Intensity Transforms

Introduction

Recap

- Spatial Operations
  - Geometric spatial transformations

- Image Interpolation

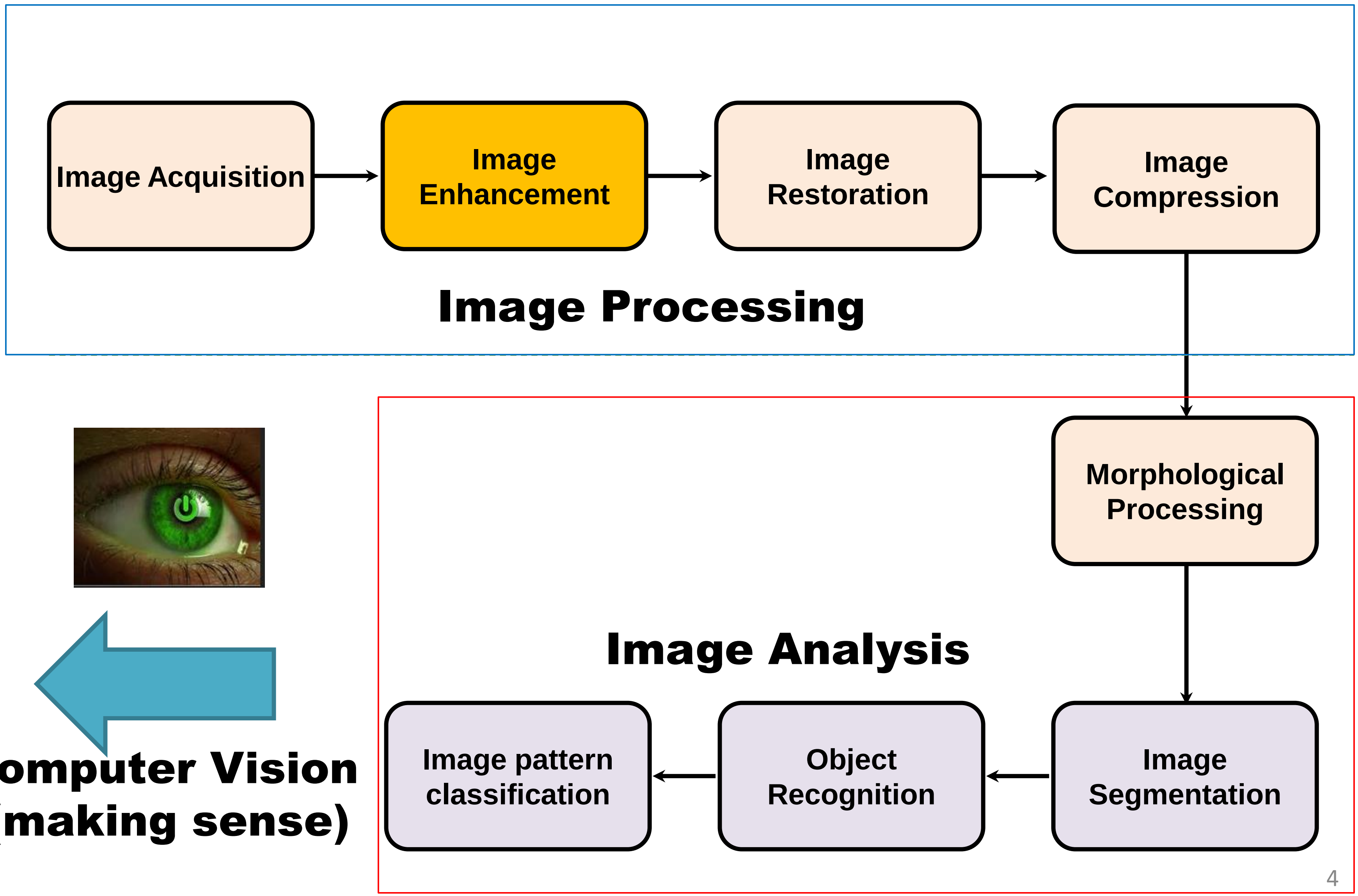
- Image Registration

- Image Domain Transforms

Lecture Objectives

- Spatial Domain Transformations – preview
- The Transformation Operator
- Intensity Transformations and examples
  - Contrast stretching
  - Image thresholding
- Basic Intensity Transformation Functions
  - Basic transforms
  - Piecewise-linear transformations

Key Stages in DIP



Computer Vision (making sense)

Image Enhancement

- Image Enhancement is:
  - The process of manipulating an image so that the result is more suitable than the original for a specific application. It's a ***subjective*** measure.

➢ Visual interpretation
  - Decision made by the user of the system (satisfaction)
  - **Ex:** visibility of detailed features in the medical image

➢ Machine perception
  - Quantified by the system efficiency
  - **Ex:** character recognition rate for number plate detection

Spatial Domain Transformations

Preview

Spatial Domain Transformations - **Preview**

- The term *spatial domain* refers to the **image plane** itself, and image processing methods in this category are based on *direct manipulation of pixels* in an image.

