A Comparative Study of Image Restoration Filters Under Spatial Domain

G.kalpana[1],MCA,CBIT,Hyderabad
NVS.Chaitanya[2],MCA,CBIT,Hyderabad

Abstract

Images play a vital role in many fields such as, in photography, medicine, biology, astronomy, industry and defence. The process of image restoration is to recover the original image by eliminating noise and blur from the image. These restoration techniques are can be classified into two domains ie. Spatial domain and frequency domain. This paper focuses on spatial domain restoration techniques and which are applied to different noise models. Evaluation measures are used to compare the restored image with the original image to judge the efficiency of different types of spatial domain filters . Performance of each filter is compared with images of different noise models. Finally conclusions are drawn about which filter is best suited for specific noise models.

Keywords: Image processing, Restoration, Noise, Filters, Spatial Domain

I. Introduction

Digital image processing deals with representation of Images, preprocessing of images, restoration, enhancement, analysis of images and image data compression. Image processing is a technique for which the input is an image or a series of images or videos, photographs or frames of video. The output can be either an image or a set of parameters or characteristics related to the image. As a result better quality objects are clearly visible as compared to the original sensed image.[1]

Image Restoration Process: *Restoration process improves the appearance and quality of the image. Reconstruction of the original image can be performed in two steps ie (a) Degradation (b) Restoration.[2]Restoration techniques are used to reconstruct or recover original image that has been degraded by using a prior knowledge of the degraded function. Thus, restoration techniques are introduced to modeling the degradation and applying the inverse process in order to preserve the original image [3]*

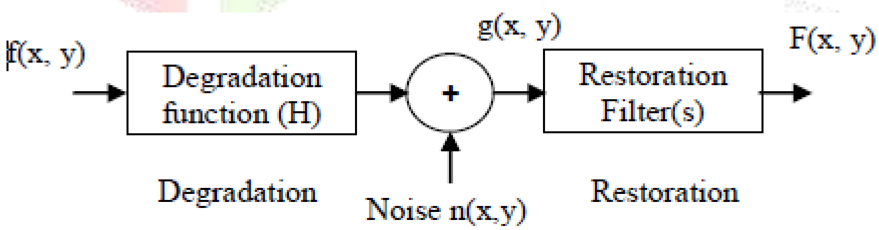

Fig.1. Model of the image degradation/restoration process[3]

$$g(x, y) = H\{f(x, y)\} + \eta(x, y)$$

II. Reasons for Occurrences of degradation

The sensor noise, random atmospheric turbulence, camera-misfocus, relative object-camera motion, random variation of brightness or color information in the image are the main reasons for image degradation .The image noise is either produced by sensor or digital camera [4]. When object moves to the camera or vice versa, motion blur is caused [5]. When the object is out of camera focus during exposure, the object region in the image is also blurred. This kind of blur is called defocus blur [6] imaging system is affected by atmospheric turbulence by virtue of wave propagation through a medium with non-uniform index of refraction. [7]

III. Noise Models

Image noise can be referred as variation of brightness or color information in images.There are two basic types of noise models. They are: a) noise in the spatial domain and b) noise in the frequency domain. Some of the additive noises are,[8]

A. Impulse noise (Salt-and-pepper noise): Impulse noise is caused by sharp, sudden disturbances in the image signal and its appearance is randomly scattered white or black (or both) pixels over the image. Impulse noise or better known as Salt & Pepper Noise appears as black and/or white impulse of the image.An image containing salt and pepper noise will have dark pixels in bright regions and bright pixels in dark regions. [9]

B. **Amplifier noise:** This type of noise also known as normal noise and has a random distribution of amplitude over time and occurs frequently.

C. **Photon noise**: This type of noise is also known as Shot noise or Poisson noise. This noise is caused due to statistical nature of electromagnetic waves such as x-rays, visible lights and gamma rays [10]. Sources of x-rays and gamma rays emit a number of photons per unit time. In x-ray and gamma ray imaging, the photon rays are injected in patient's body from sources which have random fluctuations.

D. **Speckle noise:** Multiplicative noise is another name of speckle noise. The appearance of speckle noise is seen in coherent imaging system such as radar, laser and acoustics etc.

