BME4120
Biomedical Image Processing

Lecture 3

Diagnosis with CAD

Computer-aided diagnosis (CAD) method is very useful technique which may help in the early detection of cancer.

CAD systems are also called computer-aided detection systems, since these are used for detecting cancer or abnormalities.

CAD techniques are supported by several computing tools such as neural network and genetic algorithms, etc. for enhanced classification and optimization of results.

Diagnosis with CAD

Goals of CAD system:

- Diagnose and detect abnormalities and suspicious regions in digital mammograms by using some important image processing steps by using
  - image enhancement
  - image segmentation
  - feature extraction
  - classification

Image Processing Flow

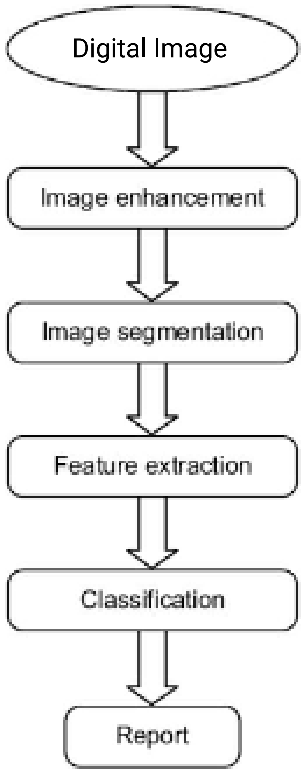

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Image Processing Flow

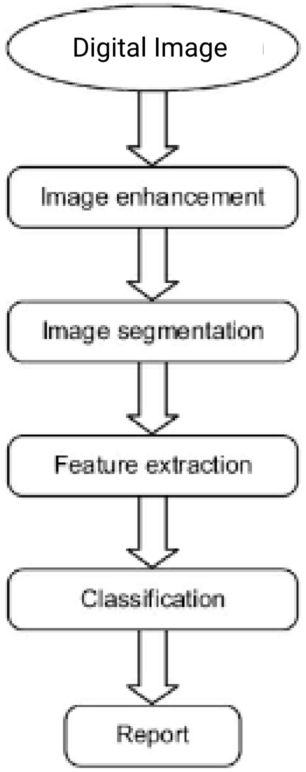

Image enhancement

Are techniques that are used to improve the quality of an image as perceived by a human as well as by a machine.

Broadly classified as spatial domain image enhancement and frequency domain image enhancement methods.

Spatial domain methods: contrast stretch, histogram modification, density slicing, edge enhancement and spatial filtering, …

Frequency domain methods: filters (smoothing, sharpening, homomorphic)

Some reasons for bad quality images: Poor illumination and lighting, improper pose conditions and other noise signals

Image enhancement is important in the analysis of digital images.

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Image Processing Flow

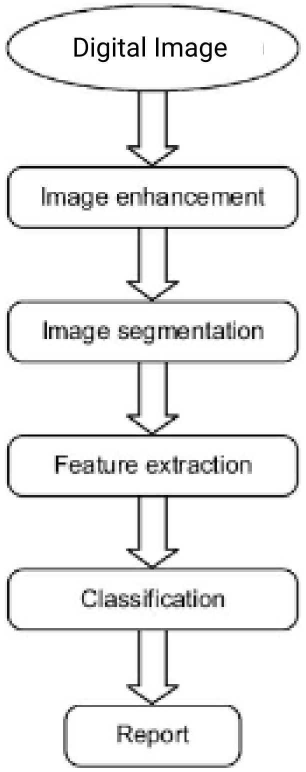

Image segmentation

Very much needed in medical image processing in context to CAD systems.

Visual inspection requires being clear in diagnosis process where the correct region which is affected, needs to be separated. → achieved by image segmentation methods.

A good segmented image can be justified based on statistical analysis.

- ❑ essential to distinguish between the region of interest (ROI) and the remaining portion (a.k.a. background)

Methods used to find ROI are known as segmentation techniques →segmenting the **foreground** from the **background**.

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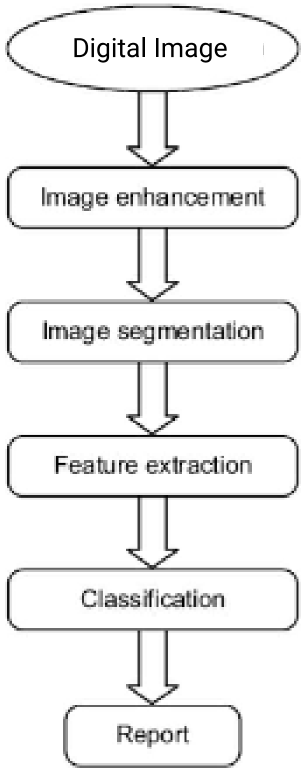
Image Processing Flow



Feature extraction

A very important process in extracting suitable features of any image processing technique.

- ❑ It could be image enhancement or image segmentation.

Few statistical parameters or features are required to compare the input image with the result obtained and therefore, feature extraction plays a crucial role in the analysis of images.

Important features could be used to discriminate between benign and malignant in tumors.

- ❑ Geometric features are based on area (a set of pixels inside ROI), perimeter (number of pixels around ROI boundary, compactness), shape, etc.

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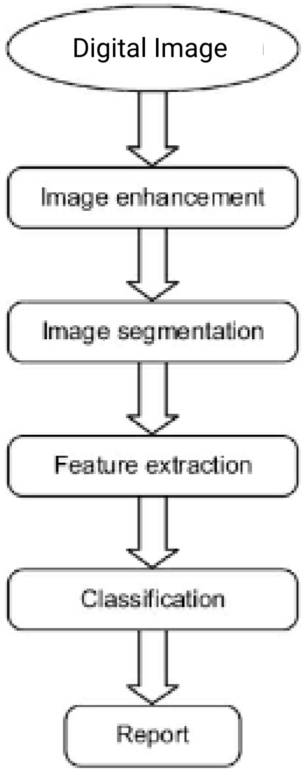
Image Processing Flow



Classification

Generally, the last step in a CAD system → plays a vital role in the implementation of computer-aided diagnosis (CAD) of imaging

Once images are enhanced, segmented and the features are extracted, classification process is applied.

After the features are extracted and selected, then subjected to the classifier to classify the detected suspicious areas into distinct categories, e.g., benign masses or malignant masses.

Image enhancement play also important part as abrupt change in gray level values occurs in the transition between some tissues, and the applied filters can enhance the structures in images representing clusters of malignant masses.

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Evaluation Parameters of CAD System

The efficiency of CAD system can be determined with statistical parameters.

Some of the parameters used for evaluation of CAD systems are

True positive (TP): A case when the suspected abnormality is malignant, i.e., the prediction is true.

True negative (TN): A case where no symptoms are found truly, i.e., no detection of abnormality in a healthy person.

False positive (FP): A case which indicates that detection of abnormality is found in healthy person. The prediction of the presence of abnormality is not true.

False negative (FN): No detection of malignant lesion is found, proves to be false.

FP and FN are very critical parameters, since the presence of malignant or microcalcification is either detected or not detected falsely.

The false positives require an invasive examination which implies patient anxiety, stress and unnecessary costs. The false negative is an even worse situation, as it compromises the health of the patient and the disease treatment too.

Sensitivity and Specificity

Sensitivity and specificity are also used for evaluating the performance and CAD systems as the most important criteria.

The sensitivity is defined as

(the proportion of patients with disease who have a positive test)

$$\text{Sensitivity} = \frac{TP}{TP+FN}$$

High values of sensitivity indicate minimal false negatives detection.

The specificity is defined as

(the proportion of patients without the disease who have a negative result)

$$\text{Specificity} = \frac{TN}{TN+FP}$$

High values of specificity indicate minimal false positive detection.

	Disease present	Disease absent
Test positive	True positive	False positive
Test negative	False negative	True negative
Total	TP + FN	FP + TN

Accuracy & Precision

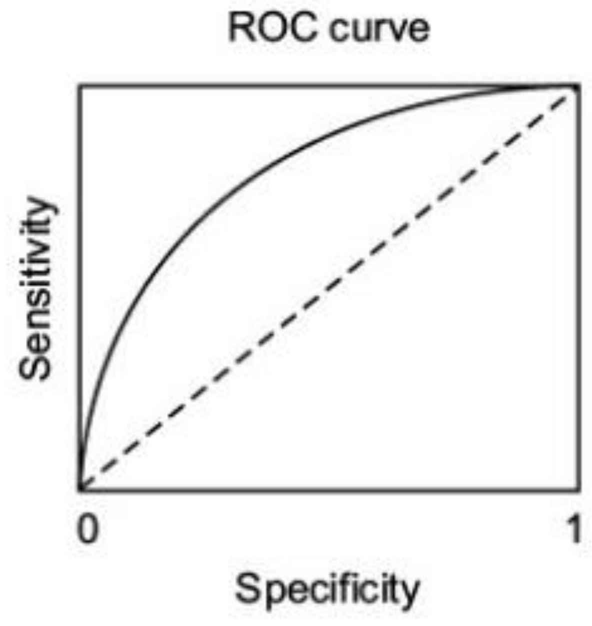
Accuracy is another criterion which is considered as a measure of the global performance of CAD systems or algorithms.

Accuracy and precision are defined as

$$\text{Accuracy} = \frac{TP+TN}{TN+TP+FP+FN}$$

$$\text{Precision} = \frac{TP}{TP+FP}$$

ROC Curve



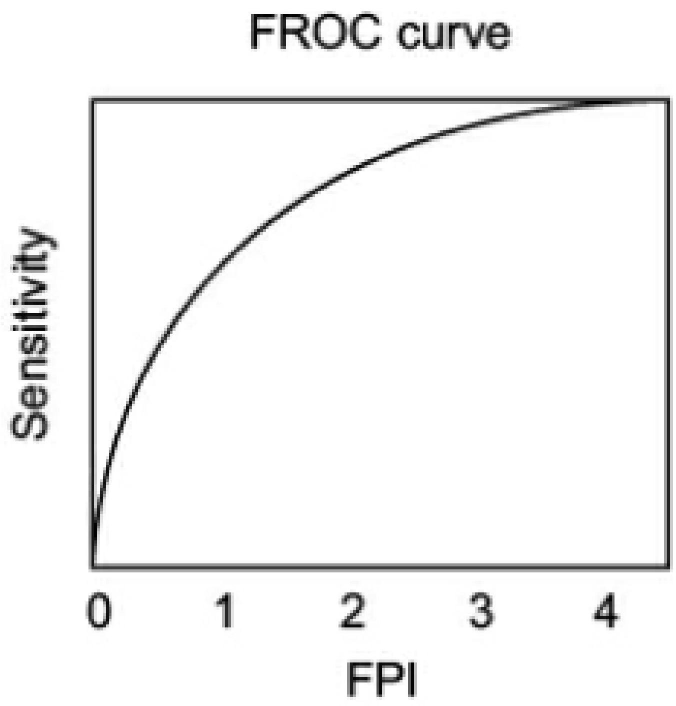
(a)

Receiver operating characteristic (ROC) curve can be represented using sensitivity and specificity.

