Image Enhancement

- Image Enhancement procedures are techniques used to achieve a subjective improvement in image "quality" for a specific application (problem-oriented).
- Typical applications: noise removal, geometric correction, smoothing,sharpening, edge enhancement or extraction.
- Usually ad hoc procedures.
- May be either in the Spacial Domain (pixel operators) or in the Frequency Domain (frequency filtering).

Image Enhancement

SPATIAL DOMAIN

$$g(x,y)=T[f(x,y)]$$

- f(x,y) is the input image,
- g(x,y) is the processed image,
- T is an operator on f, defined over some neighborhood of (x,y)
  - 1x1, point processing (gray-level transformation)
  - mask processing
- T can also operate on a set of input images

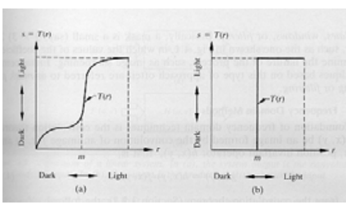
$$g(x,y)=T[f_1(x,y),f_2(x,y),\ldots,f_n(x,y)]$$

Image Enhancement

SPATIAL DOMAIN $g(x,y)=T[f(x,y)]$

- the simplest form of T is when the neighborhood is 1x1, in this case, g depends only on the value of f at (x,y)
- T becomes a gray-level transformation (mapping) function

$$s=T(r)$$



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FREQUENCY DOMAIN

$$g(x,y)=h(x,y)*f(x,y)$$

f(x,y) ⇨ **h(x,y)** ⇨ *g(x,y)*

- f(x,y) is the input image,
- g(x,y) is the processed image,
- h(x,y) is a linear, position invariant operator

  (a position invariant operator is one whose result depends only on the value of f(x,y) at a point in the image and not on the position of the point)

$$G(u,v)=H(u,v).F(u,v)$$

F(u,v) ⇨ **H(u,v)** ⇨ *G(u,v)*

- G, H, and F are the Fourier transforms of g, h, and f, respectively
- H(u,v) is the transfer function
- h(x, y) is called the impulse response (point spread function).

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FREQUENCY DOMAIN

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$$g(x,y)=h(x,y)*f(x,y)$$

f(x,y) ⇨ **h(x,y)** ⇨ *g(x,y)*

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$$G(u,v)=H(u,v).F(u,v)$$

F(u,v) ⇨ **H(u,v)** ⇨ *G(u,v)*

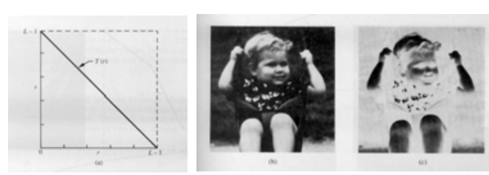
1

$$g(x,y)=F^{-1}[G(u,v)]=F^{-1}[H(u,v)]=h(x,y)$$

Image Enhancement

ENHANCEMENT BY POINT PROCESSING $s=T(r)$

- Image Negatives



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ENHANCEMENT BY POINT PROCESSING $s = T(r)$

Contrast Enhancement

- **If the pixel values *f(x, y)* occupy only a limited range *(m, M)* in the available range *(n, N),* contrast may be enhanced in the displayed image *g(x, y)* by the linear transformation.**

$$g(x,y) = \frac{f(x,y) - m}{M - m}(N - n) + n$$

linear gray scale transformation

- **The same transformation may also be used to stretch a small range of gray levels of interest to the available display range.**
- **This is useful in displaying computed tomography images, which have a large dynamic range of (-1024, 1024).**
- **A small density range of interest may be extracted from the full range for improved display; the method is then known as *density slicing or gray ever windowing*.**
- **Nonlinear transformations may also be used for selective gray level stretching and compression.**

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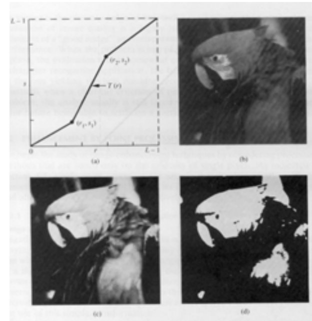
ENHANCEMENT BY POINT PROCESSING $s = T(r)$

Contrast Stretching



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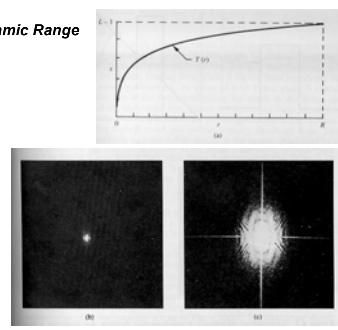
ENHANCEMENT BY POINT PROCESSING $s = T(r)$

