Contrast Enhancement Techniques for Images– A Visual Analysis

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ABSTRACT
Image enhancement is one of the most interesting and visually appealing areas of image processing. It involves operations such as enhancing contrast, reducing noise for improving the quality of the image. This paper presents an analysis of the mathematical morphological approach with comparison to various other state-of-art techniques for addressing the problems of low contrast in images. Histogram equalization (HE) is one of the common methods used for improving contrast in digital images. This method is simple and effective for global contrast enhancement of images but it suffers from some drawbacks. Contrast Limited Adaptive Histogram Equalization (CLAHE) enhances the local contrast of the images without the amplification of the noise. Morphological Contrast enhancement is performed using the white and black top-hat transformation. It can be performed at a single scale or at multiple scales of the structuring element. The structuring element can be of various shapes and sizes.

General Terms
Image Processing, Image Enhancement

Keywords
Contrast Enhancement, Histogram Equalization, CLAHE, Multiscale Morphology, Morphological Operations.

1. INTRODUCTION
Image Processing is among rapidly growing technologies today, with its applications in various aspects of a business. Image processing is a method to convert an image into digital form and perform some operations on it, in order to get an enhanced image or to extract some useful information from it. It forms core research area within engineering and computer science disciplines too. In addition to applications in medicine and the space program, digital image processing techniques now are used in a broad range of applications. Computer procedures are used to enhance the contrast or other features of the image for easier interpretation of x-rays and other images used in industry, medicine and the biological sciences [2].

Image enhancement is one of the most interesting and visually appealing areas of image processing. The basic idea behind image processing techniques is to make details more obvious or to simply highlight certain features of interest in an image. There are many aspects of images that are ambiguous and uncertain. Image enhancement operation improves the qualities of an image in terms of contrast, brightness characteristics, reduction of noise contents etc. Sometimes an image may be too dark containing blurredness and therefore it is difficult to recognize the different objects or scenery contained in the image. This type of image requires enhancement. A large number of image enhancement techniques exist for reducing image noise, highlighting edges, or displaying digital images. It is difficult to judge the effectiveness of these techniques due to various reasons such as the outcome depends on the exact application. An enhancement technique performing well in enhancing biomedical images may not be identically efficient in enhancing satellite images. Thus, the objective of image enhancement is dependent on the application context.

The area of Image Enhancement also addresses the problem of contrast enhancement. Contrast enhancement deals with improving the contrast in an image in order to make various features more easily perceived. Many contrast enhancement algorithms have been developed over the years, driven by different considerations.

This paper presents a survey of several contrast enhancement techniques for images. The purpose of this paper is to give a comparative overview along with the discussion of visual results of several techniques used for contrast enhancement of images. In the following sections of this paper, the conventional techniques of contrast enhancement are being reviewed and compared. The Section II provides a brief coverage of the need and application of image enhancement techniques. Section III gives an overview of various techniques of Contrast Enhancement. Some of the techniques have been applied on a set of medical images and the computer simulated results are shown in Section IV. Section V provides a discussion of the visual results presented in Section IV. Finally, the study is concluded in Section VI.

2. IMAGE ENHANCEMENT
Image enhancement is a preprocessing step in many image processing applications. The aim of image enhancement is to improve the interpretability or perception of information in images for human viewers, or to provide better input for other automated image processing techniques. [2] There are various reasons for poor quality of an image such as distortion being introduced by the imaging systems, lack of expertise of the operator or the adverse external conditions at the time of image acquisition.

Mainly, Image enhancement includes intensity and contrast manipulation, noise reduction, edges sharpening and filtering, etc. Contrast Enhancement is focused on the problem of improving the contrast in an image to make various features more easily perceived. Contrast of an image is determined by its dynamic range, which is defined as the difference between lowest and highest intensity level. Contrast enhancement techniques have various application areas for enhancing the visual quality of low contrast images. Many contrast enhancement algorithms have been developed over the years. Contrast enhancement algorithms can broadly be divided into two categories: spatial domain techniques and frequency domain techniques.

In spatial domain techniques, the image enhancement is based on direct manipulation of the pixels in an image. Frequency domain processing techniques are based on modifying the Fourier transform of an image. In frequency domain methods, the image is first transferred in to frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are then performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image.

