Decoding bilateral filtering

Eq. 6 from fast bilateral filtering:

$$J_s = \frac{1}{k(s)} \Sigma_{p \in \pi} f(p - s) g(I_p - I_s) I_p$$

Eq. 4 of Flash paper:

Joint bilateral filter:

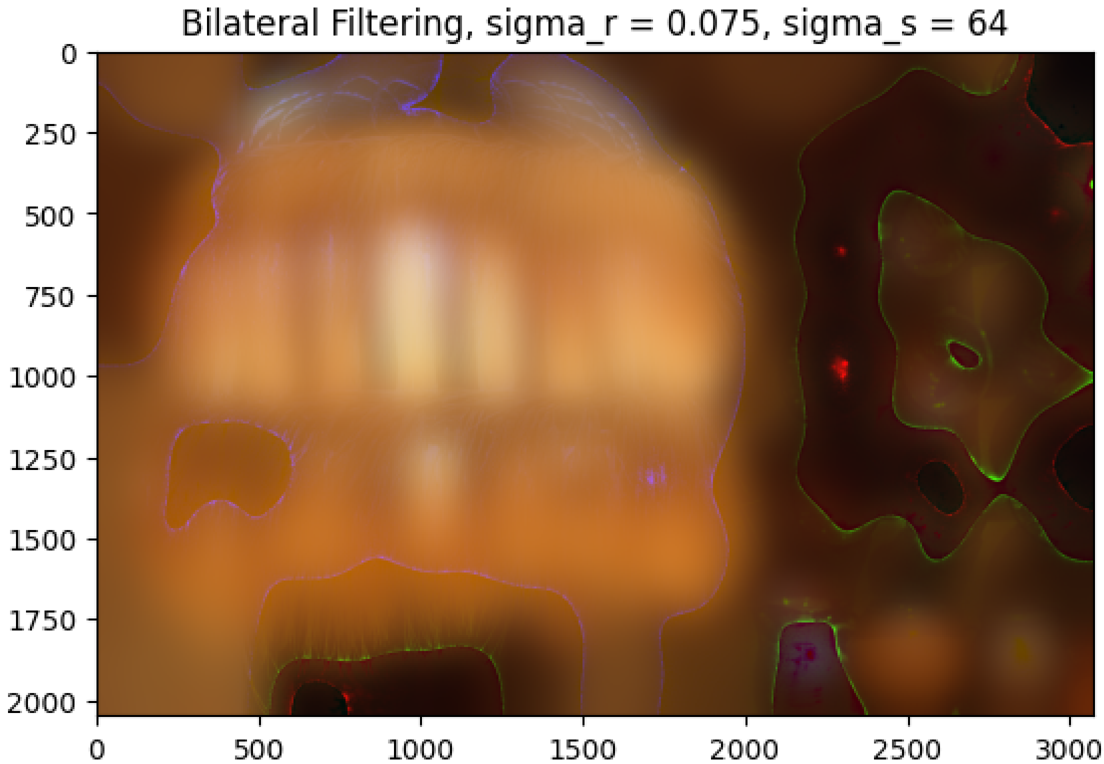
$$A_{NR} = \frac{1}{k(s)} \Sigma_{p \in \pi} f(p - s) g(F_p - F_s) I_p$$

Bilateral Filtering

Varying σ_s: (Notice the over-blurring and loss of detail in higher values)

σ_s = 64 | σ_s = 16

- | -



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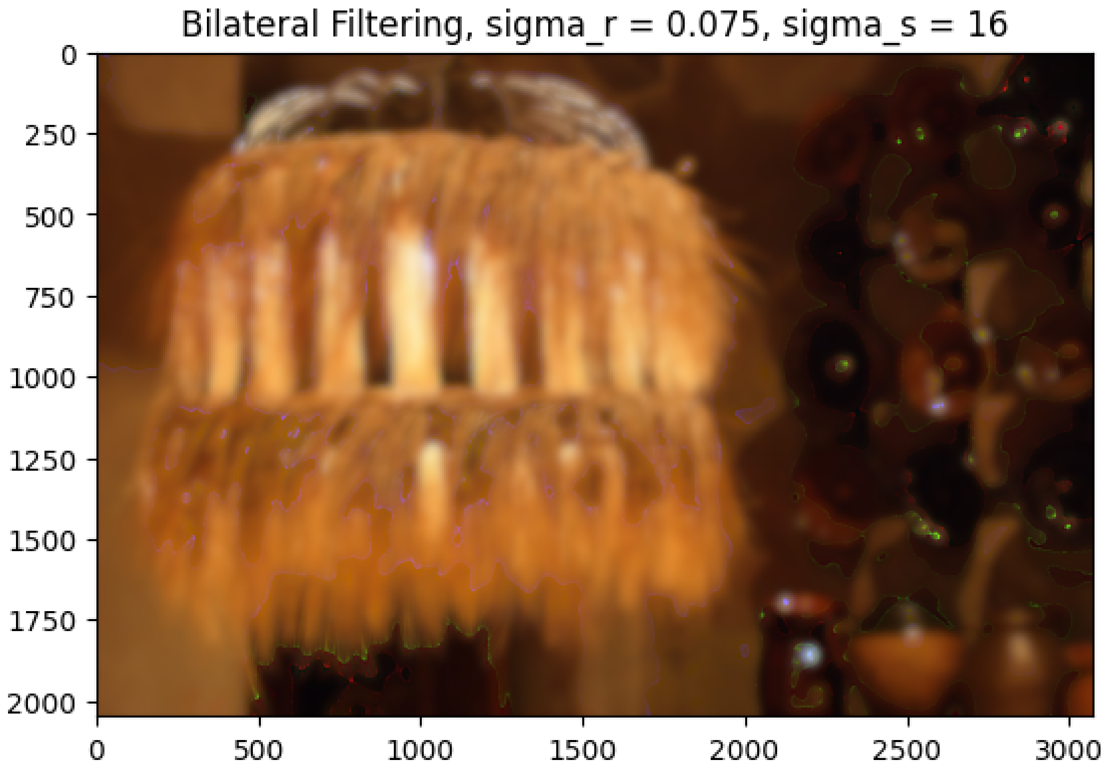
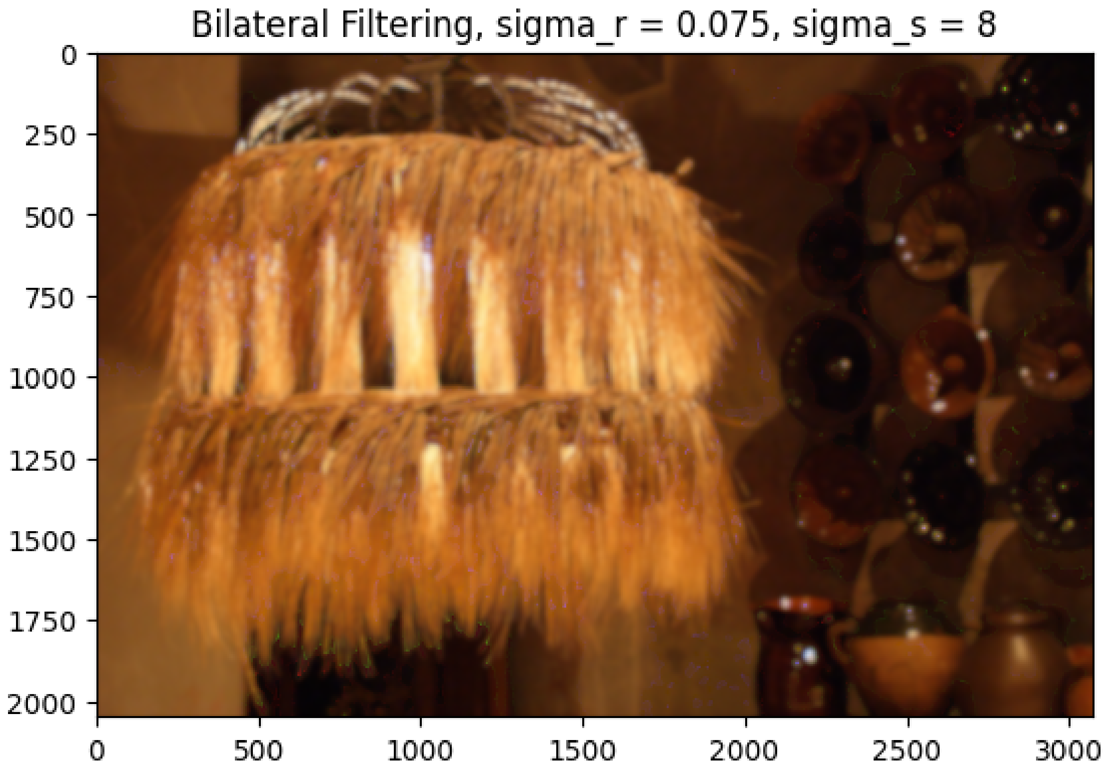