- In contrast, image processing in a *transform domain* involves:
  1. first transforming an image into the transform domain
  2. doing the processing in the transform domain, and
  3. obtaining the inverse transform to bring the results back into the spatial domain

Spatial Domain Transformations - **Preview**

- Two principal categories of spatial domain processing are:
  1. Intensity transformations
  2. Spatial filtering

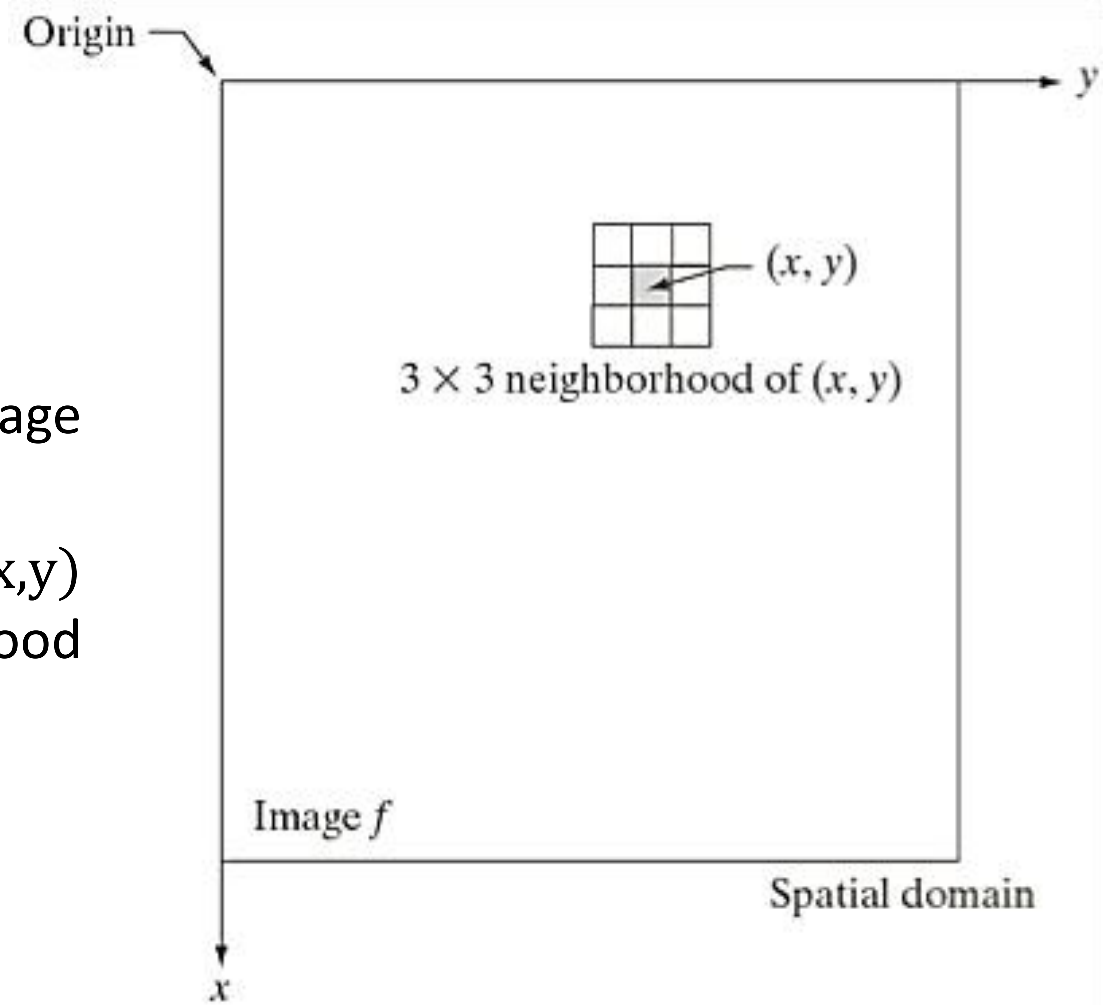
- *Intensity transformations* operate on **single pixels** of an image for tasks such as contrast manipulation and image thresholding.

- *Spatial filtering* performs operations on the **neighborhood of every pixel** in an image. Examples of spatial filtering include image smoothing and image sharpening.

Spatial Domain Transformations

Spatial filtering

- $g(x,y)=T[f(x,y)]$
  - ***f(x,y)*** is the input image
  - ***g(x,y)*** is the output image (transformed image)
  - ***T*** is an operator on f(x,y) defined over a neighborhood of point (x,y)



The center of the neighborhood is moved from pixel to pixel, and then the operator ***T*** is applied to the pixels in the neighborhood to yield an output value at that location.

