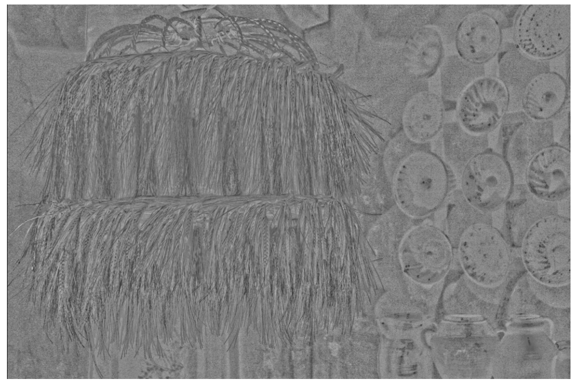
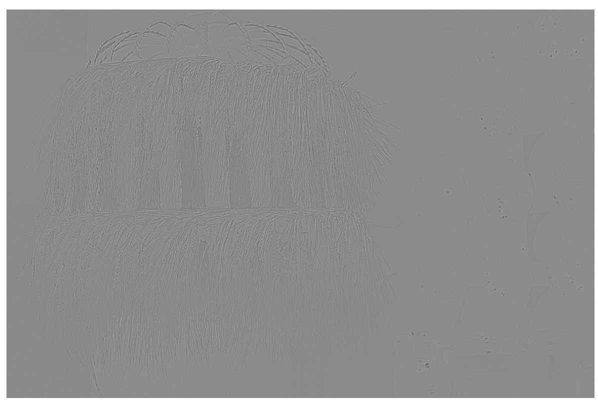
Answer 1

The provided image lamp_ambient.tif was used as an example in this section. Shown below are the outputs and the difference images at every step, starting from bilatering filtering to detail transfer and then to shadow/specularity masking

Step1 : A_{base} formed by piecewise bilateral filtering with $\boldsymbol{\sigma_r}$ **=0.05 and** $\boldsymbol{\sigma_s}$ **=32** From the difference image it can be seen that a lot of detail around the edges in the hay and the pottery has been smoothed out along with the noise

Step2 : A_{NR} formed by joint bilateral filtering with $\boldsymbol{\sigma_r}$ **=0.05 and** $\boldsymbol{\sigma_s}$ **=2** From the difference image it can be seen that the denoising is more cautious here, preserving a lot of the details. The effect is more subtle compared to the vanilla bilateral filter