σ_s = 8 | σ_s = 4 | σ_s = 1

- | - | -



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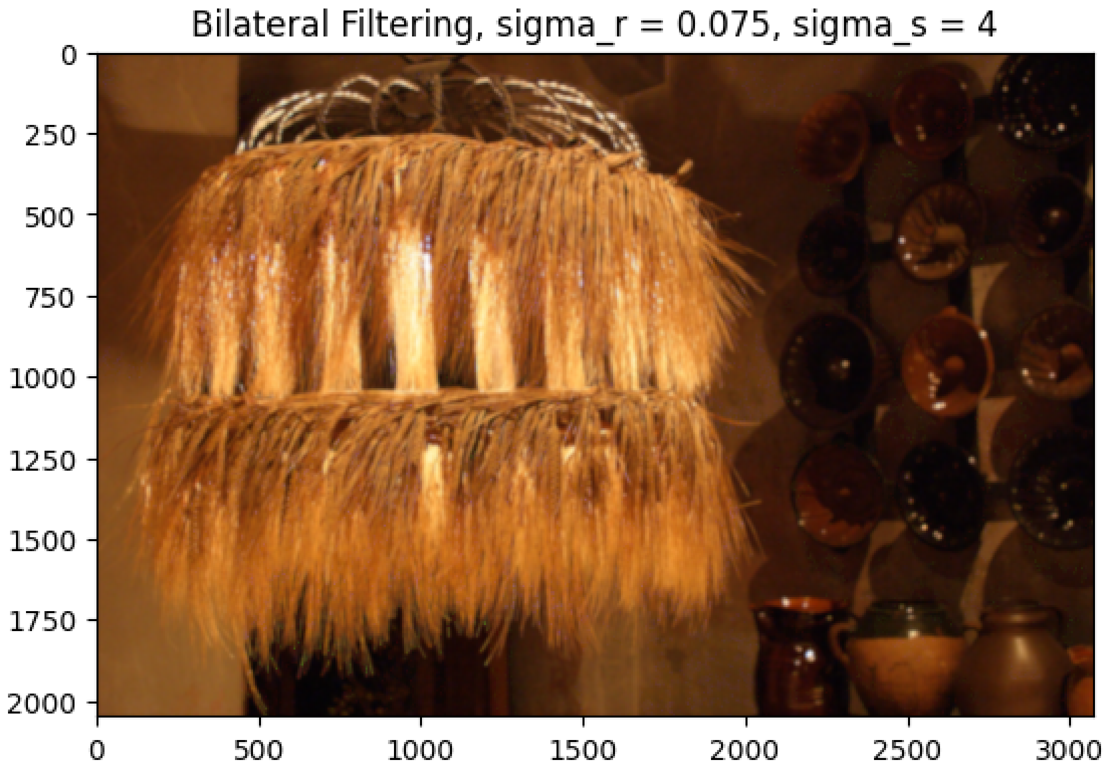

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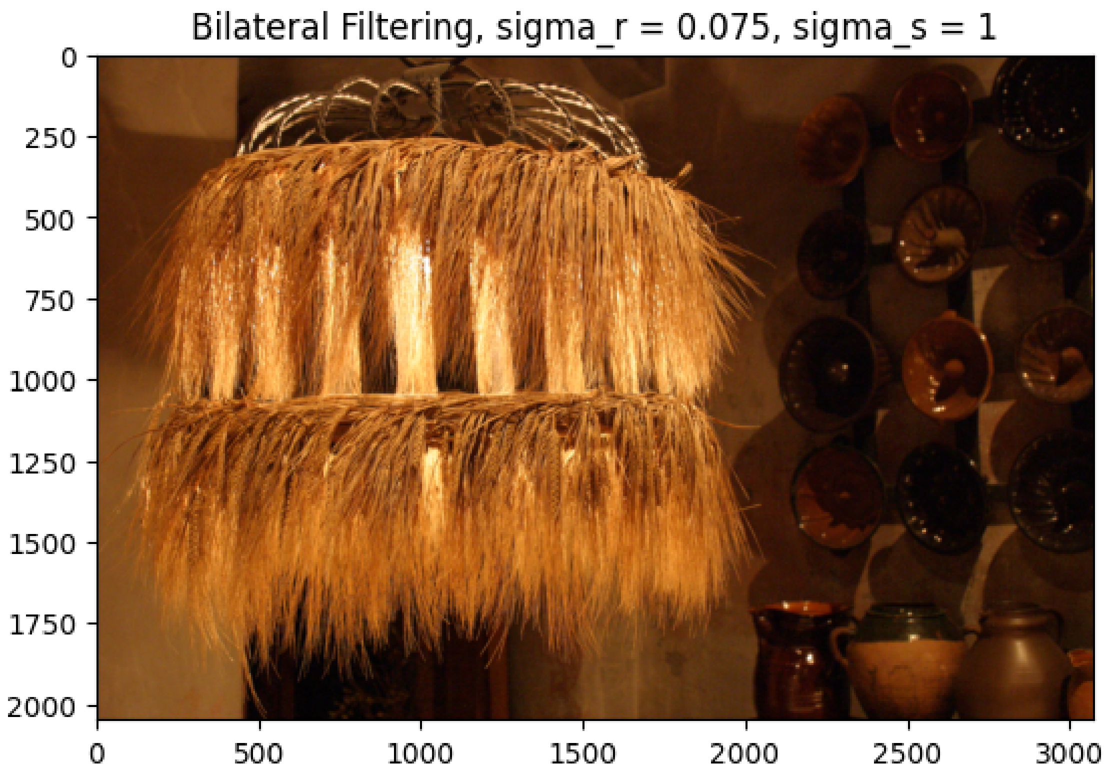
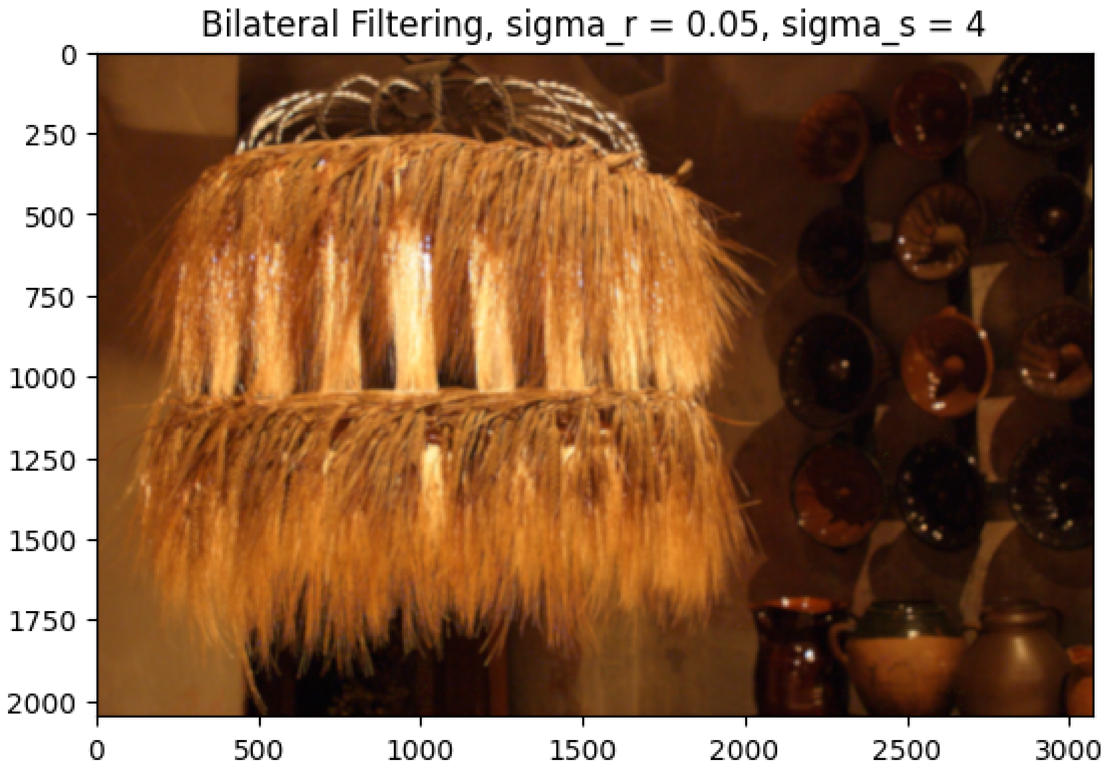