Compression of Dynamic Range

$$s = c.\log(1 + |r|)$$



[0, 2.5x10^6]

[0, 255]

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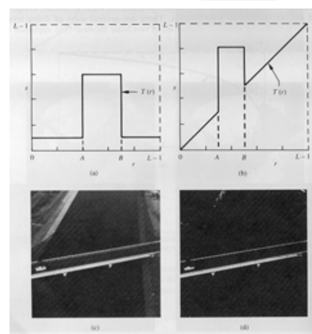
ENHANCEMENT BY POINT PROCESSING $s = T(r)$

Gray-level slicing



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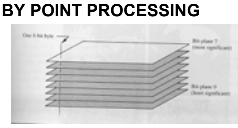
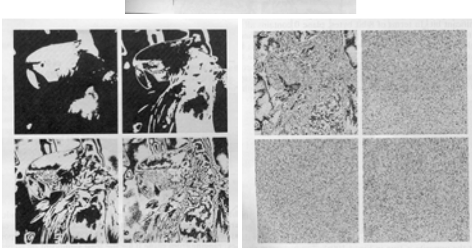
ENHANCEMENT BY POINT PROCESSING

Bit-plane slicing





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ENHANCEMENT BY POINT PROCESSING $s = T(r)$

Histogram Techniques

- **The histogram of an image is a plot of the numbers of occurrences of the various gray levels in the image against the gray level values.**
- **If we normalize the histogram by dividing the numbers of occurrences by the total number of pixels in the image, we get an estimate of the probability density function (PDF) of the (random) process generating the image gray levels.**
- **According to information theory, the entropy of the image, which is a measure of *its statistical information content*, is maximized when the PDF is uniform or flat.**

$$H = -\sum_{i=1}^{M} p_i.\log_2 p_i$$

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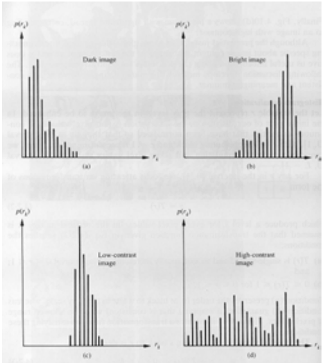

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HISTOGRAM EQUALIZATION

- **Consider the PDF $p_r(r)$ of an image with normalized gray levels in the range $0 \le r \le 1$.**
  (if the maximum gray level in the given image is 255, the gray levels are normalized to the range (0,1) by dividing by 255).
- **If we were to apply a transformation s = T(r) to the random variable r, the PDF of the new variable s is given by**

$$p_s(s) = p_r(r)\frac{dr}{ds}\Big|_{r=T^{-1}(s)}$$

Consider the transformation

$$s = T(r) = \int_0^r p_r(\omega)\,d\omega ;0 \le r \le 1$$

- **This is the cumulative (probability) distribution function of r.**

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T(r) has the important and desired properties:

- **T(r) is sigle-valued and monotonically increasing over the interval $0 \le r \le 1$.**
  This is necessary to maintain *black ↔ white transition order between the original and processed images.*
- ***0*** **$\le$ T(r) ≤ 1 for *0* $\le$ r ≤ 1 (required in order to maintain the same range of values in input and output images).**

As $\frac{ds}{dr} = p_r(r)$ ***, we have***

$$p_s(s) = \left[p_r(r)\frac{1}{p_r(r)} \right]_{r=T^{-1}(s)} = 1; \quad 0 \le s \le 1.$$

- **Thus T(r) *equalizes* the histogram of the given image.**

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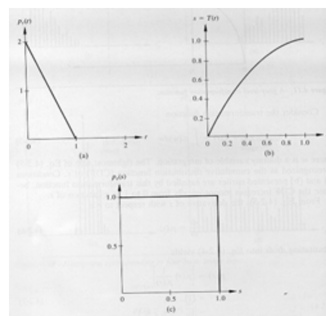

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DISCRETE VERSION OF HISTOGRAM EQUALIZATION

- **For a digital image with a total of *n* pixels and *L* gray levels** $r_k, k = 0,1,..., L-1, 0 \le r_k \le 1,$ **occurring n_k times respectively, the PDF may be approximated by the histogram**

$$p_r(r_k) = \frac{n_k}{n}; k = 0,1,..., L-1.$$

- **The histogram equalizing transformation is given by**

$$s_k = T(r_k) = \sum_{j=0}^{k} p_r(r_j) = \sum_{j=0}^{k} \frac{n_j}{n}; k = 0,1,..., L-1.$$

- **Note that this transformation may yield values of** s_k **which may not equal the available quantized gray levels.**
- **The values will have to be quantized, and hence the output image may only have an approximately uniform histogram.**

