



Image Enhancement (Point Processing)

(EE663 – Image Processing)

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Contents



- In this lecture we will look at image enhancement point processing techniques:
 - What is point processing?
 - Negative images
 - Thresholding
 - Logarithmic transformation
 - Power law transforms
 - Grey level slicing
 - Bit plane slicing

Some Basic Relationships Between Pixels



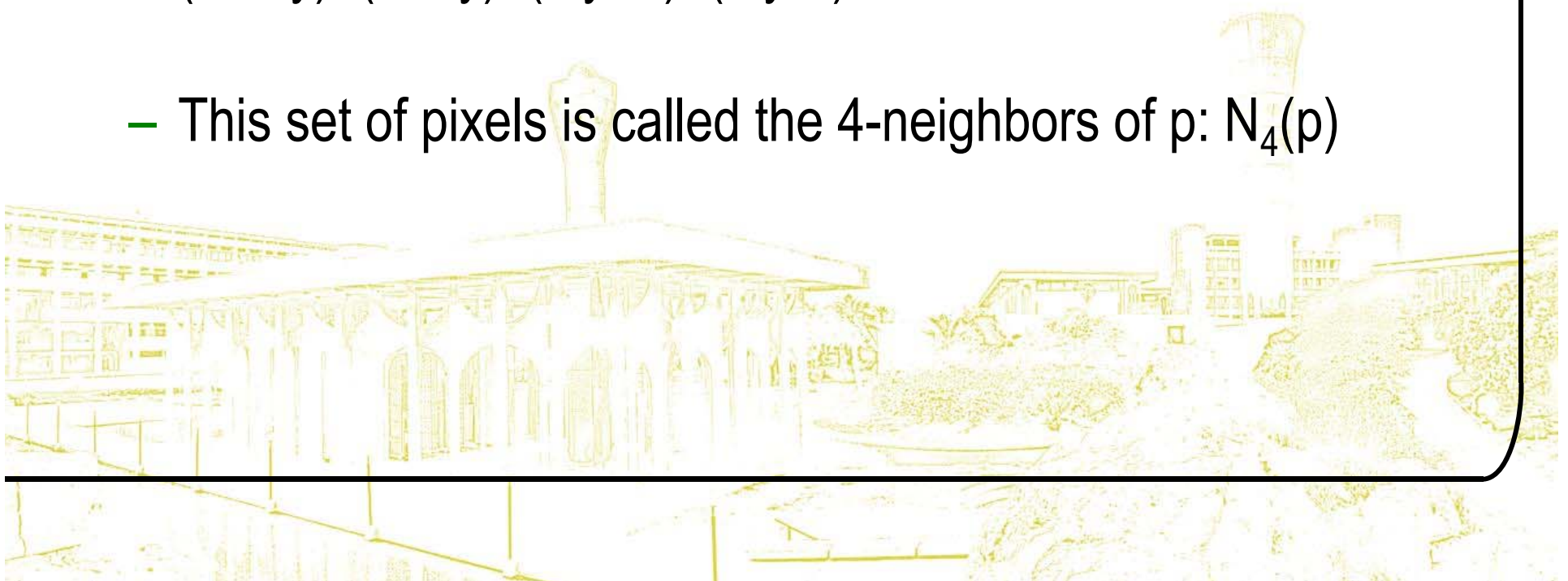
- Definitions:
 - $f(x,y)$: digital image
 - Pixels: q, p
 - Subset of pixels of $f(x,y)$: S





Neighbors of a Pixel

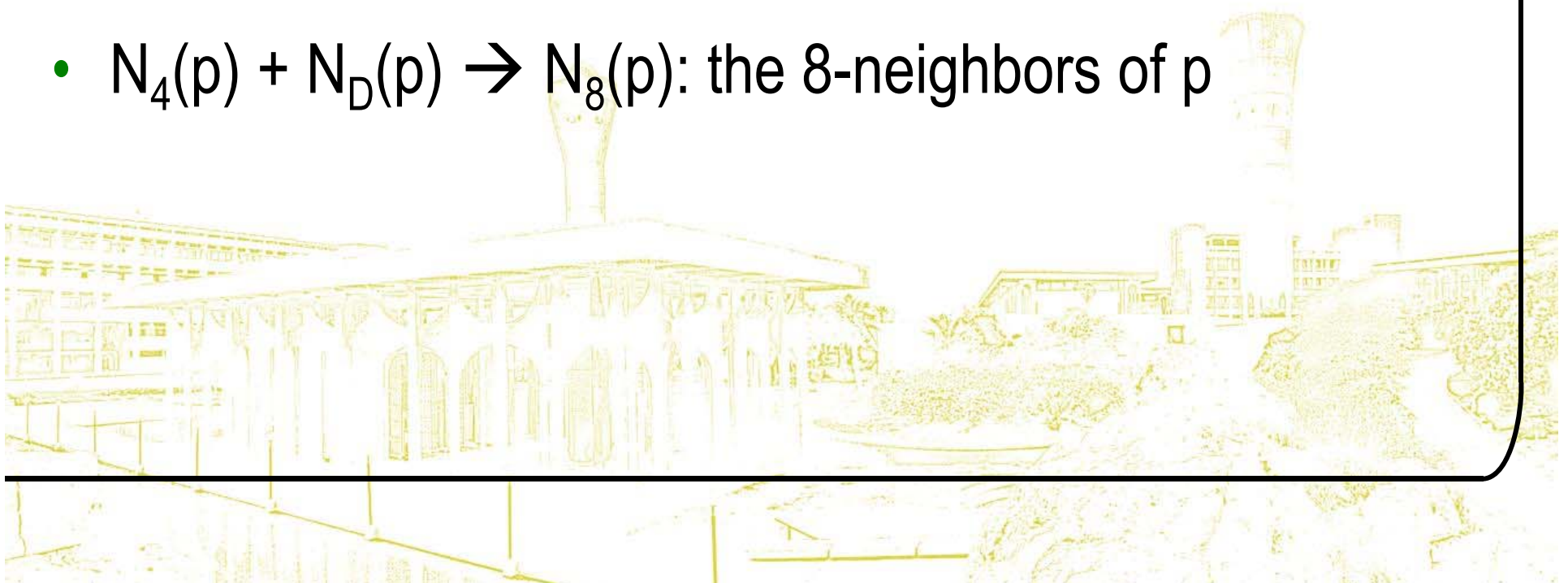
- A pixel p at (x,y) has 2 horizontal and 2 vertical neighbors:
 - $(x+1,y)$, $(x-1,y)$, $(x,y+1)$, $(x,y-1)$
 - This set of pixels is called the 4-neighbors of p : $N_4(p)$





Neighbors of a Pixel

- The 4 diagonal neighbors of p are: $(N_D(p))$
 - $(x+1, y+1), (x+1, y-1), (x-1, y+1), (x-1, y-1)$
- $N_4(p) + N_D(p) \rightarrow N_8(p)$: the 8-neighbors of p



Connectivity



- Connectivity between pixels is important:
 - Because it is used in establishing boundaries of objects and components of regions in an image



Connectivity



- Two pixels are connected if:
 - They are neighbors (i.e. adjacent in some sense -- e.g. $N_4(p)$, $N_8(p)$, ...)
 - Their gray levels satisfy a specified criterion of similarity (e.g. equality, ...)
- V is the set of gray-level values used to define adjacency (e.g. $V=\{1\}$ for adjacency of pixels of value 1)

Adjacency



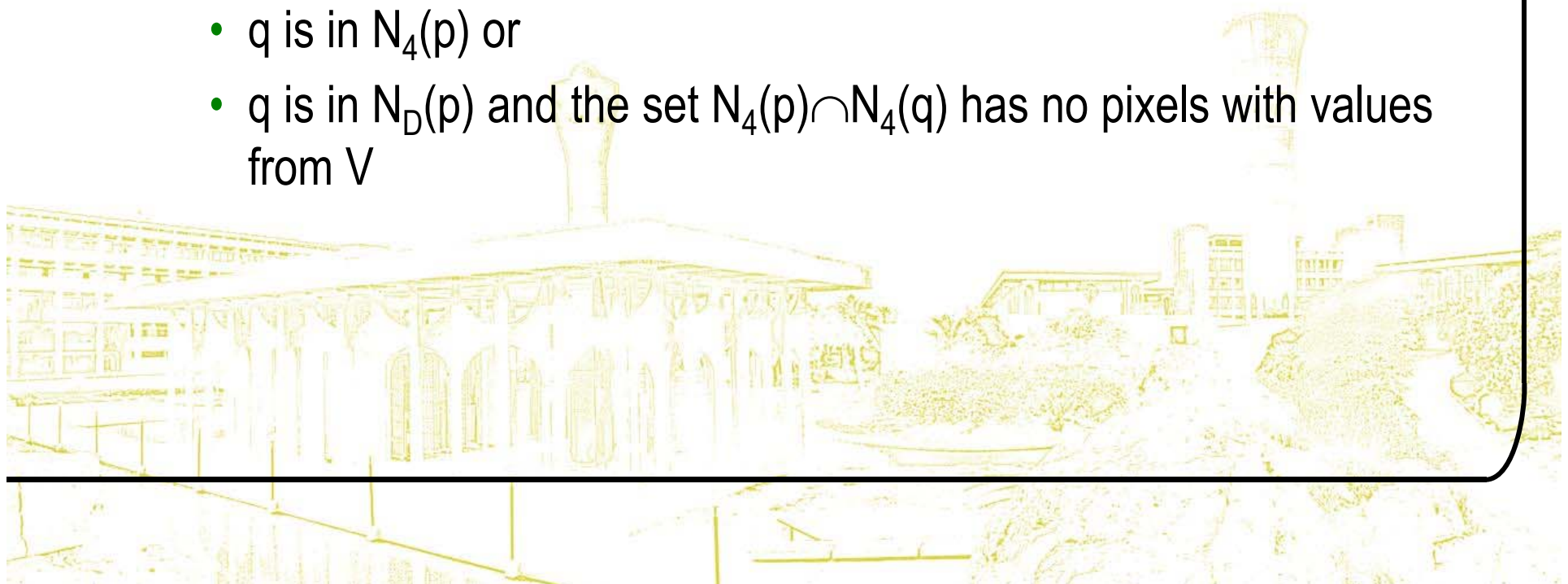
- We consider three types of adjacency:
 - **4-adjacency**: two pixels p and q with values from V are 4-adjacent if q is in the set $N_4(p)$
 - **8-adjacency** : p & q are 8- adjacent if q is in the set $N_8(p)$



Adjacency



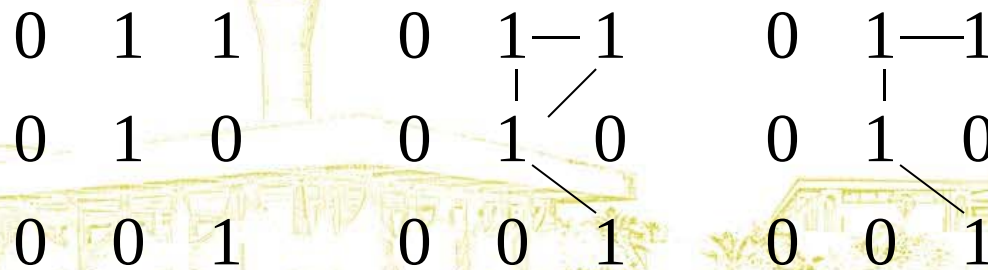
- The third type of adjacency:
 - **m-adjacency**: p & q with values from V are m-adjacent if
 - q is in $N_4(p)$ or
 - q is in $N_D(p)$ and the set $N_4(p) \cap N_4(q)$ has no pixels with values from V





Adjacency

- Mixed adjacency is a modification of 8-adjacency and is used to eliminate the multiple path connections that often arise when 8-adjacency is used.



Adjacency



- Two image subsets $S1$ and $S2$ are adjacent if some pixel in $S1$ is adjacent to some pixel in $S2$.



Path

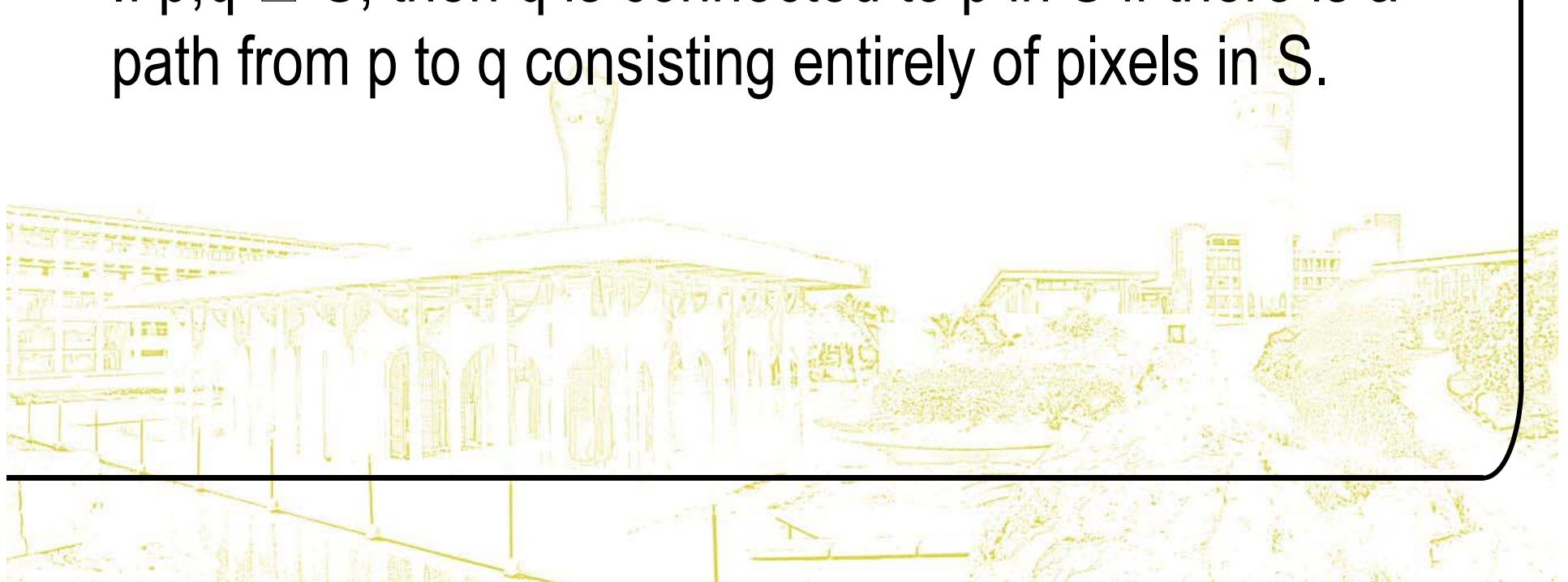


- A path (curve) from pixel p with coordinates (x,y) to pixel q with coordinates (s,t) is a sequence of distinct pixels:
 - $(x_0, y_0), (x_1, y_1), \dots, (x_n, y_n)$
 - where $(x_0, y_0) = (x, y)$, $(x_n, y_n) = (s, t)$, and (x_i, y_i) is adjacent to (x_{i-1}, y_{i-1}) , for $1 \leq i \leq n$; n is the length of the path.
- If $(x_0, y_0) = (x_n, y_n)$: a closed path

Paths



- 4-, 8-, m-paths can be defined depending on the type of adjacency specified.
- If $p, q \in S$, then q is connected to p in S if there is a path from p to q consisting entirely of pixels in S .



