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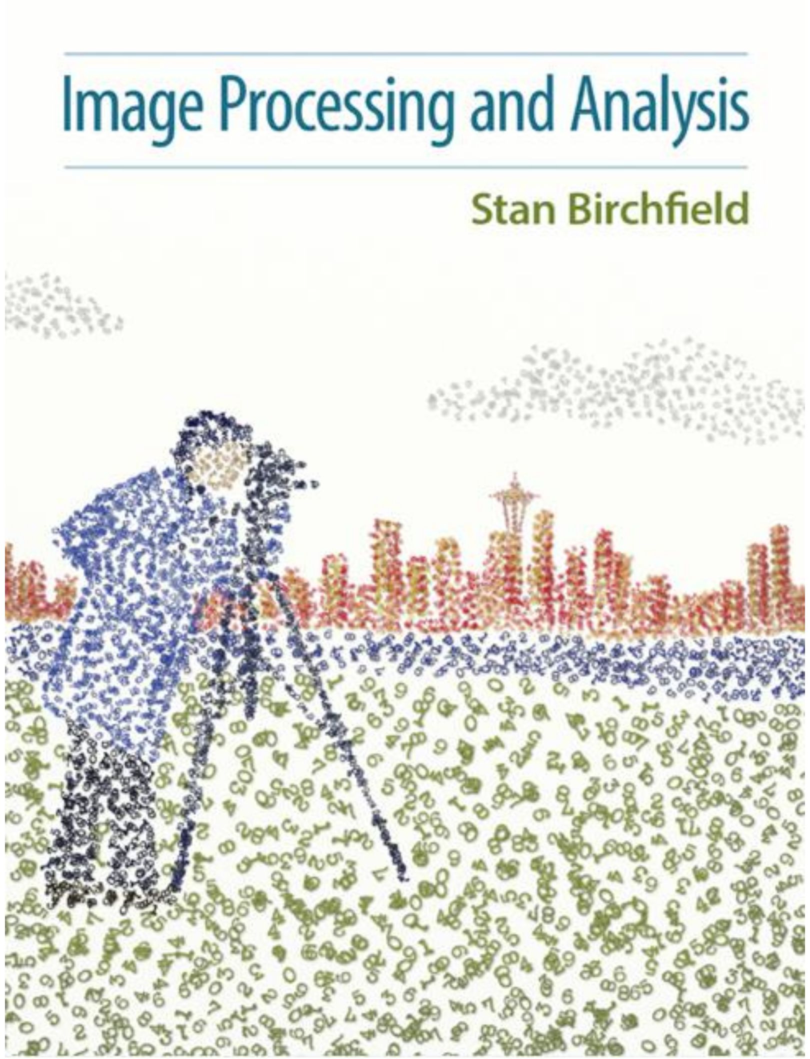
ELE510 Image processing and computer vision

Nonlinear filtering (chap 5.5 Birchfield) 2023



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Spatial domain filtering - Nonlinear filtering

Three points from the topic:

1. What do we seperate in linear and non-linear filtering?
2. Why can non-linear filtering be good in ex. Enhancement/denoising?
3. Give example on filters that both perserve edges and smooth other regions

Remember – linear shift-invariant filters

Filters so far: linear and shift-invariant filters. Convolution formula is valid. *w* and *h* are the width and height of the kernel.

$$I'(x,y) = I(x,y) \circledast G(x,y) = \sum_{i=0}^{w-1}\sum_{j=0}^{h-1} I(x+\tilde{w}-i, y+\tilde{h}-j)G(i,j)$$

Effect of mean /box filtering

3x3 5x5 7x7

Salt & Pepper noise

Gaussian noise

Side effect - blur

(5.5) Non-linear filtering

- filters that are not linear are called **non-linear filters**
- **Common example: Median filter -** replaces each pixel with the median of all the gray levels in a local neighborhood, generally defined by a square window.

Median filter

- Different type of noise needs different filters.
- We have seen that for **salt and pepper** noise the Gaussian, or flat mean (box filters) does not work well. These are both examples of linear low pass (LP) filters.
- For salt/pepper noise a median filter is a good alternative
- A *median filter* operates over a window by selecting the median intensity in the window.

