Image Filtering

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What is Image filtering ?

Image filter is the process of enhancing images by applying different filters , these enhancement vary from denoising , edge detection , smoothening or sharpening of image and plays a crucial role in any kind of image usage as such unnecessary elements like noises can hinder the image related processes , while certain noises can also be used to train the model for more robustness.

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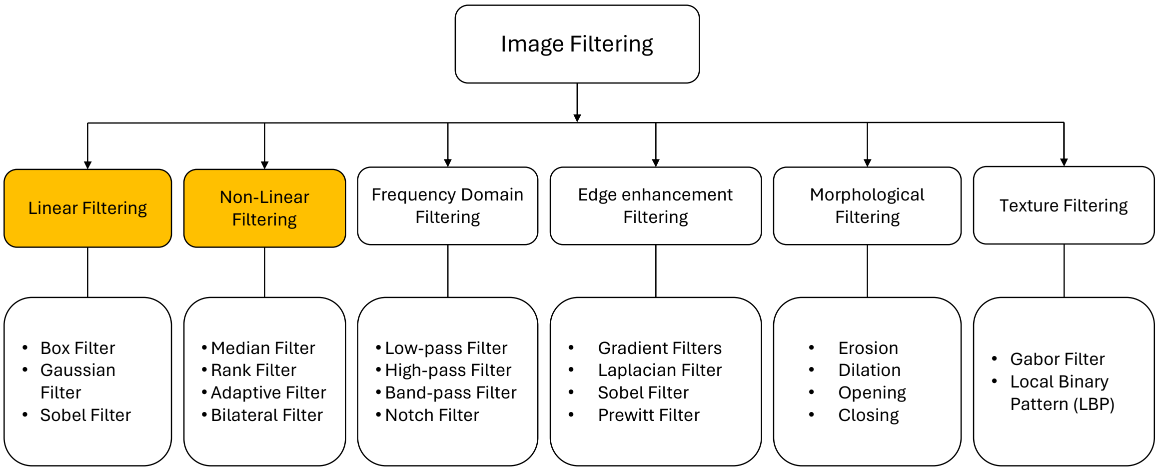
Types of Image filtering



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Linear Filtering

Linear filter as the name says mostly deals with linear data or homogeneity (refers to constant change for example: a constant multiplied to matrix) , the output will also be of linear nature after convolution or multiplication with any constant. Linear filters are commonly used in image processing for various tasks such as smoothing, sharpening, noise reduction, and edge detection. Examples of linear filters include:

- Gaussian Filter
- Box Filter (Average Filter)
- Sobel Filter

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Box/Average filter

Box filtering involves replacing each pixel of an image with the average in a box / filter for that bounding box. A Box Filter is a simple linear filter that applies a uniform filter kernel to the input image. It computes the average value of the pixel values within the kernel window and replaces the central pixel value with this average. This filter is effective for smoothing an image, reducing noise, and blurring edges. It is fast but can lead to loss of image details.

Box/Average filter output

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Gaussian filter

The Gaussian Smoothing Operator performs a weighted average of surrounding pixels based on the Gaussian distribution. The Gaussian Filter applies a Gaussian kernel to the input image. It gives more weight to the central pixel and less weight to the surrounding pixels, following a Gaussian distribution. This filter effectively reduces noise while preserving edges better than the Box Filter. It is commonly used for image blurring which helps in increasing robustness of model and noise reduction/denoising , edge detection, feature extraction.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

where, $G(x, y)$ *is the value of the Gaussian kernel at coordinates* (x, y)

σ *(sigma) is the standard deviation of the Gaussian distribution, which determines the amount of blurring or smoothing applied to the image*