ROC curve shows the relation between sensitivity and specificity. A trade-off between the true positive rate and the false positive rate is indicated which is useful in selecting specific thresholds on which the prediction might be done.

The area over the ROC curve represents an error. The overall performance is evaluated in terms of area under the ROC curve and the relative error.

FROC Curve



(b)

Free-response receiver operating characteristic (FROC) curve which is plotted between the sensitivity and FP per image (FPI).

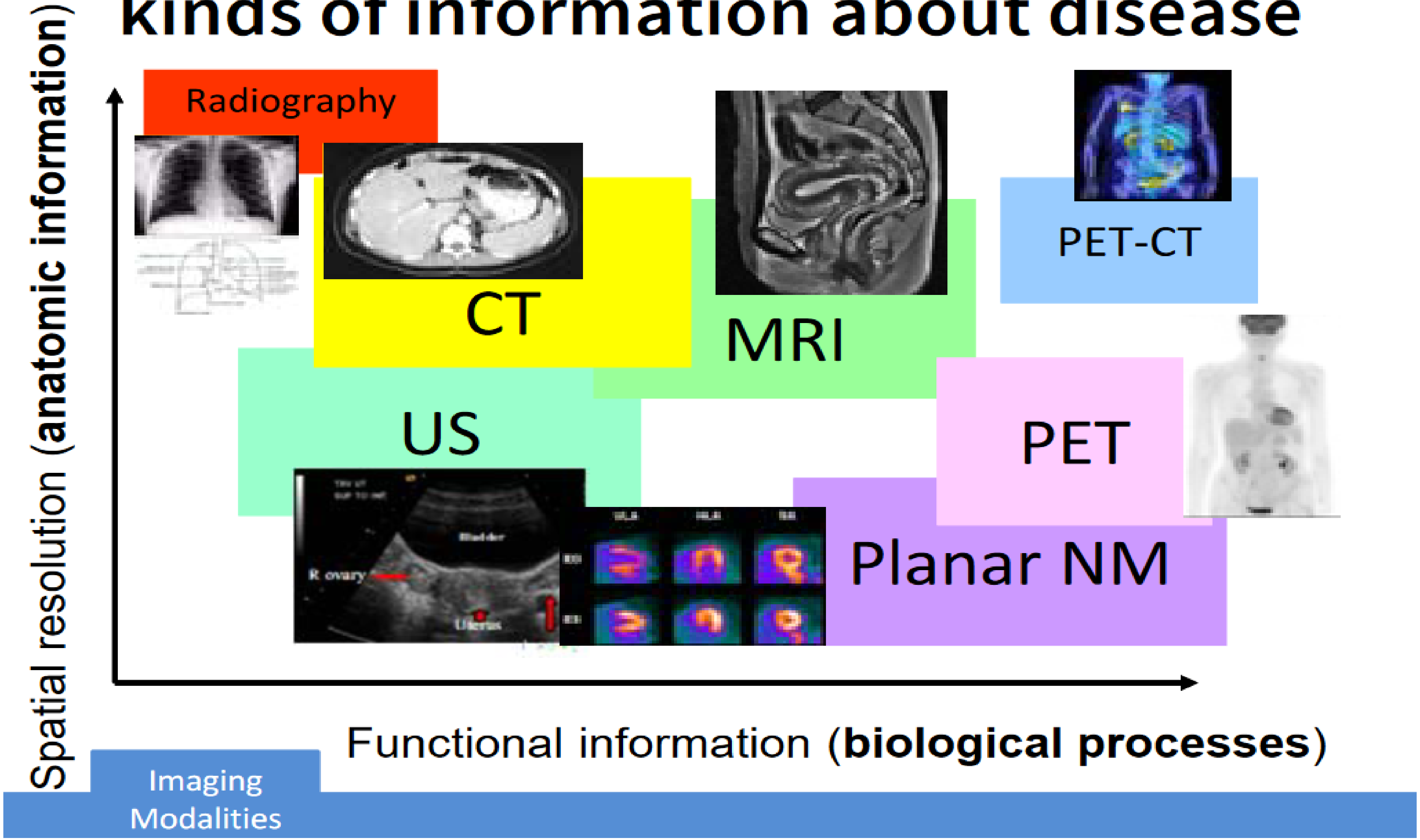
The complexity of the input images is not addressed by these curves and it is difficult to transform the subjective measurement, i.e., radiologist’s observation to the objective measurement of FROC curve

Medical Imaging Modalities

Modality	Radiation Detected	Clinical Information	Cost	Exam Duration	Pros	Cons
Radiography	X-rays (transmission)	Anatomic structures (e.g broken bones)	< $100	Seconds	Quick, cheap, accessible, lower doses than CT	Radiation dose, anatomic noise from overlaying structures
Computed Tomography (CT)	X-rays (transmission)	Anatomic structures	$1000-$3000	Minutes (actual scan time is seconds)	Fast, great anatomic detail	Radiation dose
Magnetic Resonance Imaging (MRI)	RF	Anatomic structures (also some functional applications)	$1000-$4000	0.5 hour	No radiation, great soft tissue contrast	Not suitable for patients with metallic implants, patients can feel clausterphobic, long scan time, expensive
Ultrasound Imaging	High frequency sound waves		$100-$1000	10-15 minutes	No radiation, real-time, no side effects, good soft tissue resolution	Highly operator-dependent, limited applications
Single Photon Emission Computed Tomography (SPECT)	Gamma-rays (emission)	Functional (e.g. brain, heart)	$3500	Hours (actual scan time 30-40 minutes)	Lesion localisation, removal of out-of-focal plane data (compared to planar imaging)	Radiation dose, risk of allergic reaction to tracer, patient is radioactive (for a short time), poor spatial resolution (1 cm)
Positron Emission Tomography (PET)	Gamma-rays (emission)	Functional	$3000-$6000	2-4 hours (actual scan time 15-35 minutes)	Can distinguish between benign and malignant lesions, good spatial resolution for functional imaging	Radiation dose, risk of allergic reaction to tracer, patient is radioactive (for a short time), expensive

Source: Winnie Wong International School on Trigger and Data Acquisition Systems Wigner Datacenter Budapest, 2014

Medical images show us different kinds of information about disease



Credit: David Paik

Biomedical Image Processing

Major challenge: Image quality and processing speed

- ❑ Big image size → increase in system time for retrieval or other processing
- ❑ Poor image quality → adversely affects the decision-making process

High noise levels, low contrast, poor resolution, etc. are some other factors causing problems in the medical image processing.

Contrast enhancement, sharpness enhancement, image magnification and reduction of distortion can be used to increase the usefulness of biomedical images.

Image Enhancement

Objective:
For a specific application (e.g., diagnosis from a medical image) process an image so that result is represents more distinguishing information than original image.

Basically, it improves ***the perception*** of information in images for human viewers.
Can also providing ***better input*** for other automated image processing techniques.

Image Enhancement

Enhancement operations are performed to modify:
- ❑ The image brightness
- ❑ The image contrast
- ❑ The distribution of the grey levels

The pixel value (intensities) of the output image will be modified according to the transformation function applied on the input values.

Image Enhancement

The image brightness

- ❑ Refers to the absolute value of colors (intensities) lightness/darkness.
- ❑ Increasing brightness of an image will light out all colors so the original light ones will become up to white (and, vice versa)

The image contrast

- ❑ The distinction between lighter and darker areas of an image,
- ❑ It rerefers to making more obvious the objects or details within an image.
- ❑ Increasing contrast on an image will increase the difference between light and dark areas (light areas will become lighter and dark areas will become darker, and, vice versa.)

The distribution of the grey levels

- ❑ Histogram of pixel values

Spatial and Frequency Domains

- ❑Spatial domain
  - ❑refers to planar region of intensity values at time t
- ❑Frequency domain
  - ❑think of each color plane as a sinusoidal function of changing intensity values
  - ❑refers to organizing pixels according to their changing intensity (frequency)

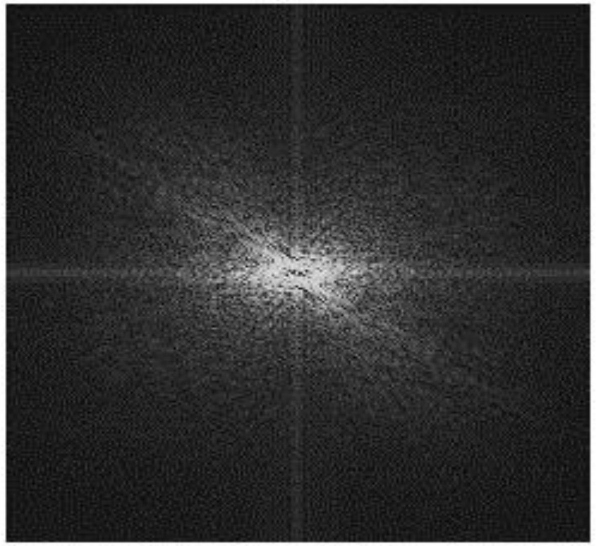


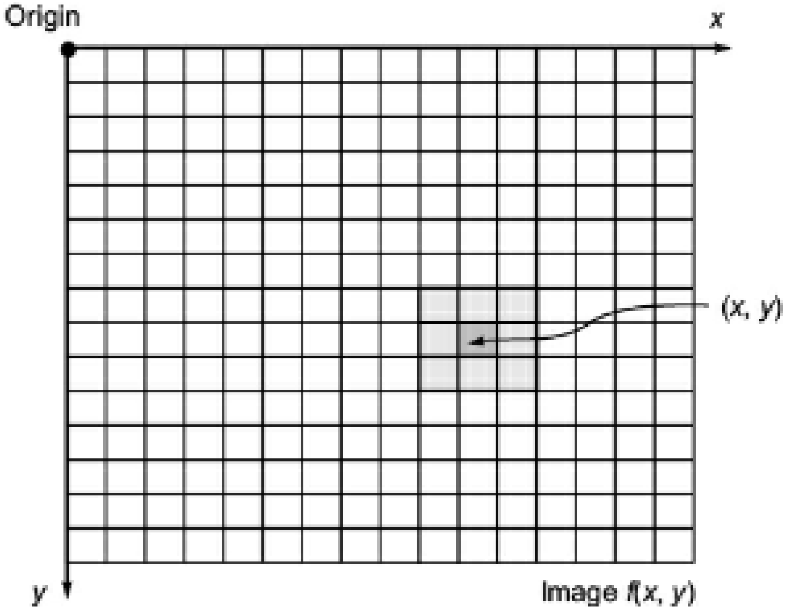
Image Enhancement

- Image Enhancement Methods
  - Spatial domain methods
  - Frequency domain methods

Spatial Domain Methods

- Directly operate over pixels.
- Modification is made over the intensity values of pixels in an image.
- The process is expressed by a transformation function given as:

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



f(x, y): input image
e(x, y): processed image or enhanced image
T: an operator that is applied over the input original image in some neighborhood of (x, y)

The neighborhood about a point (x, y) is defined using a square or rectangular sub-image area of suitable size centered at (x, y)

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Spatial Domain Methods

The center of the sub-image is moved from pixel to pixel starting from the top left corner. A transformation operator is applied to all the pixels scanning down to the bottom right pixel of an image. If r is the input grayscale value, then the output grayscale value s will be computed as

$$s = T[r]$$

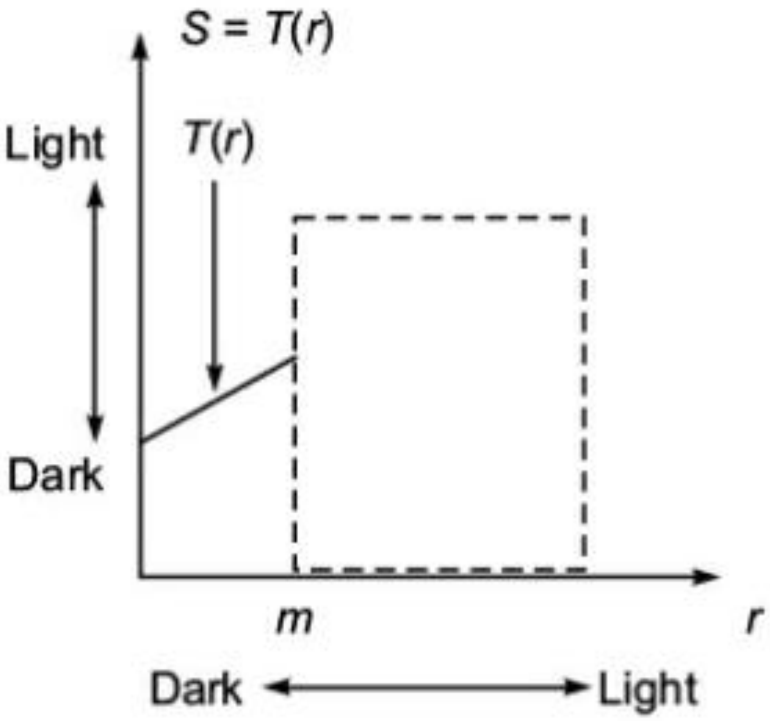
r: gray level of f(x, y) at any point (x, y)
s: gray level of e(x, y) at any point (x, y)

Contrast Stretching

If T(r) is of the form, as shown in figure, then the effect of this transformation is to get an image of higher contrast.

Darkening the level below m and brightening the level above m in the original image.

This is called contrast stretching because the gray values are compressed, and the opposite effect takes place for the value above m.



Contrast Stretching

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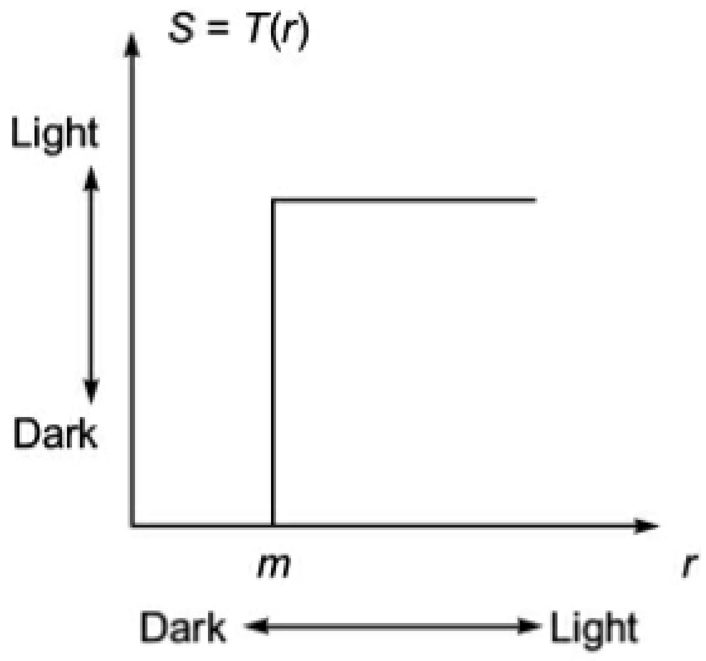
Point Processing

The transformation function T(r) producing binary image.

Produces the gray level in output image at the location (x, y) which depends only on the gray level of the input image at that location.

This operation is generally called point processing.



Point Processing

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Linear vs. Non-Linear Transformations

Linear Transformation: The grayscale values change with the direct proportion to input grayscale values

Non-Linear Transformation: The grayscale values change without the direct proportion to input grayscale values.

A linear contrast enhancement may be expressed as $y = f(x)$, where x is the input data value and y is the output data value.

The transfer functions which do not observe this linear transfer function are called non-linear transfer functions.

Some Examples of Spatial Domain Operations

Binary Image Output

Negative of an Image

Log Transformation

Power Law Transformation

Contrast Enhancement

Histogram Processing

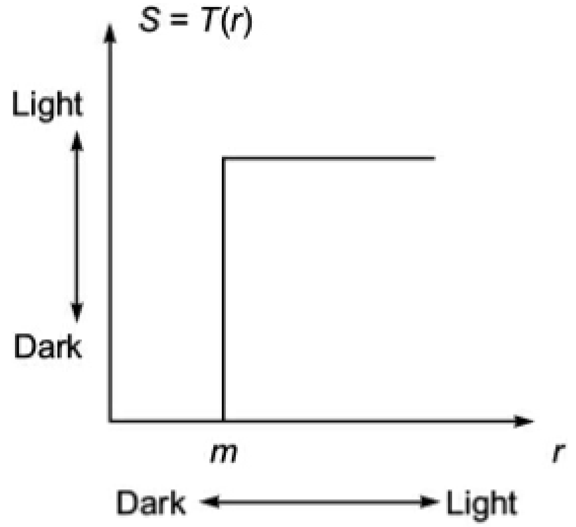
Binary Image Output

Binary images are identified with pixels having only two possible intensity values, i.e., 0 and 1.
Generally displayed as black and white.

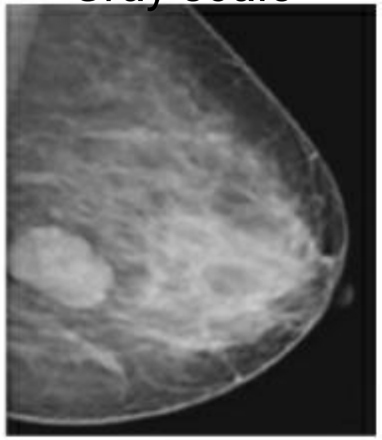
Are often produced by separating an object in the image from the background.

The color of the object is referred to as the foreground color and the remaining area is known as the background color.

Generation of binary image of a mammographic image and other medical images.



Gray scale



Binary

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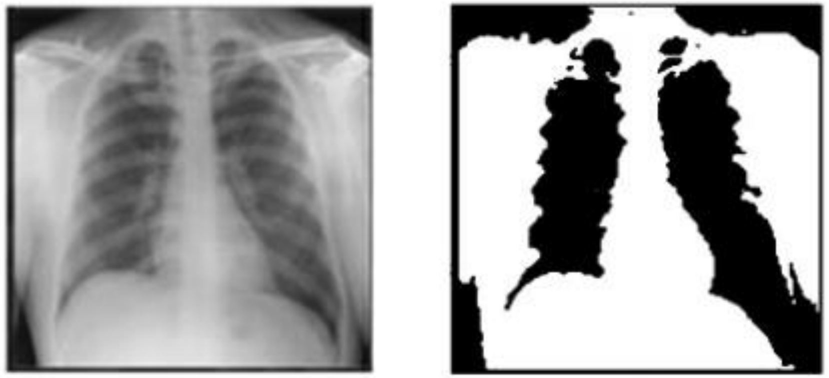
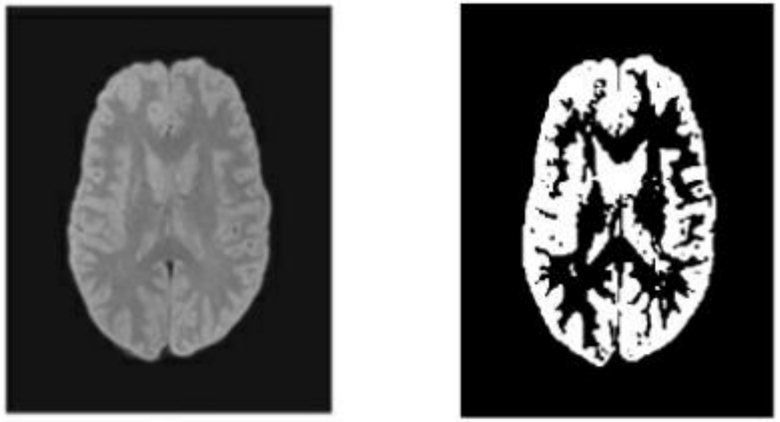
Binary Image Output





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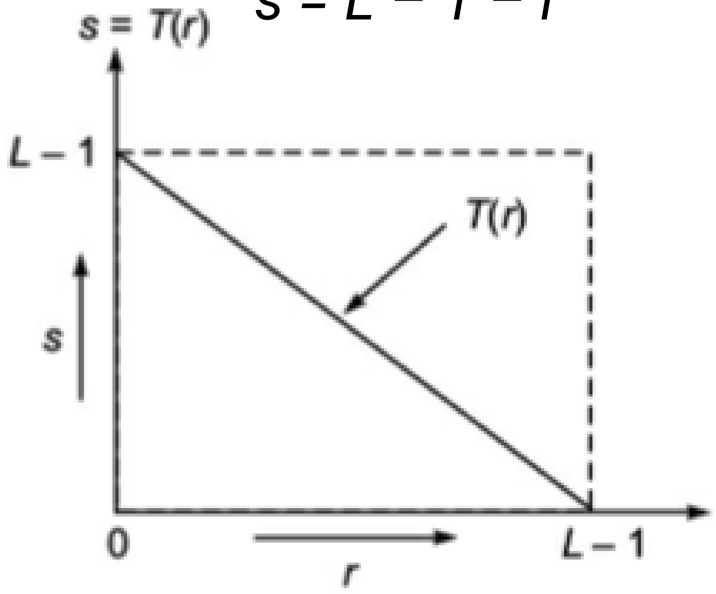
Negative Image Output

In many applications, negative image is useful.