Median filter – not linear

A *median filter* operates over a window by selecting the median intensity in the window.

Median filter is an example of non-linear filtering, and an example of rank-order filter

$$Median(f_1(x)+f_2(x)) \neq Median(f_1(x)) + Median(f_2(x))$$

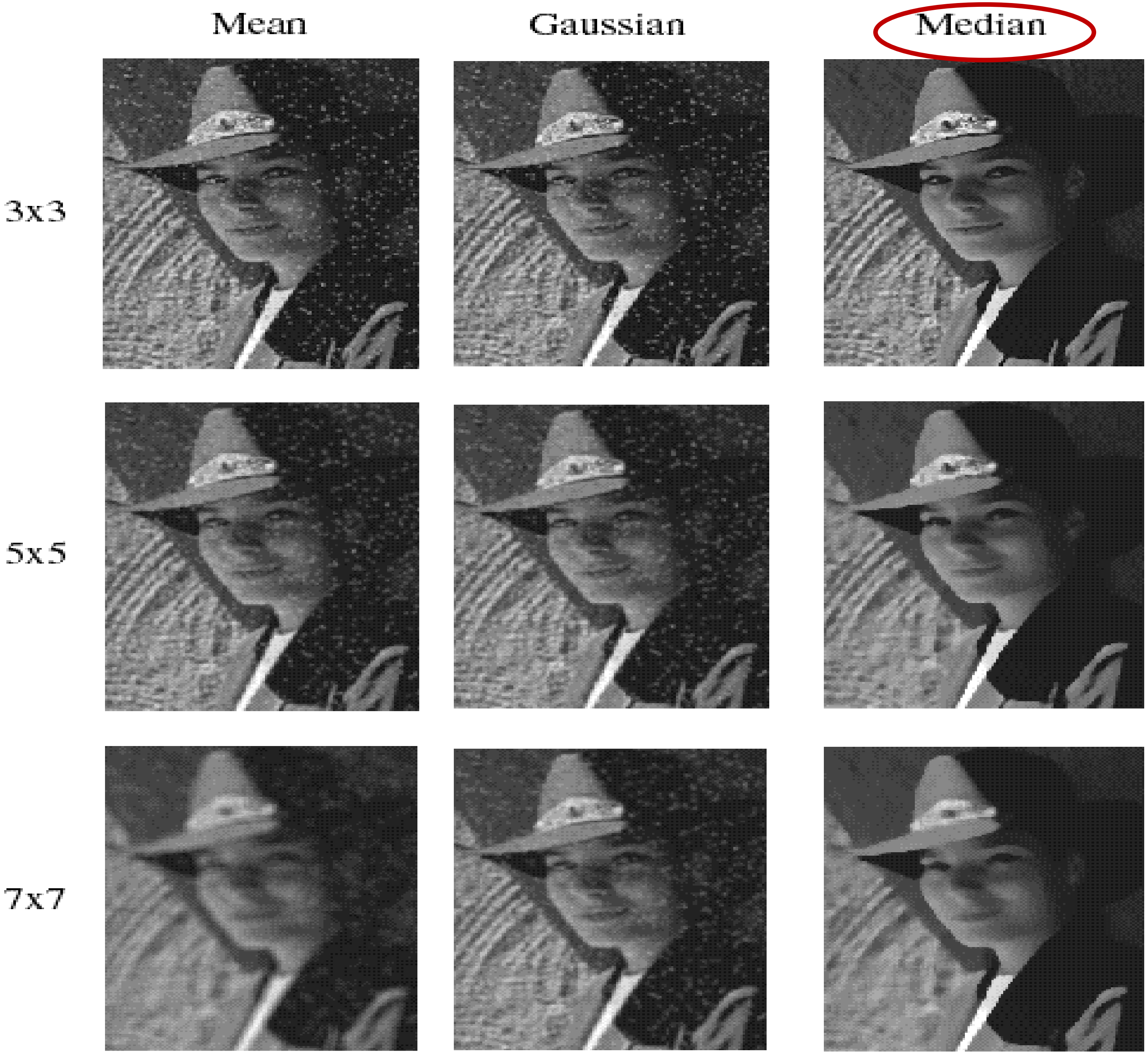
$$1 = Median(\begin{bmatrix} 1 & 1 & 1 \\ 1 & 3 & 1 \\ 1 & 1 & 1 \end{bmatrix}) = Median(\begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} + \begin{bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{bmatrix}) \neq$$

$$Median(\begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}) + Median(\begin{bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{bmatrix}) = 1 + 1 = 2$$