Fig 1: Image Enhancement

3. CONTRAST ENHANCEMENT

Contrast enhancement is one of the important research issues of image enhancement. There are many contrast enhancement methods which have been proposed in the literature. A very popular technique for image enhancement is histogram equalization (HE). This technique is commonly employed for image enhancement because of its simplicity and comparatively better performance on almost all types of images. This technique has certain limitations which are being discussed in the following section. Some researchers have also focused on improvement of histogram equalization based contrast enhancement such as adaptive histogram equalization which helps to enhance the contrast locally [3]. Mathematical morphology is a relatively new approach to image processing and analysis. The top hat transformation is used to improve the contrast of the images based on the shape and the size of the structuring element.

(a) (b)

Fig 2: Contrast Enhancement (a) A Low Contrast image (b) A High Contrast Image

Figure 2(b) shows the results of enhancing the contrast of the image given in Figure 2(a). The low contrast image has been enhanced using the Histogram Equalization technique.

3.1 Histogram Equalization

Histogram Equalization (HE) is a very popular technique for enhancing the contrast of an image. Its basic idea lies on mapping the gray levels based on the probability distribution of the input gray levels. This technique flattens and stretches the dynamic range of the image's histogram, resulting in overall contrast enhancement. The specialty of the conventional histogram equalization technique is that it treats the image globally. The method is useful in images with backgrounds and foregrounds that are both bright or both dark. In particular, the method can lead to better views of bone structure in x-ray images, and to better detail in photographs that are over or under-exposed.

HE has been applied in various fields such as medical image processing and radar image processing. A key advantage of this technique is that it is fairly straightforward and effective. The calculation is not computationally intensive. It is powerful in highlighting the borders and edges between different objects, but may reduce the local details within these objects, especially smooth and small ones.

Another disadvantage of the method is that it is indiscriminate. It may increase the contrast of background noise, while decreasing the usable signal. This technique may produce images with over enhancement. HE tends to introduce some annoying artifacts and unnatural enhancement.

Moreover, the conventional histogram equalization technique treats the image globally but the image characteristics differ considerably from one region to another in the same image so it is reasonable to adopt a context-sensitive technique based on local contrast variation.

3.2 CLAHE

Contrast-Limited Adaptive Histogram Equalization (CLAHE) is an adaptive contrast enhancement method. It is based on adaptive histogram equalization. Adaptive Histogram Equalization is an extension to conventional Histogram Equalization technique. This technique computes several histograms, each corresponding to a distinct section of the image known as tiles, rather than the entire image. Each tile's contrast is enhanced to redistribute the pixel values of the image. The neighboring tiles are then combined using bilinear interpolation in order to eliminate artificially induced boundaries. The contrast, especially in homogeneous areas, can be limited in order to avoid amplification of the noise which might be present in the image. This method is therefore suitable for improving the local contrast of an image and bringing out more detail. This method emphasizes local contrast, rather than overall contrast.

CLAHE is a technique for avoiding the excess amplification, while maintaining the high dynamic range of the sub-block. This technique was originally developed for medical imaging and has proven to be successful for enhancement of low-contrast images such as portal films.

3.3 Morphological Enhancement

The application of mathematical morphology to image processing and analysis has initiated a new approach for solving a number of problems in the related field. This approach is based on set theoretic concepts of shape. In morphology objects present in an image are treated as sets. The identification of objects and object features through their shape makes mathematical morphology become an obvious approach for various machine vision and recognition processes.

In morphology, the objects in an image are considered as set of points and operations are defined between two sets: the object and the structuring element (SE). Basic morphological operations are erosion and dilation. Other operations like opening (closing) are sequential combinations of erosion (dilation) and dilation (erosion) operations. Dilation adds pixels to the boundaries of objects in an image, while erosion removes pixels on object boundaries. The number of pixels added or removed from the objects in an image depends on the size and shape of the structuring element used to process the image. A structuring element is a matrix consisting of only 0's and 1's that can have any arbitrary shape and size. The pixels with values of 1 define the neighborhood.

There are two main characteristics that are directly related to structuring elements: Shape and Size. The shape of the structuring element can be a ``ball" or a line; convex or a ring, etc. the size of the structuring element is usually odd like 3 × 3, 5 × 5, 7× 7 etc. The overall selection of a structuring element depends upon the geometric shapes which are to be extracted from the image.