Can be obtained by using the negative transformation

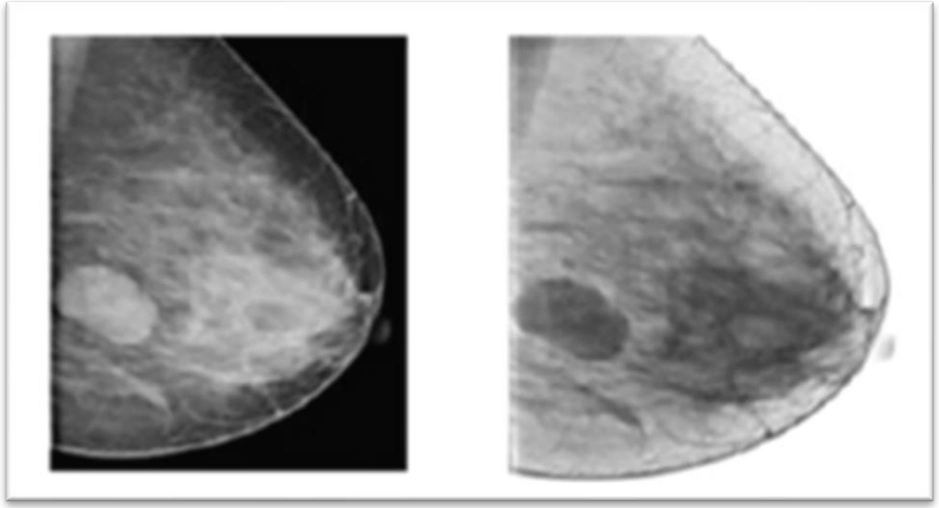
$$s = L - 1 - r$$

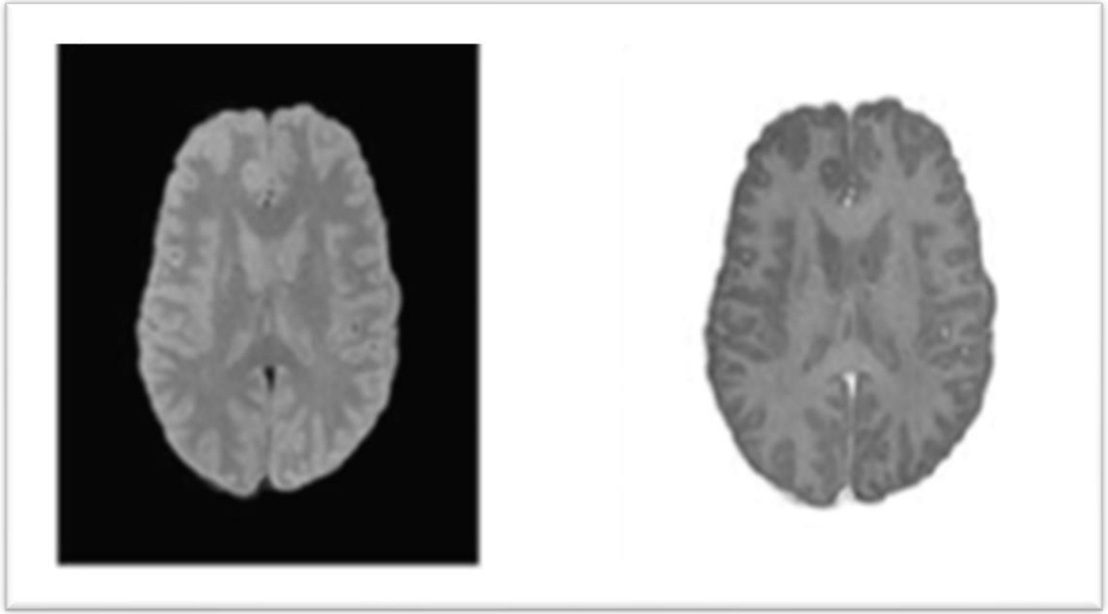


Reverse the grayscale values from black to white so that the intensity of the output image decreases as the intensity of the input increases.

L: number of gray level (e.g., 256).
The grayscale values are in the range of [0 to (L – 1)].

Negative Image Output





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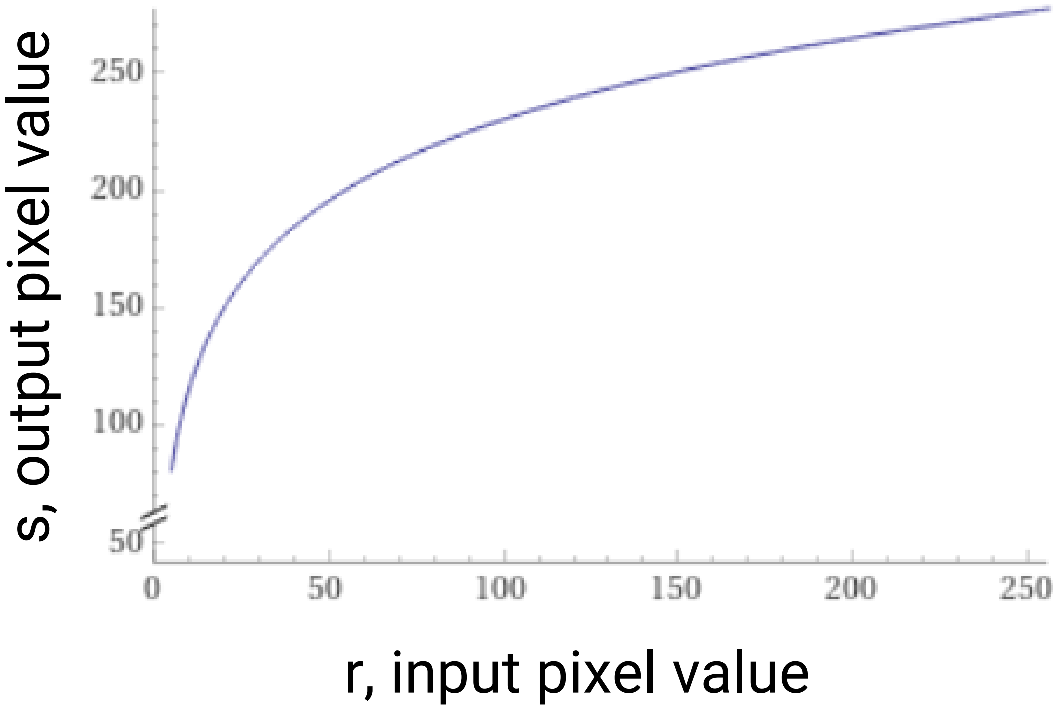
Log Transformation

A transformation that maps a narrow range of grayscale values in the input image onto a wider range of output levels (opposite is also true.)

$$s = C\ log(1 + r)$$

s: output grayscale value
r: grayscale value of input image
C: constant.



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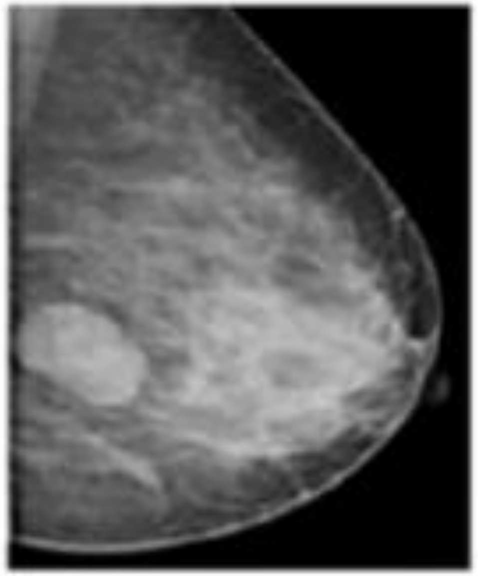
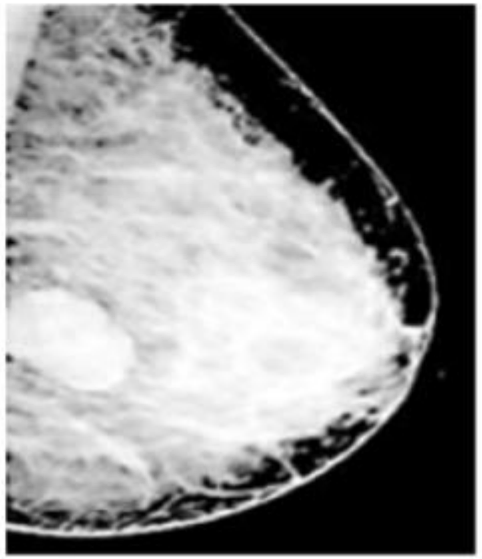
Log Transformation





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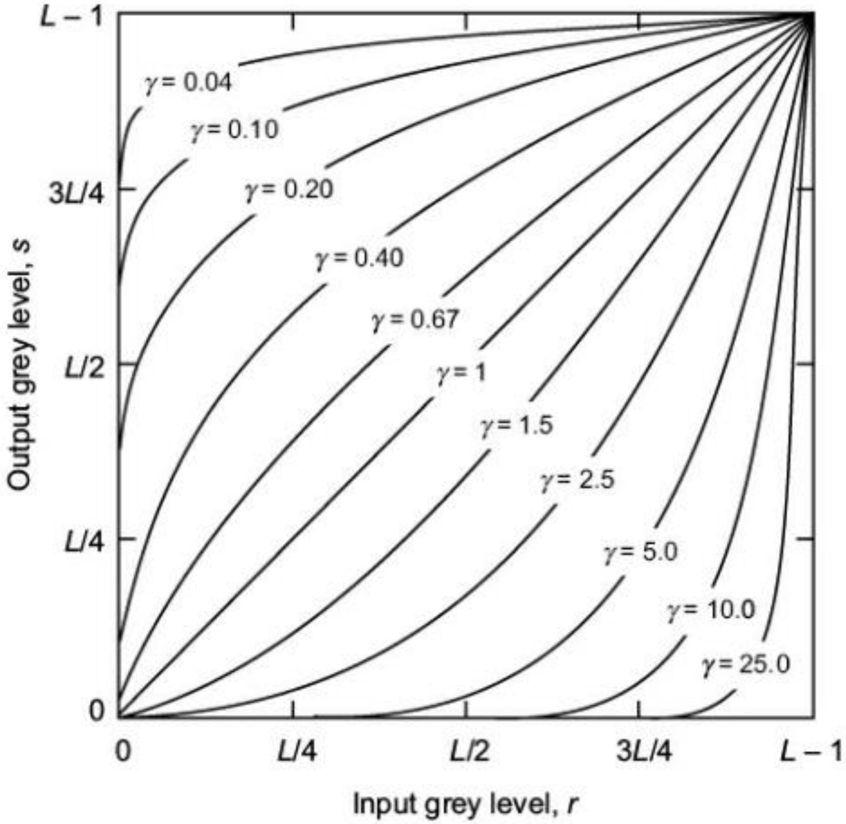
Power Law (Gamma) Transformation (Correction)

Gamma defines the relationship between a pixel's numerical value and its actual luminance.

Gamma correction can be used to control the overall brightness of an image.

$$s = C\, r^{\gamma}$$

s: output grayscale value
r: grayscale value of input image
C, γ : positive constants.