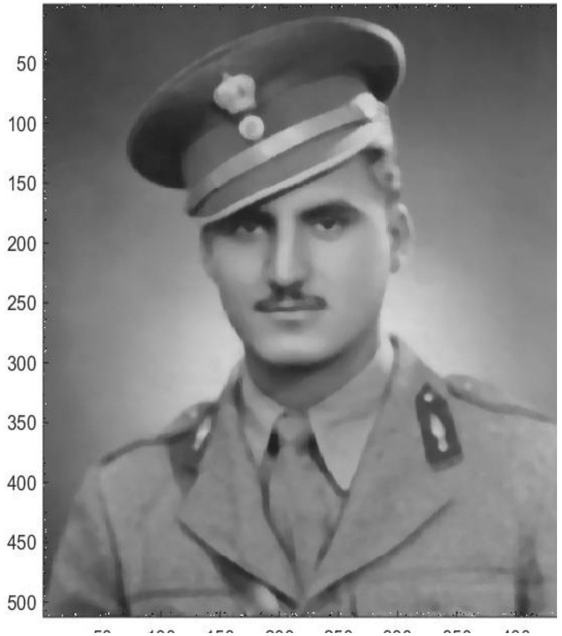
Median filter

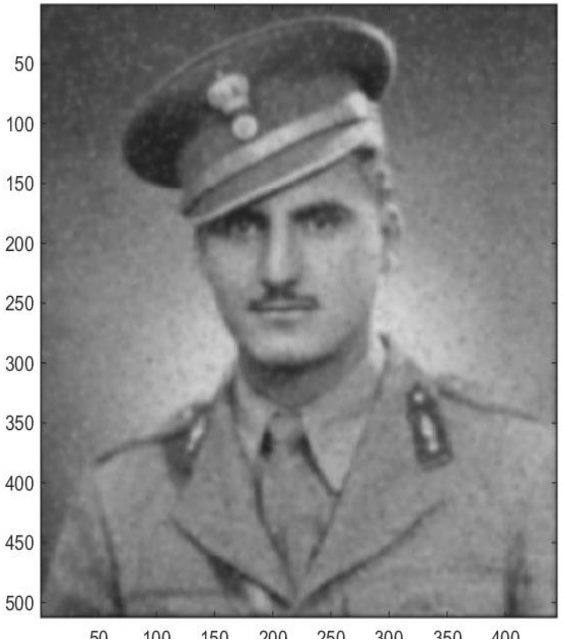
Median filter, salt end pepper noise. Mask 3x3, 5x5, 7x7

