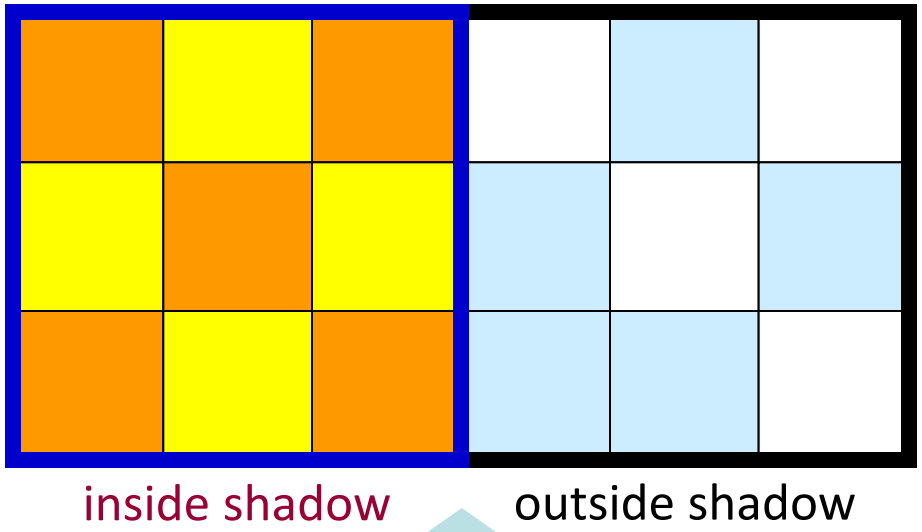


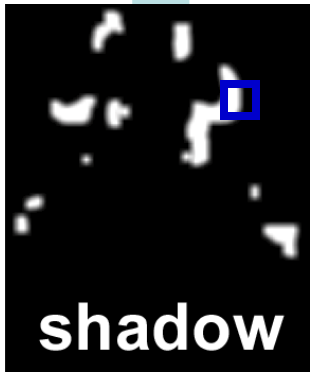
neighborhood
of a shadow pixel

Eisemann's slides

Shadow Color Correction



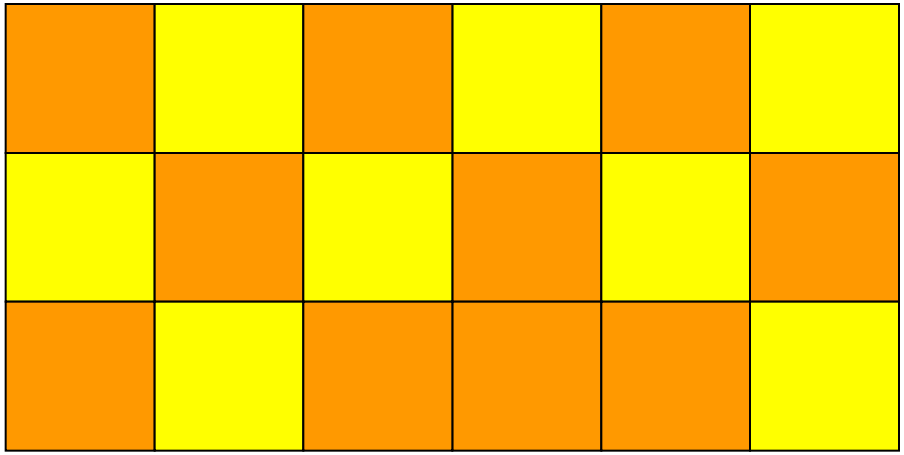




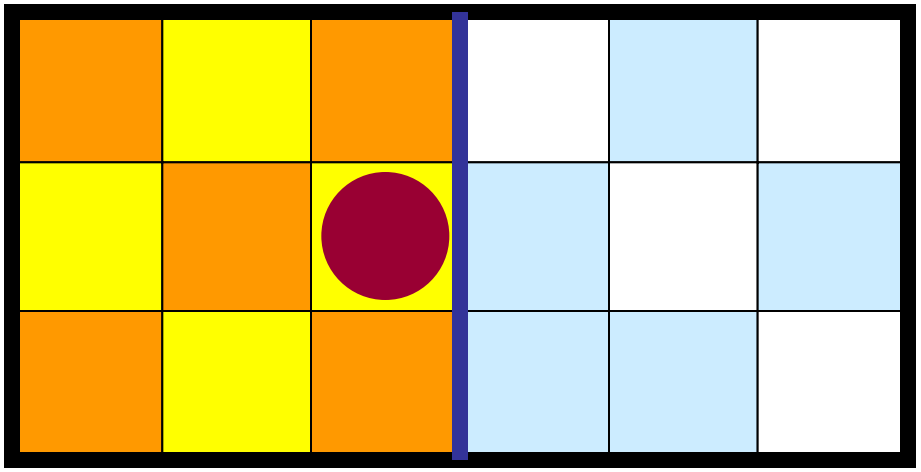
Eisemann's slides

Shadow Color Correction

no-flash



flash



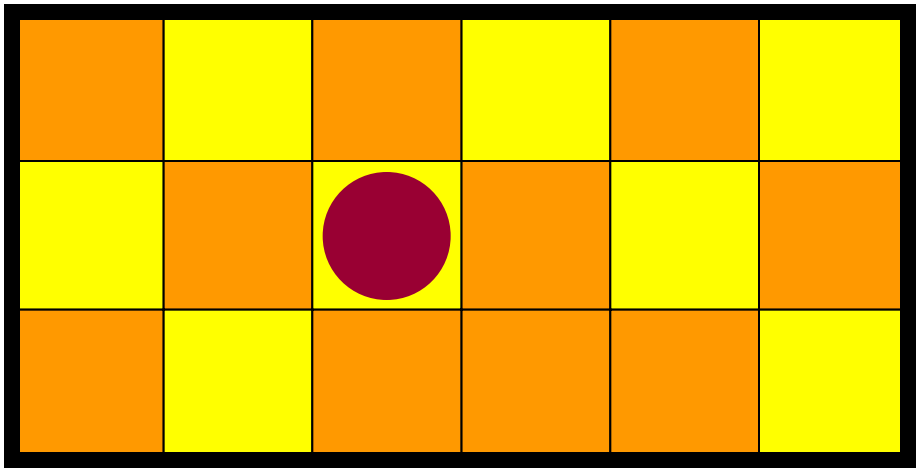
inside shadow outside shadow

select pixel in shadow

Eisemann's slides

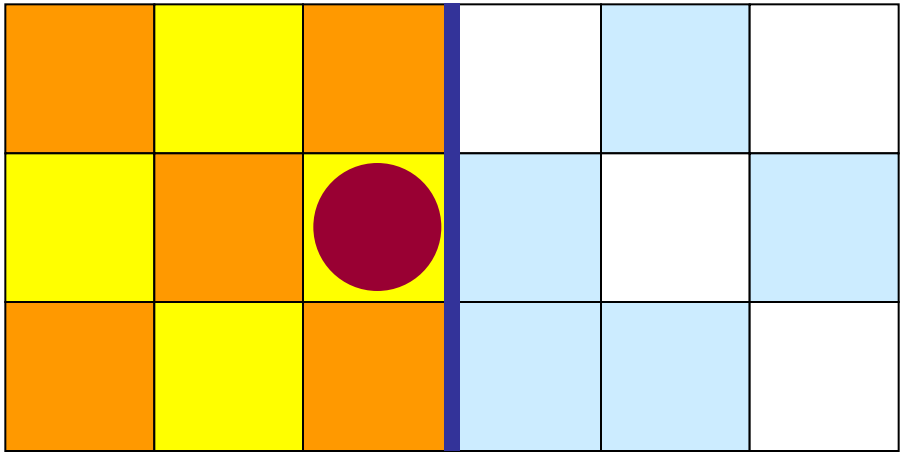