The Transformation Operator: T

The Transformation Operator: T

- Intensity transformation: neighborhood size is **1×1**
  - $\mathbf{T}$: intensity (grey-level) transformation function

- Spatial filtering: neighborhood is usually an **odd sized window** of the size **a×b**, where $a=2k+1$ or $b=2k+1$ for $\mathbf{k} \in \mathbf{Z}^{+}$
  - $\mathbf{T}$: spatial filter/spatial mask/kernel/template/window

Intensity Transformation
Examples

Intensity Transformation - examples

- The intensity transformation function operate on *neighborhood of size* **1×1** for a pixel:

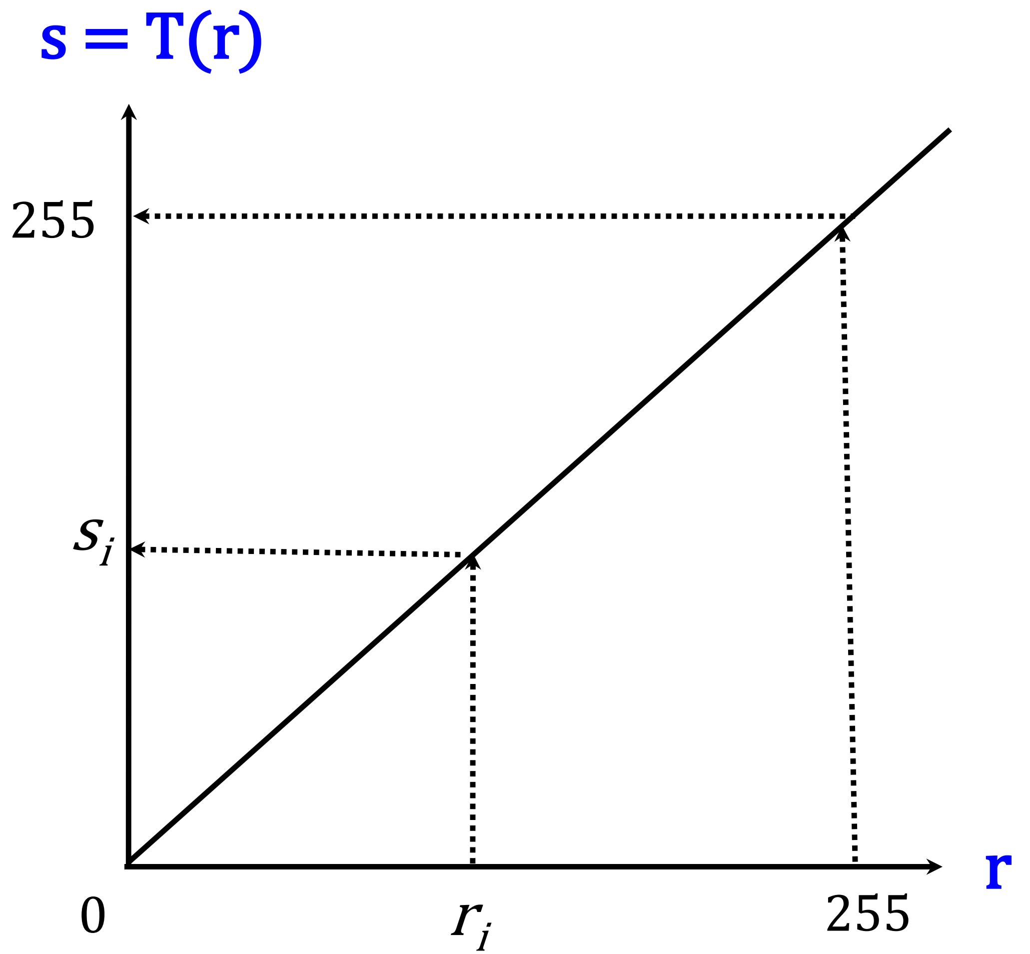
$$s=T(r)$$

- Example:
  - Contrast stretching/Image stretching/Image normalization
  - Image thresholding