E. **Quantization noise:** The name of Quantization noise is uniform noise. This type of noise appearance exists in amplitude quantization process [10]. Quantization noise is caused by conversion of analog data into digital data. In quantization model, signal to noise ratio (SNR) is limited by minimum and maximum pixel value, P_{min} and P_{max} respectively.

F. **Periodic noise:** Periodic noise cannot be eliminated in spatial domain, due to electrical and electro mechanical interface during acquisition. Periodic noise cannot be fully removed by spatial domain masks. By studying their response in frequency domain this type of noise can only be eliminated [11]

G. Brownian Noise (Fractal Noise): Brownian noise is also called with many names Colored noise or pink noise or flicker noise or 1/f noise[12].Power spectral density is proportional to square of frequency over an octave in Brownian noise, i.e., its power falls on ¼ th part (6 dB per octave). Brownian noise is caused by Brownian motion [12].Brownian motion is caused due to the random movement of suspended particles in fluid [12]. Brownian noise can also be generated from white noise.[13]

H. **Rayleigh Noise**

Radar range and velocity images contain noise that can be modeled by the Rayleigh distribution

I. **Gamma Noise**

Gamma noise can be obtained by the low-pass filtering of laser based images [18].[14]

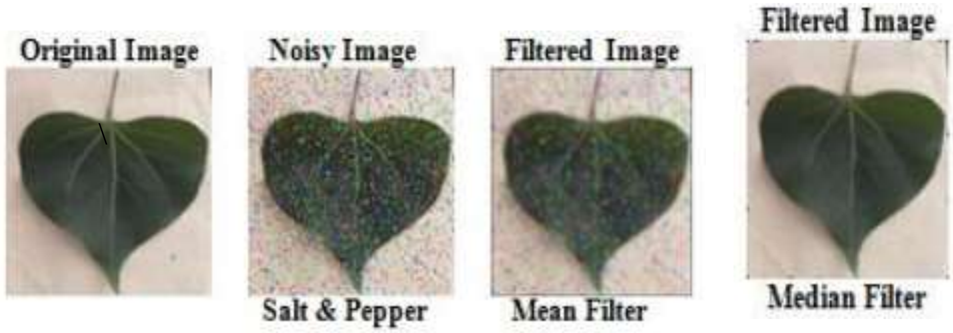

Fig2:Images with various noises[15]

IV. Spatial Filtering

Spatial filtering is an operation on image where each pixel value *I* (*x*, *y*) is transformed by some function of the intensities of pixels present in the 8-neighborhood of (*x*, *y*) including the point (*x*, *y*) taking 3□3 masking into consideration, i.e. *I* (*x*, *y*)□ *f* (*x*, *y*) . Spatial filtering is the next step of point processing. It overcomes the limitations of point operations like blurring/smoothing, sharpening, etc. This filtering technique performs various operations like identifying a function, finding the mean, shift left or right by one pixel, sharpening an image.[16]

The output of the filter at any point (*x*, *y*) is represented as *J* (*x*, *y*) and given by:

J(x,y)=m(-1,-1)I(x-1,y-1)+m(-1,1)I(x-1,y)+...........+m(0,0)I(X,Y)I(X+1,Y)+m(1,1)I(x+1,y+1) (1)

Representing (1) in generalized form

$$j(x,y) = \sum_{k=p}^{p} \sum_{l=p}^{q} m(k,l) I(x+k, Y+l) \quad (2)$$

The size of the window is $u \times v$; where u =2 p +1 and v = 2q +1. For p □=1 and q =1 the size of the mask is 3×3.