Shadow Color Correction

no-flash



corresponding pixel

flash

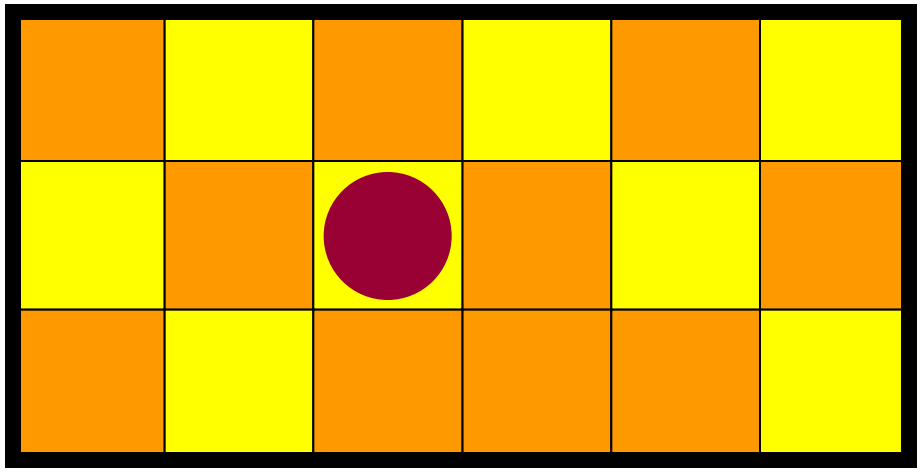


inside shadow outside shadow

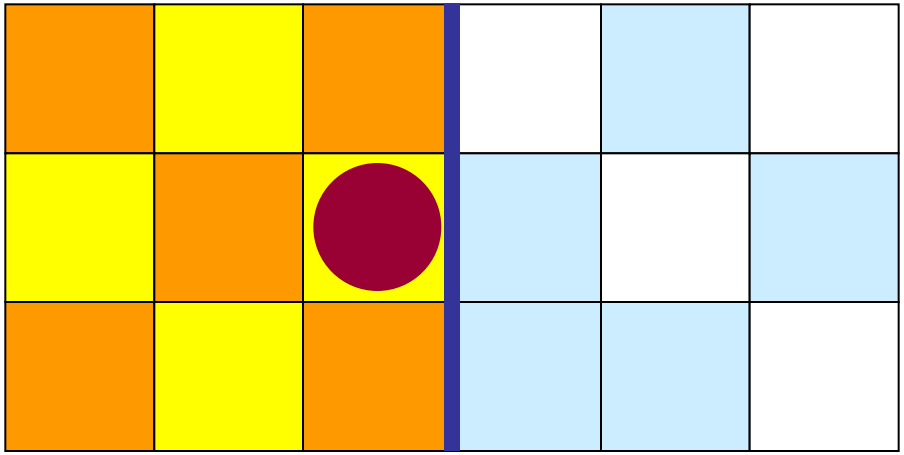
Eisemann's slides

Shadow Color Correction

no-flash

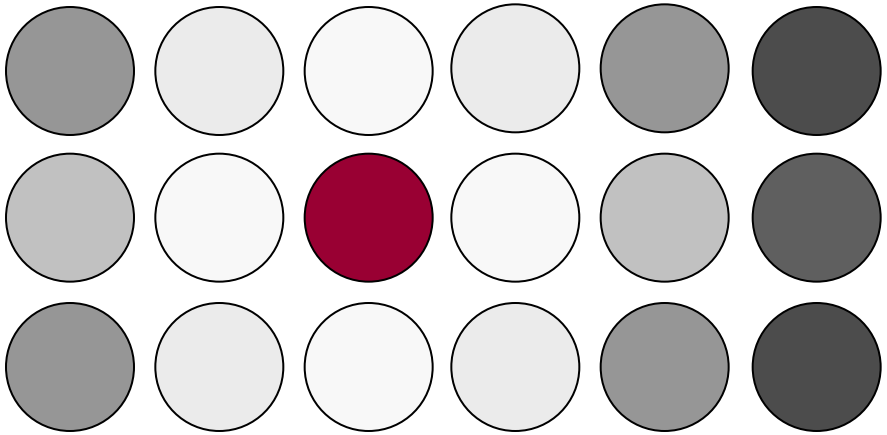


flash



inside shadow outside shadow

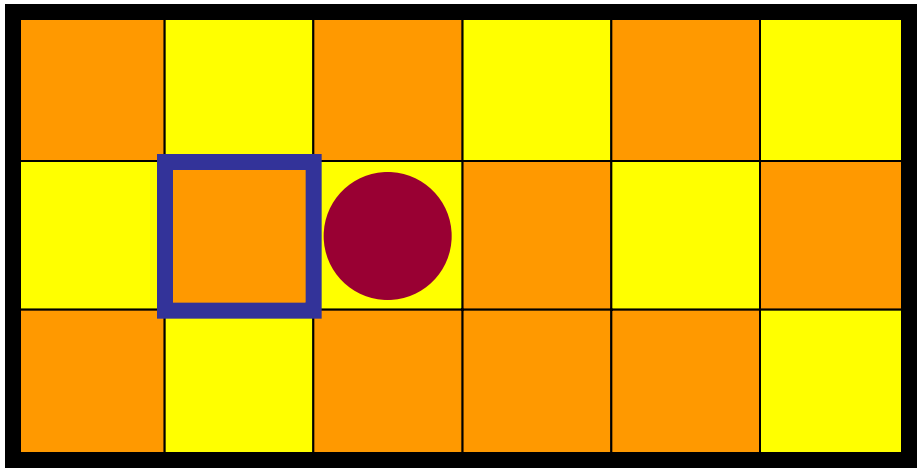
spatial weights



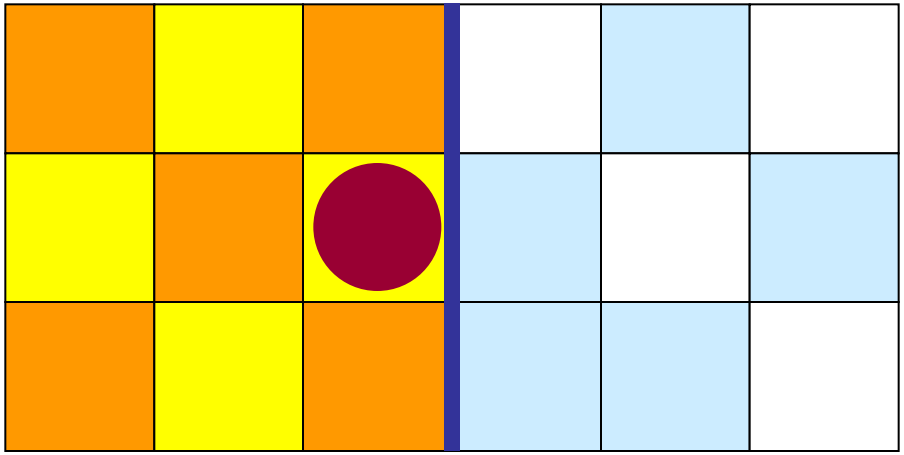
Eisemann's slides

Shadow Color Correction

no-flash