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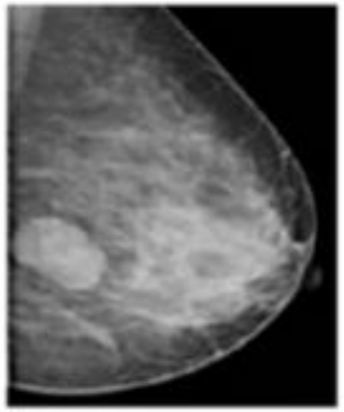
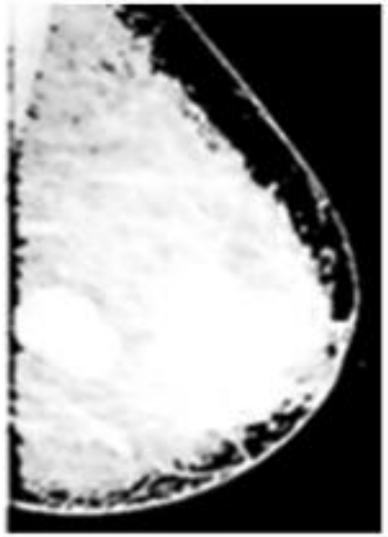
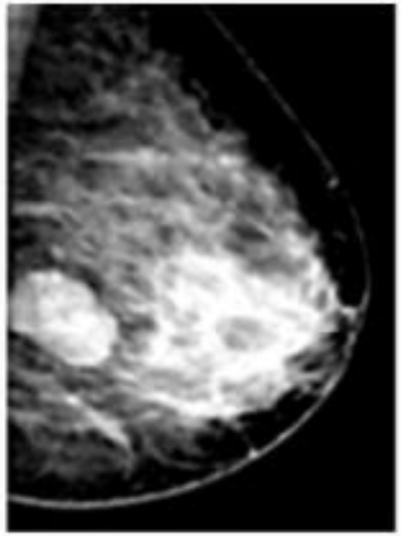
Power Law (Gamma) Transformation (Correction)



Original

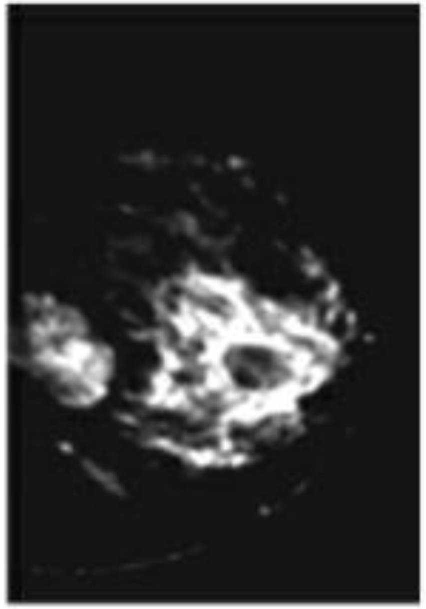


$\gamma = 0.1$

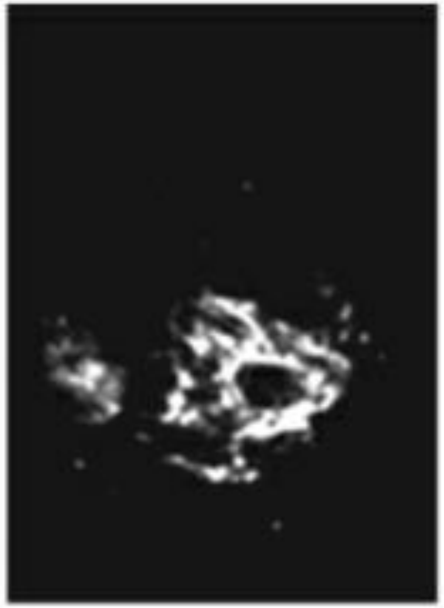


$\gamma = 0.9$

$\gamma = 5$



$\gamma = 10$



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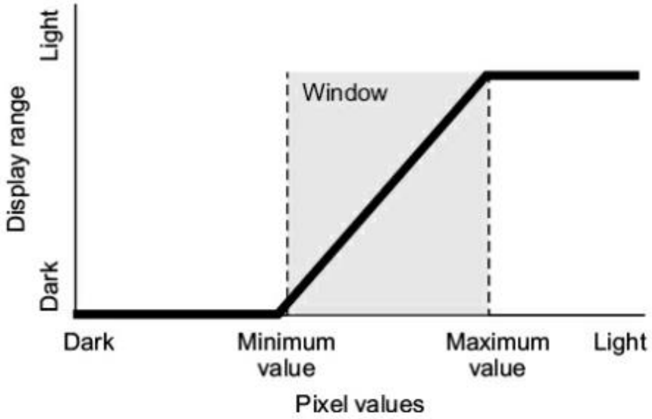
Contrast Enhancement

Is used to improve the contrast of an image by expanding or stretching the range of intensity values.

The features or details obscuring in the original image are now clear in the contrast enhanced image.

$$s = (r - c)\left(\frac{b - a}{d - c}\right) + \alpha$$



Contrast algorithm involves identifying lower and upper bounds from the histogram (minimum and maximum grayscale values).

After applying a transformation in this range, the image is enhanced.
a: lower limit, b: upper limit
limiting values are determined in the image without enhancement (lower = c and upper =d)

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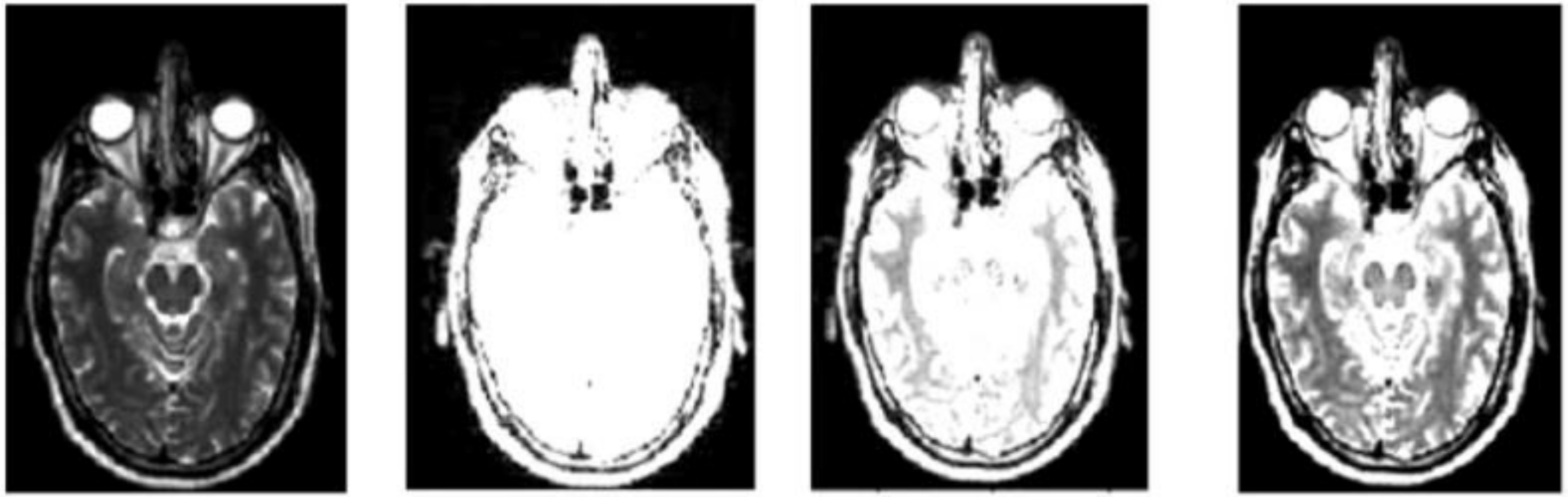
Contrast Enhancement

Original | $\alpha = 0.15$ | $\alpha = 0.3$ | $\alpha = 0.45$



(i) (j) (k) (l)

(m) (n) (o) (p)

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Histogram Processing

In an image, there may be several pixels which have the same intensity values.

The number of pixels is plotted against the intensity value which is known as **histogram**.

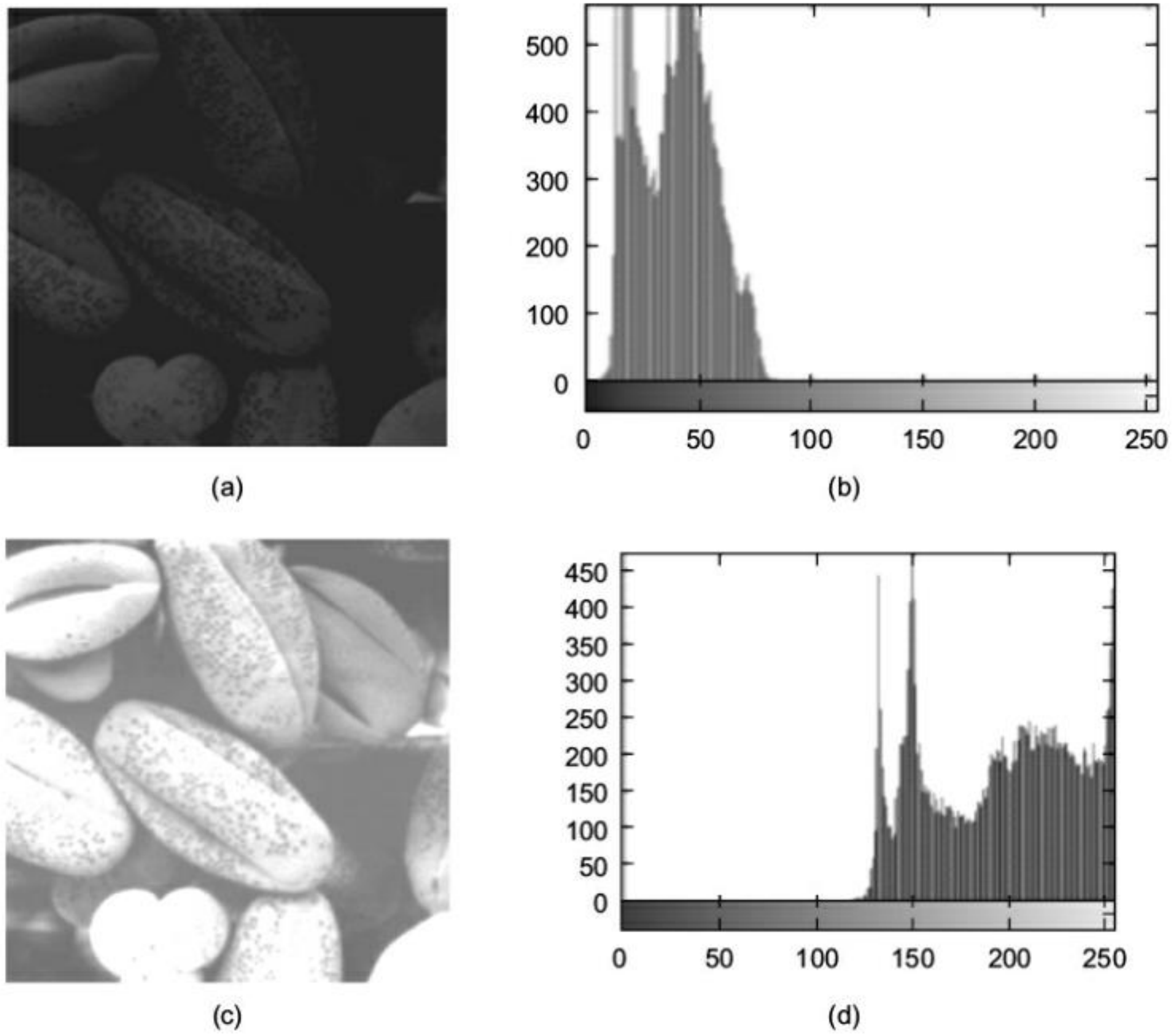
Histogram is a graph or a kind of bar diagram.