Connectivity



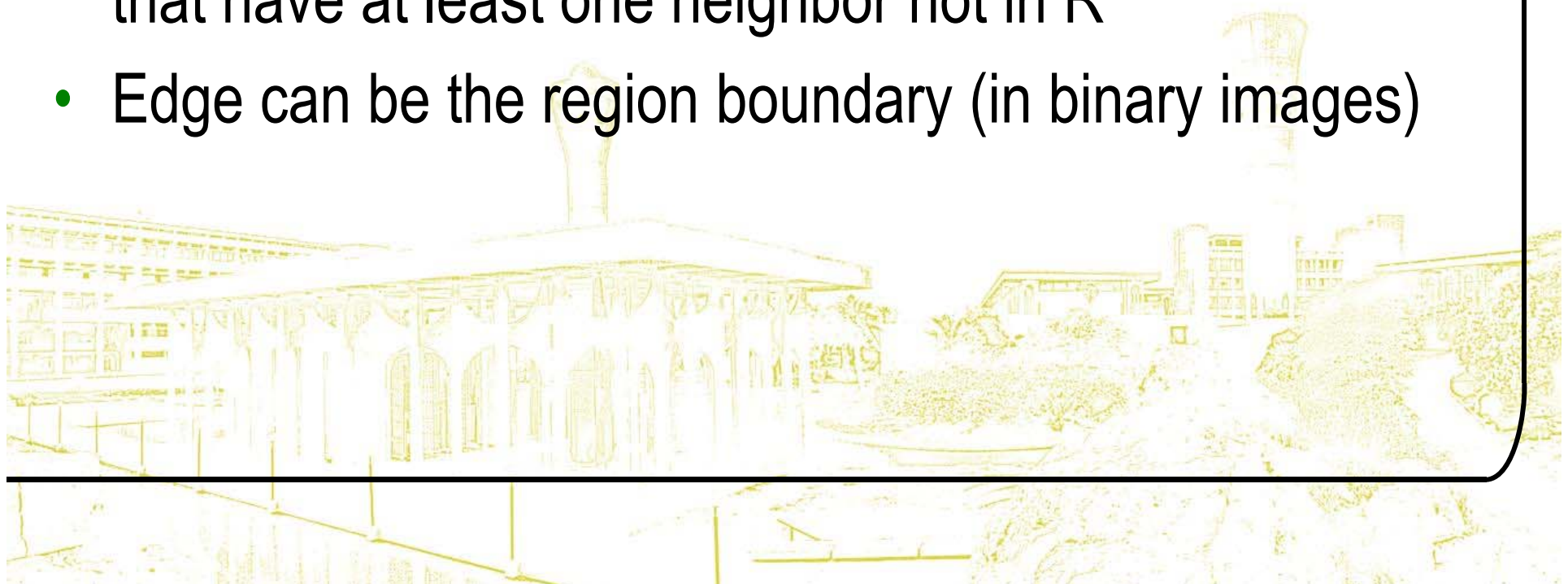
- For any pixel p in S , the set of pixels in S that are connected to p is a **connected component** of S .
- If S has only one connected component then S is called a connected set.



Boundary



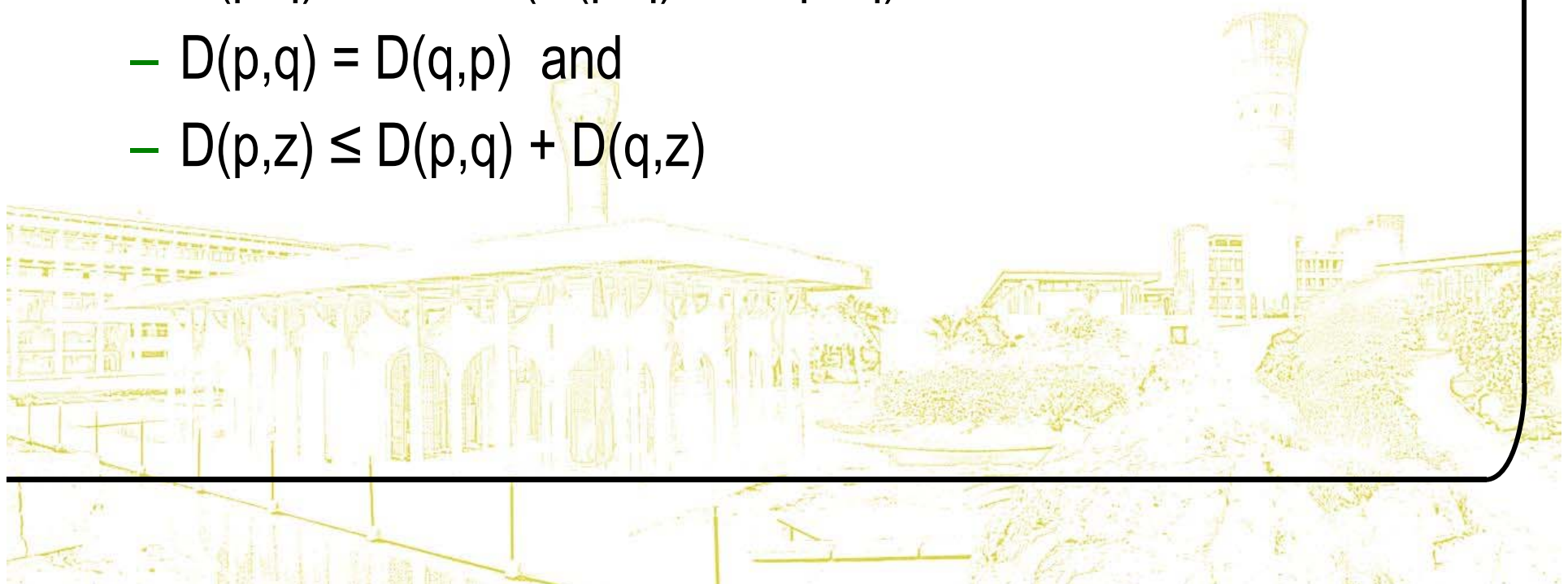
- R a subset of pixels: R is a region if R is a connected set.
- Its boundary (border, contour) is the set of pixels in R that have at least one neighbor not in R
- Edge can be the region boundary (in binary images)



Distance Measures



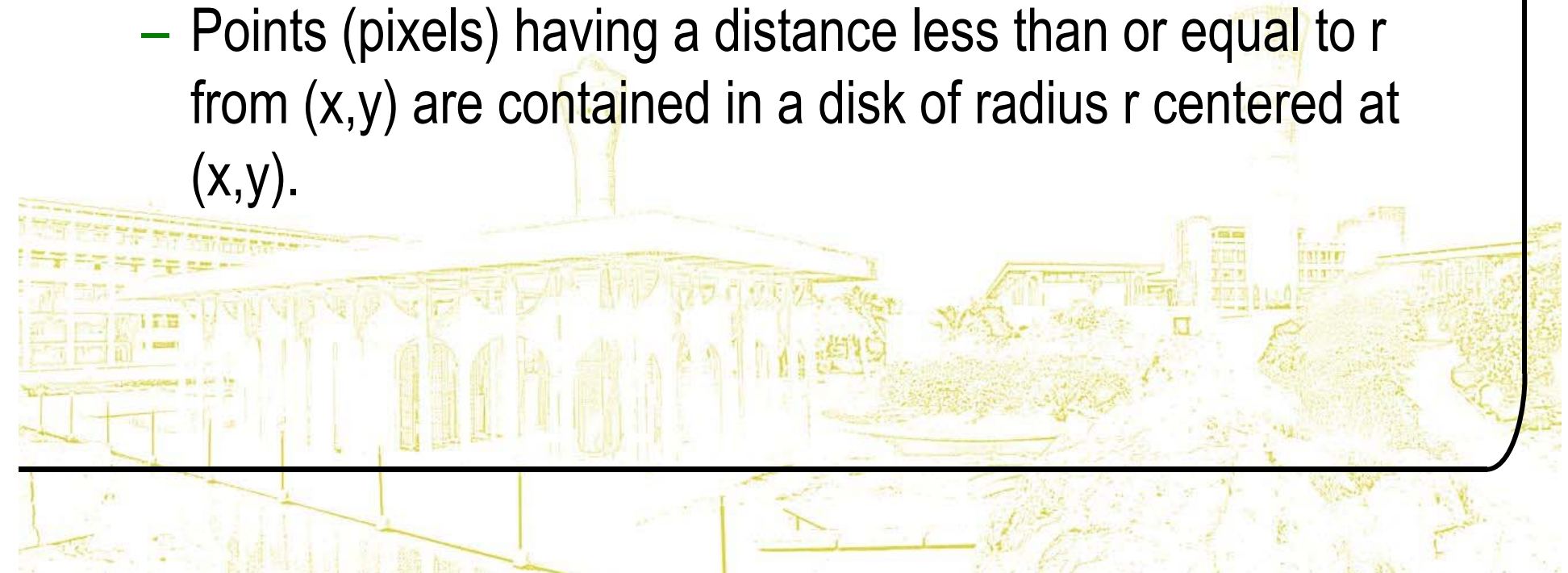
- For pixels p, q, z with coordinates (x, y) , (s, t) , (u, v) , D is a distance function or metric if:
 - $D(p, q) \geq 0$ ($D(p, q) = 0$ iff $p = q$)
 - $D(p, q) = D(q, p)$ and
 - $D(p, z) \leq D(p, q) + D(q, z)$



Distance Measures



- Euclidean distance:
 - $D_e(p,q) = [(x-s)^2 + (y-t)^2]^{1/2}$
 - Points (pixels) having a distance less than or equal to r from (x,y) are contained in a disk of radius r centered at (x,y) .



Distance Measures



- D_4 distance (city-block distance):

- $D_4(p,q) = |x-s| + |y-t|$
- forms a diamond centered at (x,y)
- e.g. pixels with $D_4 \leq 2$ from p

		2		
	2	1	2	
2	1	0	1	2
	2	1	2	
		2		

$D_4 = 1$ are the 4-neighbors of p

Distance Measures



- D_8 distance (chessboard distance):

- $D_8(p, q) = \max(|x-s|, |y-t|)$
- Forms a square centered at p
- e.g. pixels with $D_8 \leq 2$ from p

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

$D_8 = 1$ are the 8-neighbors of p

Distance Measures



- D_4 and D_8 distances between p and q are independent of any paths that exist between the points because these distances involve only the coordinates of the points (regardless of whether a connected path exists between them).



Distance Measures



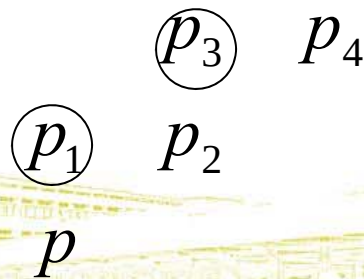
- **However**, for m-connectivity the value of the distance (length of path) between two pixels depends on the values of the pixels along the path and those of their neighbors.



Distance Measures



- e.g. assume $p, p_2, p_4 = 1$
 $p_1, p_3 =$ can have either 0 or 1



If only connectivity of pixels valued 1 is allowed, and p_1 and p_3 are 0, the m-distance between p and p_4 is 2.

If either p_1 or p_3 is 1, the distance is 3.