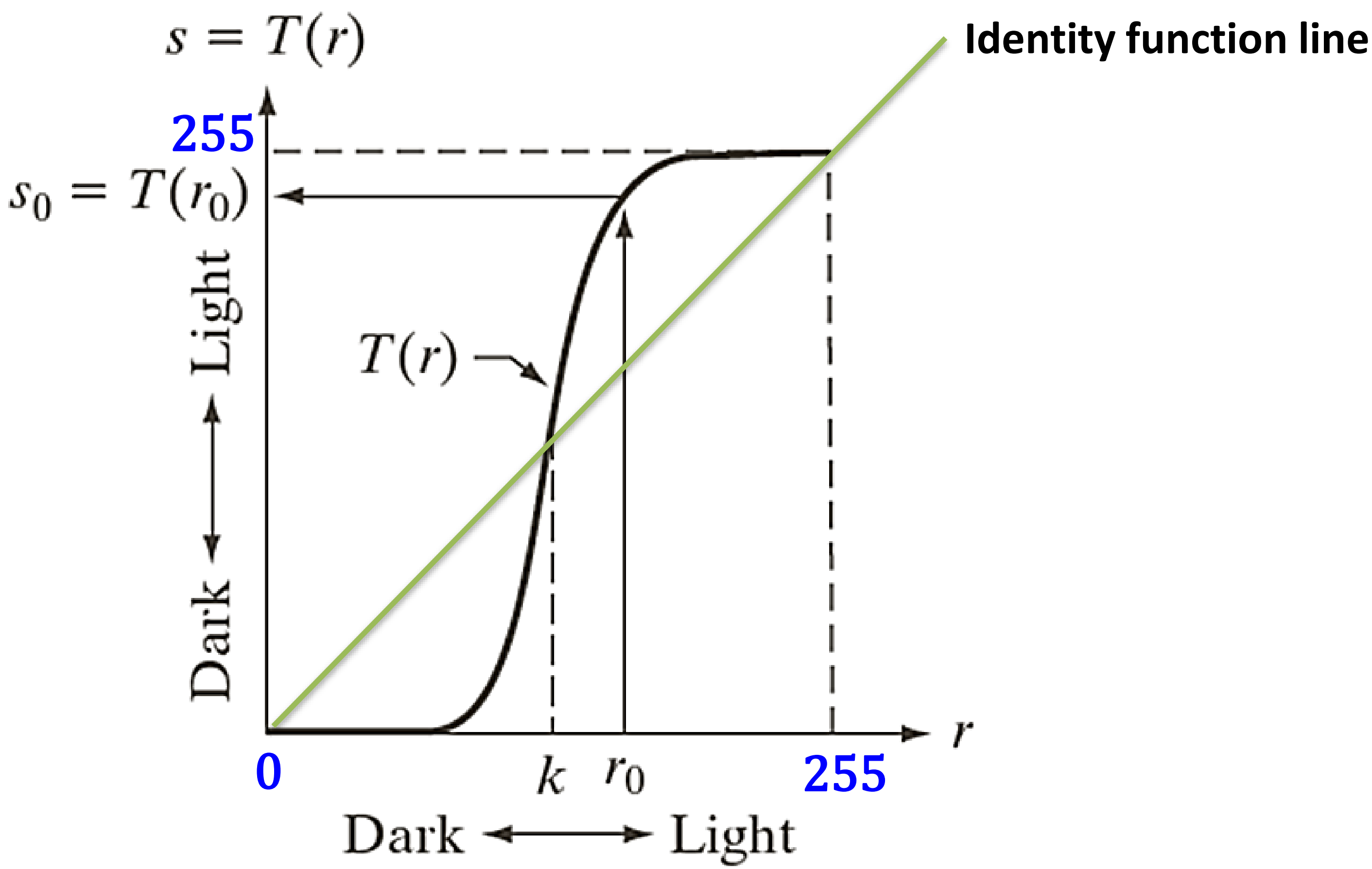
- The intensity transformation function whose results depend only on the **intensity at a point** sometimes are called *point processing techniques*, as opposed to the *neighborhood processing techniques*.

Identity Function

- The identity function is the trivial case in which the input and output intensities are ***identical*** (same).



Contrast stretching



- Values of ***r*** lower than ***k*** *reduce* (darken) the values of ***s***, *toward black*.
- Values of ***r*** higher than ***k*** *increase* (lighten) the values of ***s***, toward *white*.

Contrast stretching - formula

$$S = (r - f_{min})\left[\frac{max - min}{f_{max} - f_{min}}\right] + min$$

S: color level of the output pixel

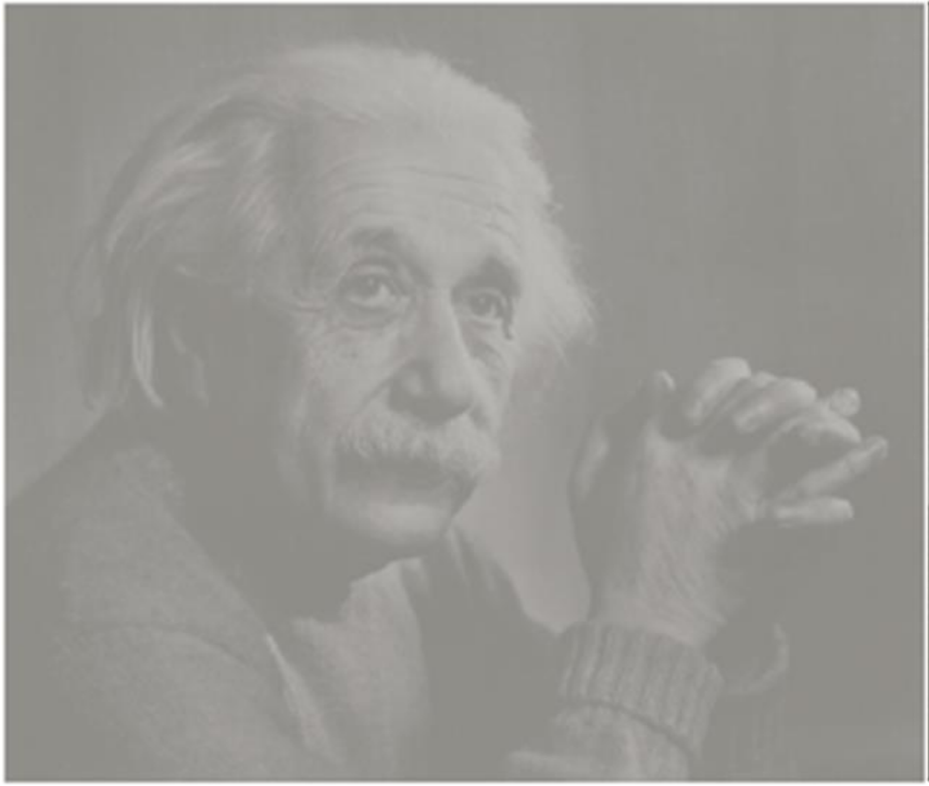
r : color level of the input pixel

$\mathbf{f_{max}}$:maximum color level values in the input image

$\mathbf{f_{min}}$: minimum color level values in the input image

max & min :desired maximum and minimum color levels that determines color range of the output image, respectively