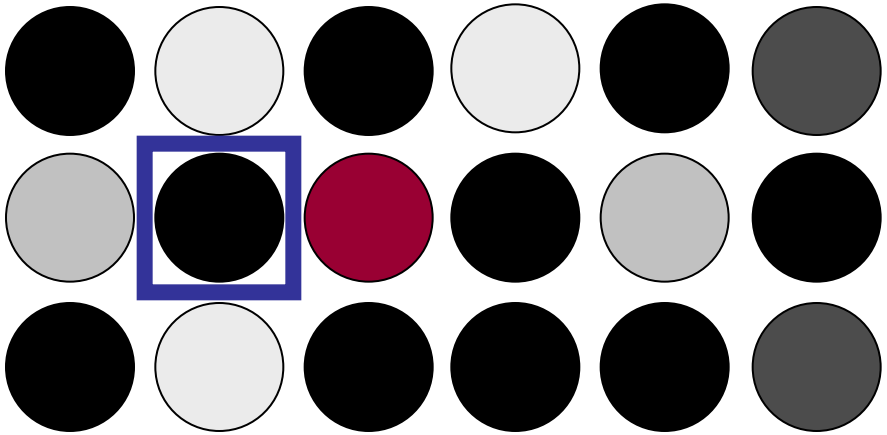


flash



inside shadow outside shadow

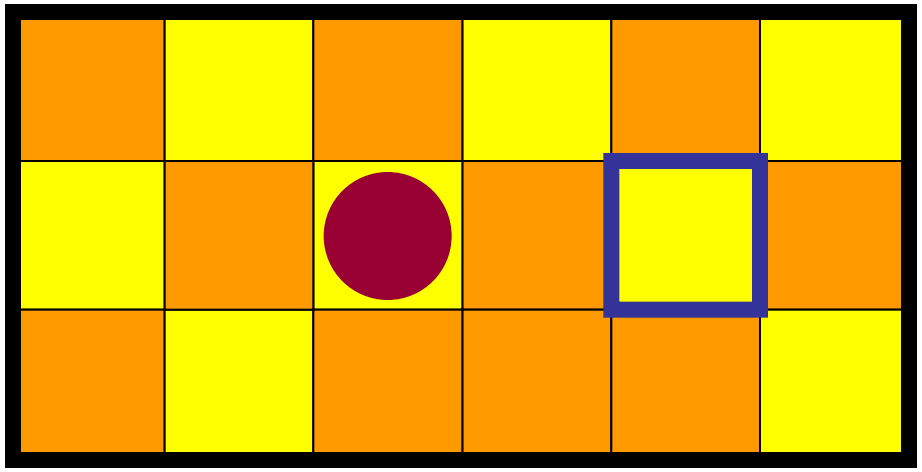
spatial and color weights



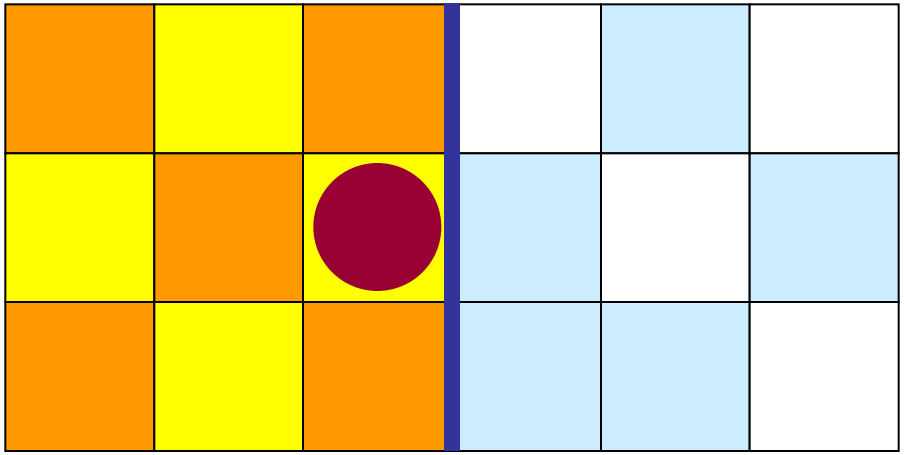
Eisemann's slides

Shadow Color Correction

no-flash



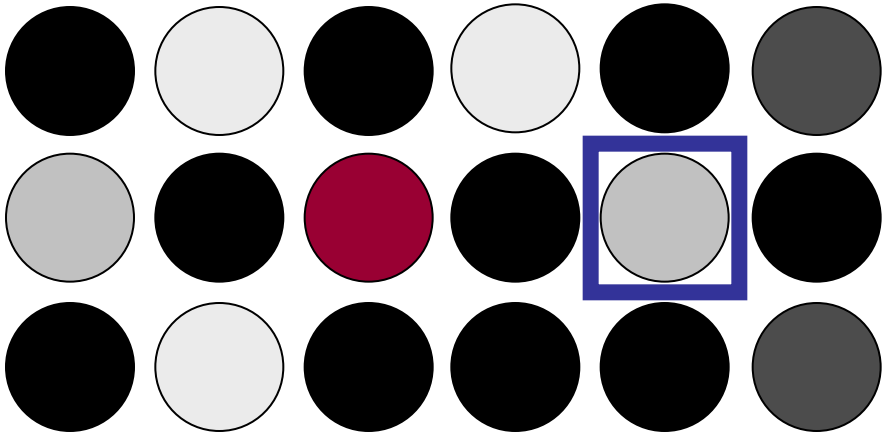
flash



inside shadow

outside shadow

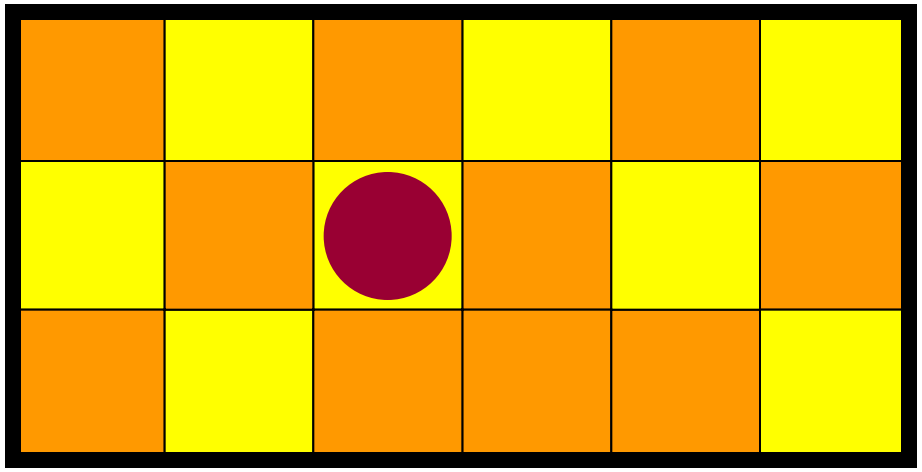
spatial and color weights



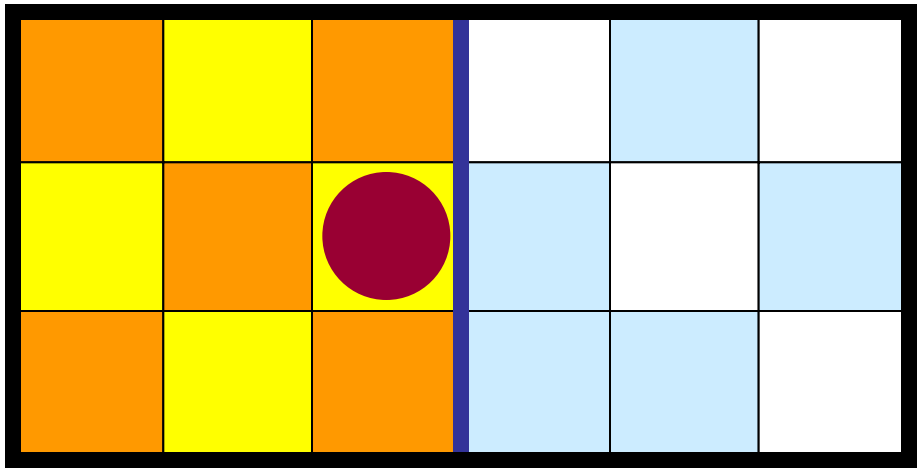
Eisemann's slides