Writing (2) in matrix notation

$$J = m_1 I_1 + m_2 I_2 + \cdots \ldots \ldots \ldots . + m_{uv}\, I_{uv}$$

$$= \sum_{k=1}^{mn} m_k I_k \quad (3)$$

$$= m^T \text{ I}$$

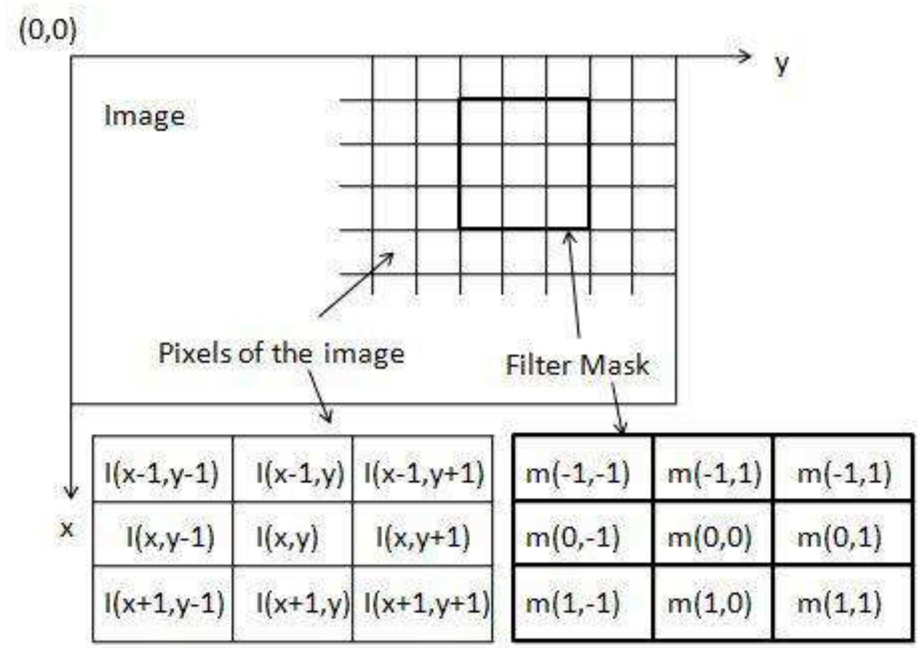

Fig.3: Spatial Filtering on Image by 3×3 mask [16]

V.Image Restoration Techniques

Depending upon the Knowledge of degradation, the Image restoration techniques can be broadly classified into two types.

a)Deterministic method
The deterministic method of image restoration can be employed, If the prior knowledge about degradation is known.
b) Stochastic method
The stochastic method of image restoration is employed, when the prior knowledge is not known before the degradation.

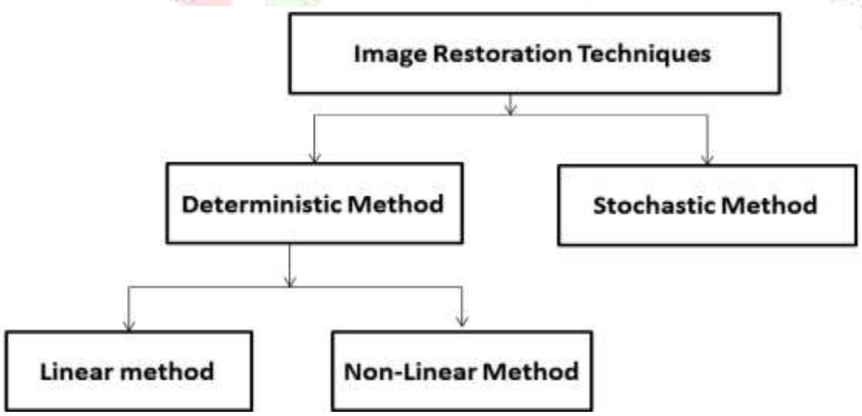

Fig4: Image Restoration Techniques [17]

Image Degradation model is a process by which image is blurred. The degradation is often modelled as a linear function which is often referred as point-spread function [17]

i)Linear Image Restoration Method

If we know Point Spread Function in the image degradation then, the noise effect can be easily ignored [17]. The easiest and fastest kind of filtering is possible with linear filters [2]. The linear filter replaces each pixel with a linear combination of its neighborhood values [18]. The main drawback of Linear Restoration method is, it will not perform well in the presence of noise and tends to amplify the noise [17].

ii)Non-Linear Image Restoration Method

The Explicit inverse implementation is not possible with this method. This Non-Linear method uses an iterative approach to produce a progressive improvement in restoration [17].o overcome the drawback of the Linear Image Restoration method, the non Linear Image Restoration methods are introduced.[19]

VI. Image Restoration Filters In Spatial Domain

Restoration Techniques can be applied in various domains like Spatial Domain, Frequency Domain and Wavelet Domain. The Spatial domain filters are used to operate directly on the pixels of an image, but the Frequency domain filters operate on intensities of an image. The spatial domain filters are very efficient. They require very less number of resources, ie a simple filter mask for showing a filter effect and it is also less expensive to perform filtering techniques in the spatial domain. Frequency domain filtering is more suitable if no simple mask can be found in the spatial domain. In the Spatial Domain, filters are broadly categorized into three groups – A) Mean Filters, B) Order Statistics Filters and C) Adaptive Filters.