If both p_1 and p_3 are 1, the distance is 4
 $(pp_1p_2p_3p_4)$

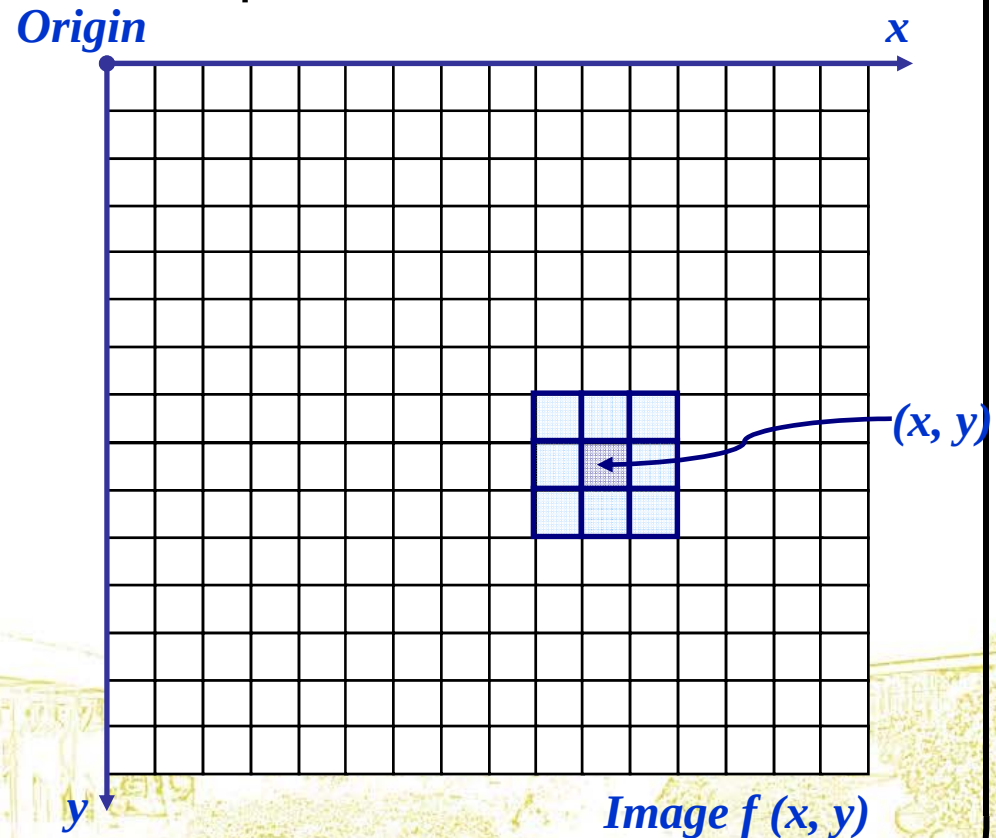
Basic Spatial Domain Image Enhancement



- Most spatial domain enhancement operations can be reduced to the form

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

- where $f(x, y)$ is the input image, $g(x, y)$ is the processed image and T is some operator defined over some neighbourhood of (x, y)



Point Processing



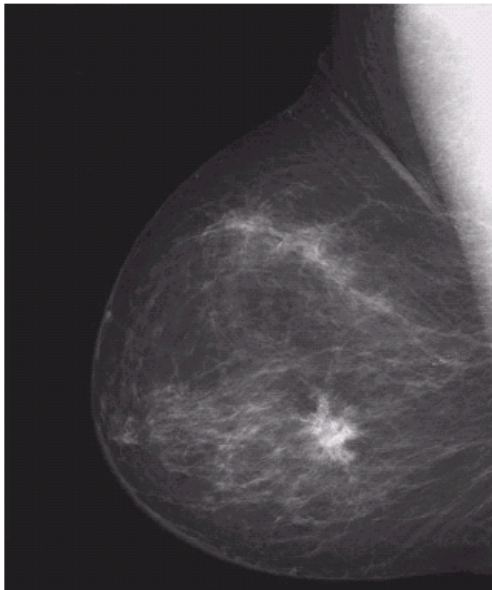
- The simplest spatial domain operations occur when the neighbourhood is simply the pixel itself
- In this case T is referred to as a *grey level transformation function* or a *point processing operation*
- Point processing operations take the form
 - $s = T(r)$
- where s refers to the processed image pixel value and r refers to the original image pixel value

Point Processing Example: Negative Images

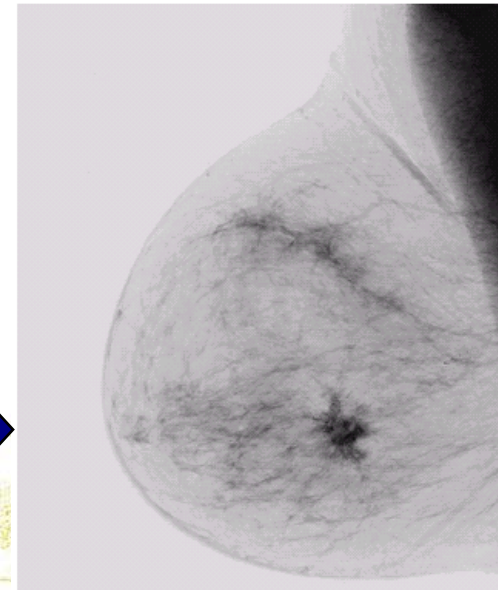


- Negative images are useful for enhancing white or grey detail embedded in dark regions of an image
 - Note how much clearer the tissue is in the negative image of the mammogram below

**Original
Image**

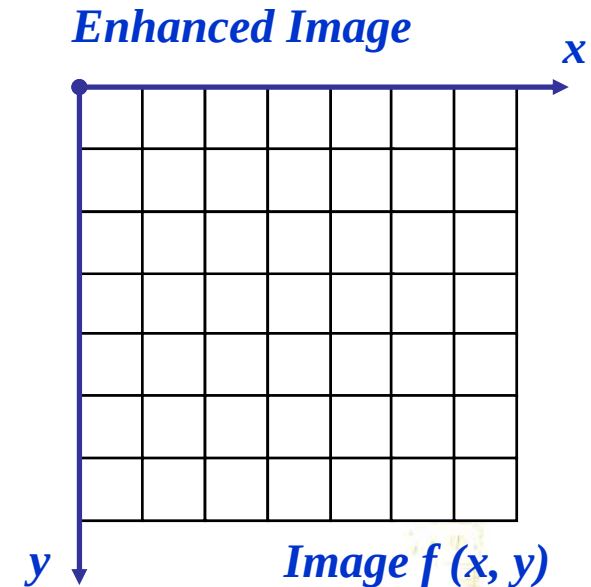
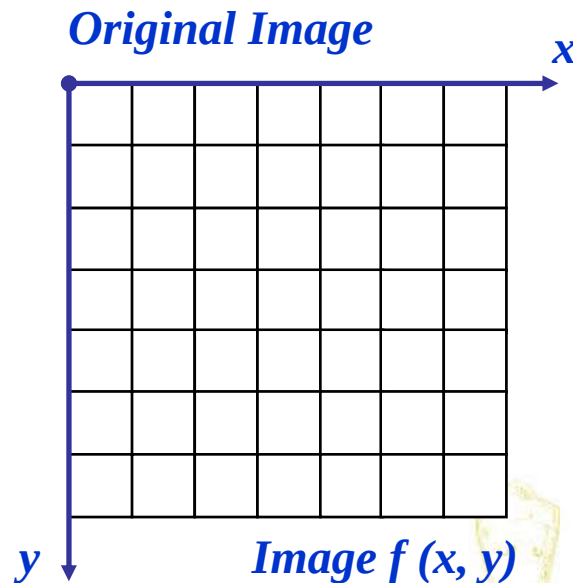


$$s = 1.0 - r$$



**Negative
Image**

Point Processing Example: Negative Images (cont...)



$$s = \text{intensity}_{\max} - r$$

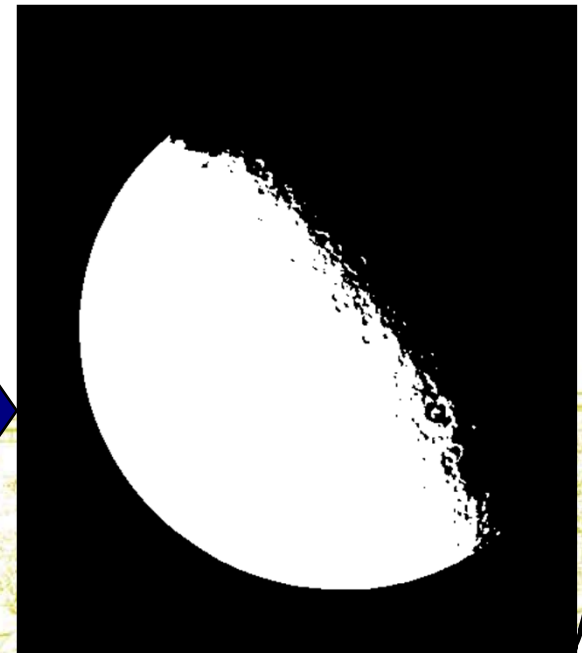
Point Processing Example: Thresholding



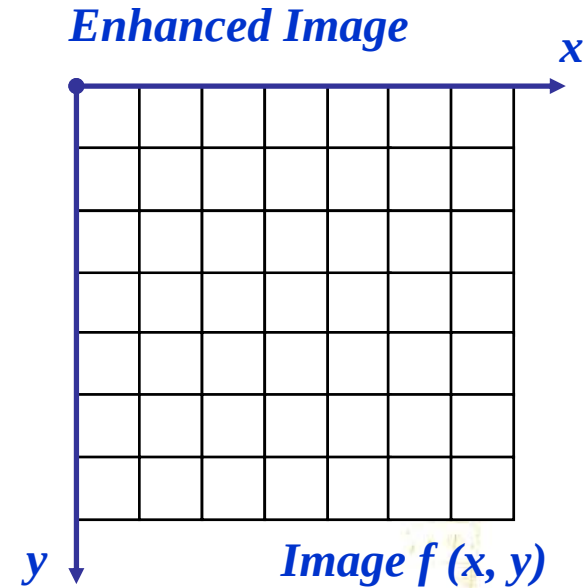
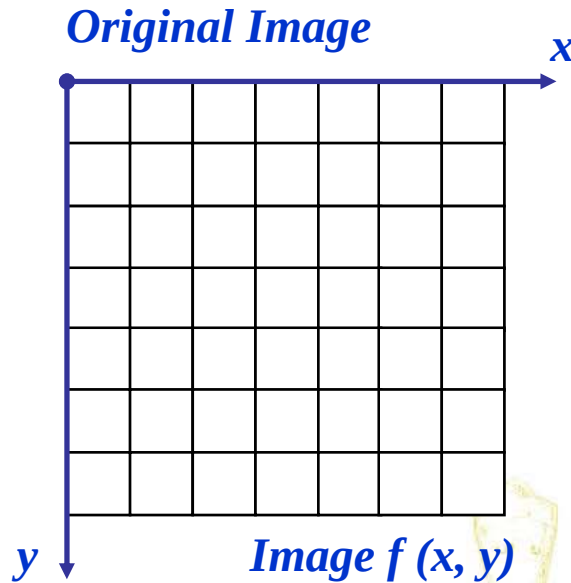
- Thresholding transformations are particularly useful for segmentation in which we want to isolate an object of interest from a background



$$s = \begin{cases} 1.0 & r > \text{threshold} \\ 0.0 & r \leq \text{threshold} \end{cases}$$

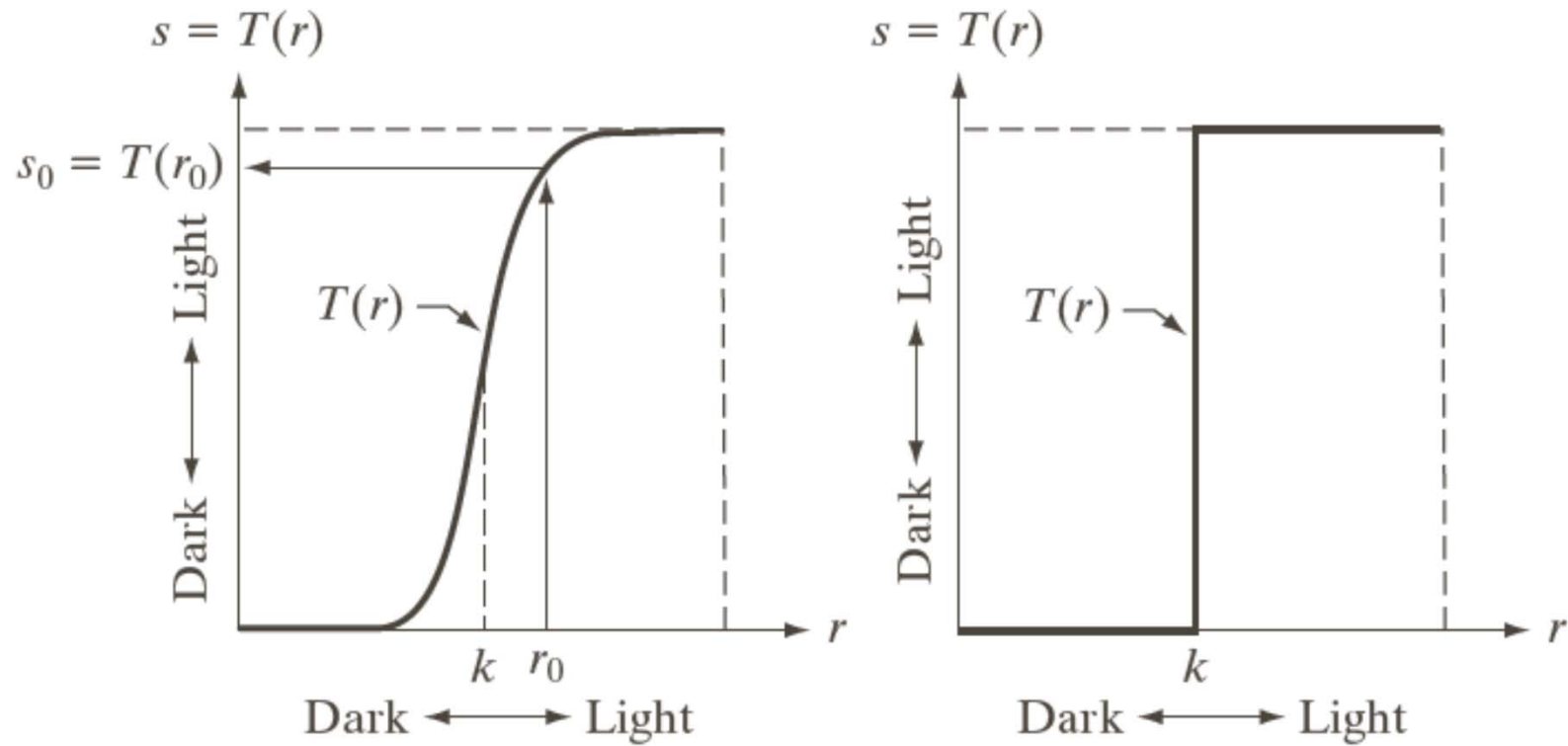


Point Processing Example: Thresholding (cont...)



$$s = \begin{cases} 1.0 & r > \text{threshold} \\ 0.0 & r \leq \text{threshold} \end{cases}$$