(x, y) *are the coordinates within the Gaussian kernel matrix*

π (3.14) *is used in the normalizing term*

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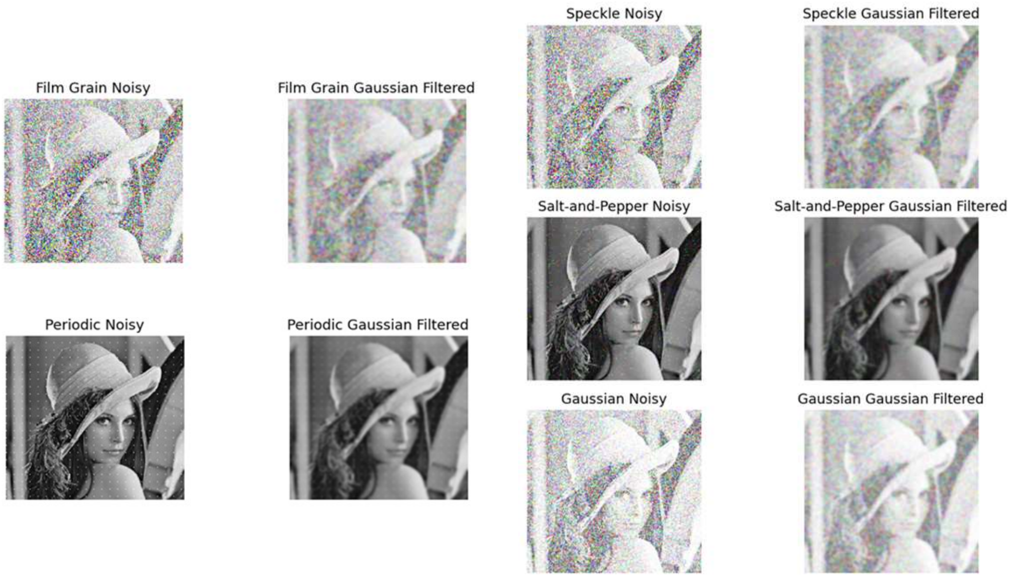
Gaussian filter output



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Sobel filter

The Sobel filter is a gradient-based linear filter used in image processing for edge detection tasks. It computes the gradient magnitude of an image by convolving it with separate kernels for horizontal and vertical changes in pixel intensities. The Sobel filter emphasizes edges in both the horizontal and vertical directions, making it an effective tool for detecting edges and boundaries , image detection ,pre-processing(object detection).

$$\Delta f = mag(\Delta f) = \left[G_x^2 + G_y^2\right]^{\frac{1}{2}}$$

$$for\ x - direction : \begin{matrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{matrix}, \quad for\ y - direction : \begin{matrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{matrix}$$

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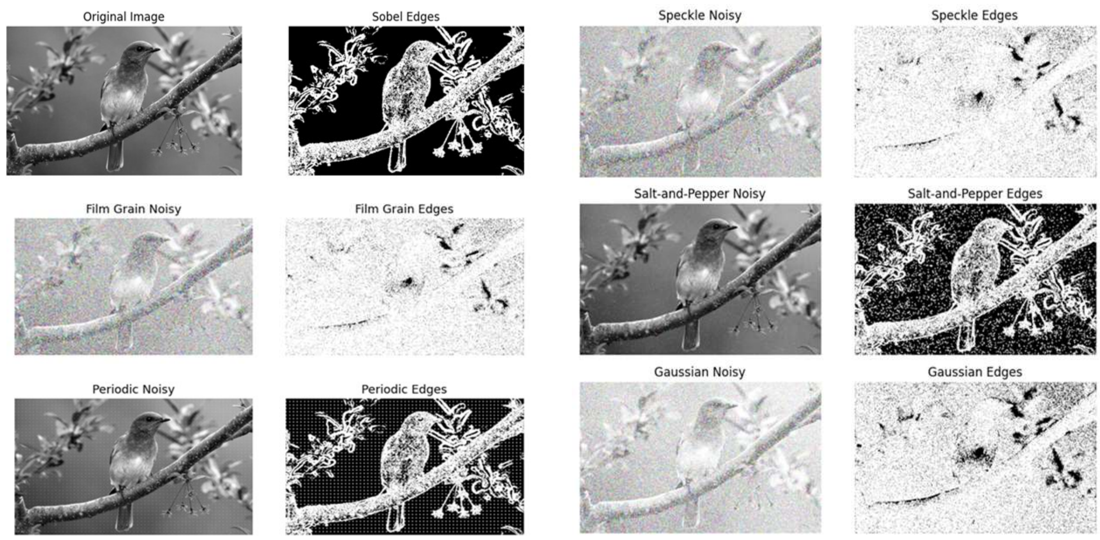
Sobel filter output



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Non-Linear Filtering

Non-Linear filters do not follow the properties like homogeneity , linearity instead they use non-linear filters use more complex operations such as ranking, thresholding, and adaptive processing to modify and enhance images , non-linear filters are mostly used for details enhancement , noise reduction , edge preservation. Few examples of non-linear filters are:

- Median Filter
- Rank Filter
- Adaptive Filter
- Bilateral Filter

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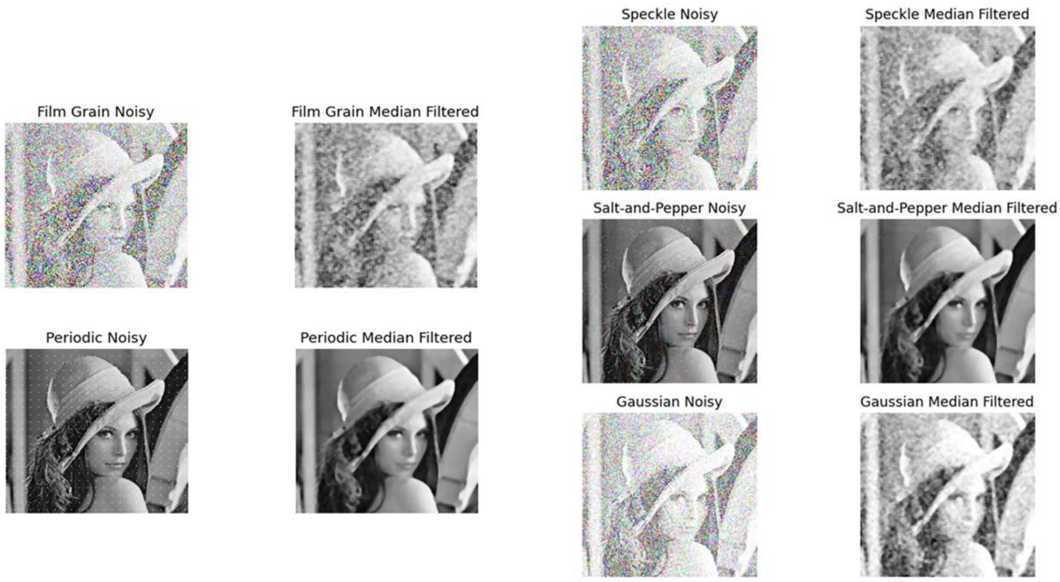
Median Filter

The Median Filter replaces each pixel's value with the median value within a specified neighborhood (kernel).It is effective for removing salt-and-pepper noise and preserving edges because it considers the pixel values rather than their intensities. This filter is computationally more expensive than linear filters but provides better noise reduction, irregularity removal ,edge preservation and digital/signal processing.

$$\hat{f}(x,y) = median\{g(s,t)\} \qquad ,(s,t) \in S_{xy}$$

Median Filter output



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Rank Filter

The Rank Filter is a generalized version of the Median Filter where the replacement value is determined by the rank (percentile) of the pixel values within the kernel window. It behaves like the Median Filter when the rank is set but can be customized to produce different effects based on the rank value resulting in details enhancement , edge preservation. Consists of max and min filters which together reduce noise.

$$\hat{f}(x,y) = \frac{1}{2}\left(\max_{(s,t)\in S_{xy}} \{g(s,t)\} + \min_{(s,t)\in S_{xy}} \{g(s,t)\}\right)$$

$where, \hat{f}(x,y)$ - This represents the output value of the rank filter at coordinates (x,y)

S_{xy} − *This represents the set of all possible neighborhoods around the pixel located at* (x,y)

(s,t) − *These variables represent the coordinates within the neighborhood* S_{xy}

$g(s,t)$ − *This represents the intensity (or value) of the pixel at coordinates* (s,t) *within the neighborhood* S_{xy}

$\max_{(s,t)\in S_{xy}} \{g(s,t)\}$ − *calculates the maximum intensity value within the neighborhood* S_{xy}

$\min_{(s,t)\in S_{xy}} \{g(s,t)\}$ − *calculates the minimum intensity value within the neighborhood* S_{xy}

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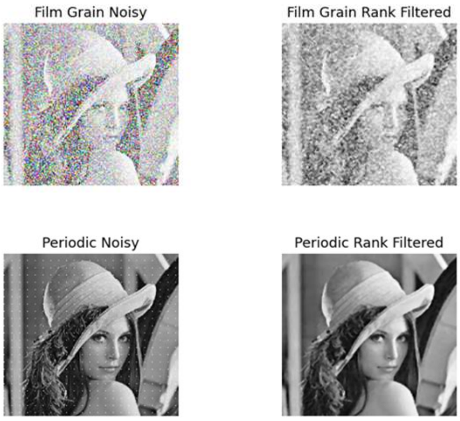
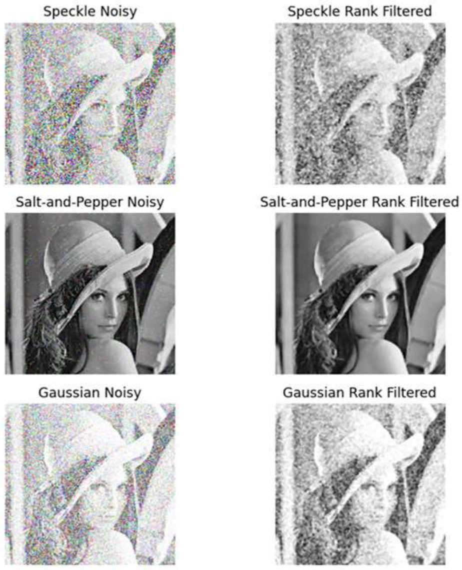
Rank Filter output