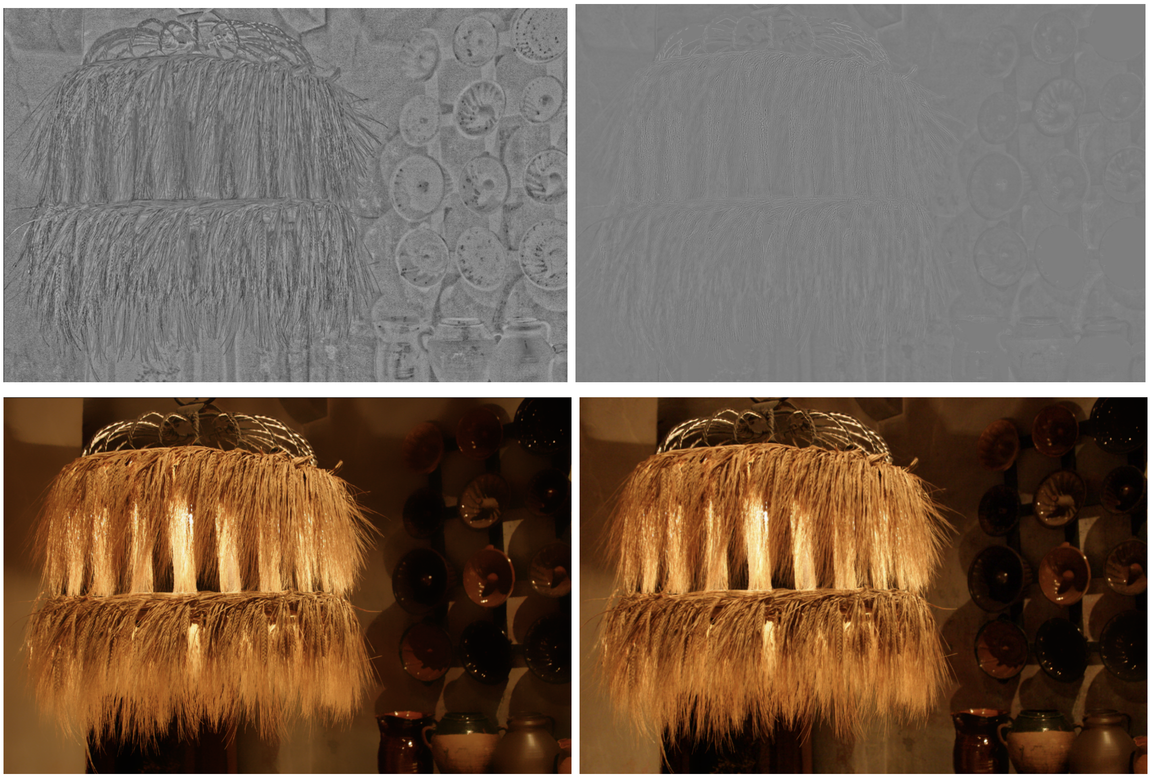
 

Step3 : A_{detail} formed after detail transfer. From the difference image with respect to A_{NR} it can be seen that this image has much more details in the hay of the lamp, in the pottery and in the circular structures on the right of the image

Step4 : A_{final} formed after shadow and specularity masking with $\boldsymbol{\tau_{shad}}$ **= 0.01**. From the difference image with respect to A_{detail} it can be seen that the main difference was made on the top of the map and in the pottery which were affected by the flash. It is to be noted that there are no major flash highlights and shadows in these pair of images, so the difference between step 3 and 4 is minimal

From here onwards, the joint bilateral filter refers to the final output after detail transfer and masking and vanilla bilateral filter refers to the simple piecewise bilateral filter. The piecewise bilateral filter by itself smooths most of the noise on the wall at the expense of a lot of details on the lamp, the pottery on the floor, and the wall itself. The joint bilateral filter manages to preserve a lot of details on the lamp and on the wall behind it, while still removing a lot of the noise. However, it is to be noted that the joint bilateral filter does a worse job of removing the noise compared to the vanilla bilateral filter at the expense of preserving those aforementioned details. The best results obtained from each of these filters along with the parameters are shown below



(Top left) Difference image of the vanilla bilateral filter output with the ambient image - The dark colours show that a lot of details in the hay of the lamp and the pottery was lost due to the smoothing. However the dark colors corresponding to dark regions in the image show that a lot of noise was also filtered out **(Bottom left) Output from vanilla bilateral filter with σ_r =0.05 and σ_s =32**

(Top right) Difference image of the joint bilateral filter output with the ambient image. The more subtle grey colors show that this filter was more cautious with the smoothing. It has also created a difference in the darker regions of the image where noise is usually present, but the effect is not as strong as the vanilla filter **(Bottom left) Output from joint bilateral filter after denoising and masking with σ_r =0.05 and σ_s =32 for A_{base}, σ_r =0.05 ; σ_s =2 for A_{NR} and σ_r =0.05 and σ_s =2 for F_{base} ; τ_{shad} = 0.01**

(Top left) The flash image showing the details on the wall. The wall looks old and is not of a single colour. The details on the pottery is also visible here **(Top right)** The output from vanilla bilateral filter has smoothed out all the details **(Bottom)** The output from the joint bilateral filter has preserved a lot of the details

(Top left) Output from the vanilla bilateral has smoothed out the noise and all the details on the wall (See bottom left flash image for details) **(Top right)** Ambient image with clearly visible noise **(Bottom left)** Flash image showing all the details/blemishes on the wall **(Bottom right)** Output from the joint bilateral filter has preserved some of the details on the wall at the expense of retaining some noise

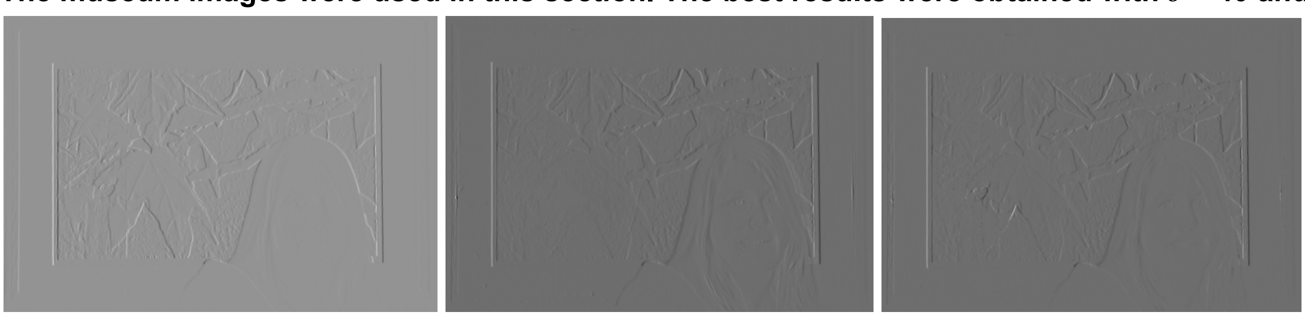
(Left) Vanilla bilateral filter with σ_r=0.15 and σ_s=4 : Increasing the size of the intensity kernel from 0.05 has led to significantly more smoothing in unwanted regions, even on dropping the size of the spatial kernel to 4 from 32 **(Right)** Vanilla bilateral filter with σ_r=0.05 and σ_s=8 : Being too cautious with the spatial kernel leads to more noise in the final output, without raising the details in the image significantly