Shadow Color Correction

no-flash

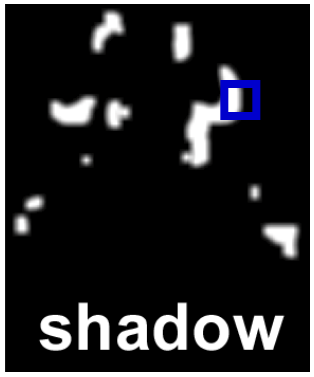


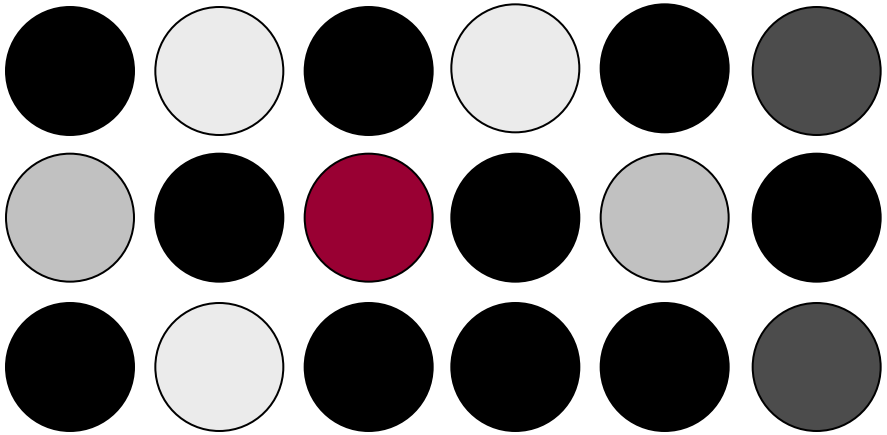
flash



inside shadow outside shadow

use shadow mask

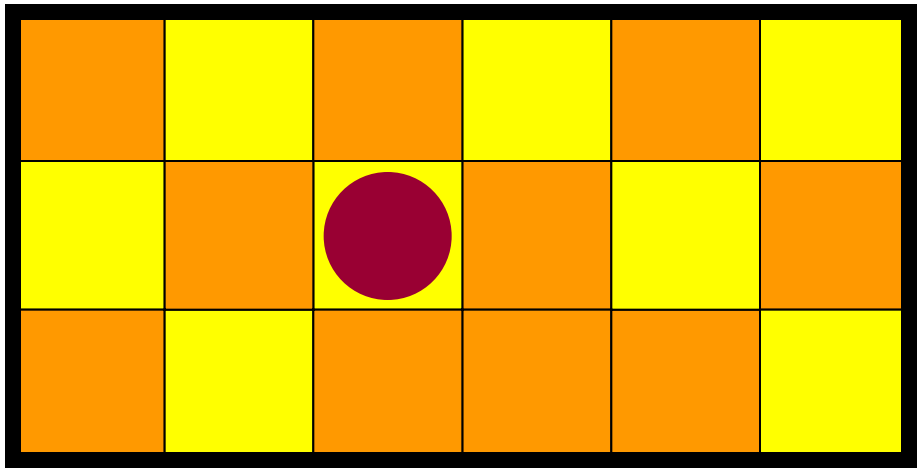




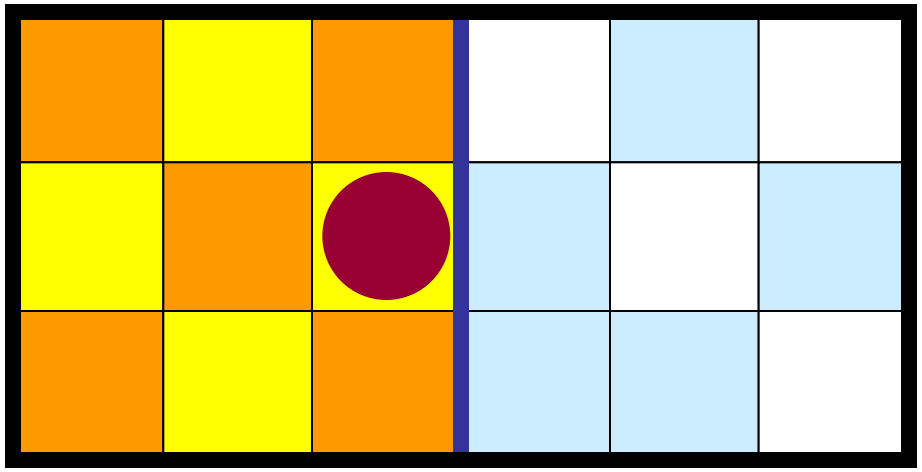
Eisemann's slides

Shadow Color Correction

no-flash

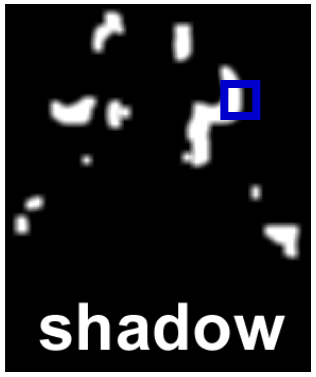


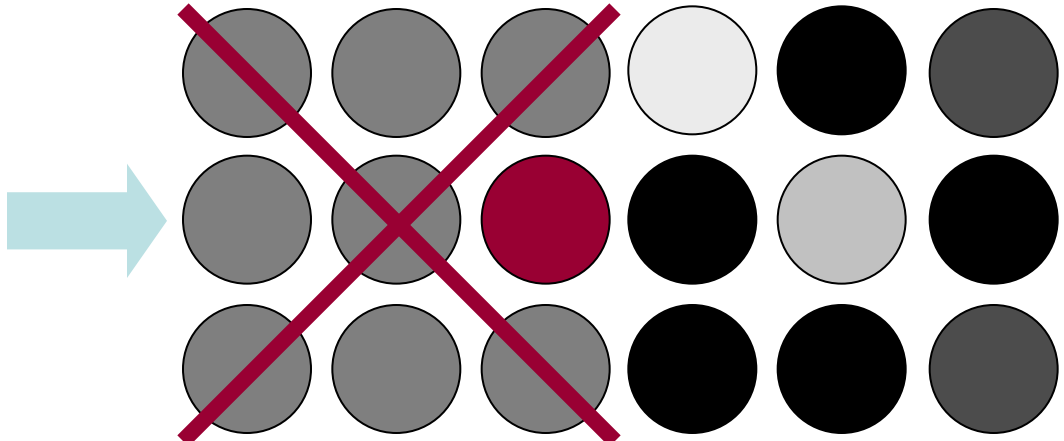
flash



inside shadow outside shadow

use shadow mask