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Adaptive Filter

The Adaptive Filter, particularly Mean Shift Filtering, is a non-linear filter that iteratively shifts the pixel values towards the mode of the pixel distribution in the neighborhood. It effectively removes noise and preserves edges while reducing the computational cost compared to some other non-linear filters. Mean Shift Filtering is commonly used for image segmentation, texture analysis, and denoising tasks.

$$\hat{f}(x,y) = g(x,y) - \left(\frac{\sigma_\eta^2}{\sigma_L^2}\right)[g(x,y) - m_L]$$

$$\begin{aligned} where\ ,\ & \sigma_L^2 - Local\ variance\ of\ the\ local\ region \\ & m_L - Local\ mean \\ & \sigma_\eta^2 - Variance\ of\ overall\ noise \\ & g(x,y) - Pixel\ value\ at\ the\ position\ (x,y) \end{aligned}$$

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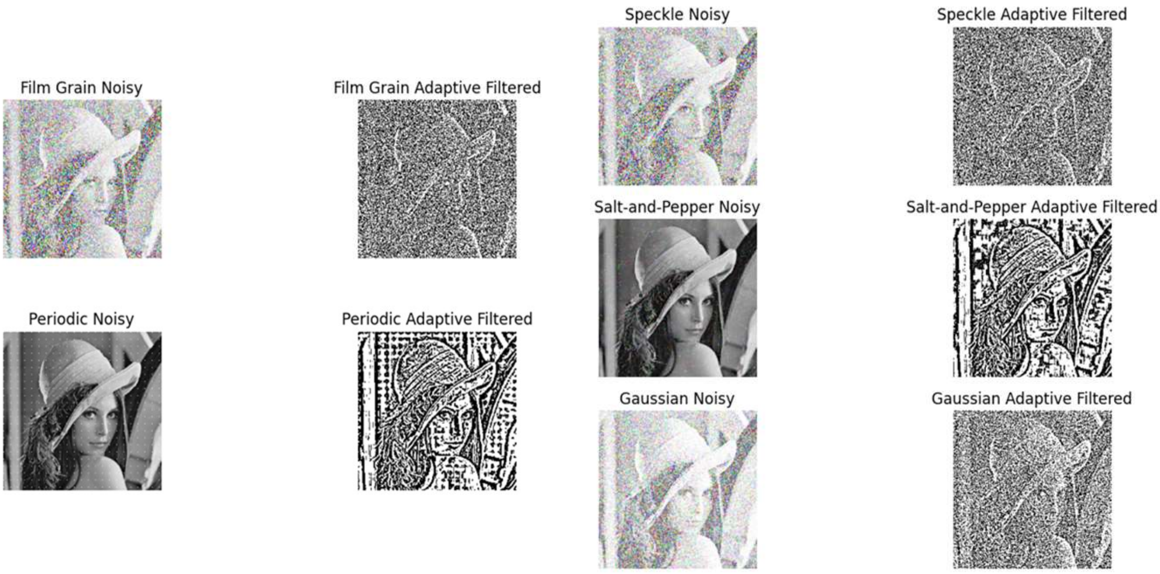
Adaptive Filter output