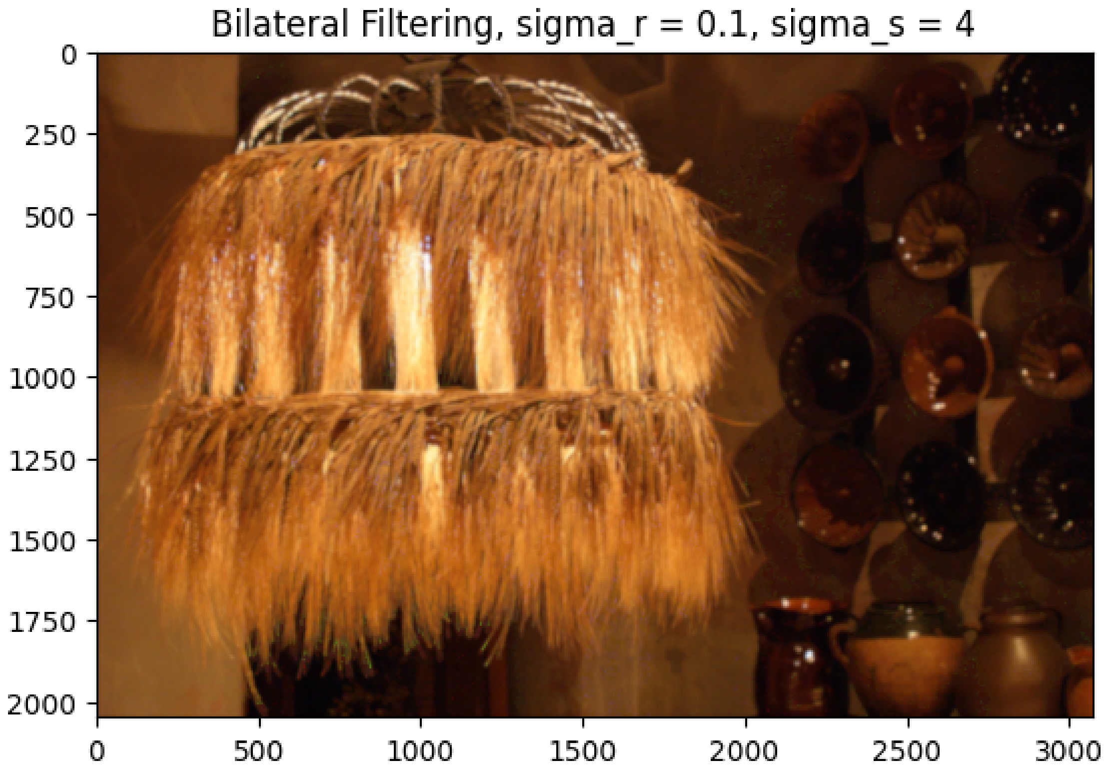
Varying σ_r: (Notice the green artifacts as we increase σ_r by a lot)

σ_s = 0.05 | σ_s = 0.1 | σ_s = 0.15 | σ_r = 0.25

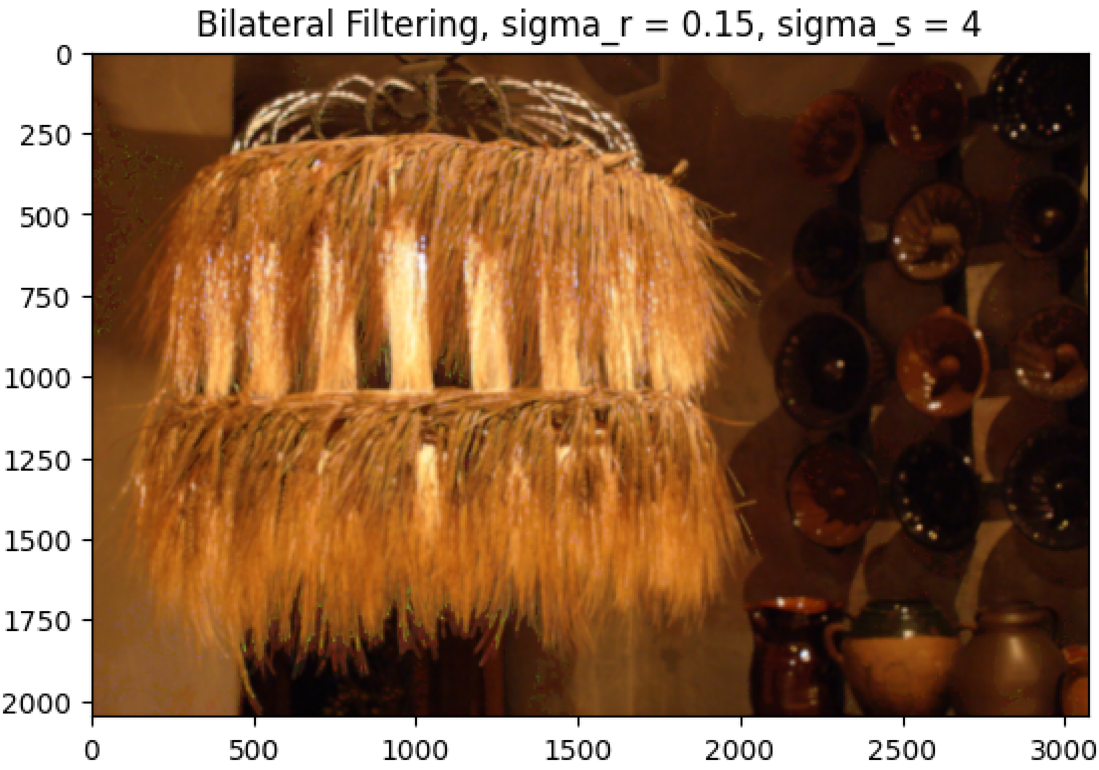
- | - | - | -


Bilateral Filtering, sigma_r = 0.05, sigma_s = 4
0
250
500
750
1000
1250
1500
1750
2000
0
500
1000
1500
2000
2500
3000

|


Bilateral Filtering, sigma_r = 0.1, sigma_s = 4
0
250
500
750
1000
1250
1500
1750
2000
0
500
1000
1500
2000
2500
3000