Represents the number of pixels in an image at each different intensity value in that image.

For an 8-bit grayscale image, 256 different possible intensities → histogram displays 256 numbers w.r.t. the # of pixels having a particular grayscale value.

The histogram of a digital image shows the probability of occurrence of grayscale values of pixels in the range 0 to 255.

Histogram Processing



The gray level distribution is concentrated on the left side of the histogram because darker pixels have low gray values.

The gray level distribution of bright image is concentrated on the right side of the histogram, as lighter pixels have high contrast values.

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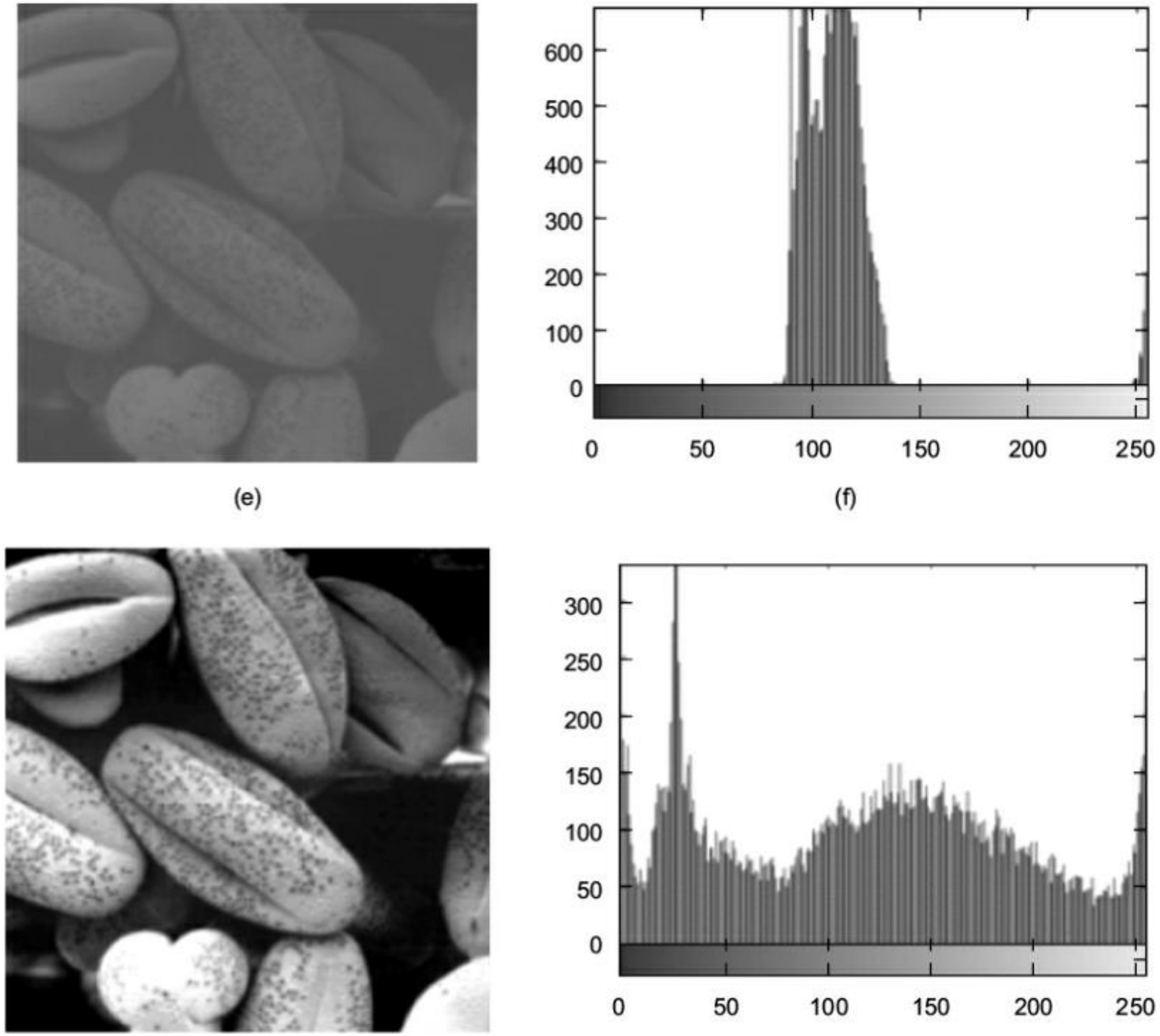
Histogram Processing



(e) (f)

(g) (h)

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Histogram Processing

Intensity values are the measured grayscale statistics in an image or regions in an image.

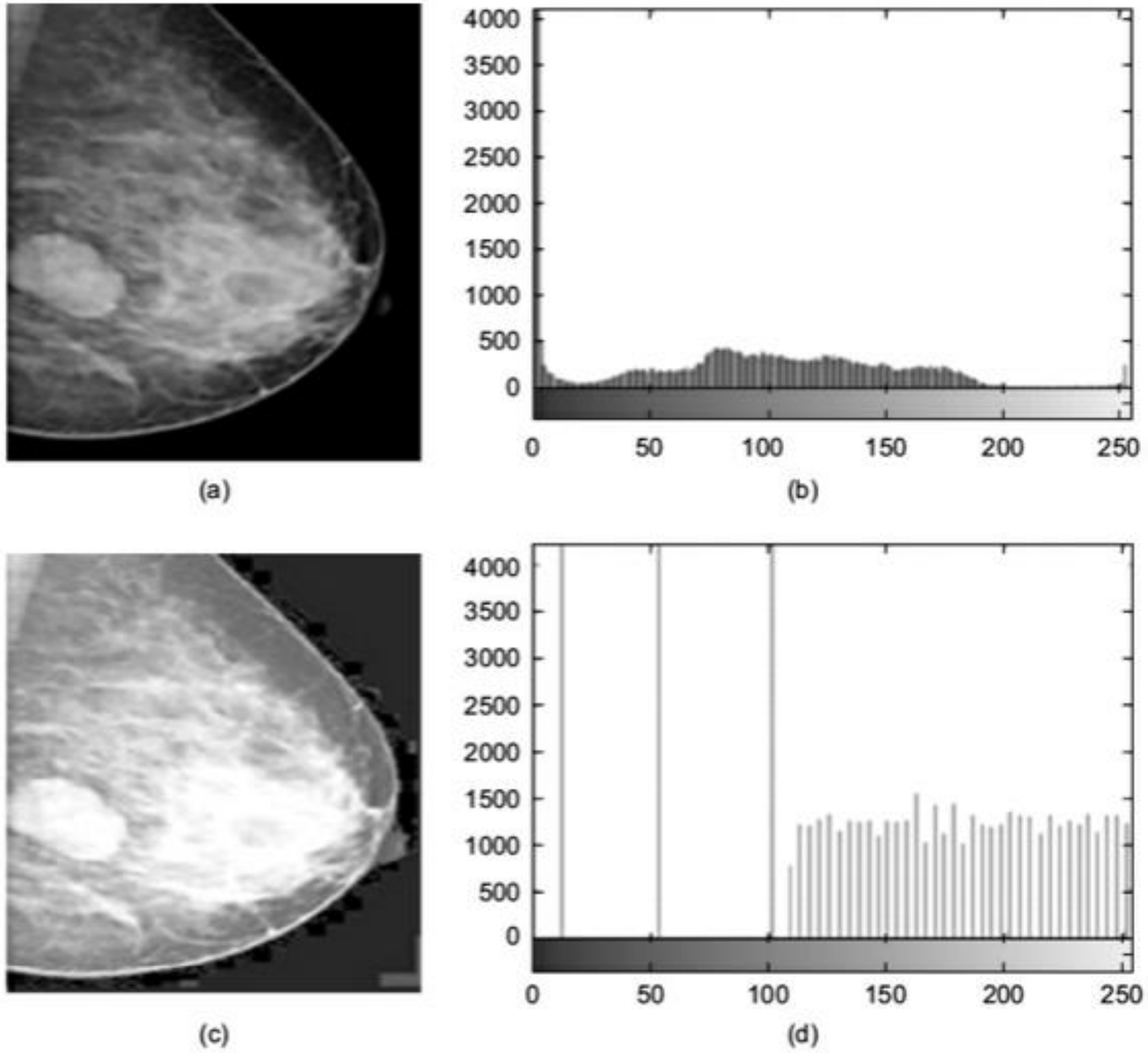
- ❑ include minimum intensity value
- ❑ maximum intensity value
- ❑ mean intensity value
- ❑ standard deviation of the intensity values

Histogram equalization is another method for contrast enhancement of an image.

Histogram equalization helps in achieving the uniform distribution of intensity values

The grayscale values are redistributed with an equal probability of occurrence.

Histogram Processing



The grayscale values are redistributed with an equal probability of occurrence.