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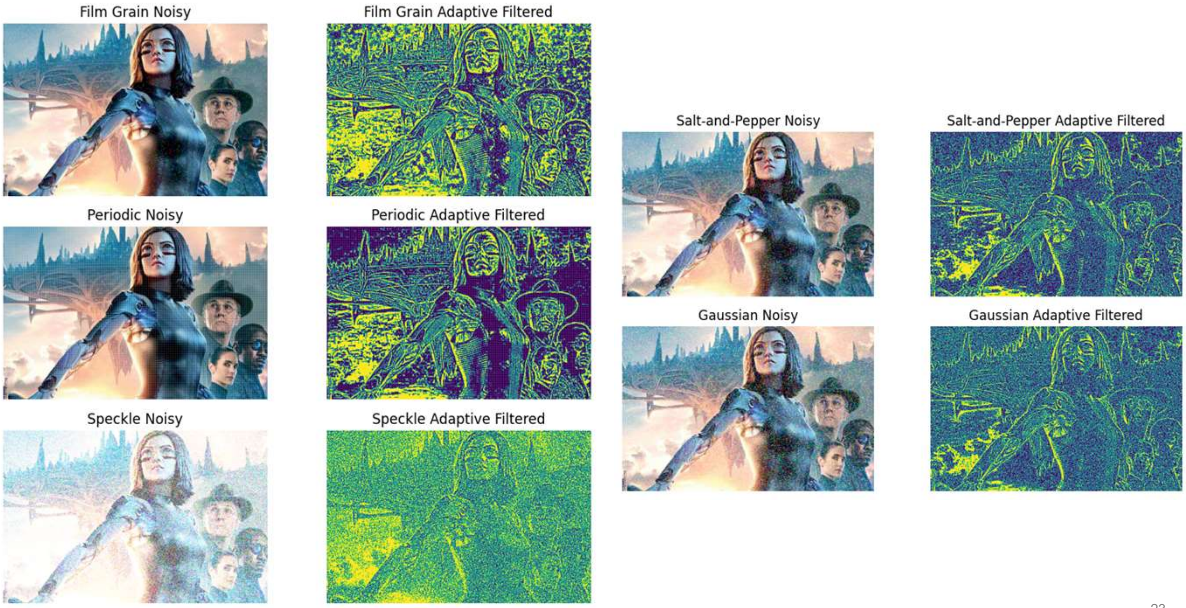

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Bilateral Filter

The Bilateral Filter is a non-linear filter that considers both the spatial and intensity differences when filtering an image. It preserves edges while smoothing the image by applying a weighted average based on both the spatial and intensity differences between pixels. This filter is useful for noise reduction while preserving important image features, making it suitable for various tasks like HDR imaging, denoising, and edge-preserving smoothing.

$$BF[I]_p = \frac{1}{W_p}\sum_{q \epsilon S} G_{\sigma_s}(||p-q||)G_{\sigma_r}(|I_p - I_q|)I_q$$

where, I *represents the input image*

p *and* q *are pixel coordinates*

S *is the spatial domain, typically a window around* p

w_p *is a normalization factor*

$\sum_{q\epsilon S} G_{\sigma_s}(||p-q||)$ *is the spatial Gaussian kernel, determined by the spatial distance* $||p-q||$ *and parameter* σ_s *controlling spatial smoothness*

$G_{\sigma_r}(|I_p - I_q|)$ *is the range Gaussian kernel, determined by the intensity difference* $|I_p - I_q|$ *and parameter* σ_r *controlling intensity similarity*

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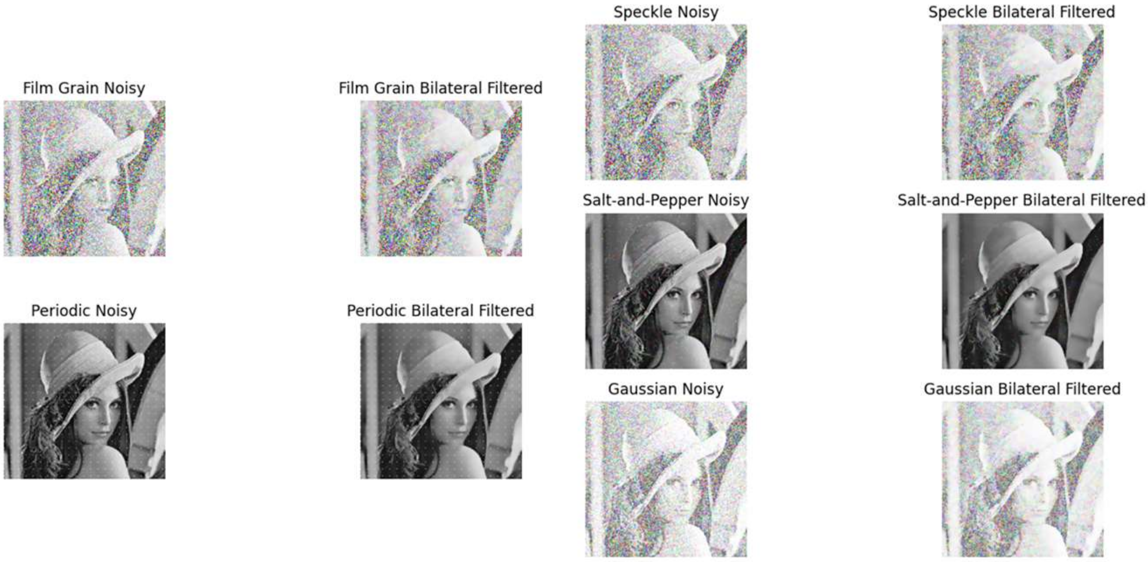
Bilateral Filter output



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