Salt & Pepper noise



Gaussian noise

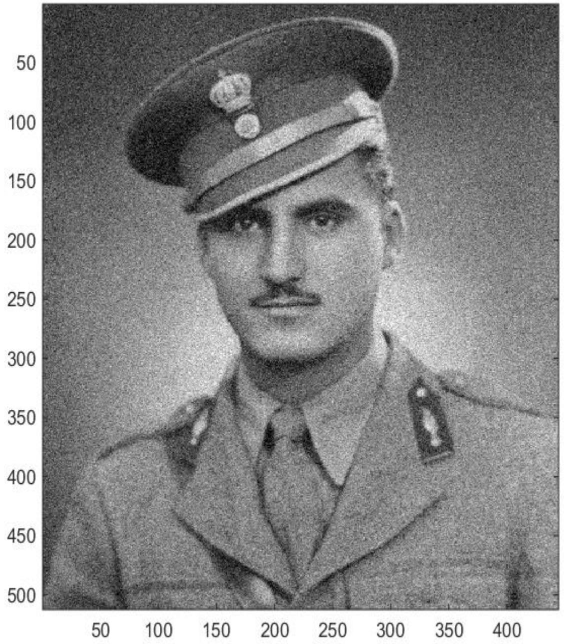


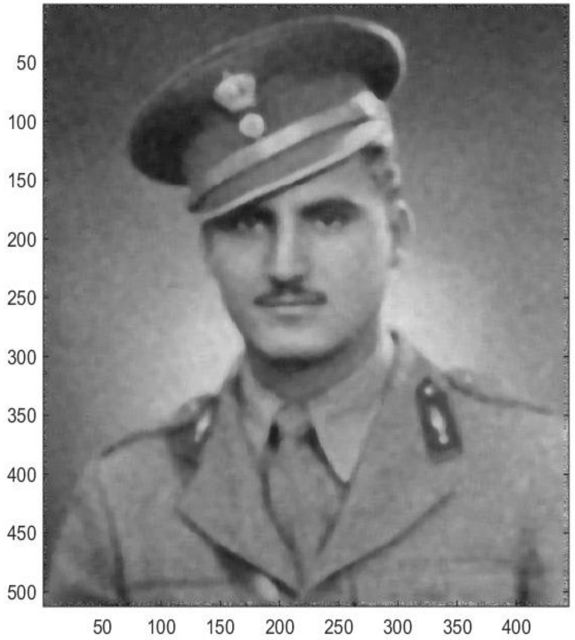


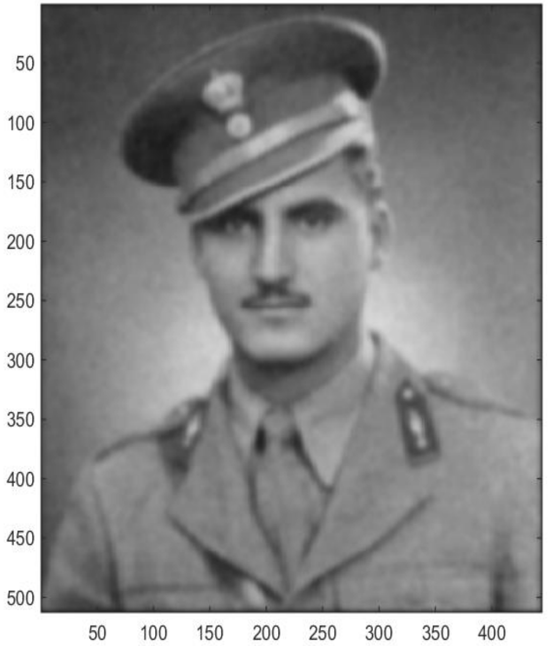
Salt and pepper noise,

median filter,

gaussian filter







Gaussian noise,

median filter,

gaussian filter

Mode filter

Example nonlinear filter - Non-local means

- **Non-local means (NLM)**: a particularly effective way to reduce the effects of noise in an image by computing a weighted average over *all* pixels in the image.
- Weight based on the similarity between the regions

ALGORITHM 5.12 Perform non-local means filtering on an image

```
NonLocalMeans(I, w)

Input:  grayscale image I, set of pixels W specifying window
Output: smoothed image from applying non-local means filtering

for (x, y) ∈ I' do                              ▷ For each pixel in the output image (same size as input image),
    val ← 0                                       initialize value to zero,
    norm ← 0                                      and normalization factor to zero.
    for (x', y') ∈ I do                          ▷ For each pixel in input image,
        d ← 0                                     initialize distance to zero.
        for (δx, δy) ∈ W do                      ▷ Compute the dissimilarity between the two windows.
            d ←+ I(x + δx, y + δy) − I(x' + δx, y' + δy)
        w ← exp(−d * d/(2 * σ * σ))              ▷ Set the weight to the similarity.
        val ←+ w * I(x', y')                     ▷ Update the sum of the weighted pixels,
        norm ←+ w                                 and the normalization factor.
    I'(x, y) ← val/norm                          ▷ Set the output pixel to the normalized value.
return I'
```

Non-local means

OpenCV, python

From documentation; https://opencv-python-tutroals.readthedocs.io/en/latest/py_tutorials/py_photo/py_non_local_means/py_non_local_means.html#non-local-means

OpenCV provides four variations of this technique.