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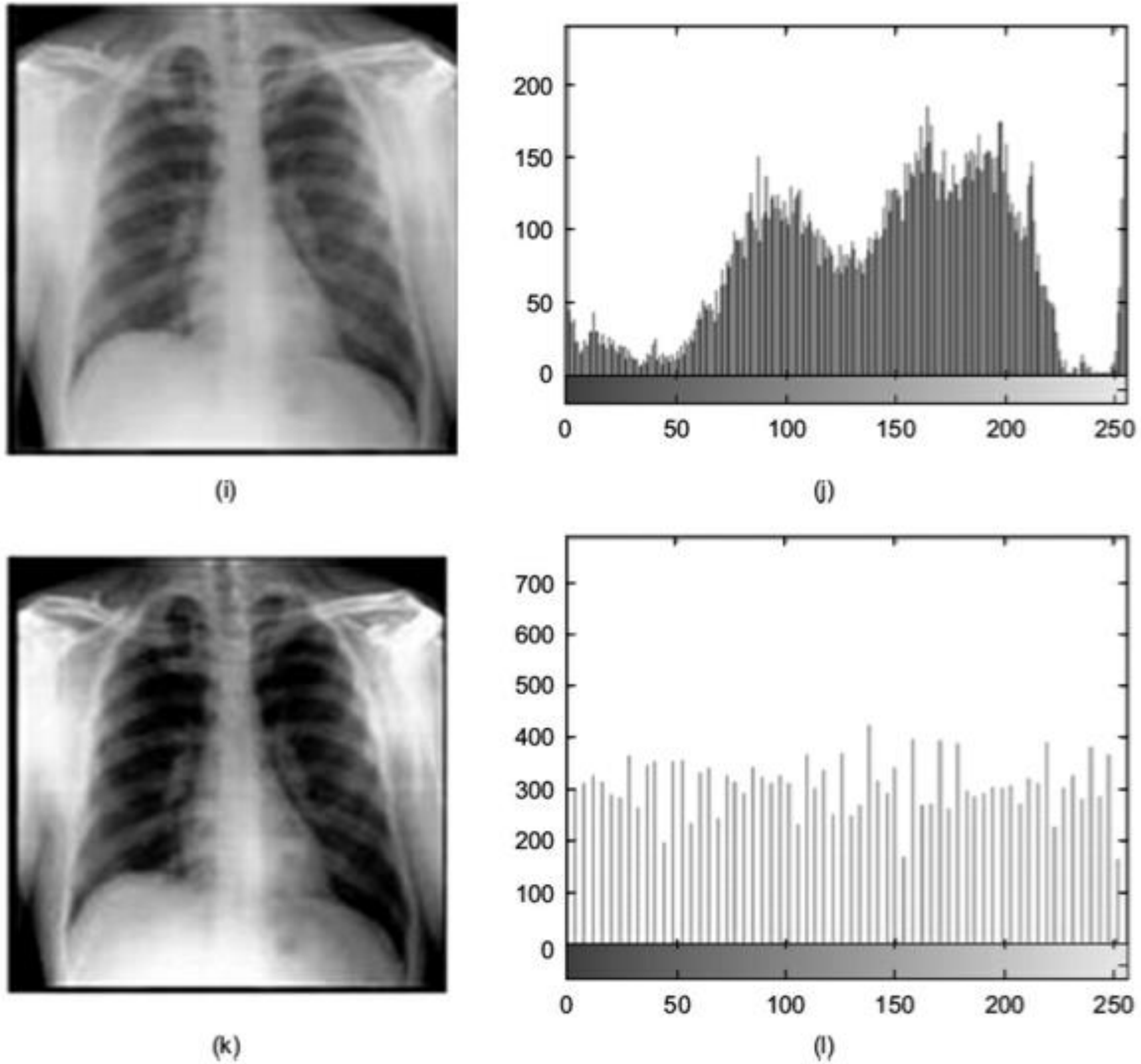
Histogram Processing



The grayscale values are redistributed with an equal probability of occurrence.

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Histogram Processing

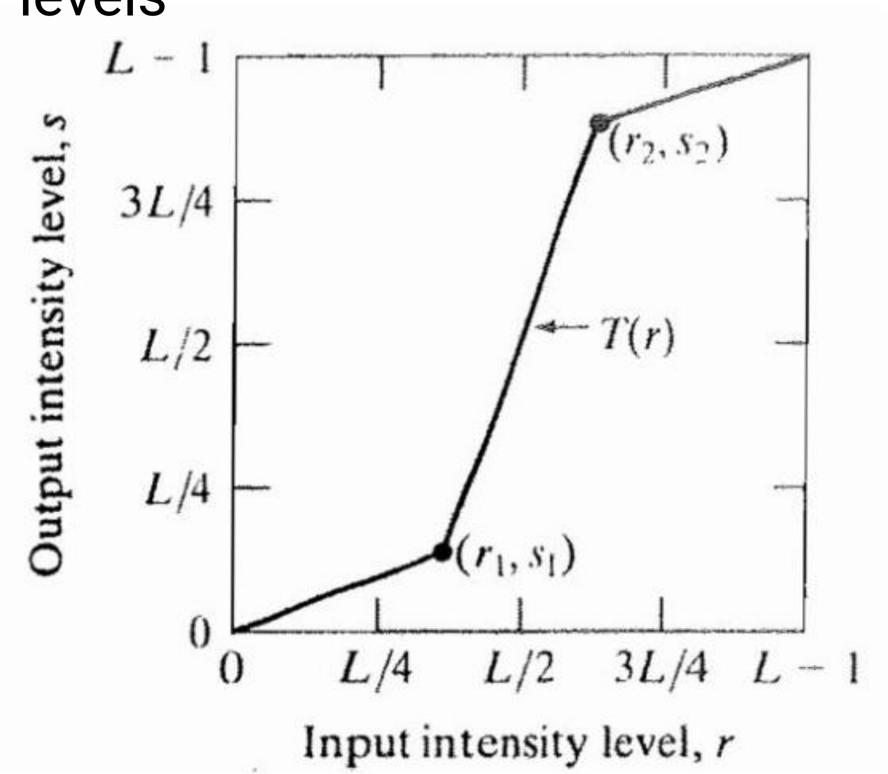
Histogram equalization is applied to enhance images and are mainly used for increasing the dynamic range of grayscale values in an image.

Some limitations of histogram equalization method:

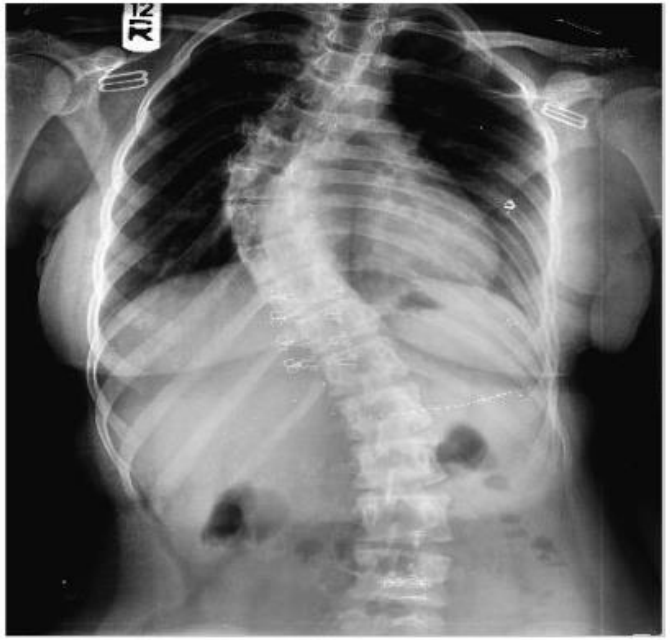
- May result in over enhancement and saturation artefacts.
- The brightness of an image may unnecessarily be changed.

Piecewise Linear Stretching

Increase the dynamic range of the gray levels



Original



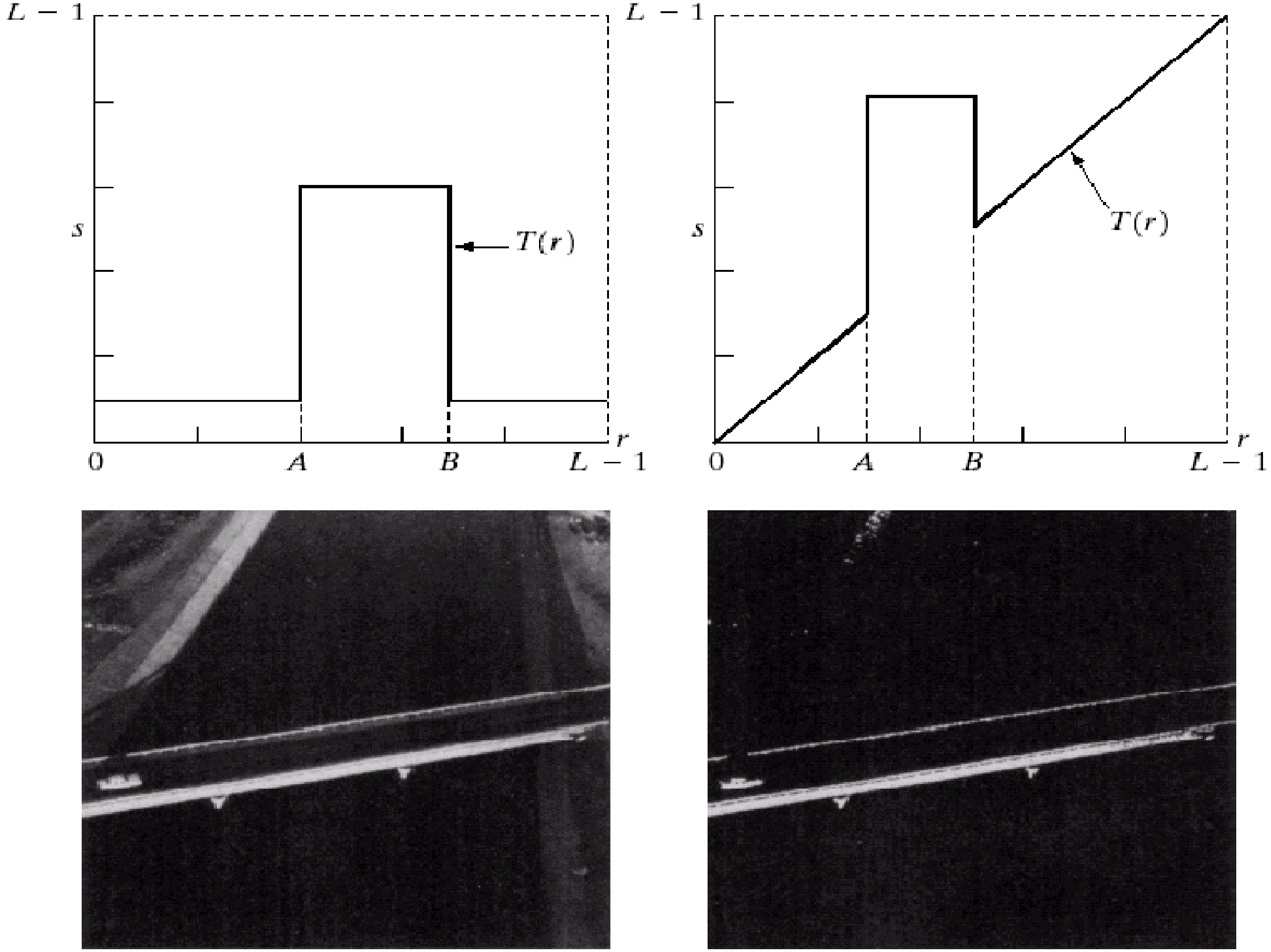
J Biomed Phys Eng 2019;9(3):317-326.
https://doi.org/10.31661/jbpe.v9i3%20Jun.730

Gonzalez RC, Woods RE. Digital Image Processing.
4th edition. New York, NY: Pearson; 2017

Gray-level Slicing

- It is used to highlight a specific range of gray levels in a given image.
  - Similar to thresholding
  - Other levels can be suppressed or maintained
  - Useful for highlighting features in an image
- Can be implemented in several ways, but the two basic themes are:
  - One approach is to display a high value for all gray levels in the range of interest and a low value for all other gray levels.
  - The second approach, based on the transformation brightens the desired range of gray levels but preserves gray levels unchanged