Intensity Transformations

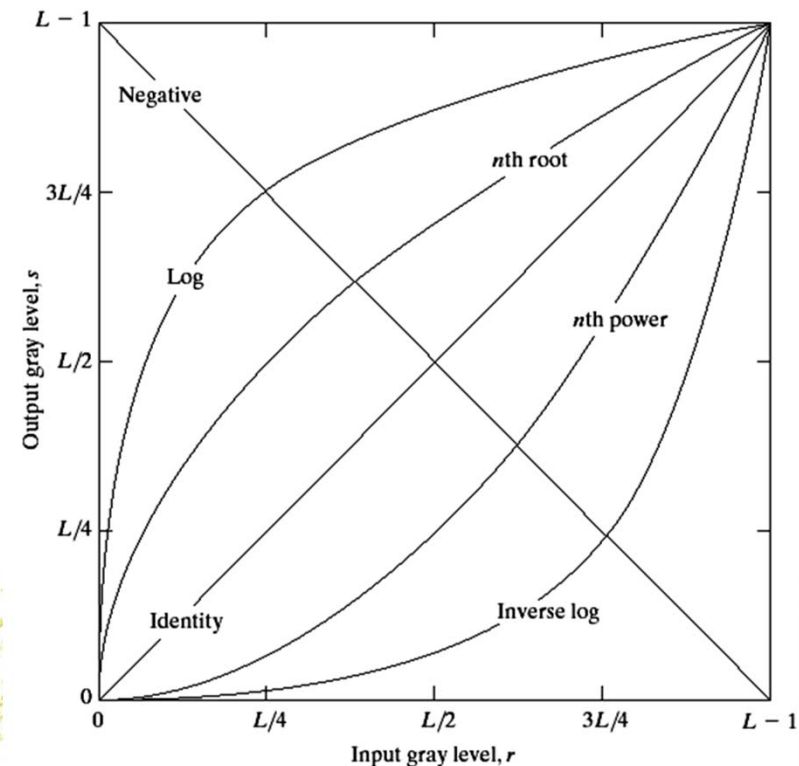


Basic Grey Level Transformations



- There are many different kinds of grey level transformations
- Three of the most common are shown here

- Linear
 - Negative/Identity
- Logarithmic
 - Log/Inverse log
- Power law
 - n^{th} power/ n^{th} root



Logarithmic Transformations



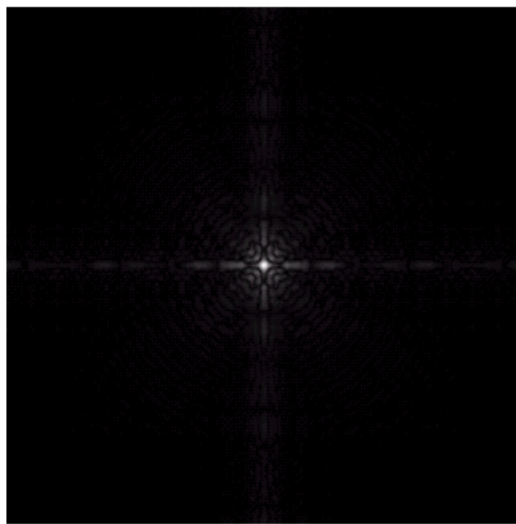
- The general form of the log transformation is
 - $s = c * \log(1 + r)$
- The log transformation maps a narrow range of low input grey level values into a wider range of output values
- The inverse log transformation performs the opposite transformation



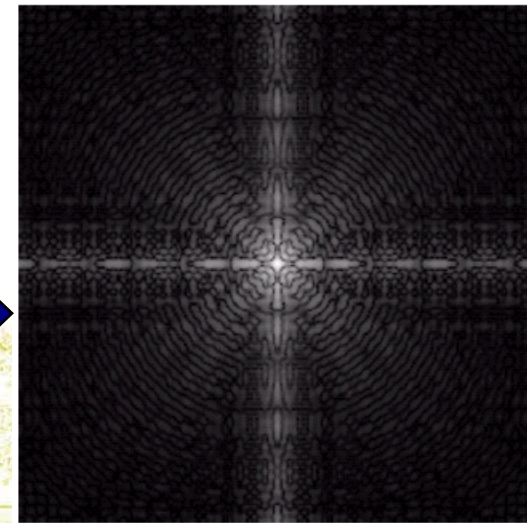
Logarithmic Transformations (cont...)



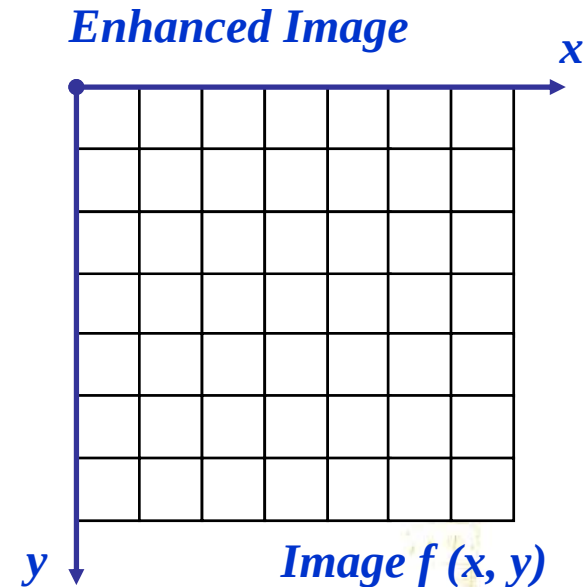
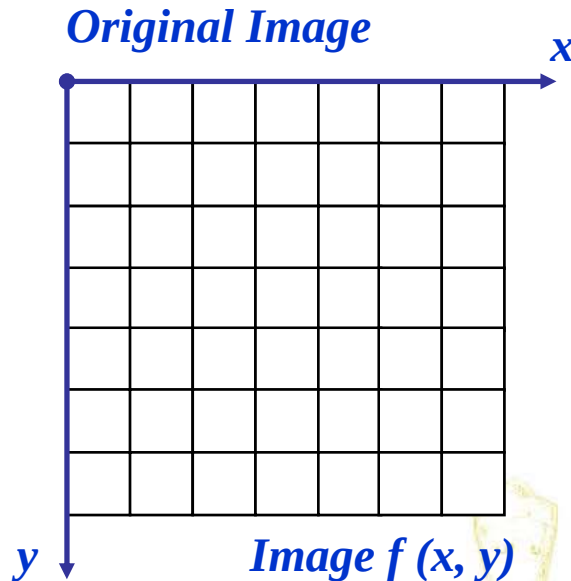
- Log functions are particularly useful when the input grey level values may have an extremely large range of values
- In the following example the Fourier transform of an image is put through a log transform to reveal more detail



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



Logarithmic Transformations (cont...)



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

We usually set c to 1

Grey levels must be in the range $[0.0, 1.0]$

Power Law Transformations

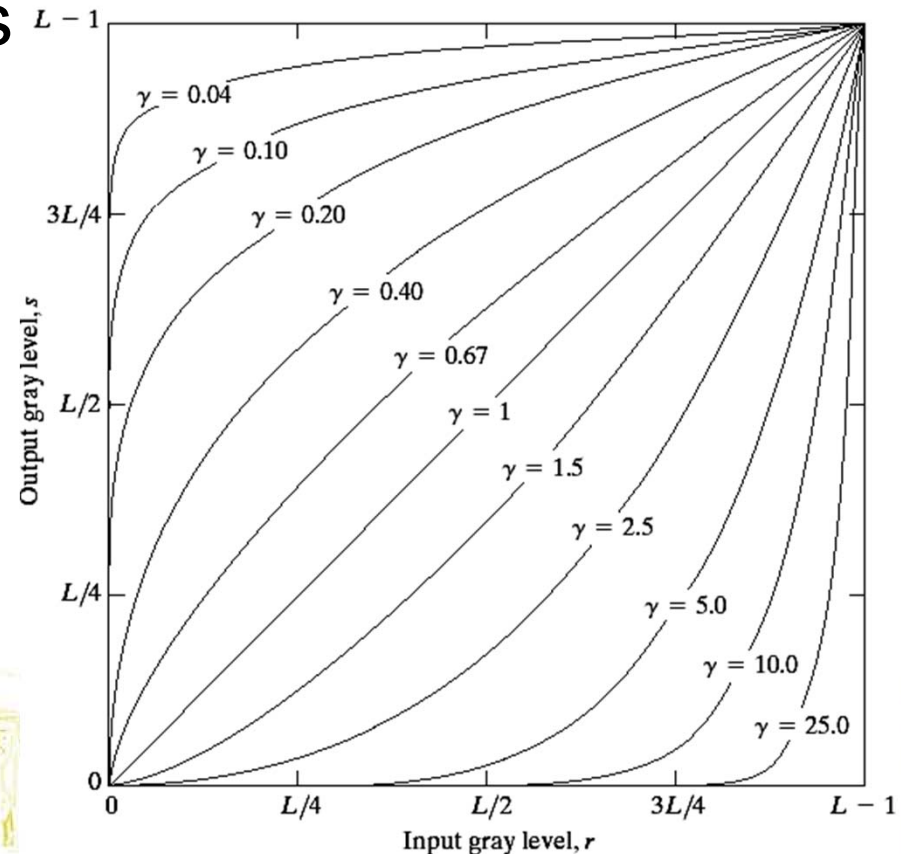


Power law transformations have the following form

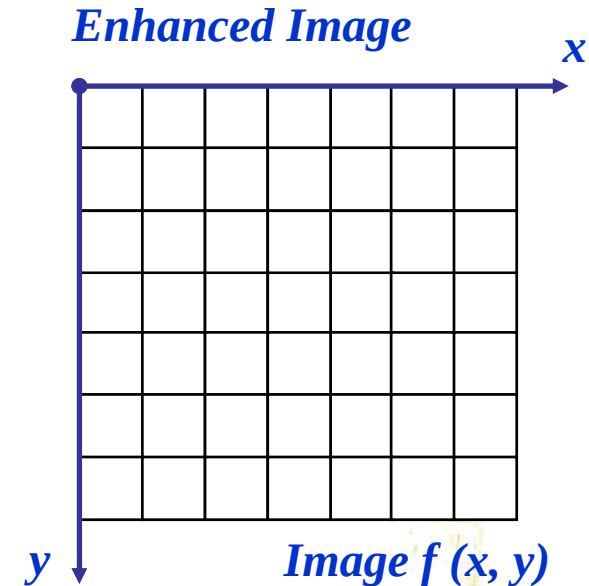
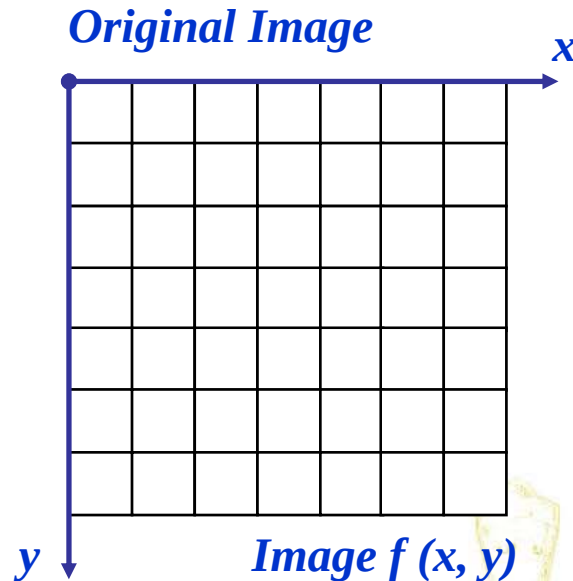
$$s = c * r^\gamma$$

Map a narrow range of dark input values into a wider range of output values or vice versa

Varying γ gives a whole family of curves



Power Law Transformations (cont...)



$$S = r^\gamma$$

- We usually set c to 1
- Grey levels must be in the range $[0.0, 1.0]$



Power Law Example



AVAILABLE AT:

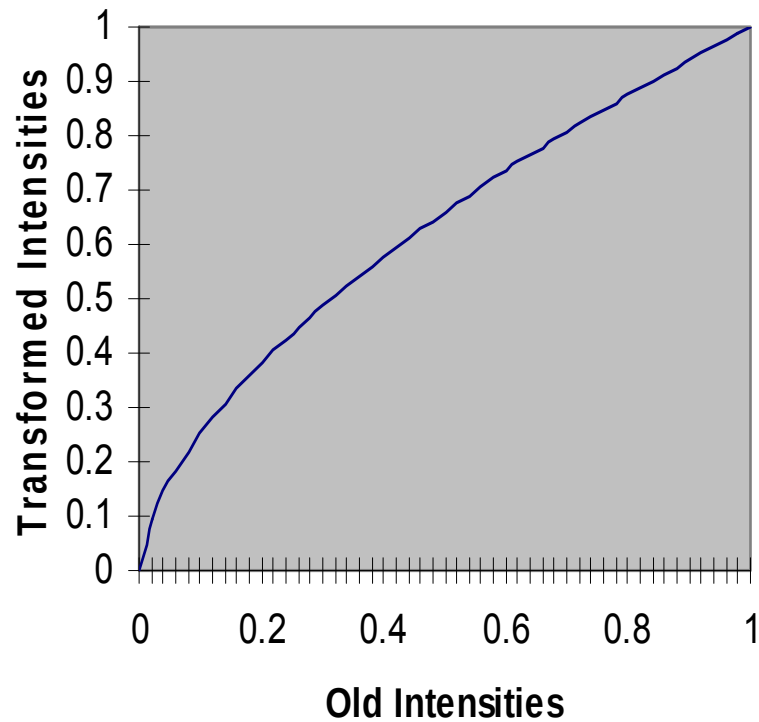
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Power Law Example (cont...)