(Left) Output from joint bilateral filter with σ_r =0.05 and σ_s =32 for A_{base}, σ_r =0.05 ; σ_s =2 for A_{NR} and σ_r =0.05 and σ_s =8 for F_{base} ; τ_{shad} = 0.01 : Increasing the size of the spatial kernel for the flash image leads to more noise in the result **(Right)** Output from joint bilateral filter with σ_r =0.05 and σ_s =32 for A_{base}, σ_r =0.05 ; σ_s =8 for A_{NR} and σ_r =0.05 and σ_s =2 for F_{base} ; τ_{shad} = 0.01 : Increasing the size of the spatial kernel in the detail transfer step can lead to extreme loss of deatil and over-smoothing the image

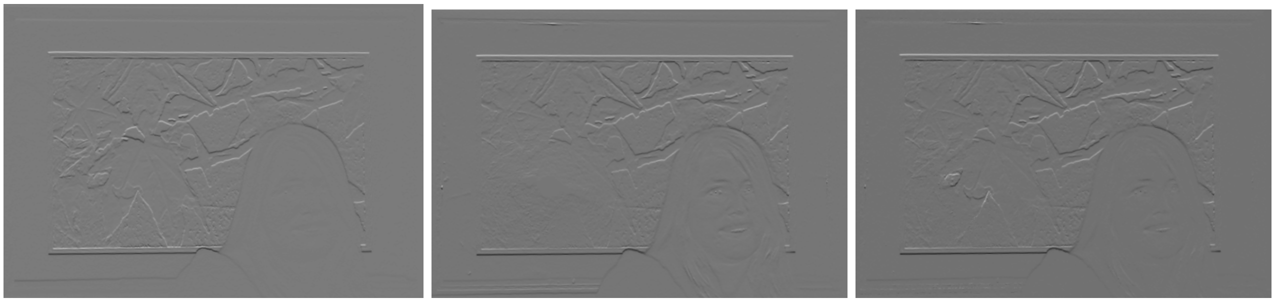
In addition to the trade-off between noise reduction and loss of details discussed before, there is another significant difference between the vanilla bilateral filter and the joint bilateral filter (with detail transfer and masking) in terms of computational complexity. The joint bilateral requires an additional flash photograph (which is often intrusive to capture) and requires the calculation of three bilateral filter outputs compared to just one for the vanilla piecewise bilateral filter.

Answer 2

The museum images were used in this section. The best results were obtained with σ = 40 and τ_{s} = 0.7