Contrast stretching



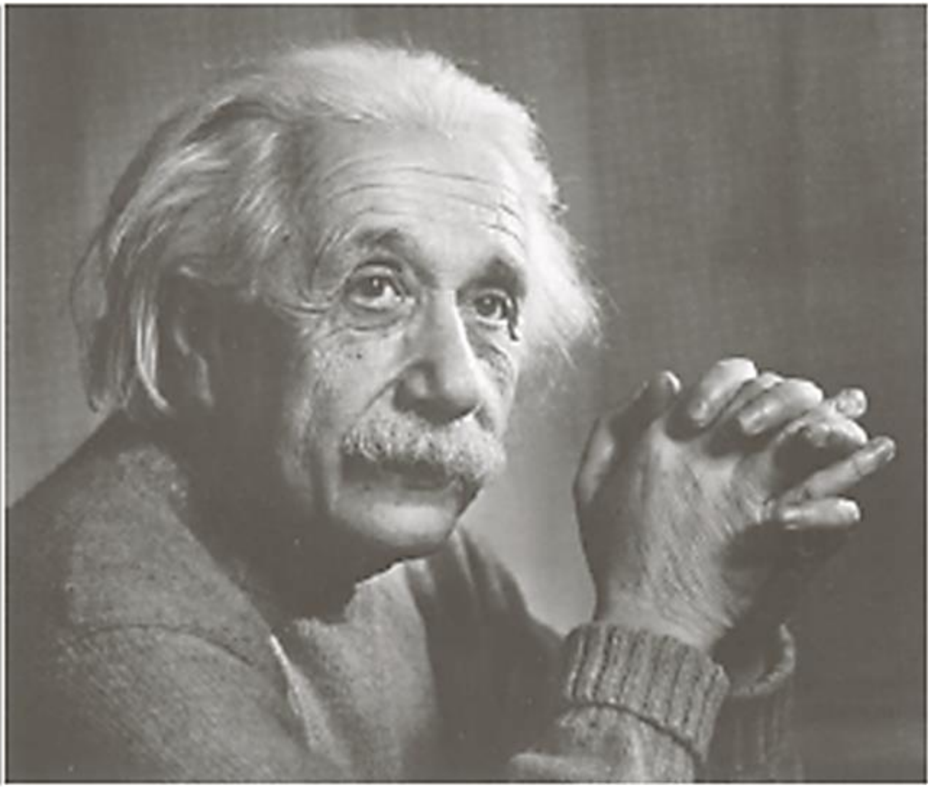


Image Thresholding

- **Limiting case** of the *contrast stretching*.

- Only two valid values
  - **0** for lower intensities
  - **1** for higher intensities

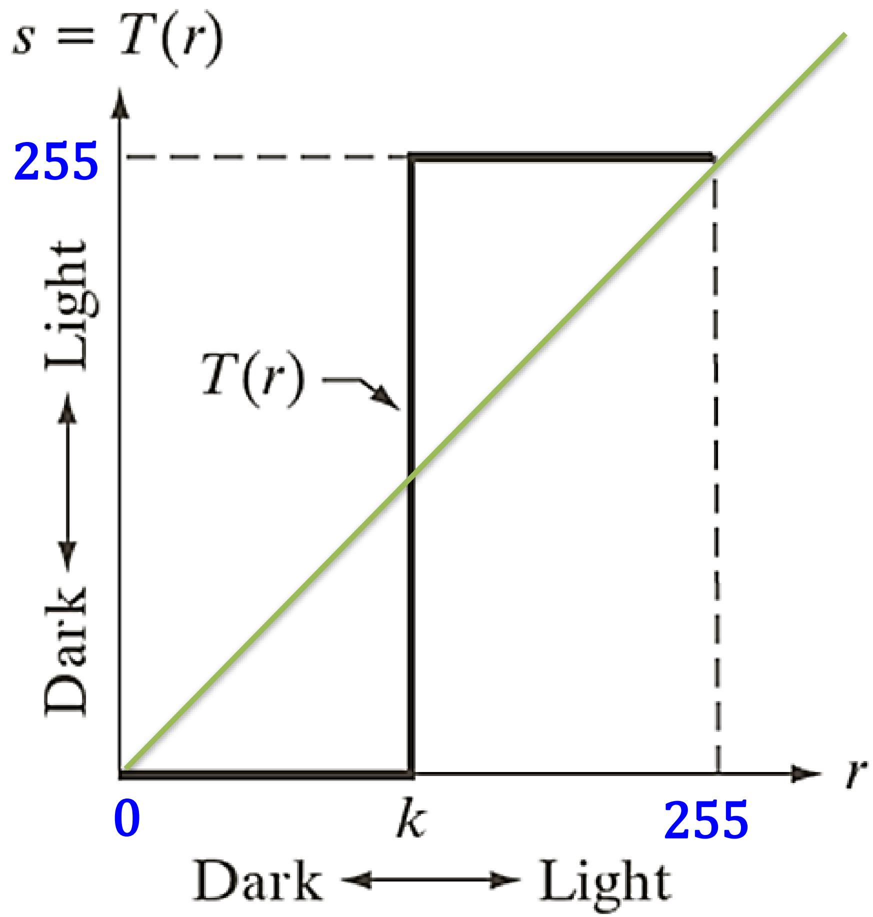


Image Thresholding

Basic Intensity Transformation Functions

Intensity Transformation Functions

- Basic transformations
  - Image negative
  - Log transformations
  - Power-Law (Gamma) transformations