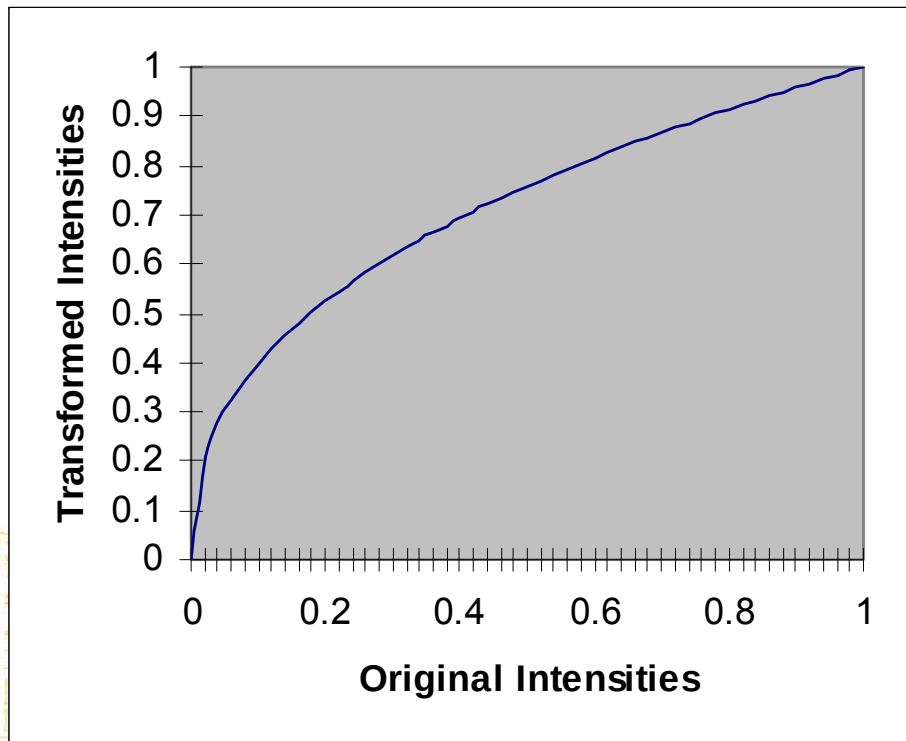
$$\gamma = 0.6$$



Power Law Example (cont...)



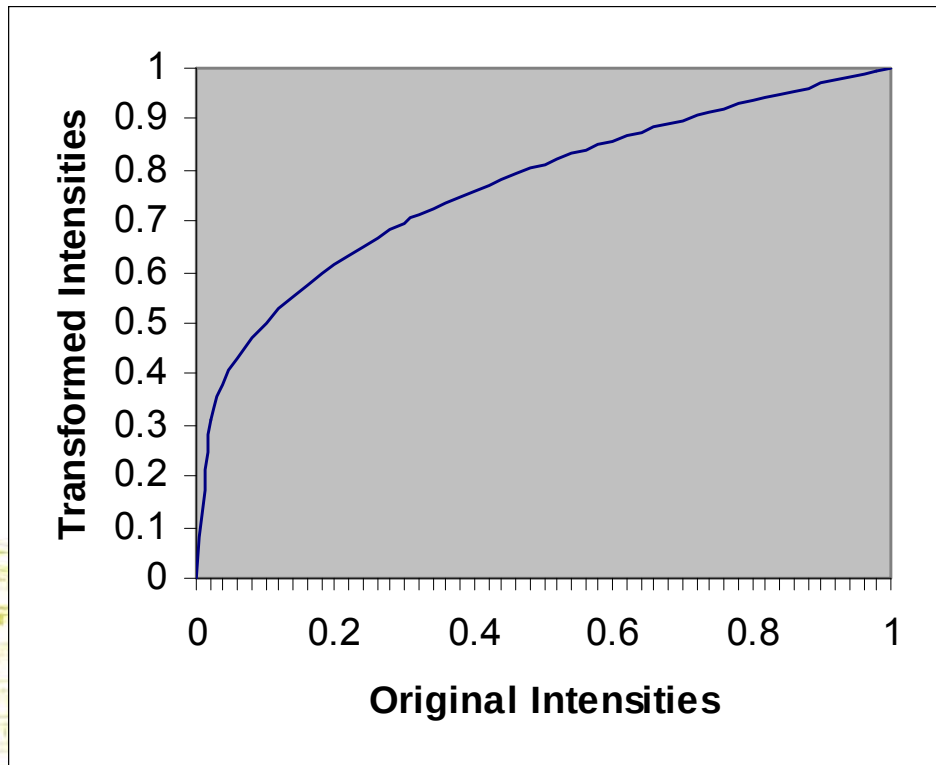
$$\gamma = 0.4$$



Power Law Example (cont...)



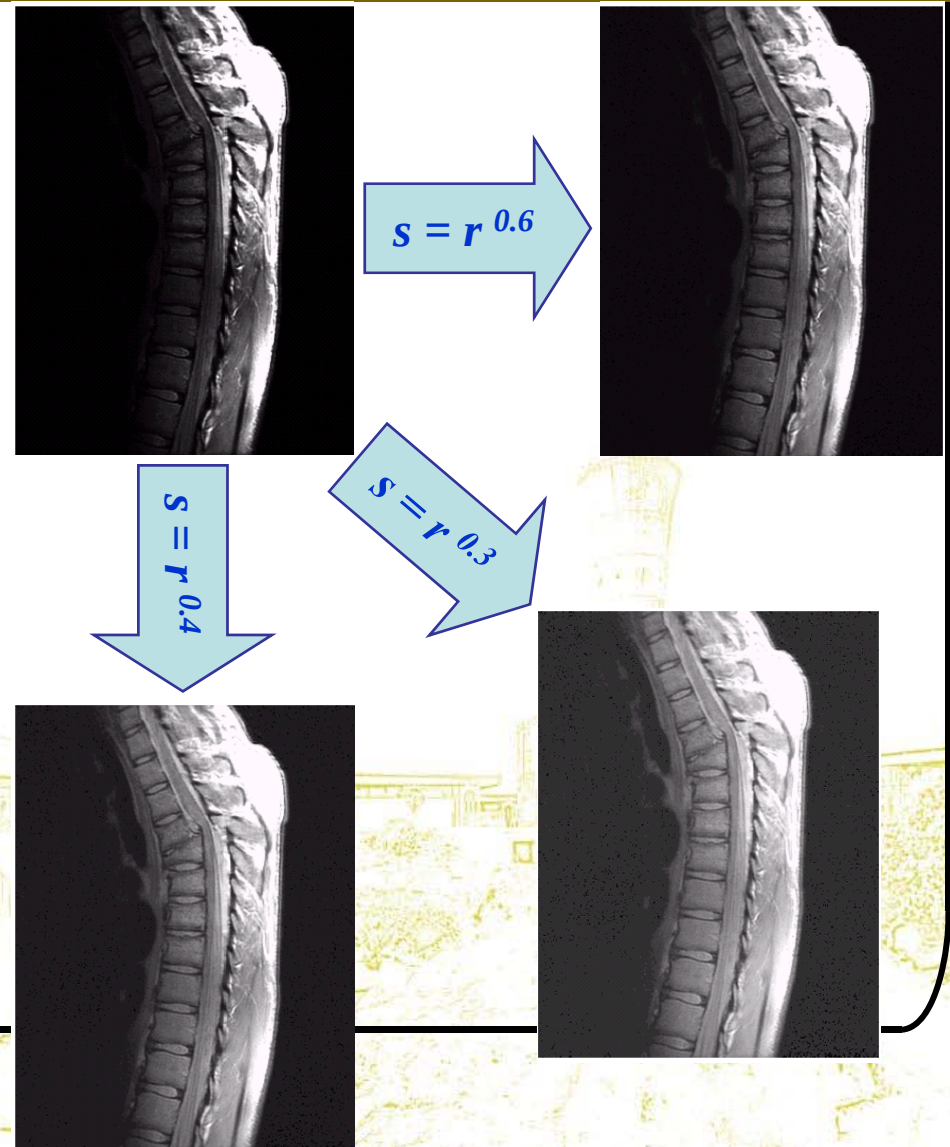
$$\gamma = 0.3$$



Power Law Example (cont...)



- The images to the right show a magnetic resonance (MR) image of a fractured human spine
- Different curves highlight different detail



Power Law Example



AVAILABLE AT:

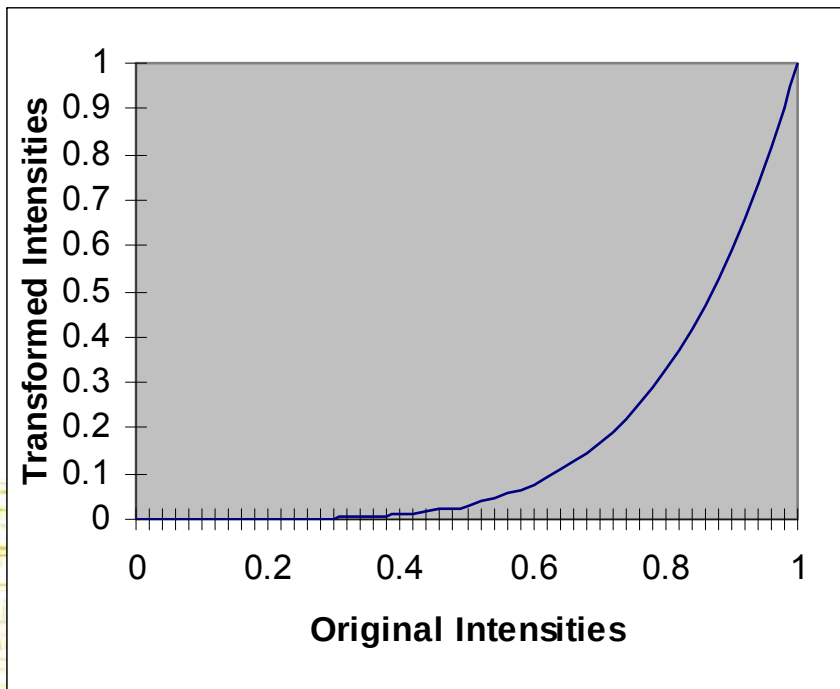
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Power Law Example (cont...)

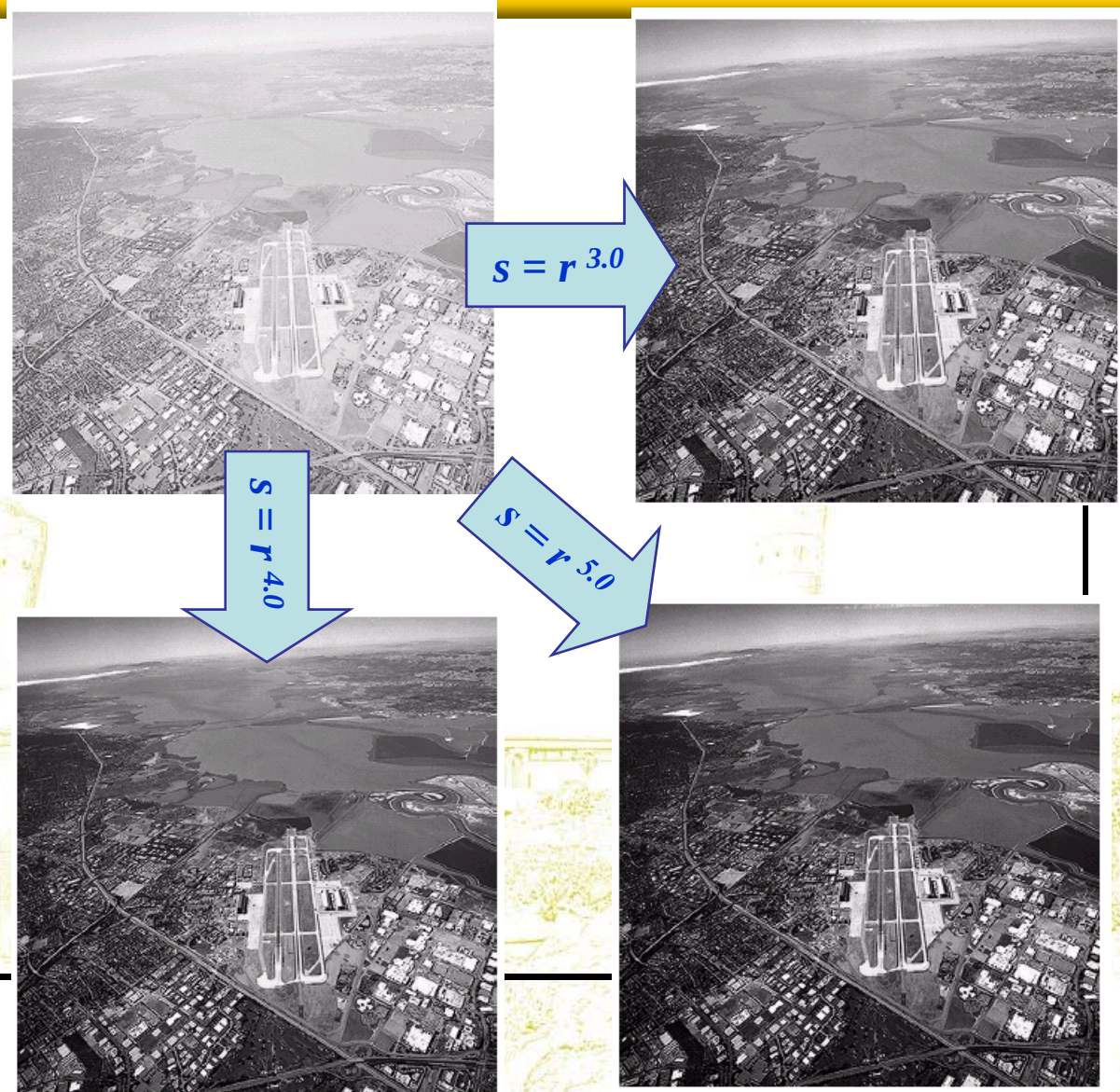


$$\gamma = 5.0$$



Power Law Transformations (cont...)