Gray-level Slicing



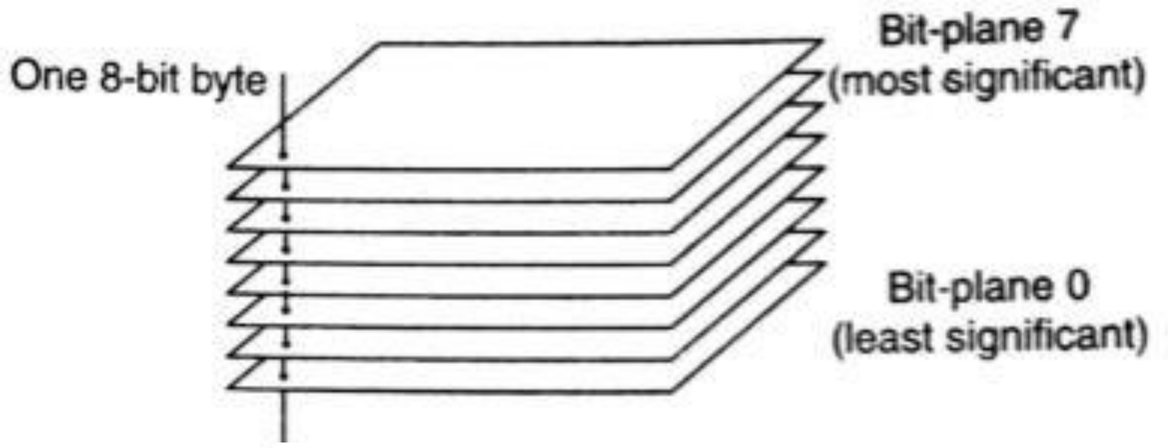
Left: Display in one value (e.g., white) all the values in the range of interest , and in another (e.g., black) all other intensities

Right: Brightens or darkens the desired range of intensities but leaves all other intensity levels in the image unchanged

Bit-plane Slicing

Pixels are digital numbers, each one composed of bits. Instead of highlighting gray-level range, we could highlight the contribution made by each bit.

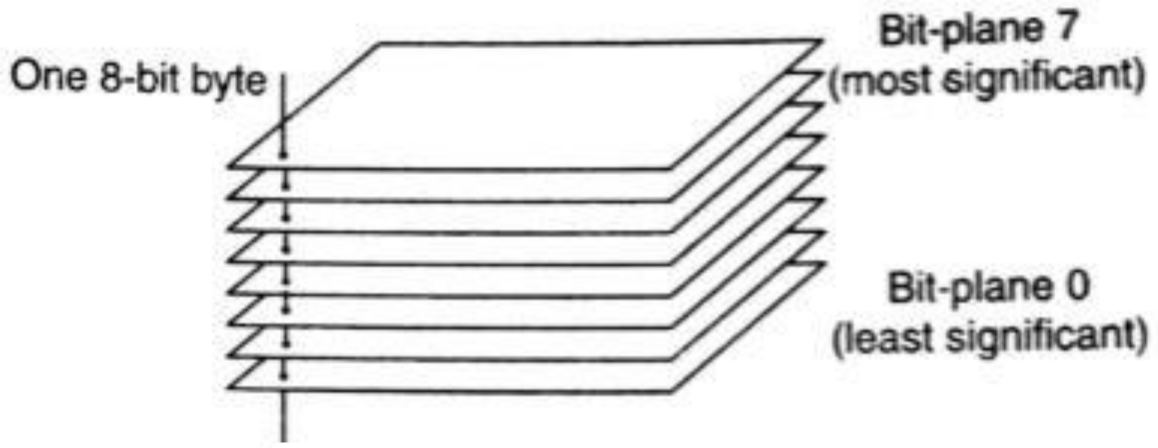
This method is useful and used in image compression.



Most significant bits contain the majority of visually significant data.

Bit-plane Slicing

Pixels are digital numbers, each one composed of bits.

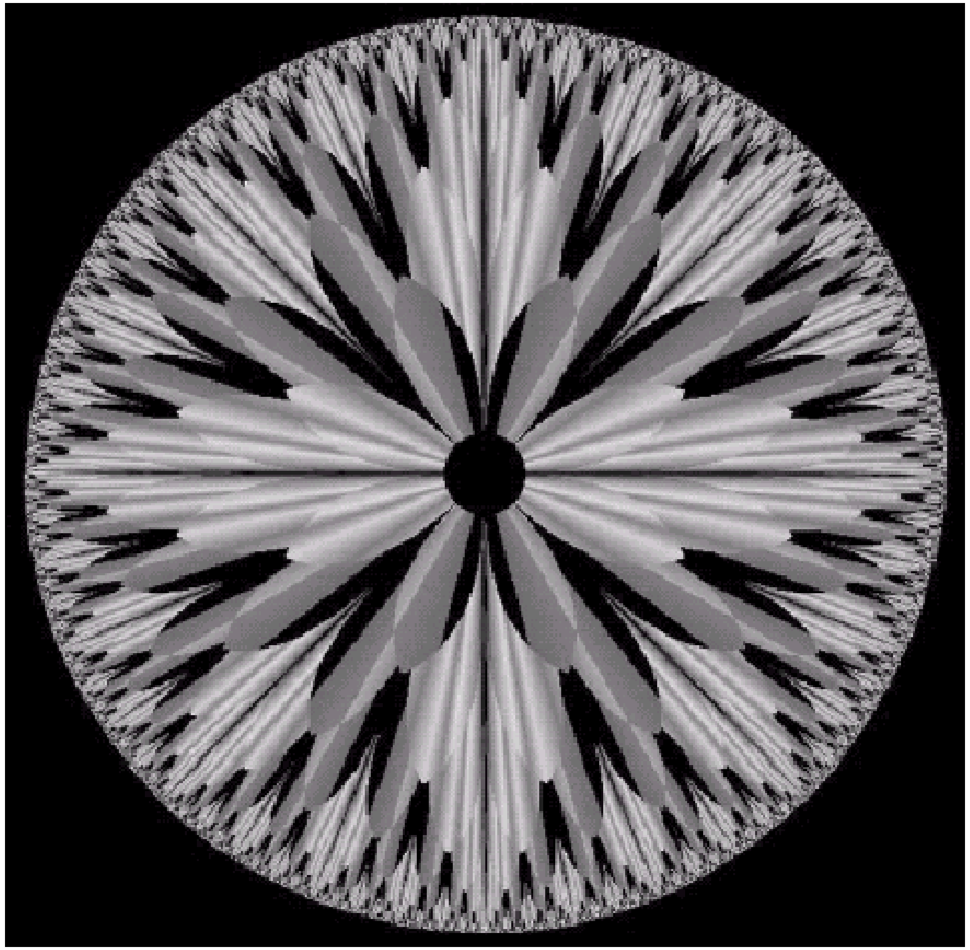


8-bit image is formed from eight 1-bit planes

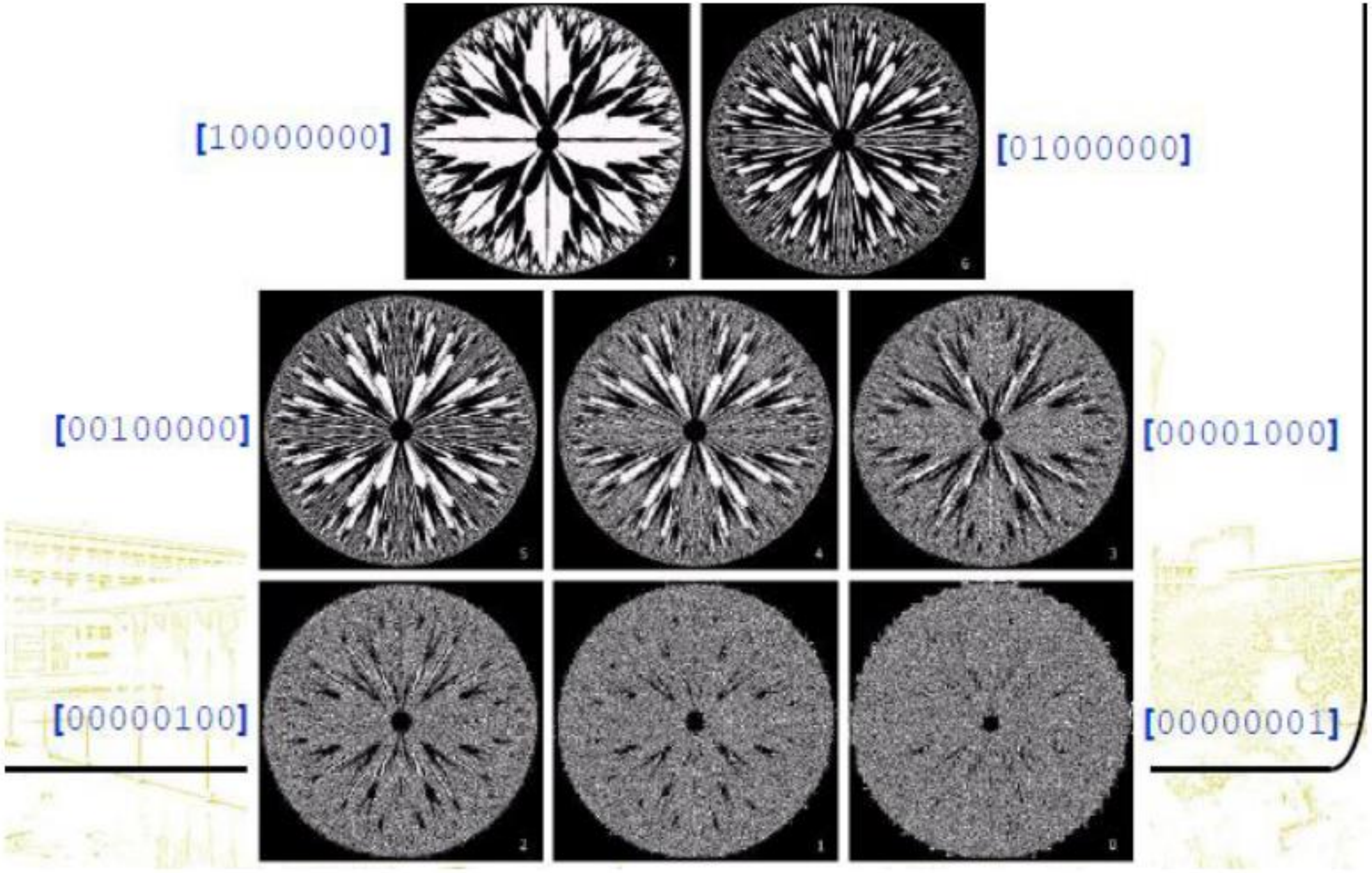
Bit-plane Slicing

By isolating particular bits of the pixel values in an image we can highlight interesting aspects of that image

- ❑ Higher-order bits usually contain most of the significant visual information
- ❑ Lower-order bits contain subtle details



Bit-plane Slicing



Bit-plane Slicing