A. Mean Filters

i) Arithmetic Mean Filter:

Mean filters also called as linear filter,operates on a m x n mask by averaging all pixel values within the window and and replacing the center pixel value in the final image with the result. It also causes certain amount of blurring in the image[13,21].Its is a smoothing filter which reduces the intensity variations between adjacent pixels.[20].

ii) Geometric Mean Filter:

Geometric Mean filter is a slightly different from the Arithmetic Mean Filter but it retains higher image detail after application as compared to the arithmetic filter. The mathematical function for this filter is [13,22] (Π)

$$\hat{f}(x,y) = \left(\prod_{(r,c)\in W} g(r,c)\right)^{\frac{1}{mn}}$$

iii) Harmonic Filter:

Harmonic Filter removes Salt noise or Gaussian Noise. It's mathematical function can be represented as follows

$$\hat{f}(x,y) = \frac{mn}{\sum_{(r,c)\in W} 1/g(r,c)}$$

iv) Contra harmonic Filter:

Contra harmonic Filter is having capability of removing in salt *or* pepper noise, but not both at a time. To get desired results it can be used in collaboration with the Harmonic Filter. And it is mathematically represented as

$$\hat{f}(x,y) = \frac{\sum_{(r,c)\in W} g(r,c)^{(R+1)}}{\sum_{(r,c)\in W} g(r,c)^{R})}$$

B. Order Statistics or Rank Filters

i) ***Median Filter***

This filter is has edge preserving nature[13,23]. Median filter works by selecting the middle pixel value from the ordered set of values within the m x n neighborhood (W) and replacing the reference pixel with the median value of the ordered set.It can be represented mathematically as follows:

$$\hat{f}(x,y) = median\{g(r,c)|(r,c) \in W\}$$

ii) The Min and Max Filters

The *min* filter replaces the reference pixel with the lowest value. And similarly the *max* replaces the reference pixel with the highest value. These mathematical functions of the Min and Max filters are as follows:

$$\hat{f}(x,y) = \min\{g(r,c)\,|\,(r,c) \in W\}$$

$$\hat{f}(x,y) = \max\{g(r,c)\,|\,(r,c) \in W\}$$

iii) Midpoint Filter

Midpoint filter finds the average value of the highest and lowest pixel values in the window, thereby combining averaging and rank filter into one filter. Its mathematical function is as follows:

$$\hat{f}(x,y) = \frac{1}{2}[mi\,n\{g(r,c)|(r,c) \in W\} + \quad max\{g(r,c)|(r,c) \in W\}]$$

iv) Alpha-Trimmed Mean Filter

“Alpha-Trimmed Mean Filter combines the order statistics and averaging that is, an average of the pixel values closest to the median, after D highest and D lowest values in an ordered set have been excluded.”[13,24] This filter can be used to control its behavior by specifying a parameter ‘D’. Mathematical Function for this filter is**[13]**

$$\text{f(x,y)} = \frac{1}{mn-2D}\sum_{(r,c)\in W} g(r,c)$$

C) Adaptive Mean Filter

It is one of the three spatial domain filters. In Adaptive median filters, the size of the filter can change. While smoothing non impulse noise it preserves the details of an image. This process works in two stages. Initially it calculates the minimum , maximum and median values of sub image of the corrupted image. In stage 1) it checks whether the calculated median itself is a salt or pepper noise or not. If the median is salt or pepper noise, then it increases the size of sub image window and re calculates the maximum, minimum and median values otherwise it proceeds to stage two. In stage 2) it checks whether the selected pixel is a salt or pepper noise or not? If it is salt or pepper noise, then it replaces the selected pixel with previously calculated median otherwise the pixel remains unchanged. This Adaptive Mean Filter is used to remove high-density noise from corrupted images.[25]

Fig.5: A Defected image and restored real image after applying filtering techniques[26]

VI. Image quality Measuring Tools

The criterion used for devising what filter is best suited for a particular type of noise model is discussed here. Two similarity measures, Peak Signal to Noise Ratio (PSNR) and 2D Cross Correlation Value were used.