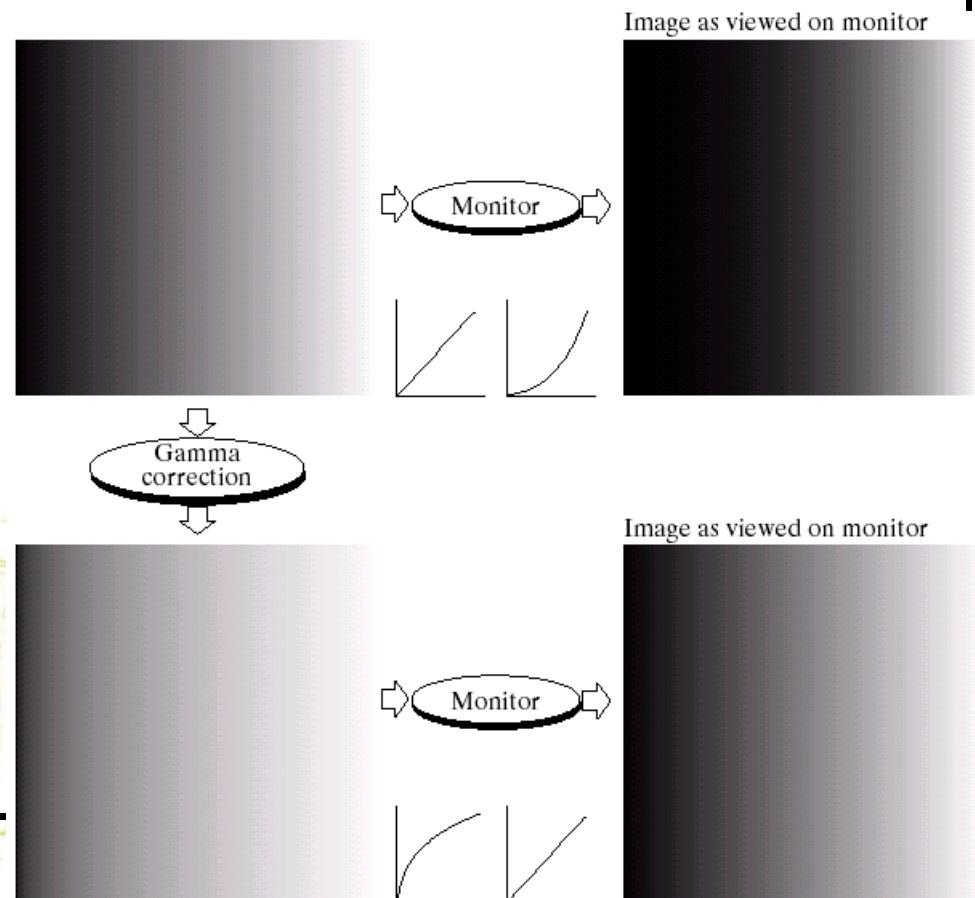
- An aerial photo of a runway is shown
- This time power law transforms are used to darken the image
- Different curves highlight different detail



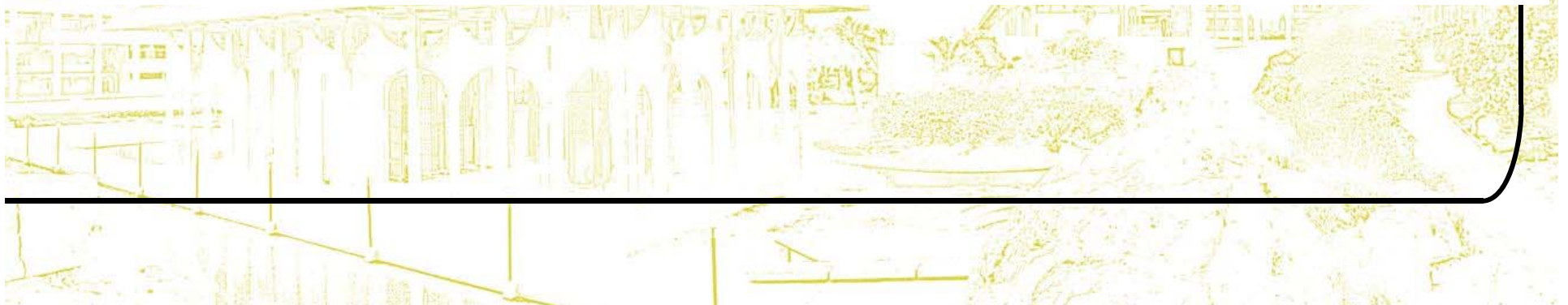
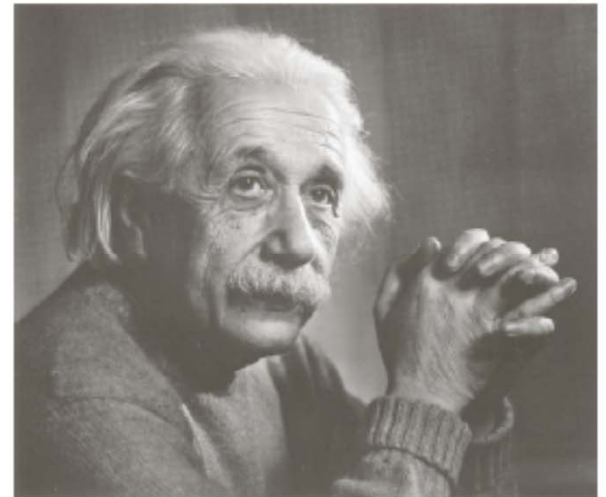
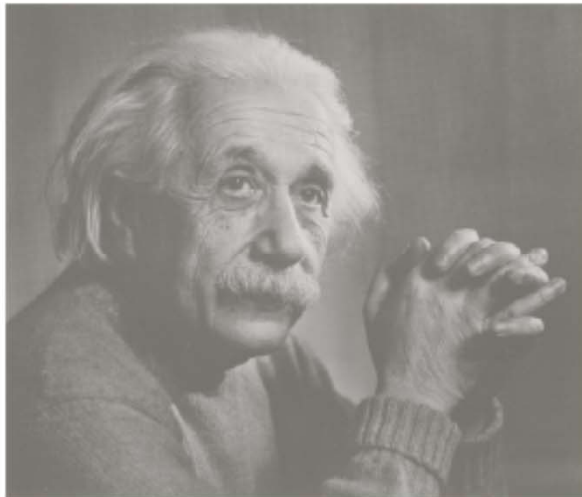
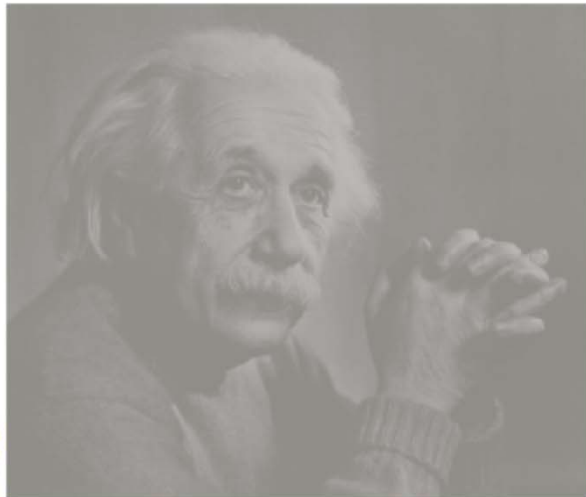
Gamma Correction



- Many of you might be familiar with gamma correction of computer monitors
- Problem is that display devices do not respond linearly to different intensities
- Can be corrected using a log transform



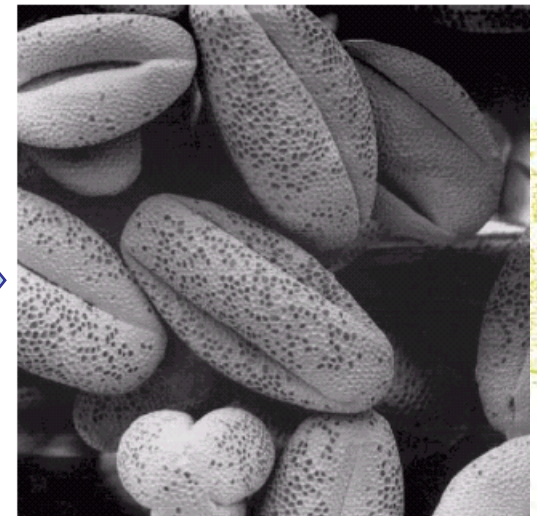
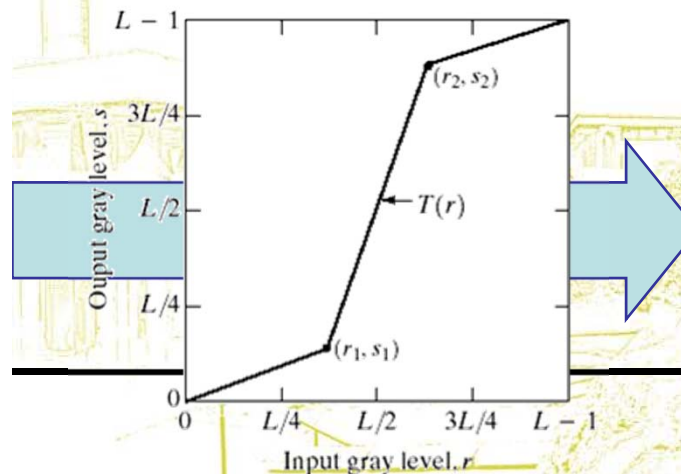
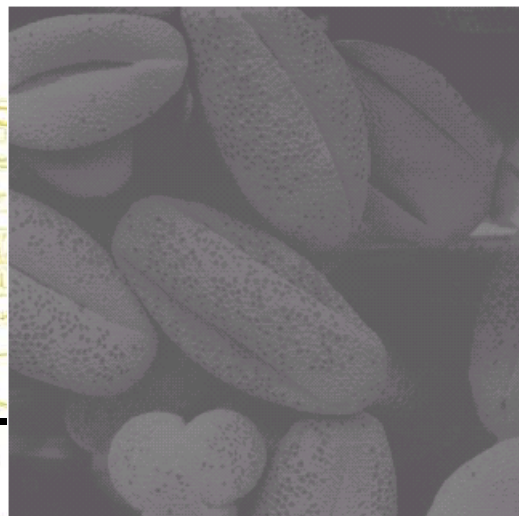
More Contrast Issues



Piecewise Linear Transformation Functions



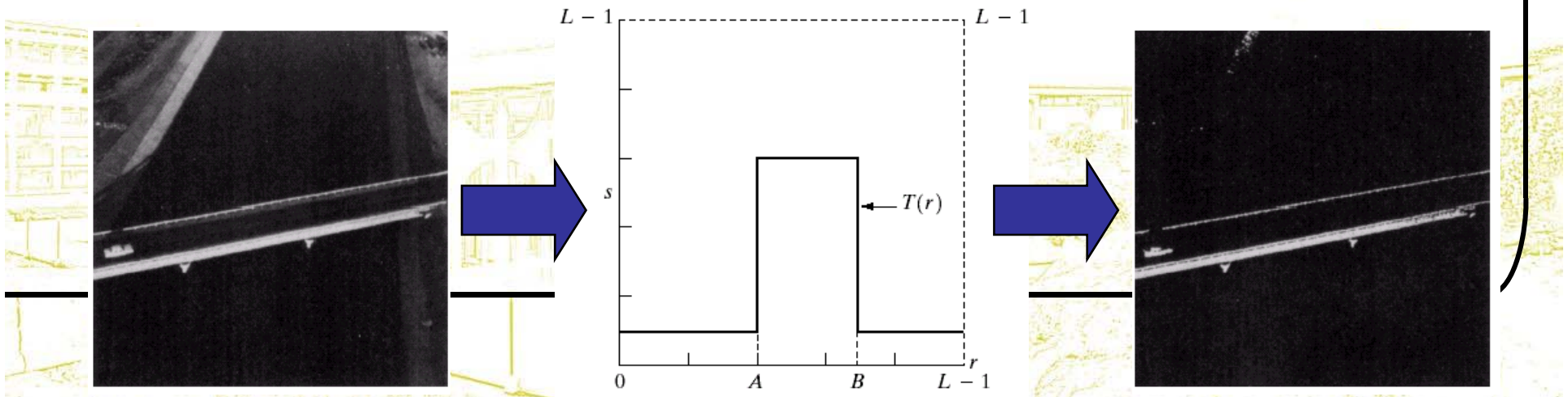
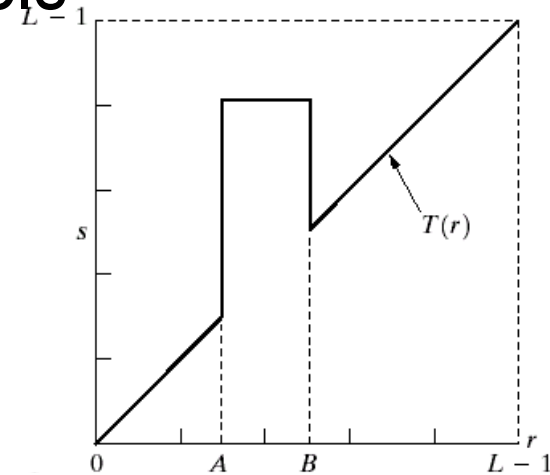
- Rather than using a well defined mathematical function we can use arbitrary user-defined transforms
- The images below show a contrast stretching linear transform to add contrast to a poor quality image