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- **In practical application, the resulting values in the range (0,1) have to be scaled to the display range of (0, 255).**
- **Histogram equalization is usually implemented via *lookup tables.***
- **Histogram equalization can provide only one output image, which may not be satisfactory is some cases.**
- **In a related procedure known as *histogram specification*, a series of histogram equalization steps is used to obtain an image with a histogram close to a *pre-specified* histogram.**
- **Then, by specifying different histograms, it is possible to obtain a range of enhanced images.**

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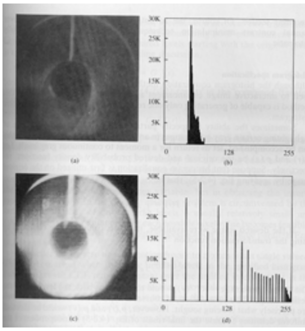

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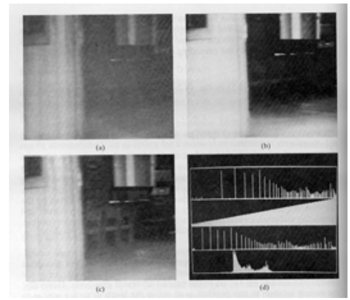
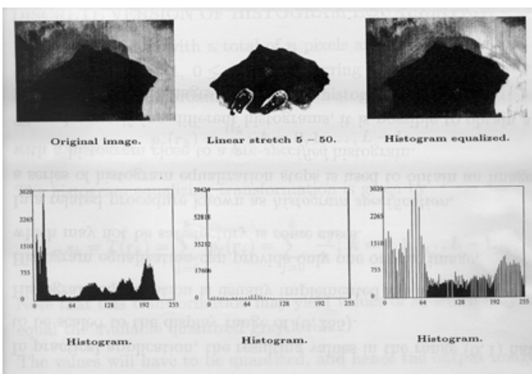
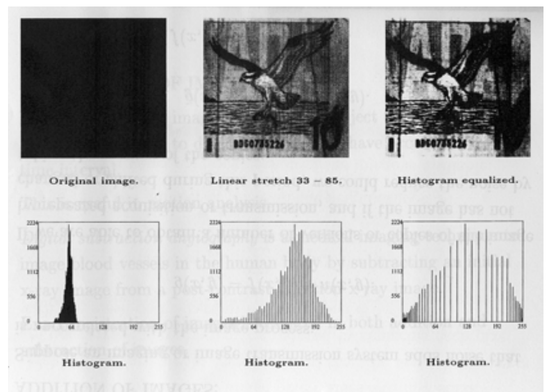




Effects of linear contrast stretching and histogram equalization.



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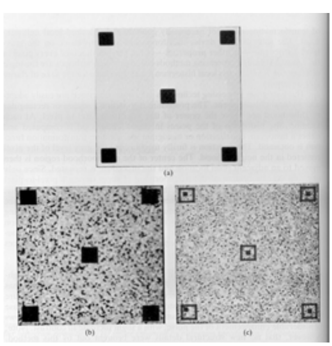
Histogram Equalization

GLOBAL
x
LOCAL
(7x7 neighborhood)



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ALGEBRAIC OPERATIONS WHIT IMAGES

ADDITION OF IMAGES:

- **Suppose an image or image transmission system adds noise that is uncorrelated with the image process:**

$$g(x,y) = f(x,y) + n(x,y)$$

- **if we are able to obtain a number of versions or copies of the image by repeated acquisition or transmission, and if the image has not changed or shifted during this period, we could reduce the noise by taking the average of the copies:**

$$g(x,y) = \frac{1}{M}\sum_{i=1}^{M} g_i(x,y).$$

$$Then \quad E\{\overline{g}(x,y)\} = f(x,y) and \sigma_{\overline{g}}^2 = \sigma_n^2 : M.$$

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- **Noise reduction by averaging**

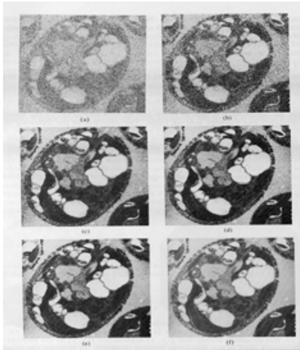

Image Enhancement

SUBTRACTION OF IMAGES:

- **By subtracting two images of a scene or object taken some time apart, it is possible to detect changes that have occurred over the time interval.**
- **This is useful in motion analysis.**
- ***Digital subtraction angiography* is a medical imaging technique to image blood vessels in the human body by subtracting an initial x-ray image from a post-contrast-injection x-ray image.**
- **Exact registration of images is essential in both addition andsubtraction of images.**

Image Enhancement

- **Image subtraction**