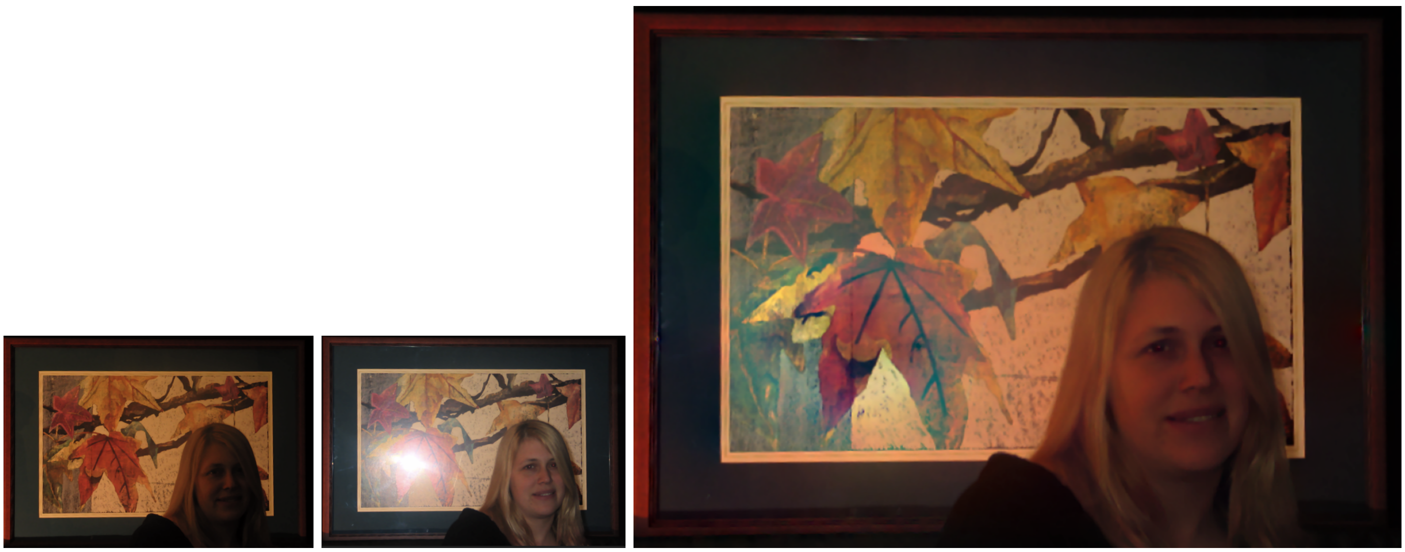


X gradients (From left to right) : a_x , Φ'_x and Φ^*_x - a_x has more edges in the picture frame. Φ'_x has more details in the face and crucially has a flat spot in the image corresponding to the flash hotspot. Φ^*_x effectively combines the information from both while avoiding the loss of detail in the hotspot



Y gradients (From left to right) : a_y , $\mathbf{\Phi}'_y$ and $\mathbf{\Phi}^*_y$ - The observations from the X gradients are repeated here

The final result after using an average of the flash and the ambient image as the boundary condition is shown below. The result was obtained with 1000 iterations and a tolerance of 0.01:



(From left to right) Ambient image, Flash Image and final fused result

Increasing the value of $\boldsymbol{\tau}_s = 0.9$, leads to the color on the face becoming a bit more natural, however the bright spot in the painting starts creeping up

Decreasing the value of σ to 20 from 40, makes the face look a little unnatural without helping with the bright spot near the leaf in the painting

Decreasing the value of τ_s to 0.5, makes the colours in the image unnatural with some artifacts

(Left) Result with ambient image as boundary initialization (Right) Result with flash image as boundary initialization - The result from the flash image has higher brightness on the face, while the result from the ambient image has slightly more contrast in the painting.

Answer 3

(Left) Captured ambient image (Right) Capture flash image

A_{base} formed by piecewise bilateral filtering with **σ_r =0.1 and σ_s = 32**

A_{NR} formed by joint bilateral filtering with $\boldsymbol{\sigma_r}$ **=0.1 and** $\boldsymbol{\sigma_s}$ **=2**

A_{detail} formed after detail transfer

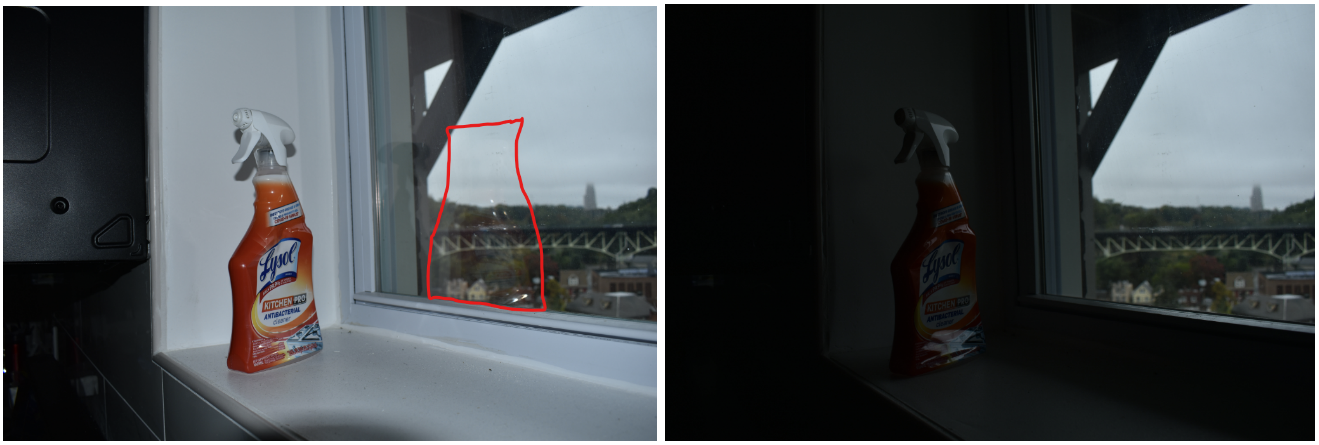
Final result after specularity and shadow masking

(Left) Noise in ambient image vs (Right) Final image

(Left) Flash image and (Right) ambient image used for the fused gradient field method. Note the bright flash hotspot in the window in the flash image and the completely dark painting in the ambient image

Final fused result with $\boldsymbol{\sigma = 5}$ **and** $\boldsymbol{\tau_s = 0.1}$ after 1000 iterations with a tolerance of 0.001

Answer 4 (Bonus)



(Left) Flash image, with red mark showing the reflection and (Right) ambient image used for the fused gradient field method

Final result obtained with **σ = 40 and τ_{ue} = 0.1** after 2000 iterations and a tolerance of 0.001