1. **cv2.fastNlMeansDenoising()** - works with a single grayscale images
2. **cv2.fastNlMeansDenoisingColored()** - works with a color image.
3. **cv2.fastNlMeansDenoisingMulti()** - works with image sequence captured in short period of time (grayscale images)
4. **cv2.fastNlMeansDenoisingColoredMulti()** - same as above, but for color images.

- Common arguments are:h : parameter deciding filter strength . Higher h value removes noise better, but removes details of image also. (10 is ok)

- hForColorComponents : same as h, but for color images only. (normally same as h)

- templateWindowSize : should be odd. (recommended 7)
- searchWindowSize : should be odd. (recommended 21)

- Parctically dont look in entire image, just the searchWindow.

Example

Upper line:
Left: original
Right: with added gaussian noise

Lower line:
left:gaussian smoothing
Right: non-local means

Example nonlinear filter - Bilateral filtering

- Contains two kernels, a *spatial kernel* and a *range kernel*.
- The spatial kernel g_s weights neighboring samples according to their proximity to the central sample, while the range kernel g_r weights neighboring samples according to their similarity in *value* to the central sample.

$$f'(x) = f(x) \circledcirc \langle g_s(x), g_r(z) \rangle = \frac{1}{\eta(x)} \sum_i f(i) g_s(x-i) g_r(f(x) - f(i))$$

- Smoothing, but

preserves edges

- Repeated applications

gives a cartoon-like image

OpenCV, python:

dst=cv2.bilateralFilter(src, d, sigmaColor, sigmaSpace[, dst[, borderType]])

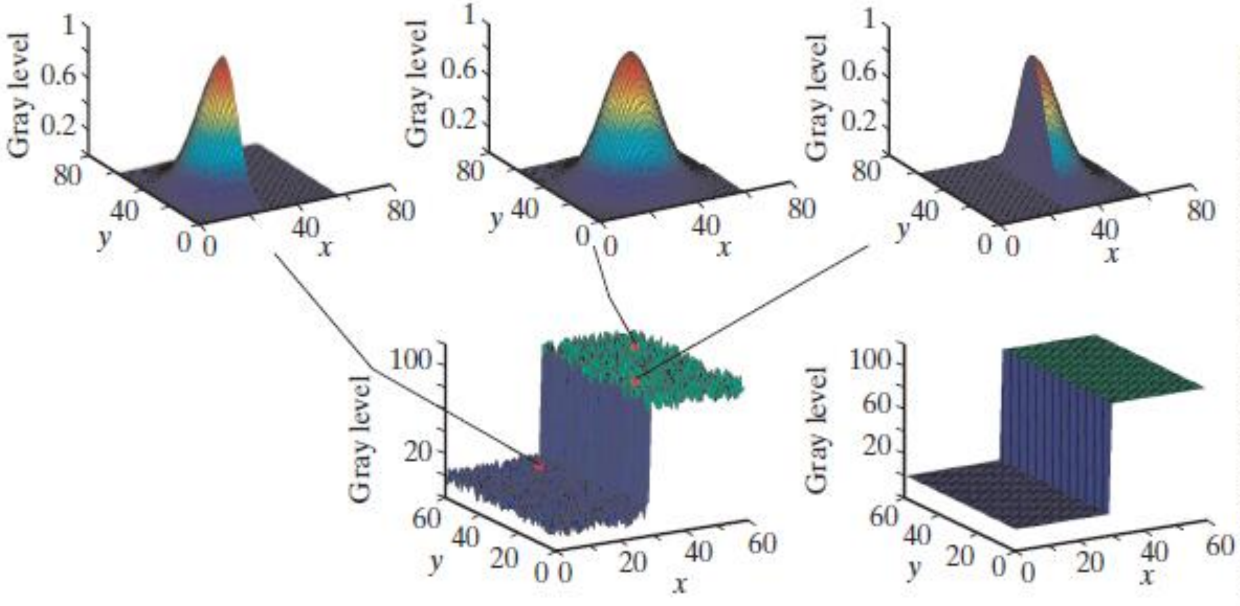


Figure 5.17 Bilateral filtering of a noisy step edge preserves the crisp edge as it smooths out the noise on either side of the edge. The top row shows the kernel at three locations: Far from the edge, the kernel approximates a Gaussian, whereas near the edge it approximates half a Gaussian.