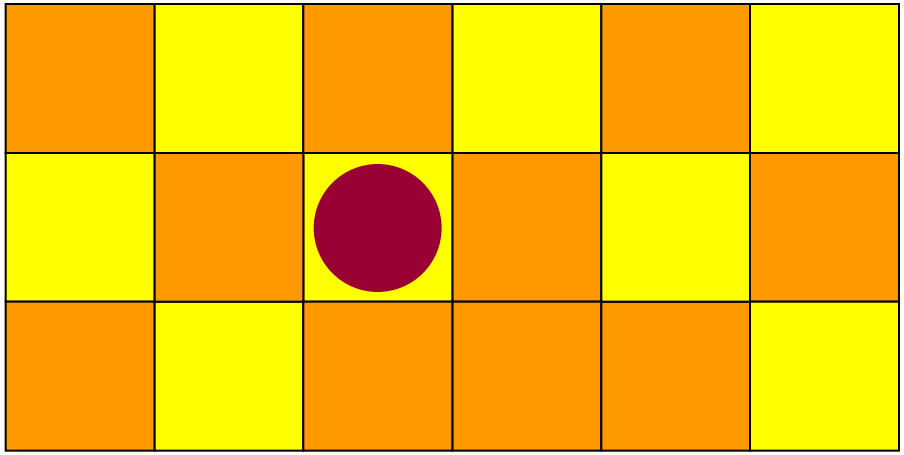




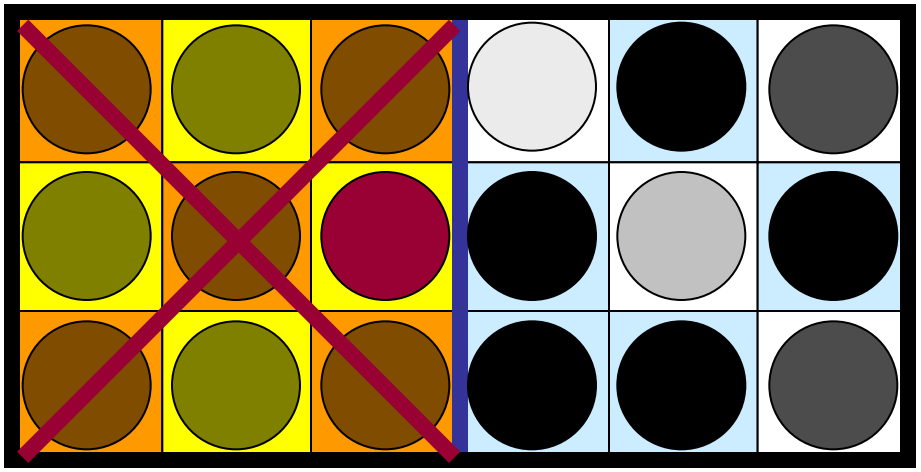
Eisemann's slides

Shadow Color Correction

no-flash



flash



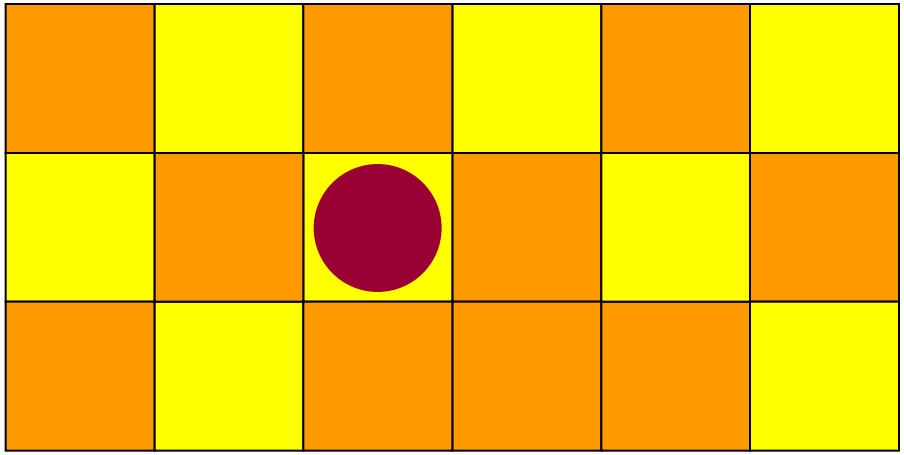
inside shadow outside shadow

use shadow mask

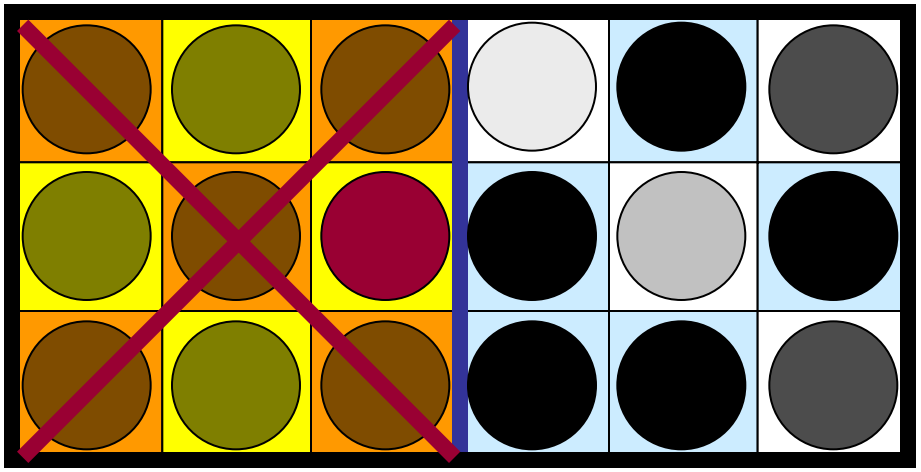
Eisemann's slides

Shadow Color Correction

no-flash



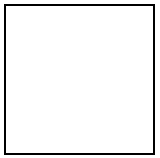
flash



inside shadow outside shadow

use weights on flash color

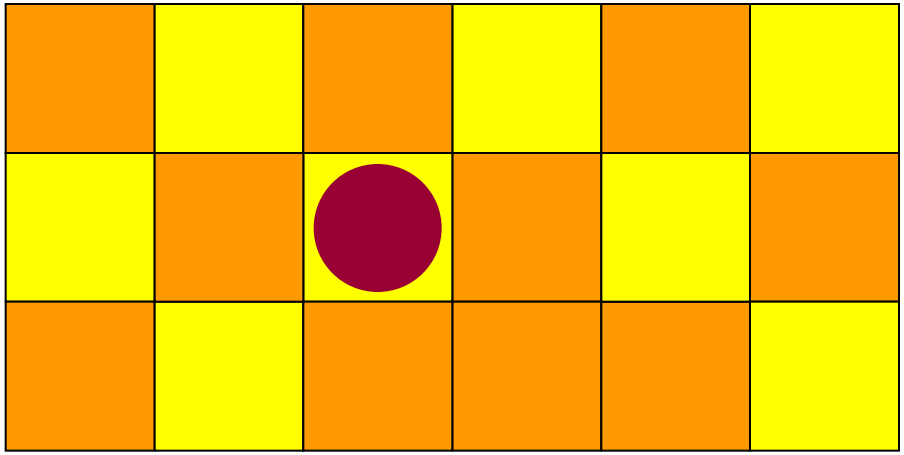