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

(a) (b) (c) (d)

Fig 3: Basic Morphological Operations (a) Original Image, (b) Dilated Image (c) Eroded Image (d) Square Shaped structuring element of size=5

Larger structuring elements preserve larger features while smaller elements preserve the finer details of image features. For example, In case of biological or medical images, which contain few straight lines or sharp angles, a circular structuring element is an appropriate choice. When shapes are to be extracted from geographic aerial images of a city, a square or rectangular element will extract angular features from the image.

Morphological analysis has traditionally been performed using flat structuring elements which have two dimensions such as 3 × 3, 5 × 5 in the case of 2D images. Two-dimensional, or flat, structuring elements are typically much smaller than the image being processed. The pixels in the structuring element containing 1's define the neighborhood of the structuring element. These pixels are also considered in dilation or erosion processing. The flat structuring elements such as disk shaped elements may be inappropriate for certain image enhancement applications like enhancement of microcalcifications in mammograms or to enhance the roundness of blood cells in medical images.

Three-dimensional, or nonflat, structuring elements are 3D structuring elements and they use 0's and 1's to define the extent of the structuring element in the x- and y-planes and also adds height values to define the third dimension. The non flat structuring elements have very little application in the literature. Wirth et al. [10] used a non flat ball shaped structuring element to enhance the contrast of microcalcifications in mammograms. Ruberto et al. [5] used a hemisphere shaped SE to enhance the roundness and compactness of red blood cells in images of stained blood slides.

3.3.1 Top Hat Transformation

The top hat transformation provides an excellent tool for extracting bright or dark features smaller than a given size from an uneven background. There are two variations of top hat transformation: white top hat and black top hat transformation. The white top hat transformation helps to extract the white or bright features of the image smaller than the size of the structuring element. The black top hat transformation is used to extract the black or dark features of the image. The white top hat transform relies on the fact that by gray-scale opening, one can remove from an image the brighter areas, i.e. features that cannot hold the structuring element. Subtracting the opened image from the original one produces an image where the features that have been removed by opening are clearly visible. Similar thing is true for closing operation also. It means that using a closing operation instead of an opening and subtracting the original image from the closed one helps to extract dark features from a brighter background. This is known as black tophat transformation opposed to white tophat transformation in case of opening.

The opening and closing operations are defined, respectively, as:

$$(f \circ g) = \text{Dilation}(\text{Erosion}(f, g), g) \qquad (1)$$

$$(f \bullet g) = \text{Erosion}(\text{Dilation}(f, g), g) \qquad (2)$$

where, f is the image, g is the structuring element, ○ denotes the opening operation and ● denotes the closing operation.

The white top-hat transformation (WTH) is defined as the residue between the original image and its opening.

$$f_{WTH} = ((f - (f \circ g))(x, y) \qquad (3)$$

The black top-hat transformation (BTH) is the residue between the closing of an image and the original image.

$$f_{BTH} = ((f \bullet g) - f)(x, y) \qquad (4)$$

where f(x, y) is a gray scale image and g is a structuring element.

3.3.2 Morphological Filtering on a Single Scale

Single scale morphological filtering performs image enhancement using the morphological top hat transform corresponding to the size/scale of the used structuring element.

Local contrast enhancement can be achieved by adding an original image to the difference between top-hat and bottom hat transformed image. This is done as follows:

$$f_{En} = f + f_{WTH} - f_{BTH} \qquad (5)$$

where f is the original image, f_{En} represents the final enhanced image, f_{WTH} represents the extracted white image regions and f_{BTH} represents the extracted black image regions at the size of the structuring element used.

Fig. 4 shows the various steps involved in morphological filtering of the image at a single scale for enhancing the contrast of the image. The contrast is enhanced by applying the white and black top hat transformation.

This single scale morphological filtering technique can be used for local contrast enhancement in medical images like digital mammograms. For certain mammographic applications, this procedure can be iteratively repeated by using the output image of iteration as the input image for the next iteration. This gives faster results with the resulting image containing small lighter details and equalized background tissue [6].