A. Peak Signal to Noise Ratio

One of the most famous and commonly used similarity measures in both Digital Image and Digital Signal Processing. The mathematical expression for the same is as follows:

$$\mathrm{PSNR} = 10\log_{10} \frac{B^2}{\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left(I_1(i,j) - I_2(i,j)\right)^2}$$

B. 2D Cross Correlation

This is one other image similarity measure which compares the original image to the restored image. Consider two images and where i=1,2 ,n are its pixels. The 2D cross correlation is represented by equation – [26]

$$\rho = \frac{\sum_{i=1}^{i=n}\left[(x_i - m_x)*(y_i - m_y)\right]}{\sqrt{\sum_{i=1}^{i=n}(x_i - m_x)^2}\sqrt{\sum_{i=1}^{i=n}(y_i - m_y)^2}}$$

Where m_x and m_y are the means of the corresponding image. Table II shows the obtained 2D Cross Correlation Values for different applied filters.

V. Experimental Results

The following tables and graphs show the experimental results obtained after the tests were done on noise affected images. Minimum and maximum filters in the case of Salt & Pepper noise was used in conjunction. First minimum filter was applied, followed by maximum filter1. [26]

VII. Comparison of Filters

Table 2. Comparative analysis of Image Restoration/Filtering Techniques[27]

Sno	**Image Restoration/ Filtering Techniques**	**Merits**	**Demerits**
1	Mean Filter	-Simple method -Intuitive method -Easy to implement method of smoothing images	-A single pixel with a very unrepresentative value can significantly affect the mean value of all the pixels in its neighborhood. -When the filter neighborhood straddles an edge, the filter will interpolate new values for pixels on the edge and so will blur that edge. This may be a problem if sharp edges are required in the output.
2	Median Filter	- The problems of mean filter are tackled by the median filter -Preserve thin line edges, sharpness and fine details from an input image.	- a median filter cannot be applied directly, if a color image is corrupted by salt-and pepper noise,
3	Arithmetic mean filters	-It is an effective smoothing technique.	-Looses details of the Image.
4	Geometric mean filters	- Similar to arithmetic mean filter it is also effective in smoothing.	- As compared to arithmetic mean filter it looses less detail
5	Harmonic mean filters	-Removes Gaussian type noise -Salt noise (not pepper noise). -Preserving edge features than the arithmetic mean filter. -The harmonic mean filter is very good at removing positive outliers	-Unable to remove the Pepper noise. -Some blurring effect.
6	Order statistics filter	-Effective in the case of Gaussian, speckle, Salt and pepper and Poisson noises.	-Blurs too much. -Underlying stationary assumption

7	Inverse Filter	-Low pass filter -Pass only low frequency parts of the image. -Removes blurring effect	-Restrict all the high frequency parts where the noise dominates over the image. -Results in amplification of noise. -Sensitive to noise.
8	Pseudo-inverse filter	-Stabilized inverse filter. -Shows much better results as compare to inverse filters. -Pass all the frequencies that satisfies the particular threshold value ε.	-Sensitive to noise.
9	Wiener filter	-Popular filter used for restoration. -Not sensitive to noise. -Exploits the statistical properties of the image. -Restore images in presence of blur as well as noise.	-Prior knowledge of the power spectral density of the original image which is unavailable in practice.
10	Constrained Least Square Filter	-Adds the Lagrange multiplier, λ, to control the balance between noise artifacts and consistency with the observed data	-Requires some additional knowledge of the original scene to be recovered

Table I: Comparison of Filter performance on the basis of PSNR(dB) [27]

	Arithmetic Mean	Geometric Mean	Harmonic mean	Contrahar-monic Mean	Median	Min	Max	Midpoint	Alpha Trimmed	Best Filter
Gaussian	24.87	24.84	24.48	24.53	**25.06**	17.60	18.05	23.88	23.07	**Median**
Salt & Pepper	23.75	24.47	14.41	21.04	**25.25**	19.32[1]	---	17.44	23.07	**Median**
Uniform	15.97	16.10	16.36	16.05	15.95	**18.85**	12.07	15.83	15.72	**Minimum**
Rayleigh	17.21	17.55	18.04	17.57	17.37	**20.53**	11.34	16.57	17.06	**Minimum**
Gamma	19.86	22.76	23.97	22.30	**24.74**	18.59	9.90	13.12	22.84	**Median**
Exponential	18.54	19.26	**20.07**	19.33	19.60	20.07	10.25	16.00	18.96	**Harmonic Mean**
Poisson	22.44	24.12	24.53	22.67	**25.32**	18.41	11.81	14.75	23.10	**Median**