filtered result



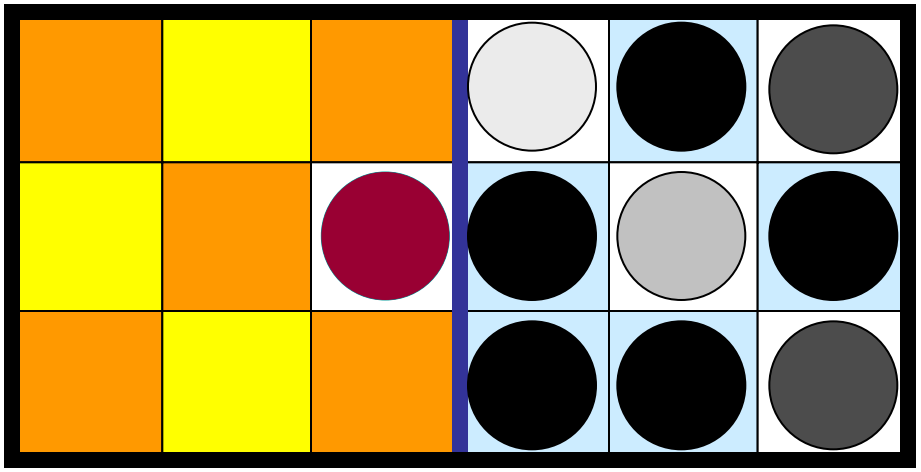
Eisemann's slides

Shadow Color Correction

no-flash



flash



inside shadow

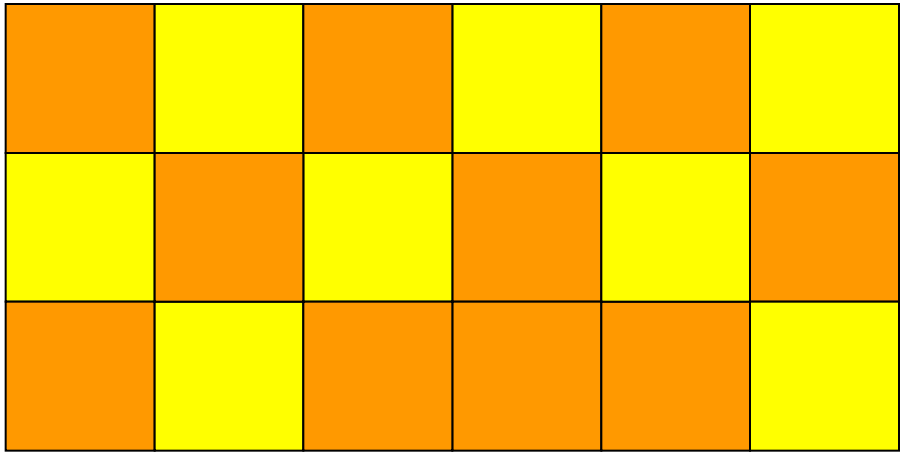
outside shadow

replace shadow pixel

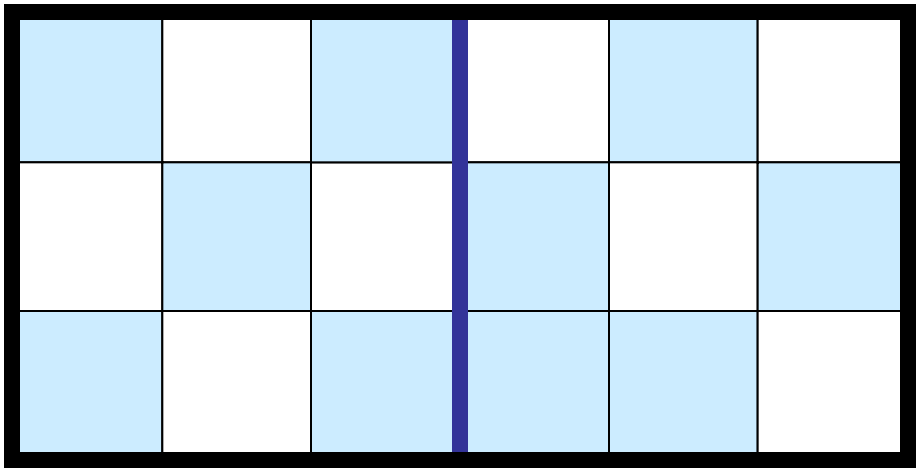
Eisemann's slides

Shadow Color Correction

no-flash



flash



inside shadow outside shadow

proceed for all shadow pixels

no-flash

flash

no-flash

flash

no-flash

flash

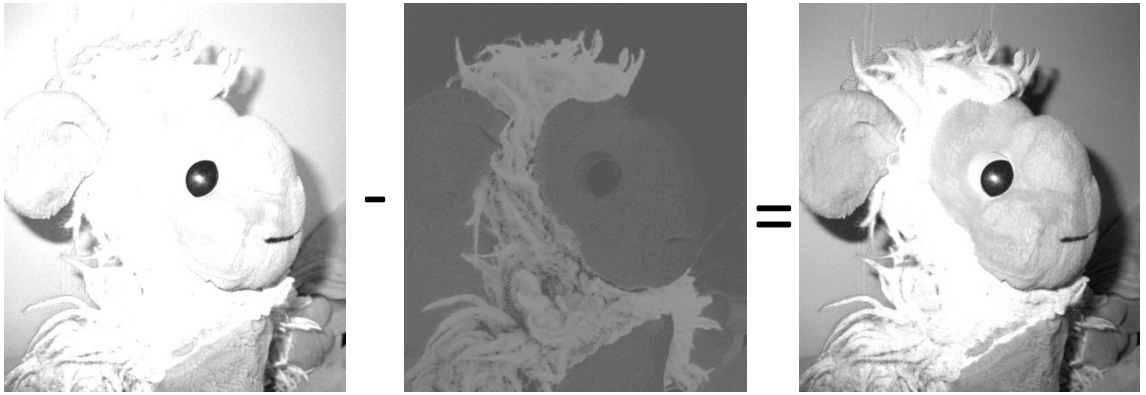
Emphasize Foreground

exploit $1/r^2$ flash intensity falloff

pseudo-distance

Pseudo-Distance

- Use shadow-corrected ΔI as pseudo-distance
  - Pixels in shadow are assigned a pseudo-distance according to their neighbors (bilateral filtering)



flash no-flash **DI**

- Multiply the large scale layer of the no-flash image by the pseudo-distance

(Inverse) White Balance


```
(1/W_r^t) * O_nf(:,:,1)
(1/W_g^t) * O_nf(:,:,2)
(1/W_b^t) * O_nf(:,:,3)
```