Gray Level Slicing

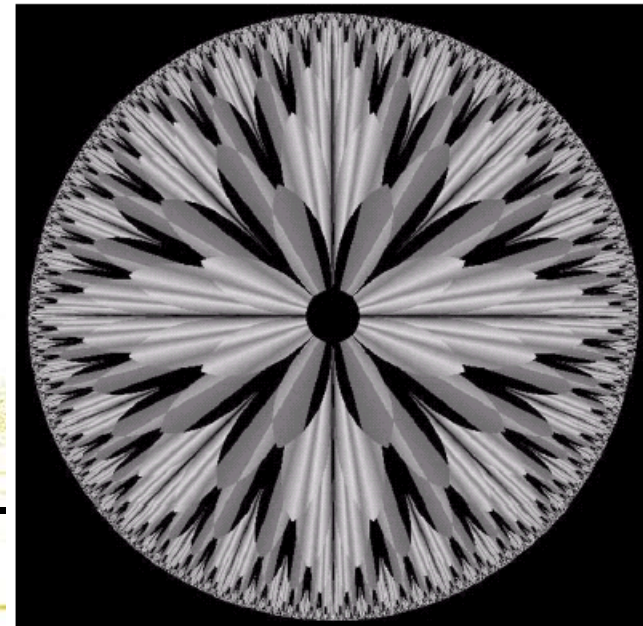
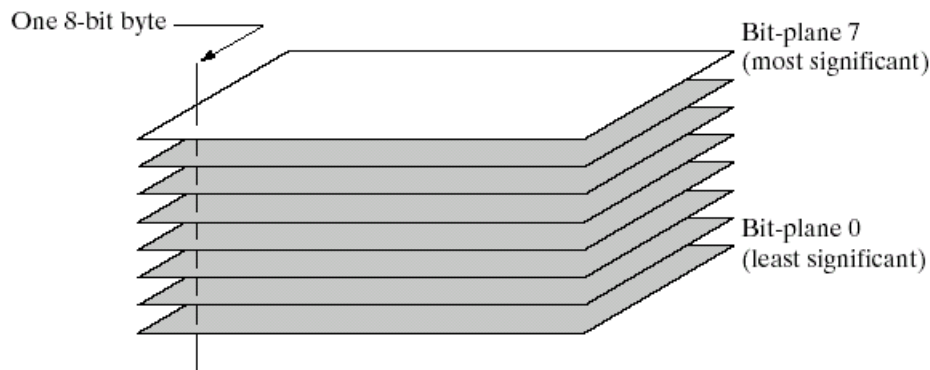


- Highlights a specific range of grey levels
 - Similar to thresholding
 - Other levels can be suppressed or maintained
 - Useful for highlighting features in an image



Bit Plane Slicing

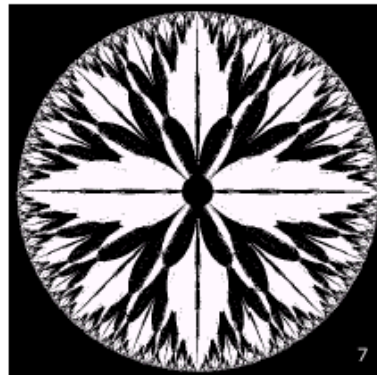
- Often by isolating particular bits of the pixel values in an image we can highlight interesting aspects of that image
 - Higher-order bits usually contain most of the significant visual information
 - Lower-order bits contain subtle details



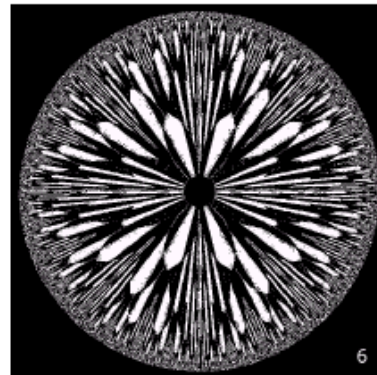
Bit Plane Slicing (cont...)



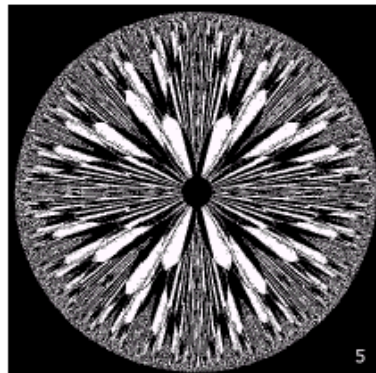
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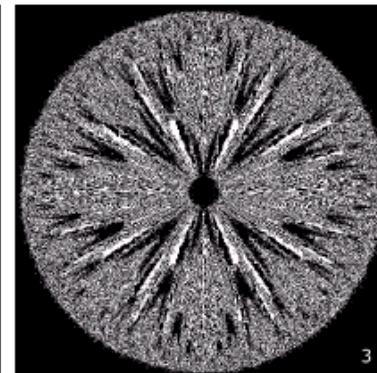
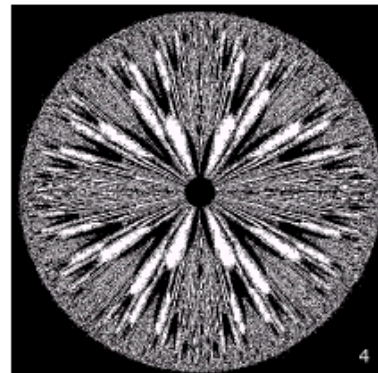
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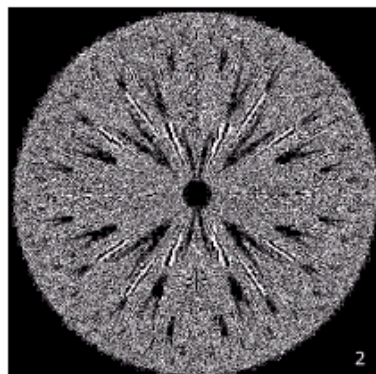
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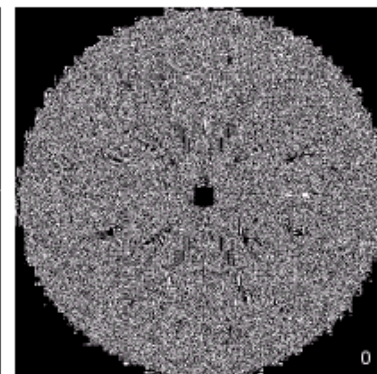
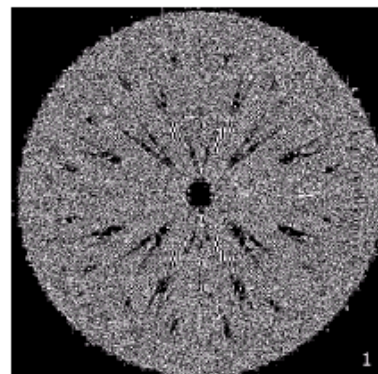
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[00000100]



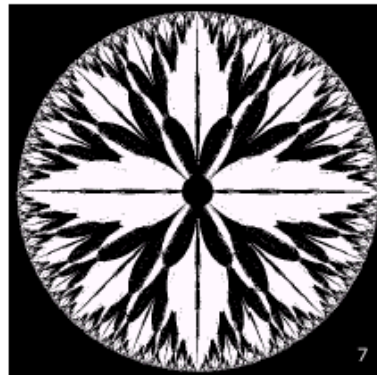
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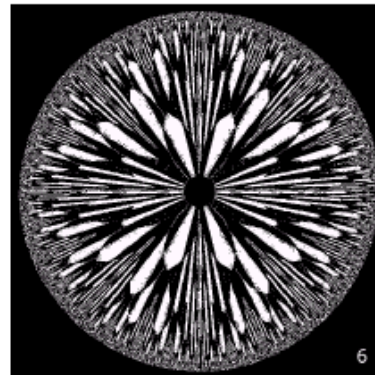
Bit Plane Slicing (cont...)



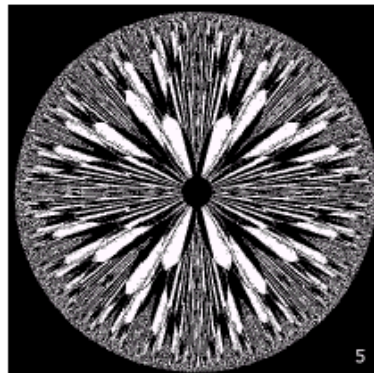
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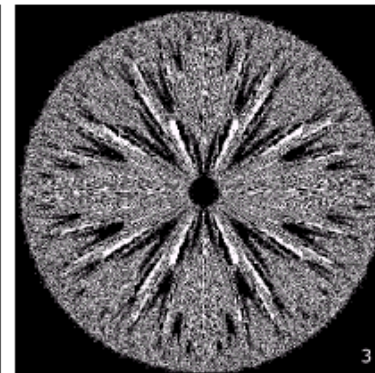
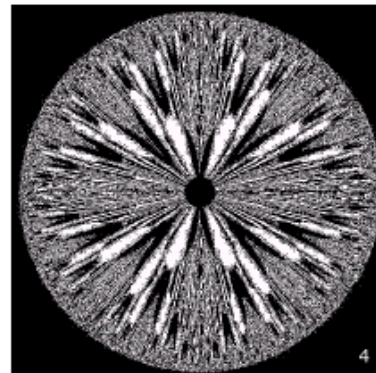
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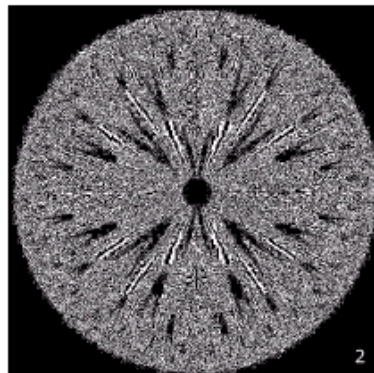
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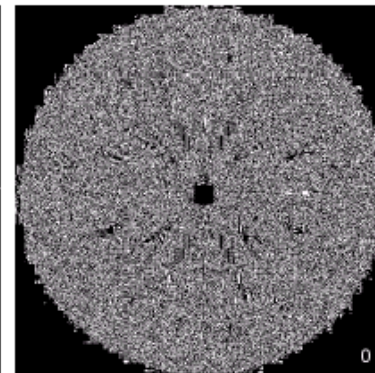
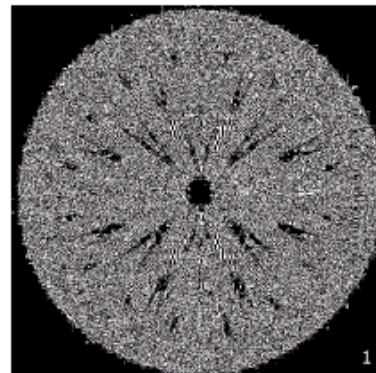
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[00000100]



[00000001]



Bit Plane Slicing (cont...)



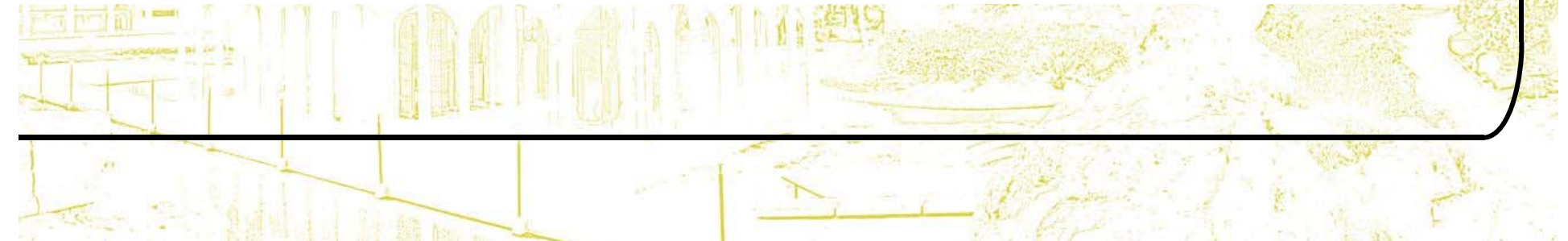
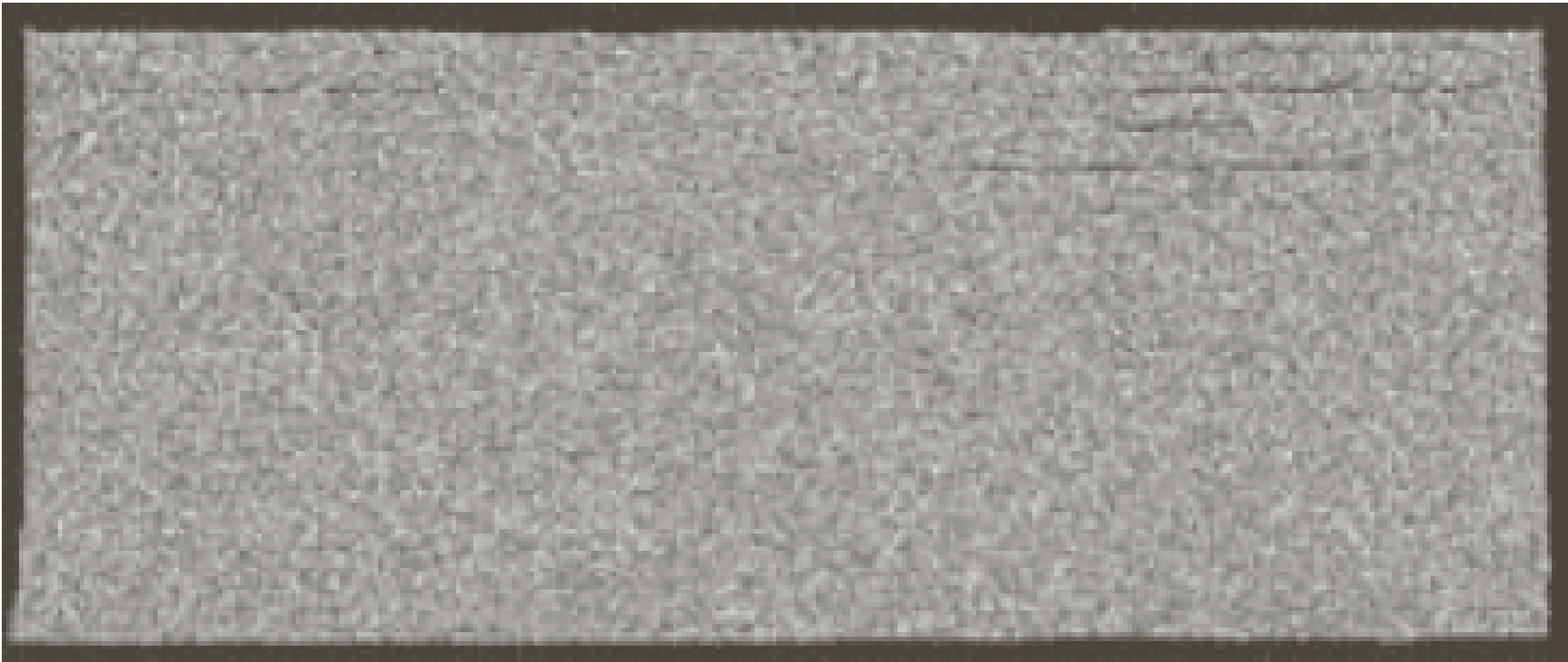
a	b	c
d	e	f
g	h	i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500×1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