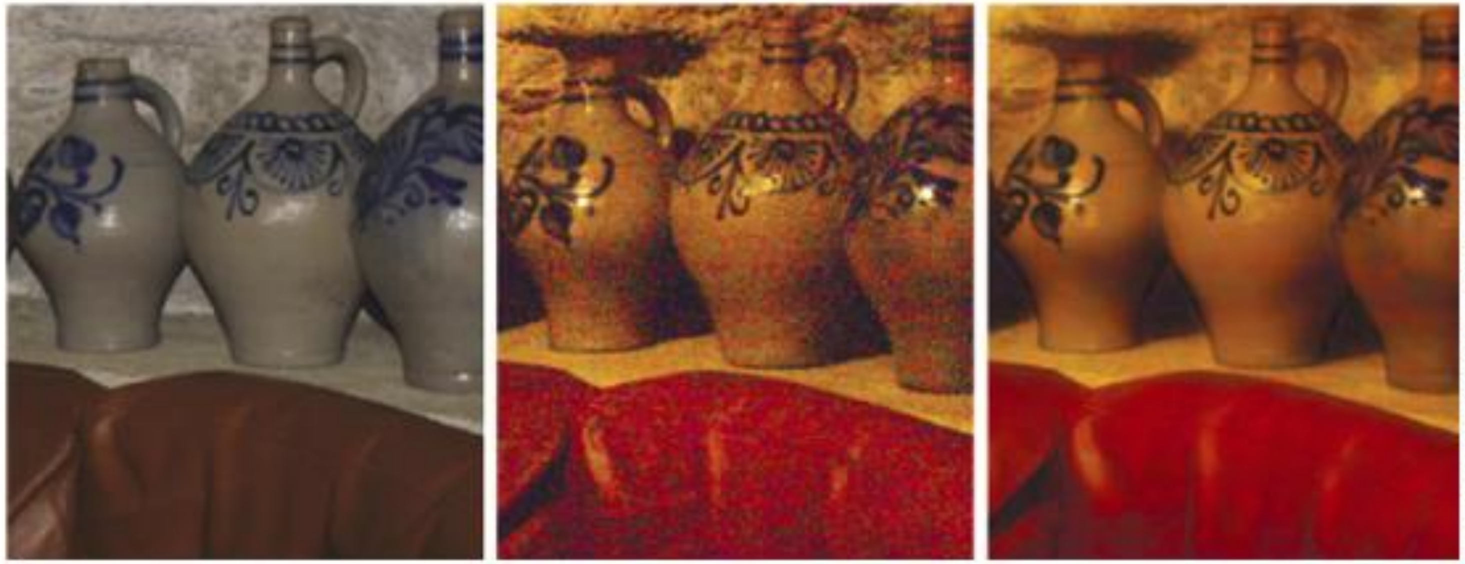


Figure 5.21 One of the more interesting applications of the bilateral filter is to combine a flash image (left) with a no-flash image (middle) to preserve both detail and the original viewing conditions of the scene (right).