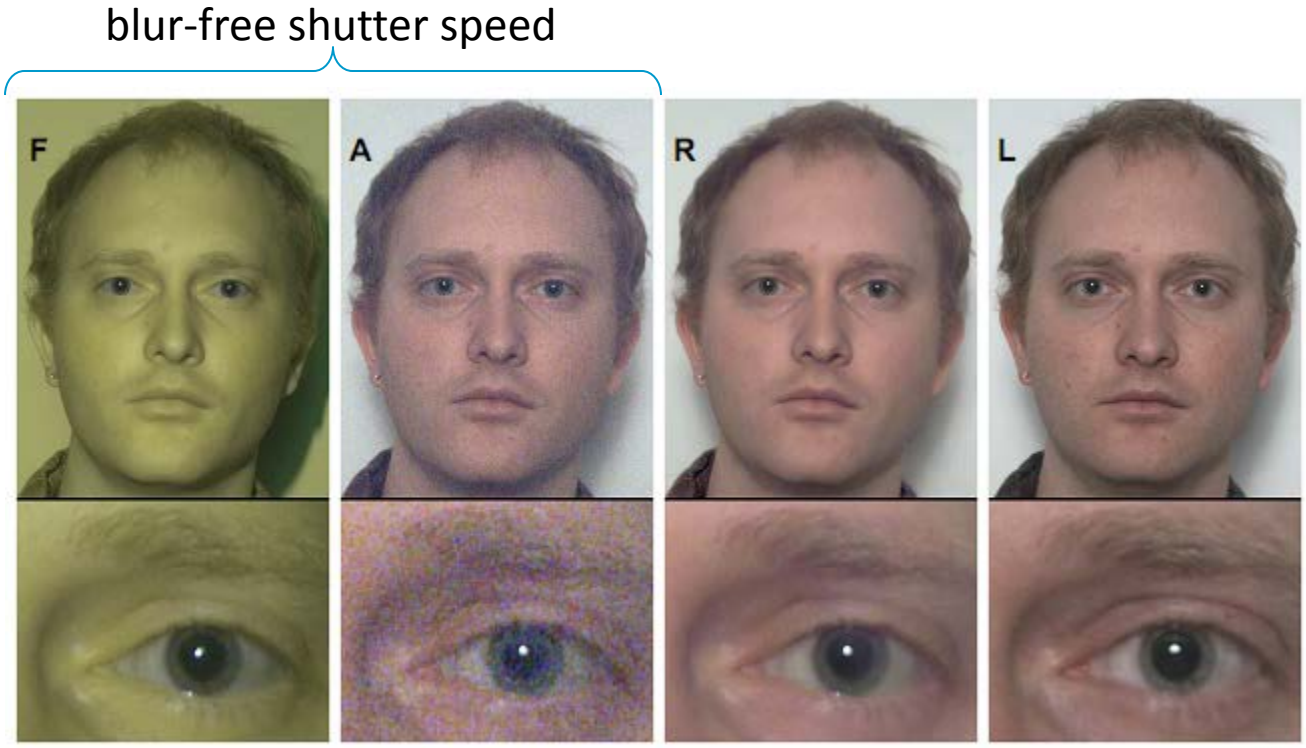
retain warm tones from available lighting

- *Flash Photography Enhancement via Intrinsic Relighting*
  - Eisemann and Durand

- *Dark Flash Photography*
  - Krishnan amd Fergus
  - SIGGRAPH 2009

Dark Flash Photography

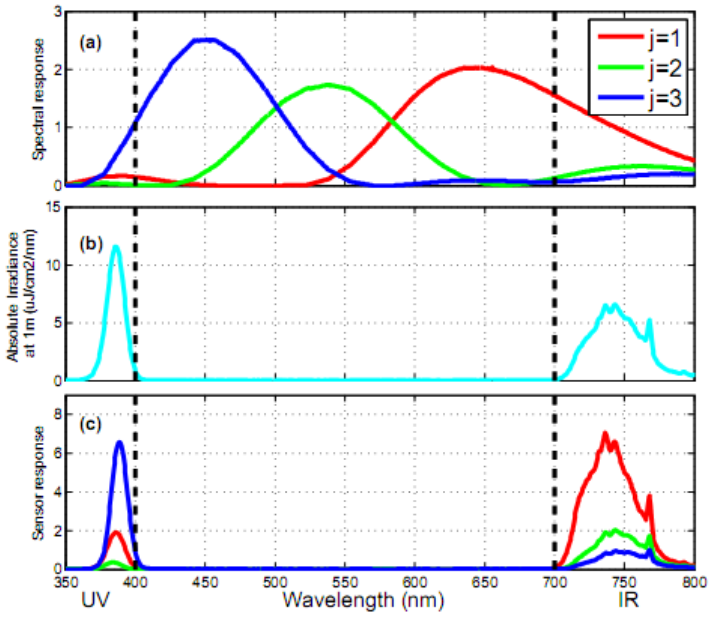
- Use a standard DLSR with the IR-block filter removed
- Multi-spectral flash (non-visible wavelengths)



Dark Flash Model

$$F_j(p) = \int C_j(\lambda) I^f(\lambda) S(p,\lambda)\ d\lambda$$

*j*th channel — response curve — dark flash — reflectance



$C_j(\lambda)$

$I^f(\lambda)$

$C_j(\lambda) I^f(\lambda)$

Spatial-Spectral Cost Function

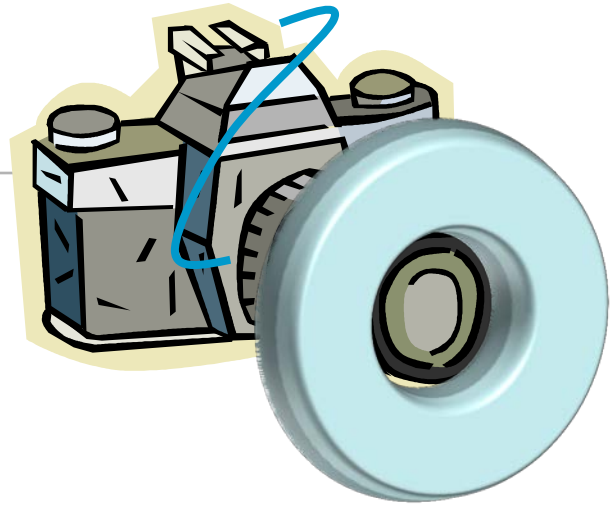
shadow mask

$$\underset{R_j}{\operatorname{argmin}} \sum_p \Big[\underbrace{\mu_j \, m(p)(R_j(p) - A_j(p))^2}_{\text{Likelihood}} + \underbrace{\kappa \, m(p)|\nabla R_j(p)|^\alpha}_{\text{Spatial}} + \underbrace{|\nabla R_j(p) - \nabla F_1(p)|^\alpha}_{\text{IR Spectral}} + \underbrace{|\nabla R_j(p) - \nabla F_3(p)|^\alpha}_{\text{UV Spectral}} \Big]$$

Reconstructed

$\alpha \leq 1$ → sparse

Ring Light/Flash



- Portrait and fashion photography

- DIY ring light
  - https://www.youtube.com/watch?v=ilt2pytLF_E
- Faking a big shot
  - https://www.youtube.com/watch?v=LDUFLWFck_g
- Cheap camera challenge
  - https://www.youtube.com/watch?v=jDAnNjRJxOQ