- Piecewise-linear Transformations
  - Contrast stretching
  - Intensity-level slicing
  - Bit-plane slicing

Basic Transformation Functions

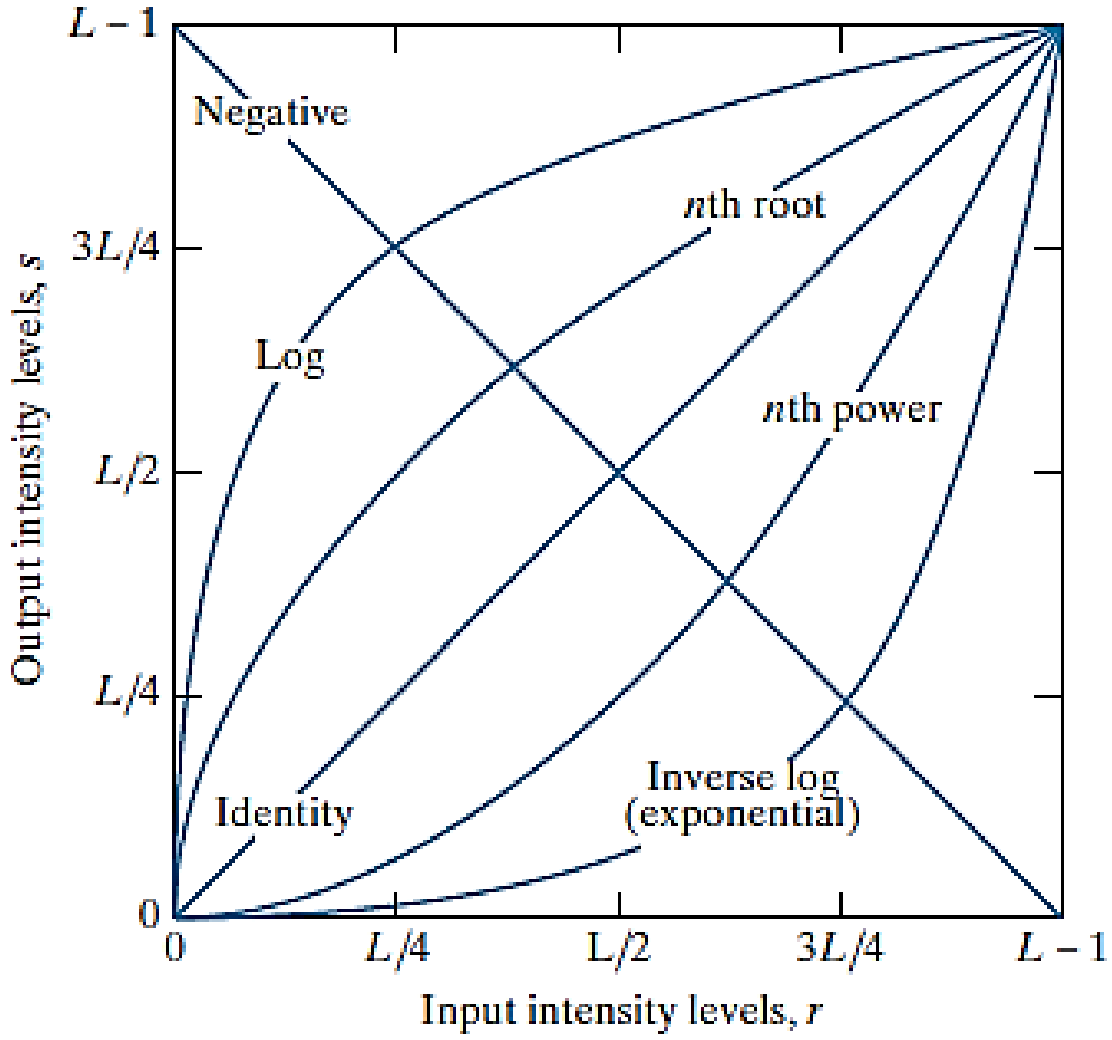


Image Negative

- Uses the transform:

  s=(L-1)-r

  where L is the intensity in the range [0, L-1].

- Similar to photographic negative function.

- Used for ***enhancing white or gray details*** embedded in dark regions of an image, especially when the black areas are dominant in size.