|



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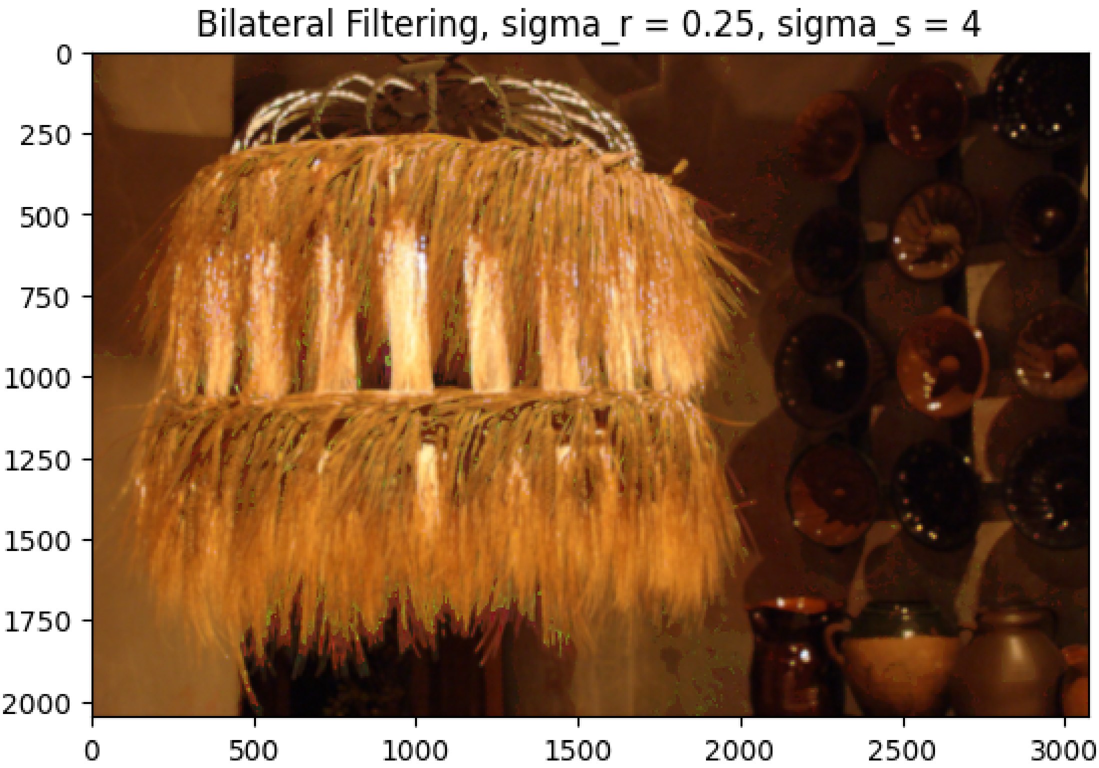


I use $\sigma_s = 0.1$ and $\sigma_r = 3$ for final bilateral filtering.

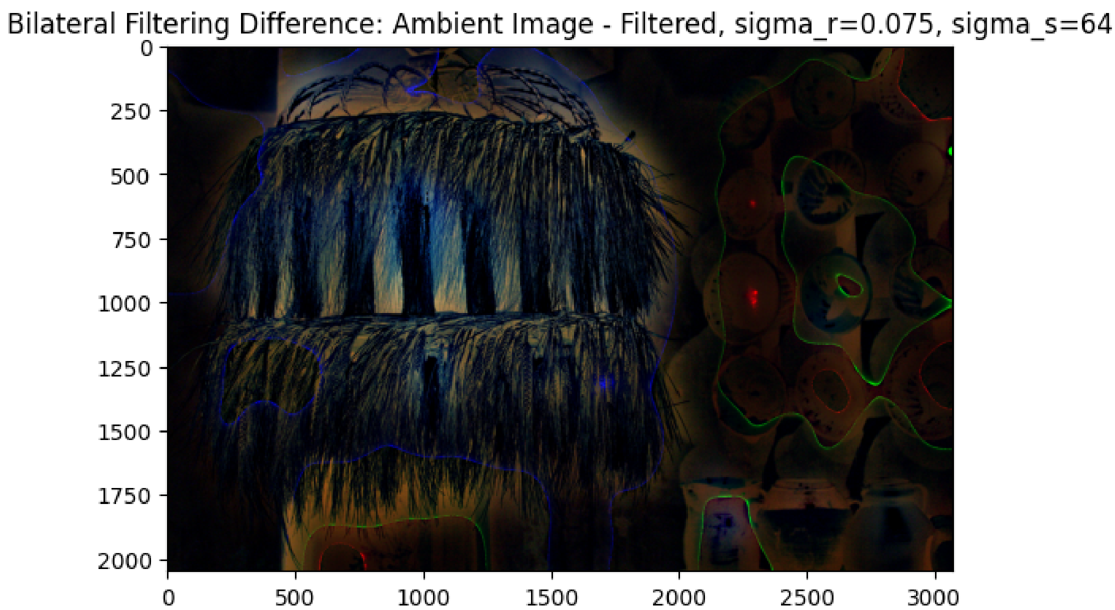
Some difference maps:

Final selected values | Higher σ_s | difference, max and min σ_r | difference, max and min σ_s