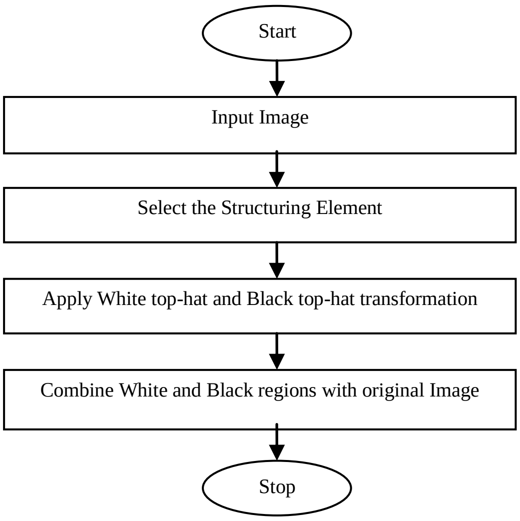


Fig 4: Flowchart of Single Scale Morphological Filtering

3.3.3 Multiscale Morphological Filtering

A morphological operation with a scalable structuring element can extract features based not only on shape but also on size. Also features of identical shape but of different size are now treated separately. Such a scheme of morphological operations where a structuring element of varying scale is used is termed as multiscale morphology.

Suppose, there is a sequence of multiscale structuring elements with the same shape and increasing sizes: g_0, g_1, $g_2 ... g_m$, where g_i is obtained as the result of i times the dilation of g0 with g_0, $1 \leq i \leq m$. The white (WTH) and black (BTH) image regions at the ith scale can be extracted as follows.

$$WTH_i = f - (f \circ g_i) \quad (6)$$

$$BTH_i = (f \bullet g_i) - f \quad (7)$$

Compute the sum of white and black image regions extracted separately at all scales as follows.

$$fw = \sum_{i=1}^{m} WTH_i \quad (8)$$

$$fb = \sum_{i=1}^{m} BTH_i \quad (9)$$

where, fw is the extracted white multi scale image regions and fb is the extracted black multi scale image regions at all scales.

The contrast of an image can be enhanced by adding the white regions and subtracting the black regions from the original image as given in Eq (5). Using the same approach, the final extracted white and black image regions given by fw and fb in Eqs (8) and (9), the image f could be enhanced as follows.

$$f_r = f + fw - fb \quad (10)$$

where f_r denotes the resulting enhanced image obtained using the multiscale morphological technique.[8]