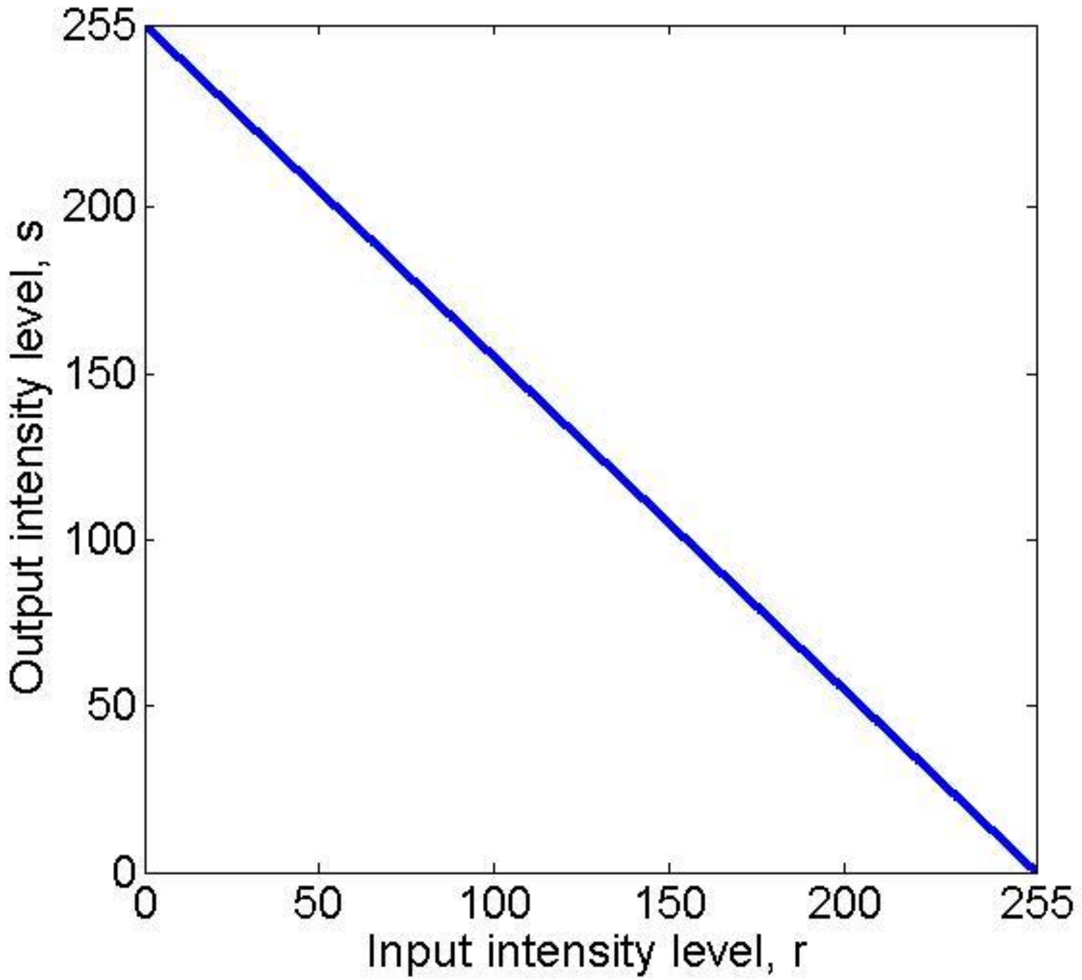
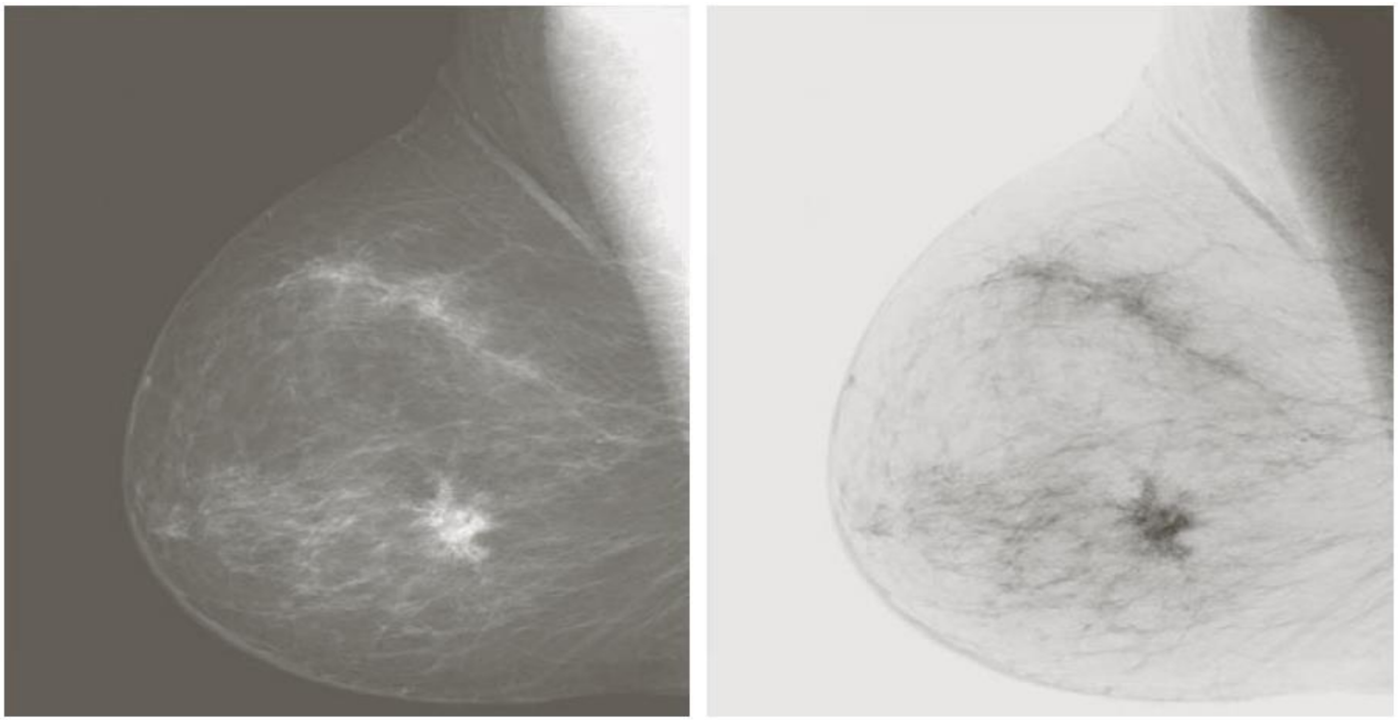