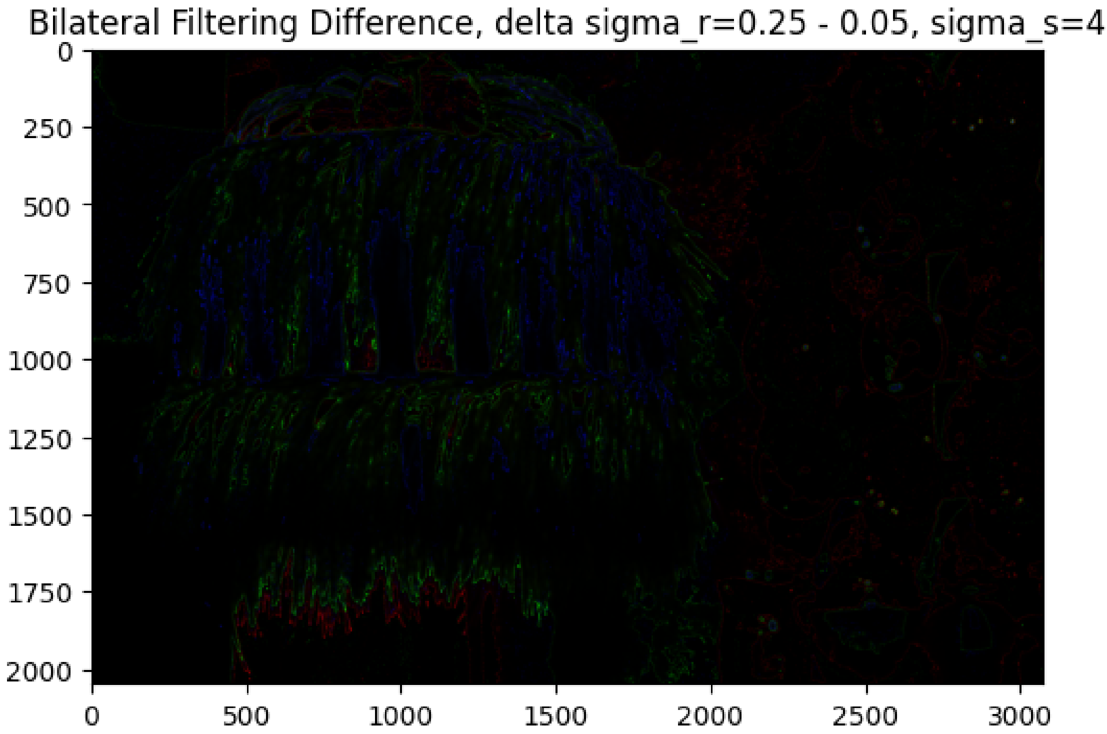
- | - | - | -

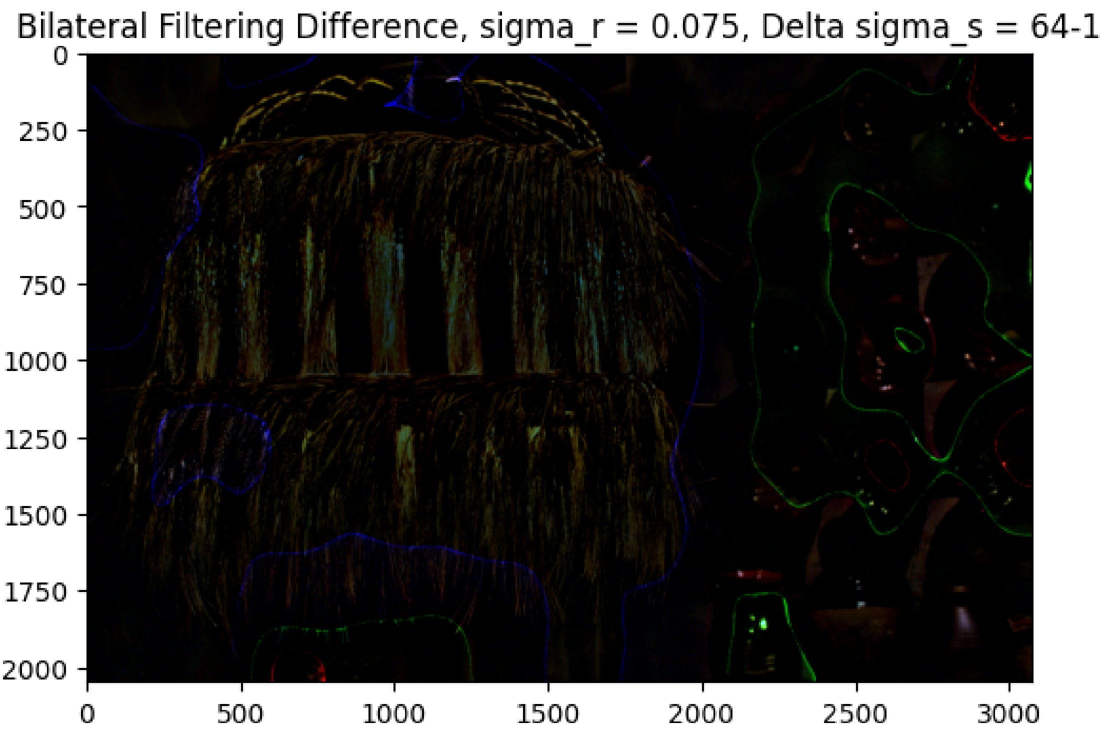

Bilateral Difference: Filtered-Ambient Image, sigma_r=0.1, sigma_s=3
0
250
500
750
1000
1250
1500
1750
2000
0
500
1000
1500
2000
2500
3000

|


Bilateral Filtering Difference: Ambient Image - Filtered, sigma_r=0.075, sigma_s=64
0
250
500
750
1000
1250
1500
1750
2000
0
500
1000
1500
2000
2500
3000

|





Joint Bilateral Filtering

Comparing basic and joint bilateral filters for same σ_r, σ_s as follows.

Observation: bilateral filter has more noise as compared to joint bilateral filter. The latter blurs by implementing the edge-stopping function on flash image which has more detail. It is more robust to noise as the flash image having less noise is used to select the details (implement the intensity gaussian function for edge-stopping). Visualizing the difference between output of bilateral and joint bilateral, we get the noise difference showing merit of joint bilateral filter:

Notice the contrast is visibly better.

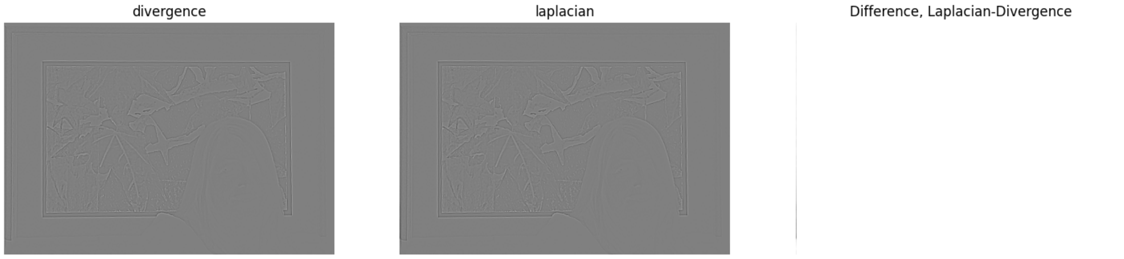
Next, Joint bilateral filtering uses the flash image F to compute intensity kernel g. Since F has little noise, the sensitivity of the filter to variance of intensity kernel σ_r is very interesting. I reduce σ_r by a large amount and observe that the filter output is robust and not very sensitive to the local neighbourhood pixel intensity (unlike bilateral filter which over-blur or under-blur due to local noise).

Detail Transfer

For generating F_{Detail}: as σ_r, σ_s are increased, F_{Base} is more smooth, hence F_{Detail} has sharper detail. I vary the amount of smoothing in F_{Base} used to create the F_{Detail} from the same noise-reduced ambient image (via joint bilateral filtering). Notice, as smoothing is increased $\sigma_s = 16$, there is more detail in F_{Detail} but at the same time I observe evident haloing effects on the edges of the round circles and bottom part of main light. F_{Base} might reduce to gaussian filter in such cases.

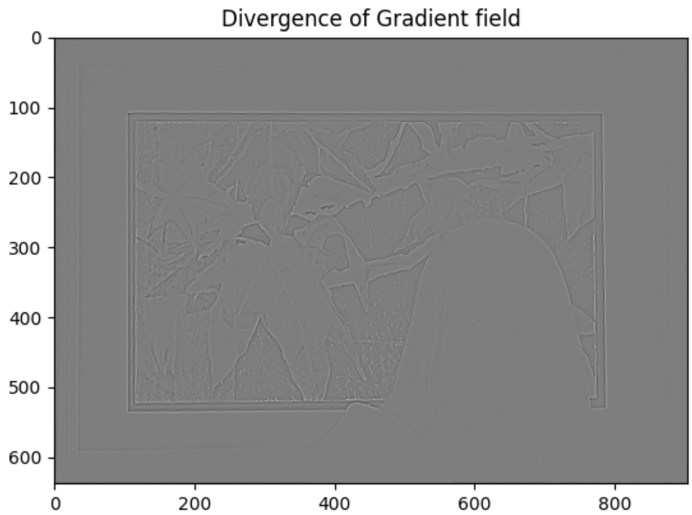
Differentiate and Re-integrate, Poisson solve implemenation

I first check my implementation of the gradient, divergence and laplacian is correct, has only non-zero borders:



Note, I inverted the 0s and 1s in order to be able to see the non-equal borders.

Next, I visualize the divergence of the gradient field (for a single channel):



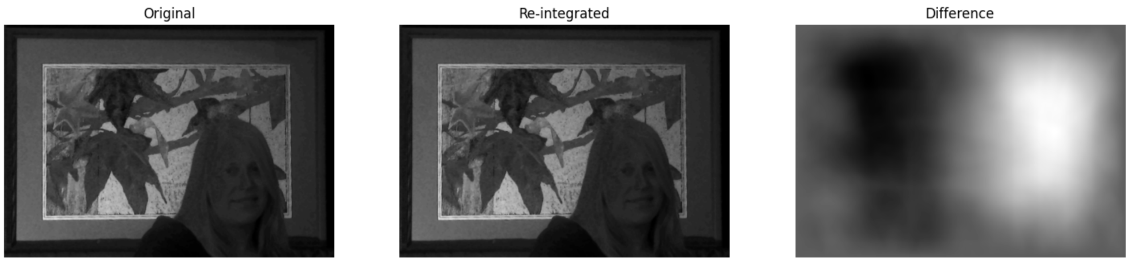
For a single channel, I re-integrate this and visualize the difference between original and re-integrated from poisson solver every 200 conjugate gradient descent iterations:

After 200

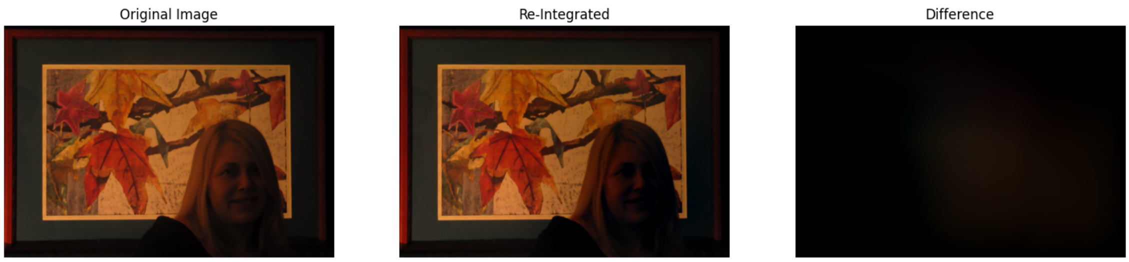
After 400

After 600

After 1000

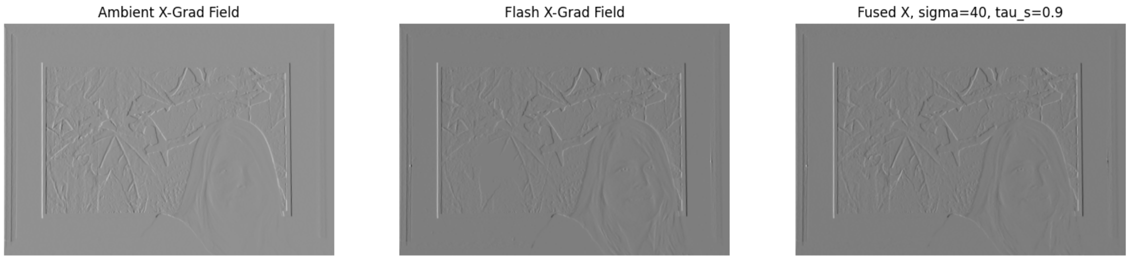


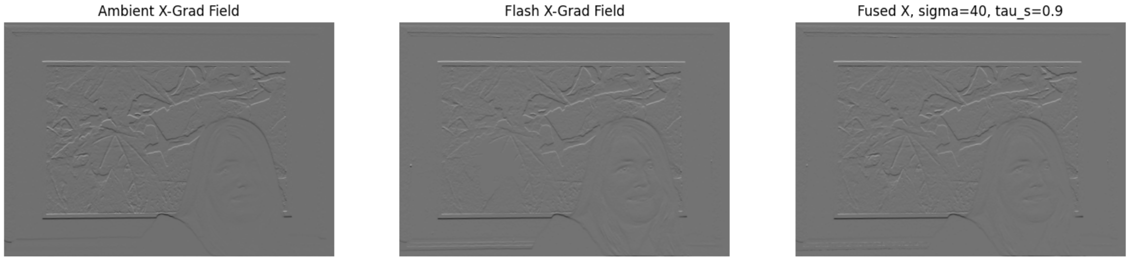
After 1000 steps, combining all 3 RGB images, I get back the following original and poisson integrated divergence of gradient: (found this really cool!)

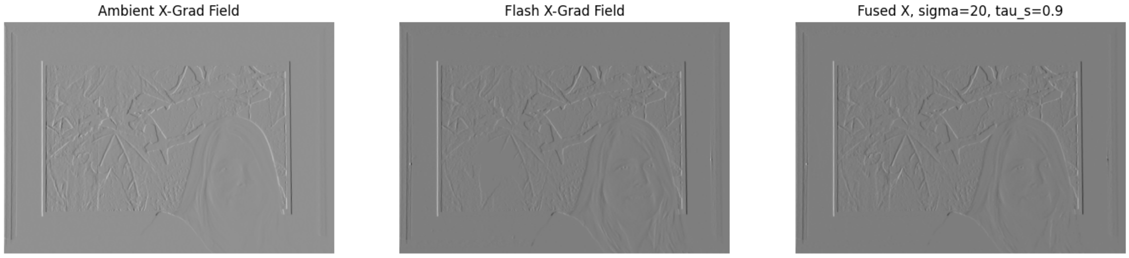


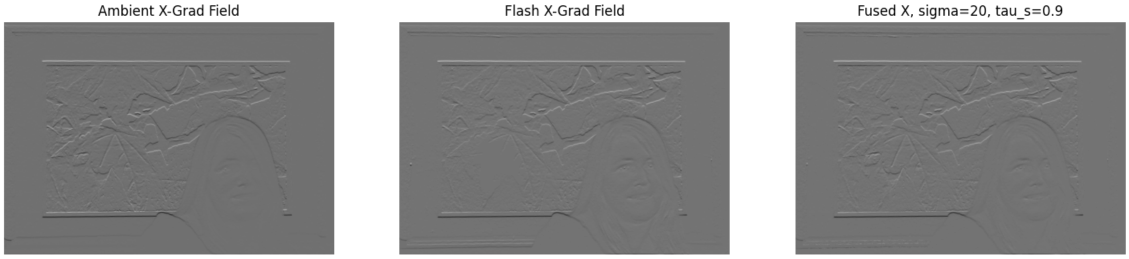
Creating fused gradient field

Variation in σ, τ_s, plotting separately for X-gradient and Y-gradient:



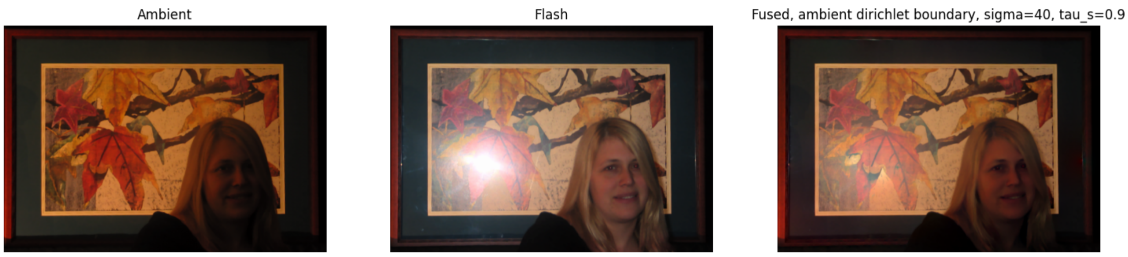






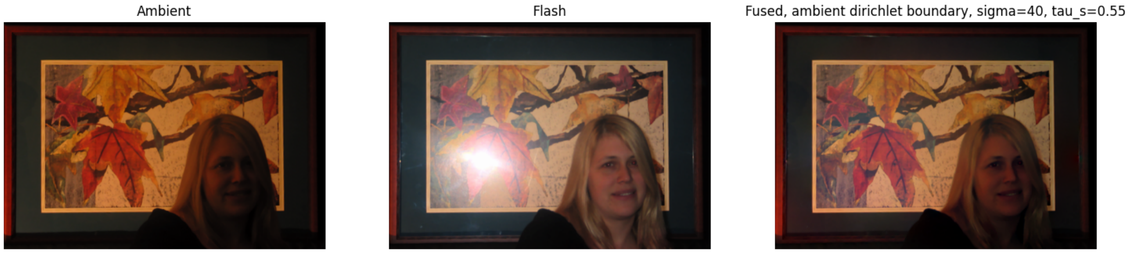
It was hard to tell just by comparing fused gradient field from the flash and ambient gradient fields. I found interesting trends plotting the integrated images over τ_s variation:

$\tau_s = 0.9$

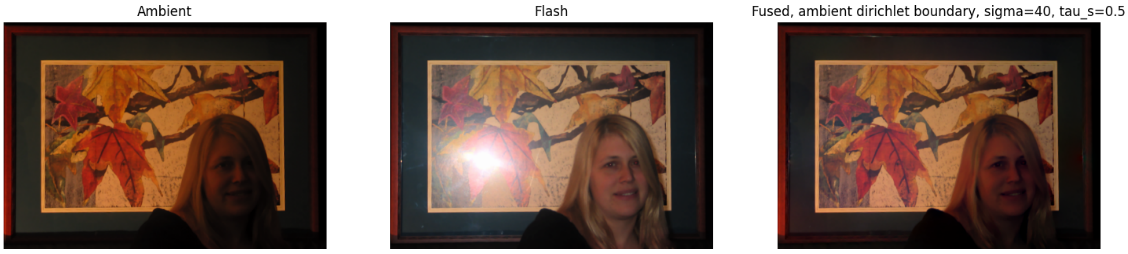


$\tau_s = 0.7$

$\tau_s = 0.55$



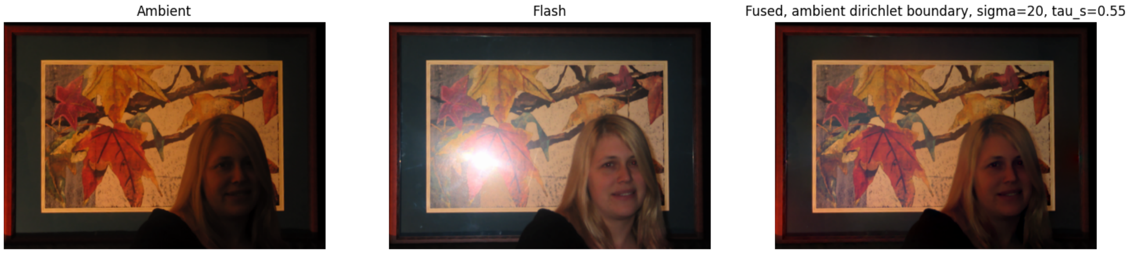
$\tau_s = 0.5$



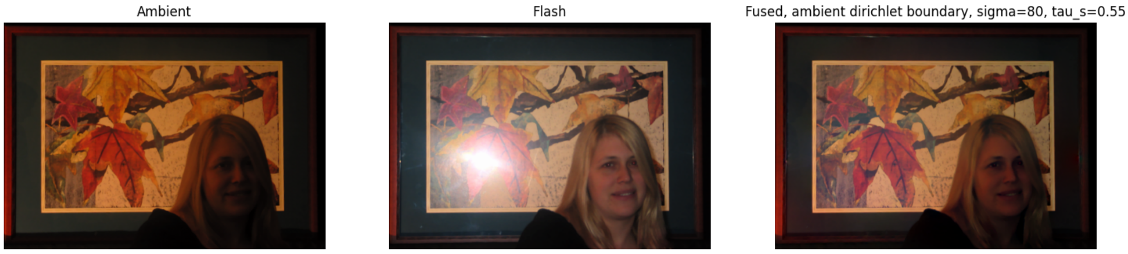
Notice, the contrast of the big red flower on painting is retained from ambient image best in $\tau_s = 0.5$, but the lady's face is the darkest. I get best trade-off in 0.55.