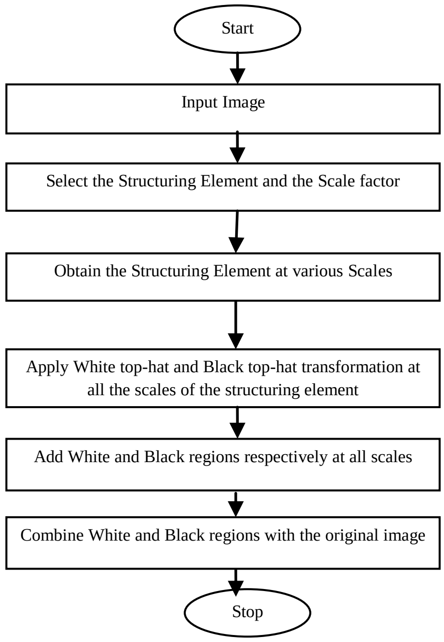


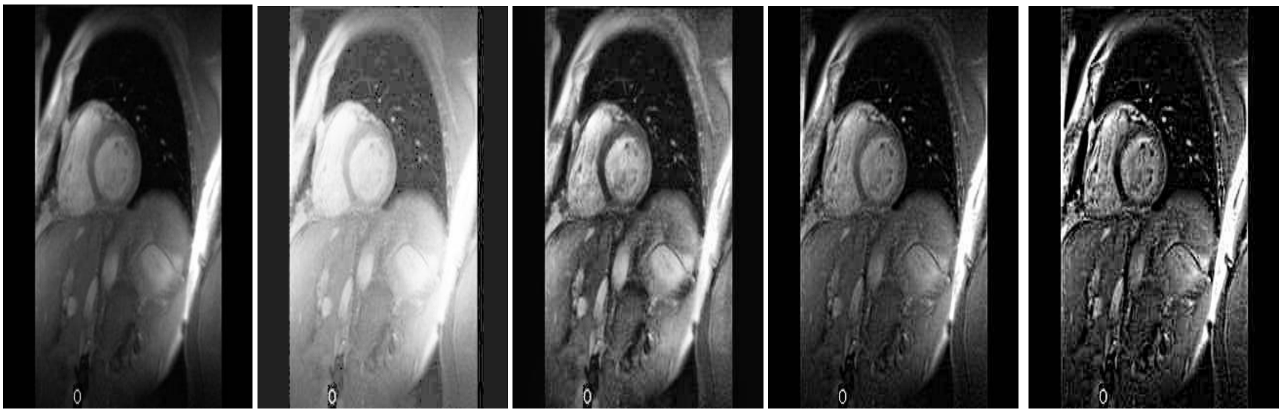
Fig 5: Flowchart of Multi Scale Morphological Filtering

Fig. 5 shows the various steps involved in multiscale morphological filtering of the image for enhancing the contrast of the image. The contrast is enhanced by applying the white and black top hat transformation at various scales of the structuring element. The scales are specified by the scale factor.

Multiscale morphology is used to enhance the contrast of the image at various scales or sizes of the structuring element. This technique can be used to enhance the vascular angiogram or to enhance the local contrast of coronary artery. Various methods like Gabor wavelet in [7] can be used to estimate the scale of the structuring element. According to the scales, morphological top hat transformations can be applied. This helps to enhance the contrast between vessels of different dimensions.

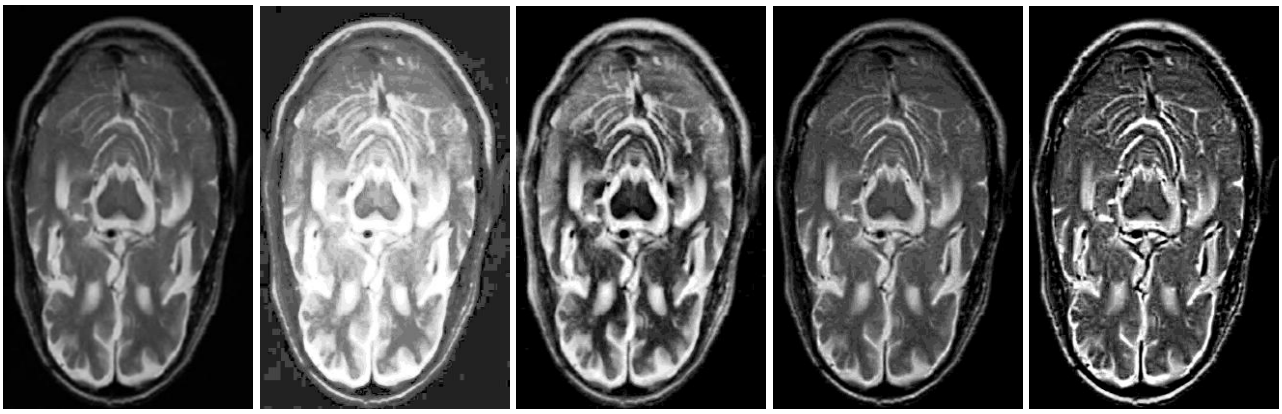
4. COMPUTER SIMULATED RESULTS

The computer simulated results have been obtained by implementing the techniques on a set of medical images and the results have been represented visually. The various techniques being implemented are Histogram Equalization, Contrast-Limited Adaptive Histogram Equalization, Single Scale Morphological Filtering and Multiscale Morphological Filtering. Fig. 6, Fig. 7 and Fig. 8 represent the visual results of implementation of the techniques using MATLAB 7.0.1. In the multiscale morphological approach, "disk" shaped structuring element has been used and the scale factor being taken is "7" for simulation.