Table II: Comparison of Filter performance on the basis of 2D Cross Correlation[27]

	Arithmetic Mean	Geometric Mean	Harmonic mean	Contra-harmonic Mean	Median	Min	Max	Midpoint	Alpha-Trimmed
Gaussian	0.9639	0.9639	0.9622	0.9626	**0.9654**	0.922	0.9220	0.9544	0.9447
Salt & Pepper	0.9531	0.9607	0.7025	0.9139	**0.9669**	0.8931[1]	---	0.7994	0.9448
Uniform	0.9624	0.9648	0.9645	0.9310	0.9652	**0.9655**	0.9196	0.9522	0.9425
Rayleigh	0.9585	0.9606	0.9601	0.9308	0.9576	**0.9608**	0.9107	0.9465	0.9410
Gamma	0.9122	0.9500	0.9575	0.9367	**0.9639**	0.8962	0.6034	0.6998	0.9432
Exponential	0.9517	0.9561	**0.9569**	0.9312	0.9519	0.9035	0.8346	0.9165	0.9395
Poisson	0.9405	0.9574	0.9609	0.9407	**0.9674**	0.8943	0.6313	0.7336	0.9451

VIII.Applications

Various application domains to Image restoration[27] :

- Image and video (de-)coding
- Denoising and artifacts removal,
- Medical images (CT, MRI, ultrasound, etc.),
- sharpness, contrast, and resolution enhancement,
- Scientific explorations,
- Legal investigations,
- Film making and archival,
- Consumer photography,
- New applications: legacy materials, HD/3D/mobile displays, web-scale data, etc. **[27]**

Conclusion

Restoration of noisy image is important task in the field of digital image processing. In this paper, we have discussed different type of noises that are induced in images during the process of image transmission. [28] This paper also focuses on comparative study of various spatial domain filters for restoration. The comparison results indicate that Average filter shows better performance in removing Speckle noise and Gaussian noise. while Gaussian filter removes Poisson noise efficiently. The adaptive median filters performed well in removing Salt & Pepper noise, Rayleigh, Uniform and Erlang noise. This comparative study can be further extended by including more noise types and by using multiple types of noise in different types of images. One can also include more spatial filters using various means filters like Arithmetic mean filter, Geometric mean filter, Harmonic mean filter, Contra harmonic mean filter and order statistics filters like Midpoint filter, Alpha trimmed filter and Adaptive filters like Adaptive local noise reduction filter for comparison. In future, one can also use hybrid filtering approach which combines two or more filters. Some other parameters like Structure Similarity Index, Entropy can also be taken for measuring the quality of the image. [29]

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Authors Profile

1) G.Kalpana,Asst.Professor,Dept.Of M.C.A,CBIT,Hyderabad

G.Kalpana is currently working as an Assistant Professor in the Department of MCA, Chaitanya Bharathi Institute Of Technology, Hyderabad, A.P., India. She has pursued her M.Tech. in Computer Science and Engineering from HITAM Affiliated Engineering College under Jawaharlal Nehru Technological University, Hyderabad, India in 2010. She did her M.C.A from Annamalai University, Tamil Nadu,India in 2007. She has 13 years experience of teaching for undergraduate students and for post graduate students. She has published/presented 8 research papers in National/international journals and Conferences. Her research interests are in the areas of Image Processing , Data Mining and Data Analytics.

2)NV.Sai Chaitanya,MCA,CBIT, Hyderabad

Chiaithanya has currently completed his MCA in Chaitanya Bharathi Institute of Technology ,Telangana,Hyderabad,India.He has recently been placed in multi national company "corecompete". He has presented 7 research papers in international/National journals/Conference. His research interests are data analytics,Block Chain,Cloud Analytics,Business Analytics and IOT.

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