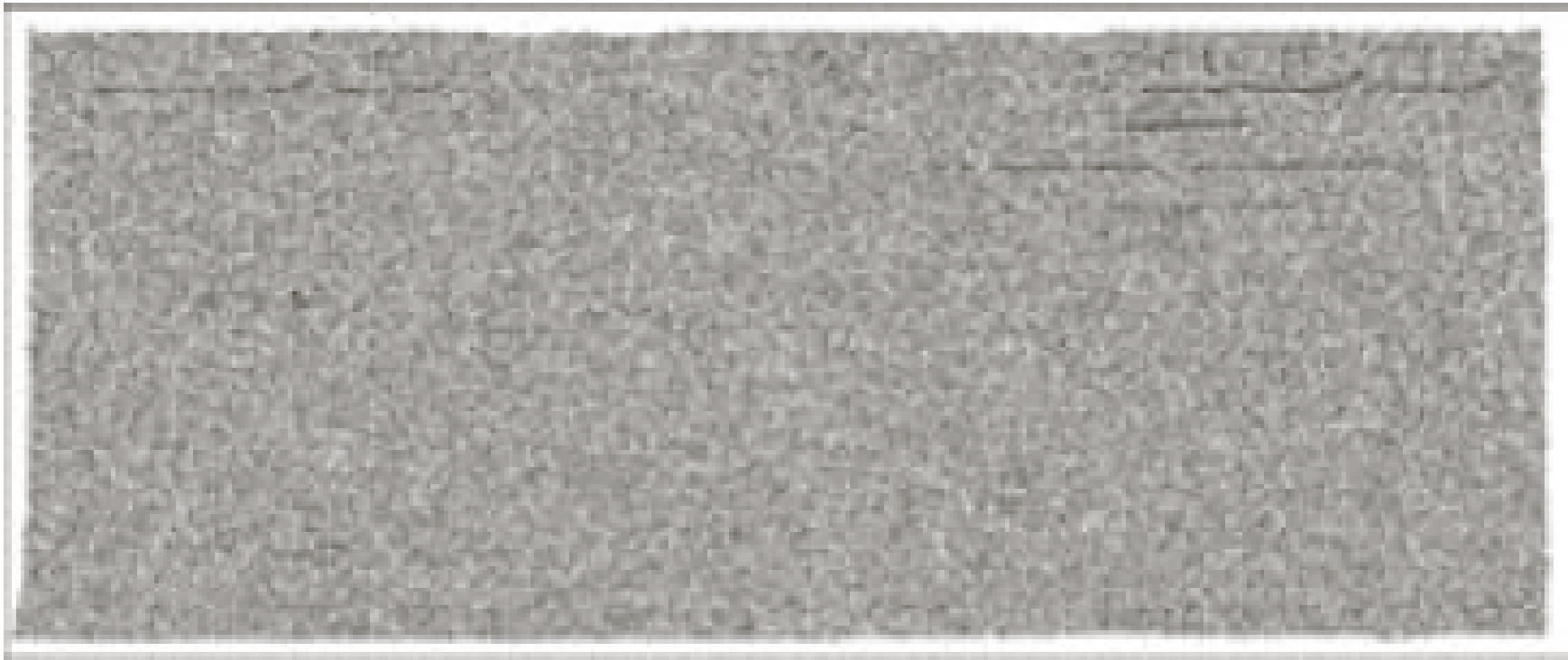
Bit Plane Slicing (cont...)



Bit Plane Slicing (cont...)



Bit Plane Slicing (cont...)



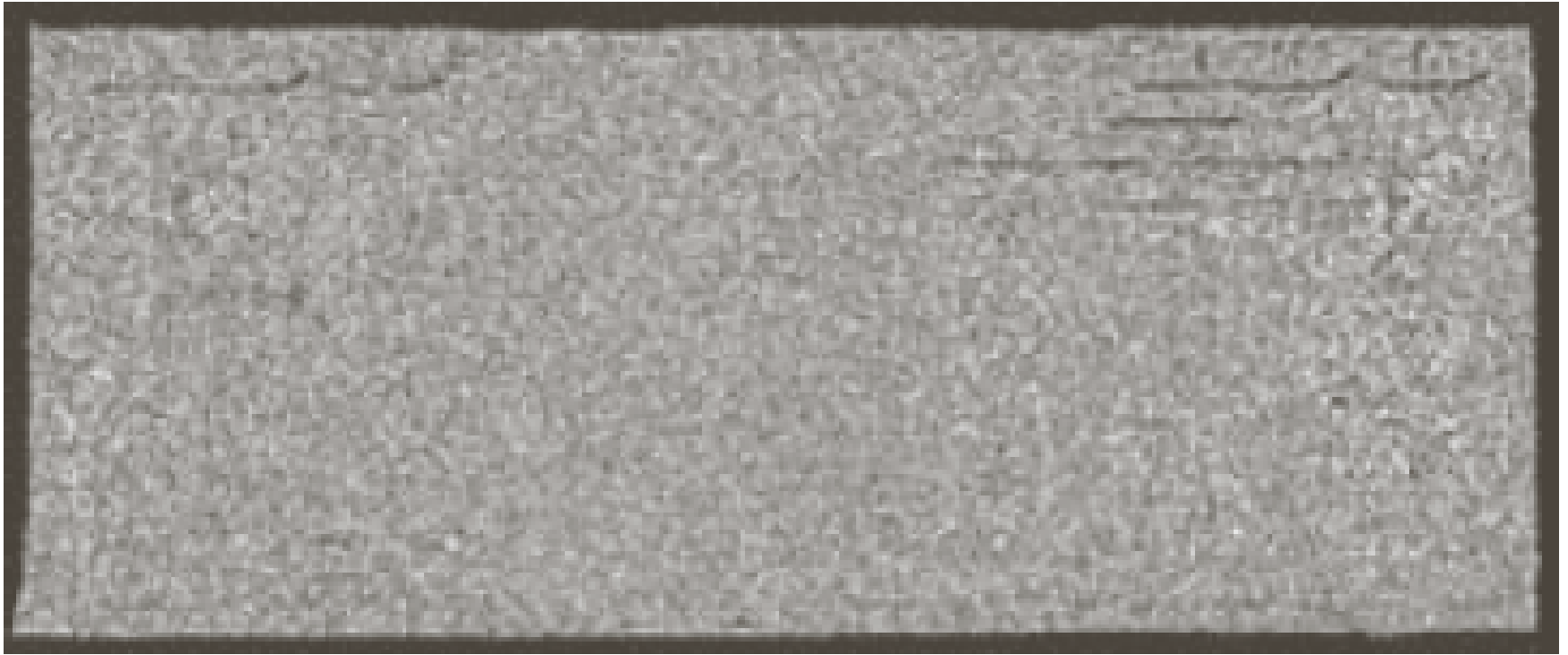
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Bit Plane Slicing (cont...)

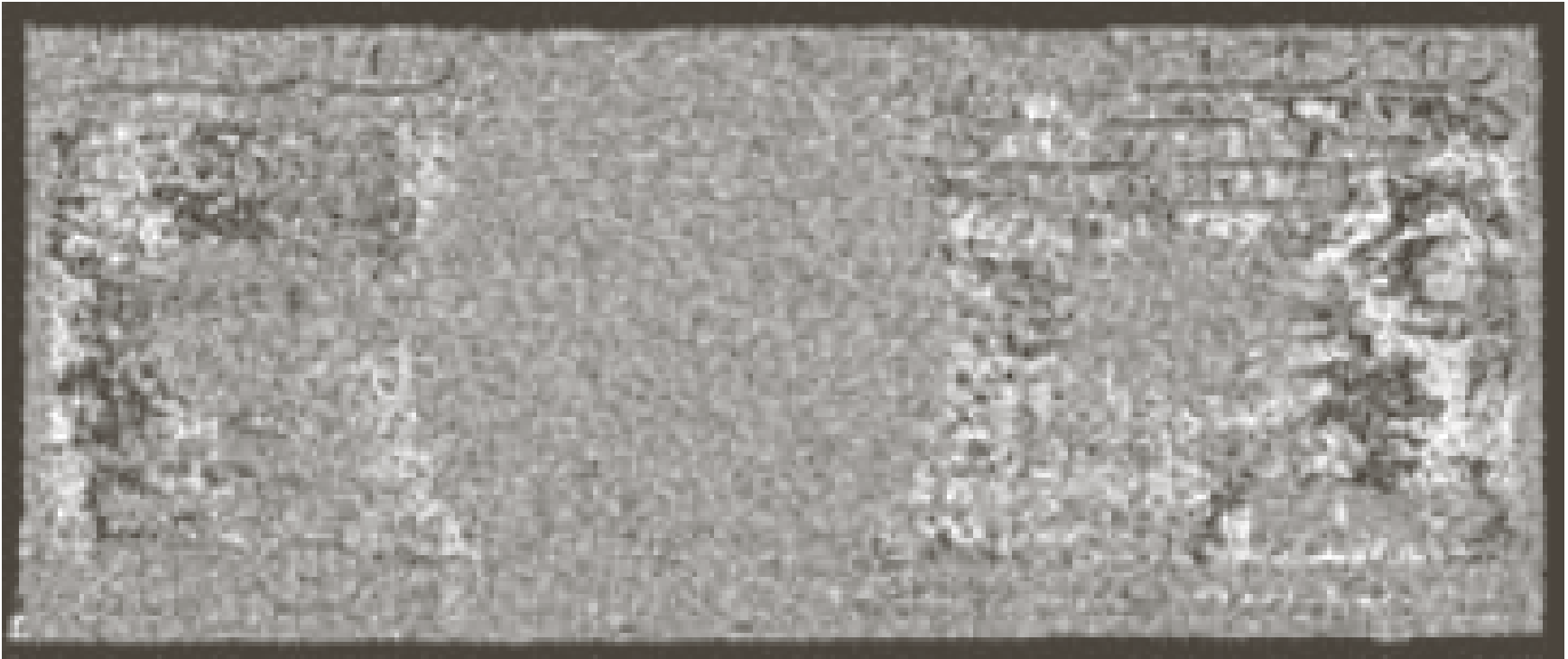


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Bit Plane Slicing (cont...)



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Bit Plane Slicing (cont...)

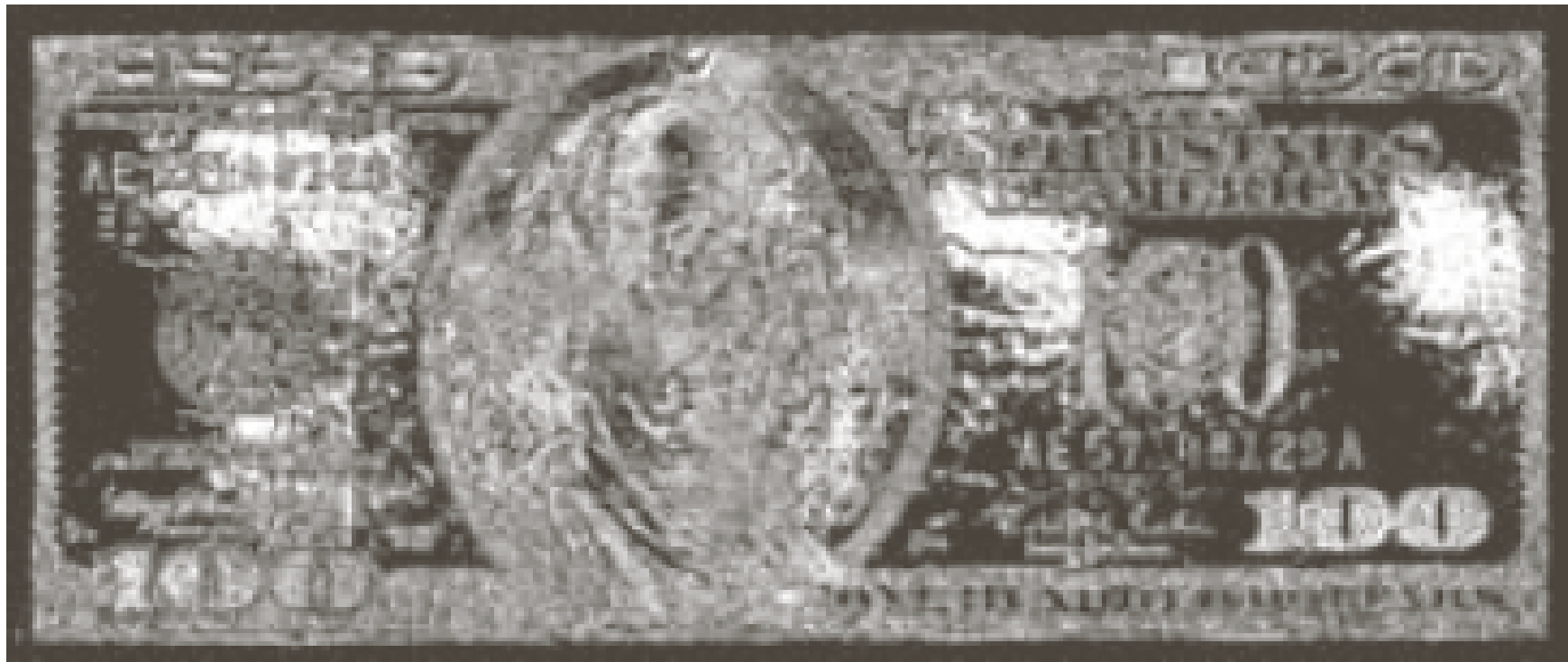


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Bit Plane Slicing (cont...)



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Bit Plane Slicing (cont...)



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Bit Plane Slicing (cont...)



Reconstructed image
using only bit planes 8
and 7



Reconstructed image
using only bit planes 8, 7
and 6



Reconstructed image
using only bit planes 7, 6
and 5

Summary



- We have looked at different kinds of point processing image enhancement