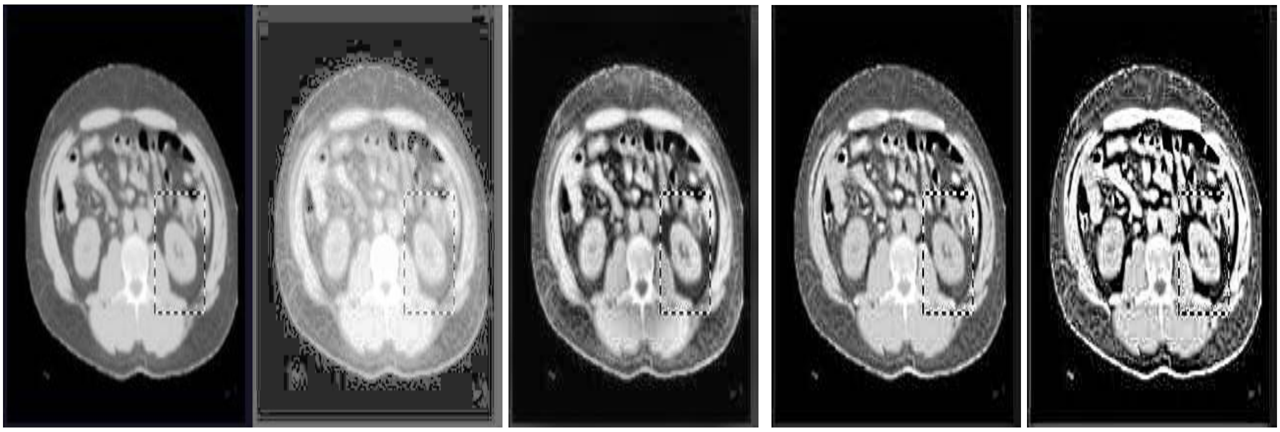
(a) (b) (c) (d) (e)

Fig. 6: Contrast Enhancement of image of heart (a) Original Image (b) Result of Histogram Equalization (c) Result of CLAHE (d) Result of Single Scale Morphological Filtering (e)Result of Multiscale Filtering



(a) (b) (c) (d) (e)

Fig. 7: Contrast Enhancement of image of brain (a) Original Image (b) Result of Histogram Equalization (c) Result of CLAHE (d) Result of Single Scale Morphological Filtering (e) Result of Multiscale Filtering



(a) (b) (c) (d) (e)

Fig. 8: Contrast Enhancement of synthetic image of kidney (a) Original Image (b) Result of Histogram Equalization (c) Result of CLAHE (d) Result of Single Scale Morphological Filtering (e) Result of Multiscale Filtering

5. DISCUSSION OF RESULTS

Section IV provides the visual results of various techniques. In the computer simulated results, the original image is blurred. Although it has good global contrast, but the local contrast is poor as the objects in the image are not easily perceivable.

Histogram Equalization when applied to the original image, improves the contrast of the image but the white regions of the image get over enhanced. This is because the Histogram Equalization treats the image globally. The HE method is useful in images with backgrounds and foregrounds that are both bright or both dark. The global techniques cannot improve the contrast of the image satisfactorily.

CLAHE is an adaptive histogram equalization technique so it gives better visual results in comparison to the conventional Histogram Equalization technique but it still lacks local contrast. It is visually apparent from the results, that there is lack of clarity within the regions enclosed by the objects.

The application of mathematical morphology to image processing and analysis has initiated a new approach for solving a number of problems in the image enhancement field. Poor local contrast is one of such problems. Mathematical Morphology can be applied at single scale or at various scales of the structuring element. The results of single scale morphological filtering enhance the contrast of the images at a single size of the structuring element. It also avoids over enhancement of the image as in the case of Histogram equalization. However, scale factor must be applied for extracting the features of the image at different sizes of the structuring element. This is done using Multiscale morphological filtering.

Multiscale morphological approach has been successfully used in local contrast enhancement. It enhances the local contrast of the images satisfactorily. With comparison to the other techniques, Multiscale morphological approach gives good visual results in terms of contrast.

6. CONCLUSIONS

In this paper, a survey of various contrast enhancement techniques is presented along with their visual comparison. Many image contrast enhancement techniques like Histogram Equalization (HE), Contrast limited Adaptive Histogram Equalization (CLAHE), Morphological enhancement at single scale and Multiscale Morphological Enhancement have been reviewed and compared. The applicability of these techniques in various application domains is also discussed.

Experimental results are obtained on various medical images including a synthetic image. The Multiscale morphological approach provides good results in comparison to the results obtained with other state-of-art techniques.

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