Also, variation in σ doesn't yeild much difference:

$\sigma = 20$



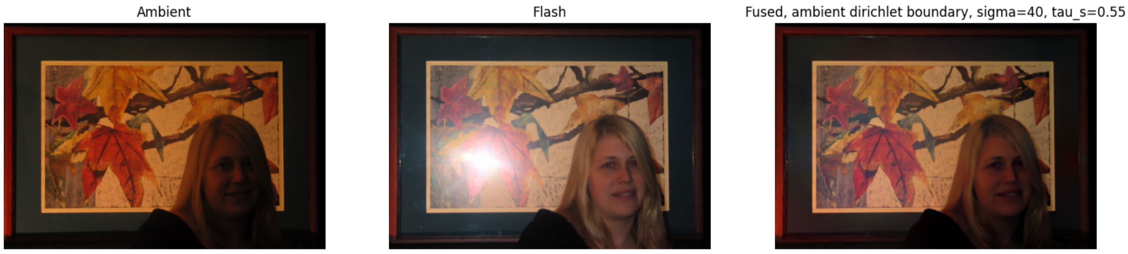
$\sigma = 80$



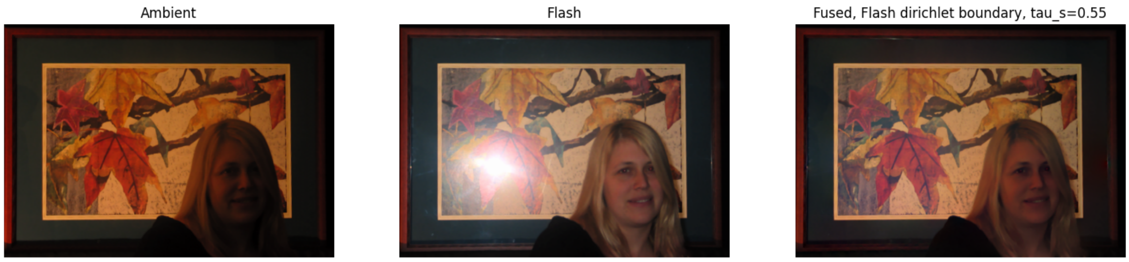
Finally, I select $\sigma = 40, \tau_s = 0.55$ for all next steps.

Boundary conditions

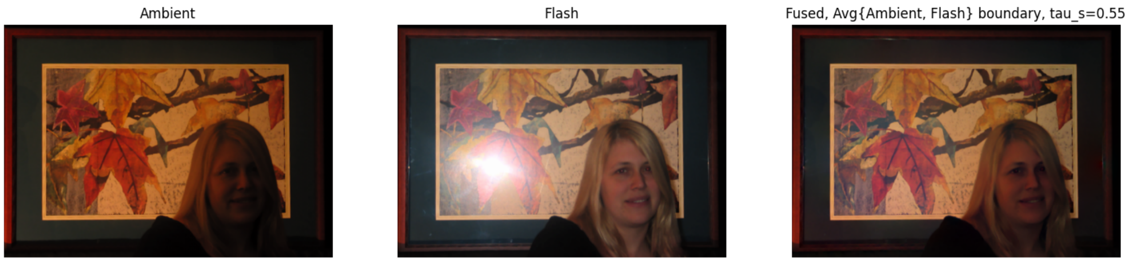
Set Ambient image as boundary pixels



Set Flash image as boundary pixels

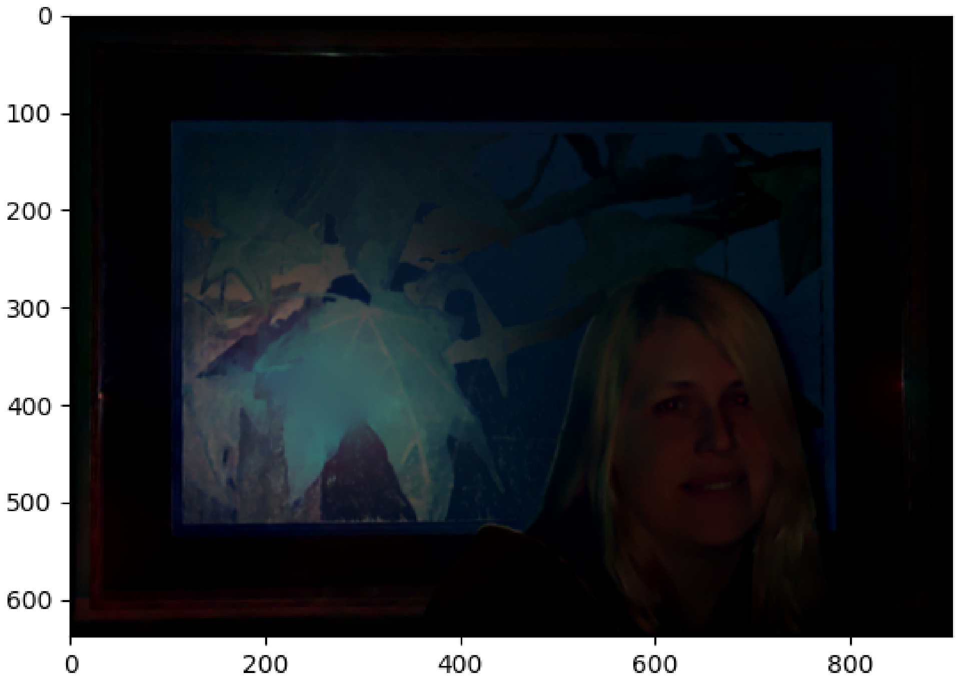


Set Average of Ambient and Flash image as boundary pixels



Averaged and flash boundary conditions seem to light up the lower parts of the lady's face. I use the averaged boundary conditions for Q3.

See difference between Ambient and gradient fused images:



Q3

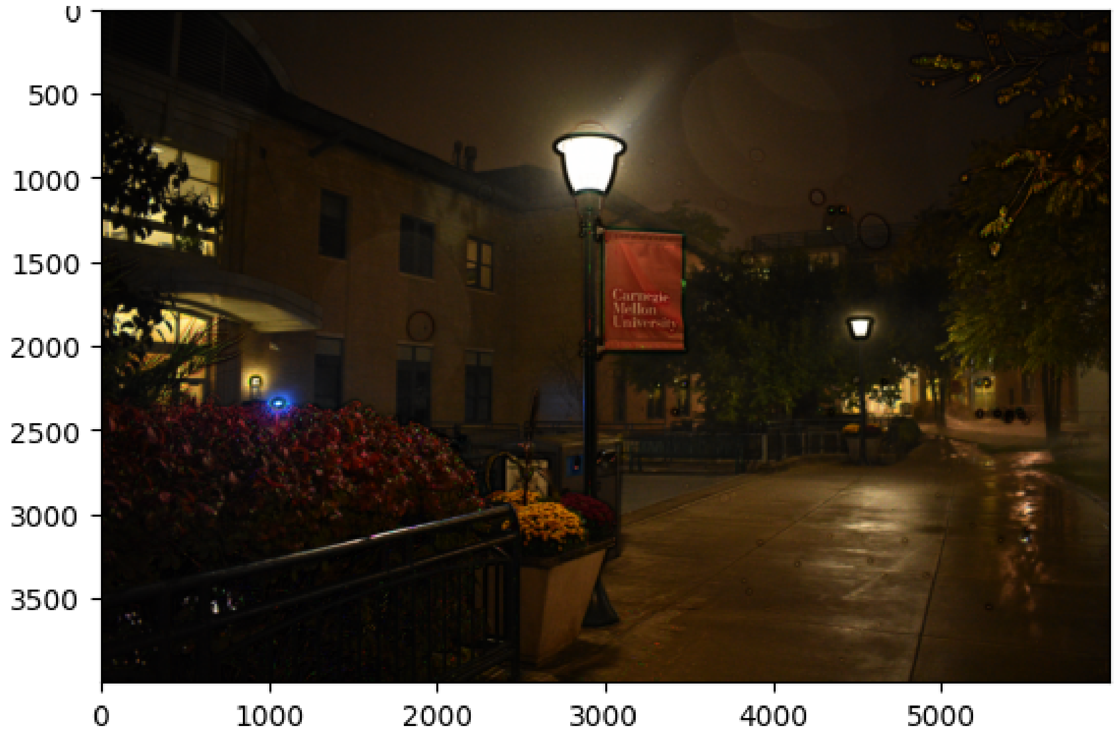
Disclaimer: both images seem slightly blurred due to slight motion in camera as I clicked buttons to change ISO and exposure time. Additionally, there was wind at the time of capture and objects like tree leaves have moved and there is inevitable motion blur. Also, in bilateral filtering image there is a circular blob at the top of the image due to rain droplet on the lens.

Bilateral

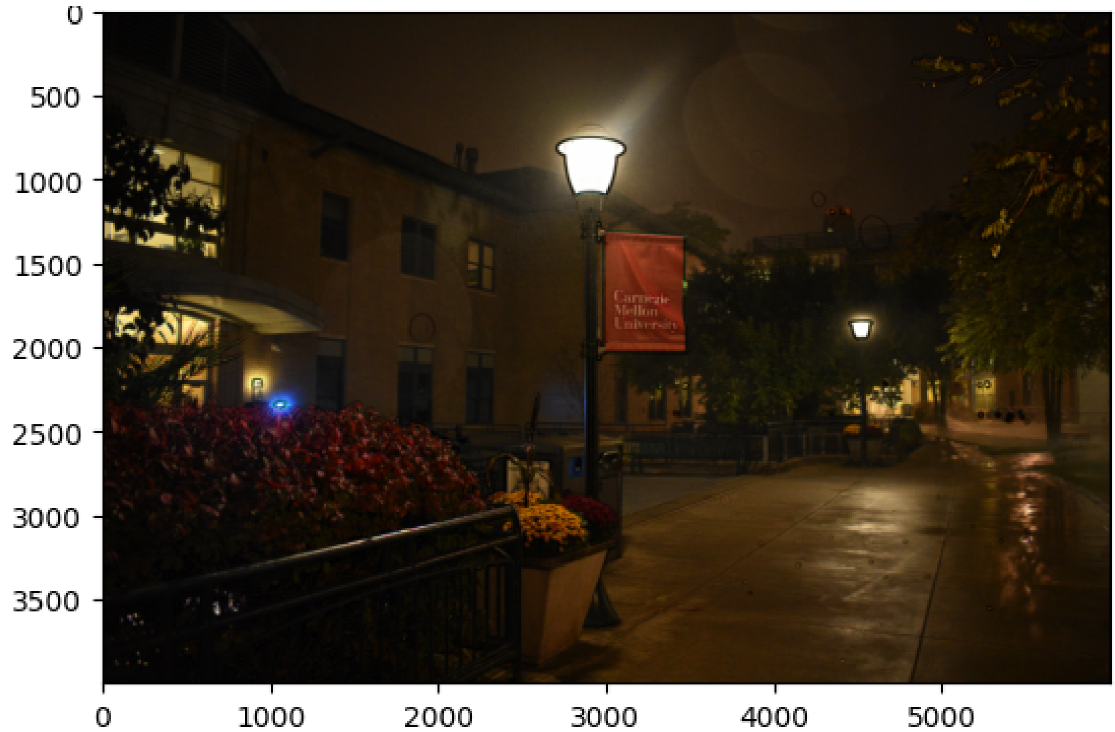
After applying joint bilateral filtering:

Difference Image: I encourage you to zoom in the original image to clearly see the leaves, noise on the windows (left side of image) and 'Carnegie Mellon University':

detail transfer $\sigma_r = 0.2, \sigma_s = 10$

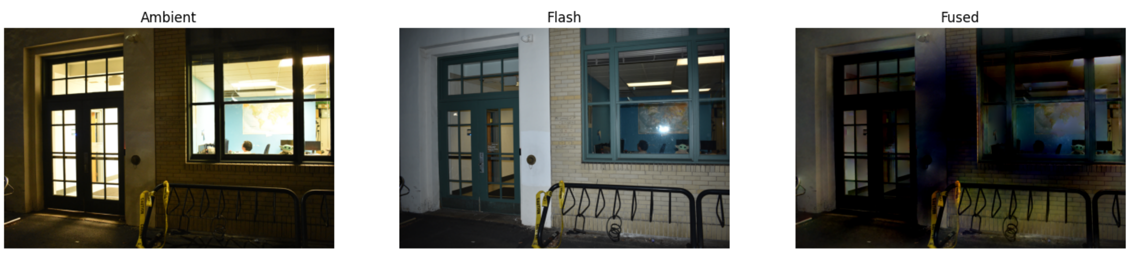


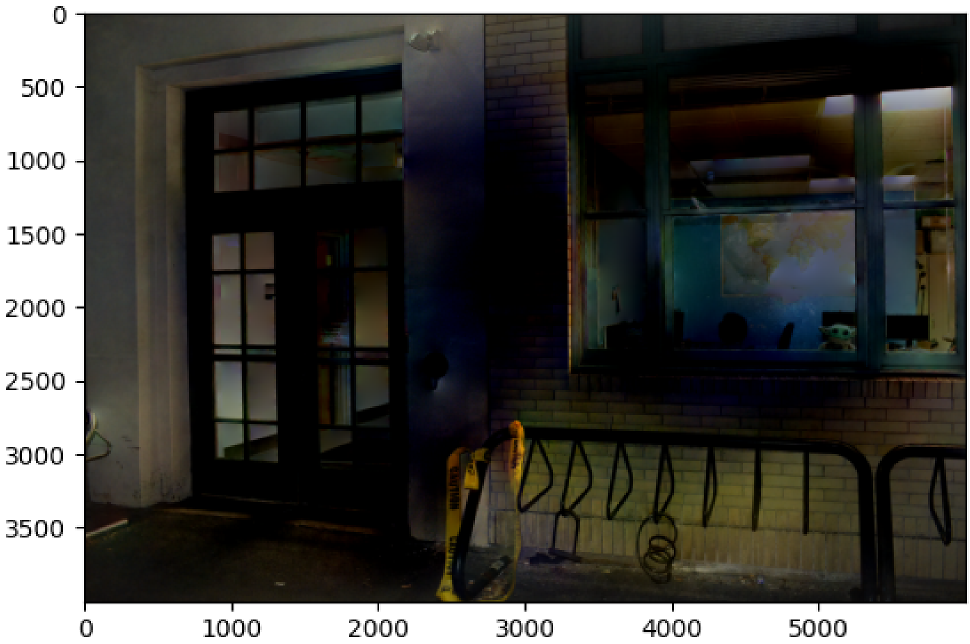
detail transfer $\sigma_r = 0.16, \sigma_s = 6$



Notice, this image is an example where flash lighting drops drastically with depth and flash image is not able to help much in the further away middle regions of the image.

Gradient Fusion and mirror reflection





observations:

- The flash-ambient gradient fusion effect is best exemplified in the bottom left of the image with the bike stands. They capture good detail from flash while preserving ambient lighting.
- The reflection from flash on mirror is successfully removed!!
- The person slightly moved in the 2 images leading to error in the rendering of the scene inside. Even though world map on the wall inside the Human sensing lab is still visible.
- The warning sign wrapped onto the bike stand was moving due to wind as a result has motion blur.
- The lighting inside the building is very strong potentially leading to the lighting effect in final image.