Example

Upper line:
Left: original
Right: with added gaussian noise

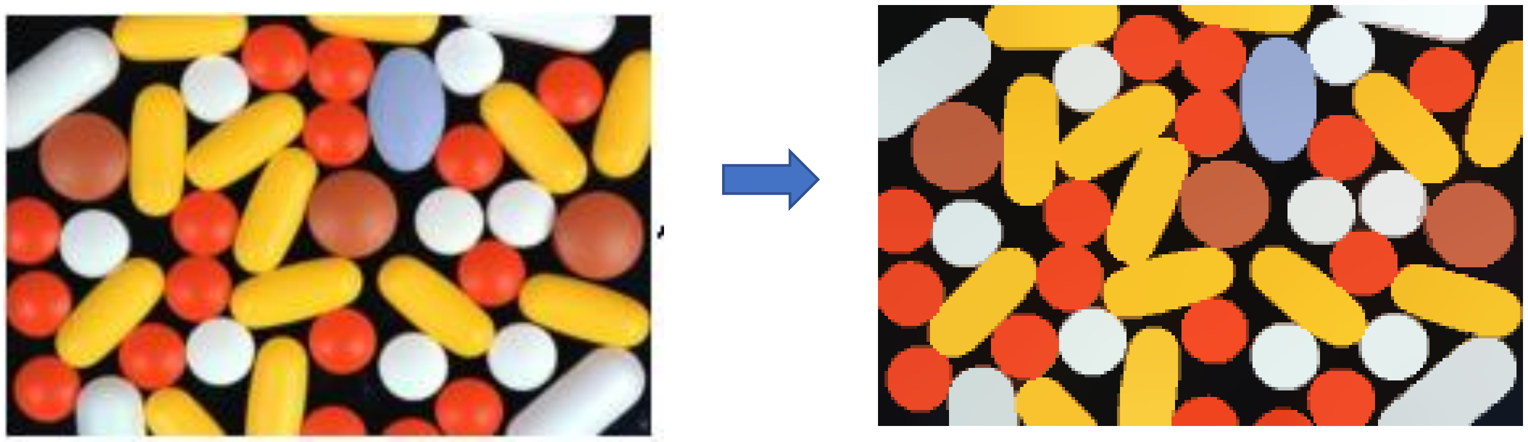
Lower line:
left:gaussian smoothing
Right: bilateral filtering

Other non-linear filters

- Anisotropic diffusion
  - The image values are smoothed by repeatdly performing local averages, but doing so in a way that weights neighbour pixels less if they lie on an intensity edge. Blurs the images within regions, but not across boundaries.
- Adaptive smoothing
  - Find weighted averages of neighbors of pixels, with weigths discourageing smoothing across boundaries. Bilateral filter is special case of adaptive smoothing.
- Gray-scale morphological operators

Other non-linear filters

- Mean-shift filter
  - Clustering both in color values and in distance. Group pixels near in color values AND distance, and recalcualte mean according to mean-shift. Iteratively replaces each pixel with the mean of the pixels in a range-r neighborhood and whose value is within a distance d until mean-shift =0.

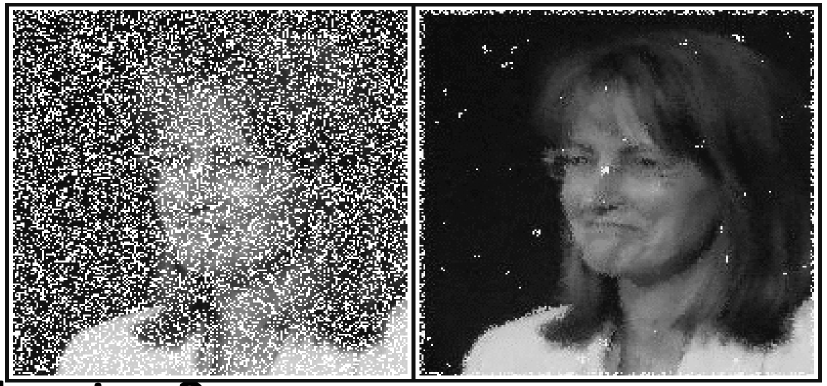


Example

Upper line:
Left: original
Right: with added gaussian noise

Lower line:
left:gaussian smoothing
Right: mean shift

Spatial domain filtering - Nonlinear filtering



Three points from the topic:

1. What do we seperate in linear and non-linear filtering?
   - ✓ Because linear filters have so many properties that make them tractable (convolution formula ..)

2. Why can non-linear filtering be good in ex. Enhancement/denoising?
   - ✓ Different noise needs different types of filters. Non-linear filters are less restrictive, and sometimes really good alternative

3. Give example on filters that both perserve edges and smooth other regions
   - ✓ Non-local means, bilateral filtering, mean-shift