Image Negative



Digital mammogram showing a small lesion in breast which may lead to breast cancer

Log Transformation

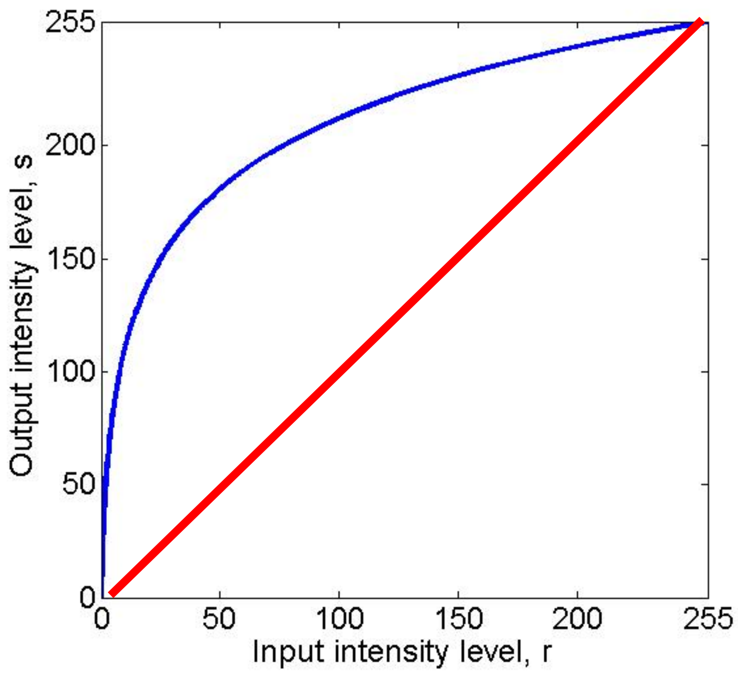
- Uses the transform:

  $$\mathbf{s = c \times \log_{10}(1+r)}$$

  where ***c*** is a constant and it is assumed that $r \geq 0$.

- Maps narrow input intensity ranges to wider output ranges for lower intensity values.

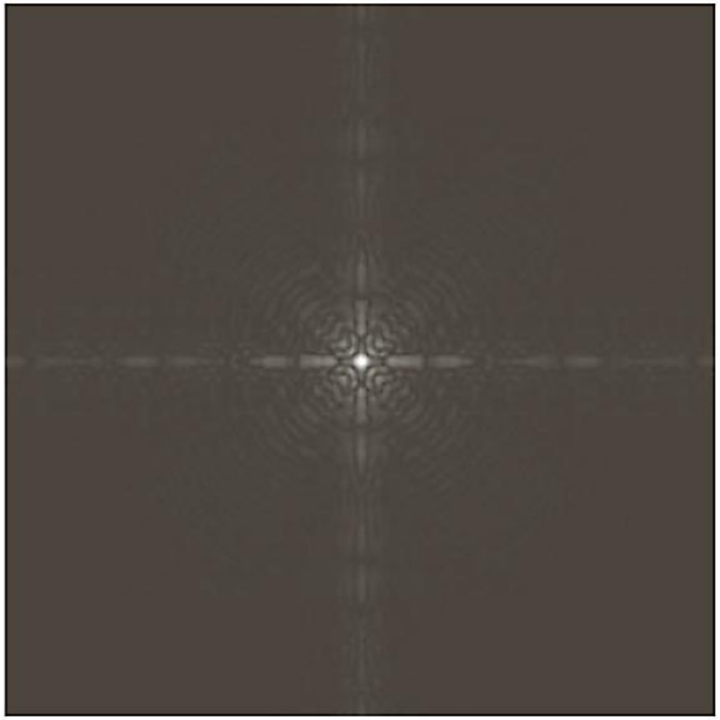
- Maps wider input intensity ranges to narrow output ranges for higher intensity values.



c=105.8865

- We use a transformation of this type to ***expand*** the values of ***dark pixels*** in an image, while ***compressing*** the ***higher-level*** values.

Log Transformation - example

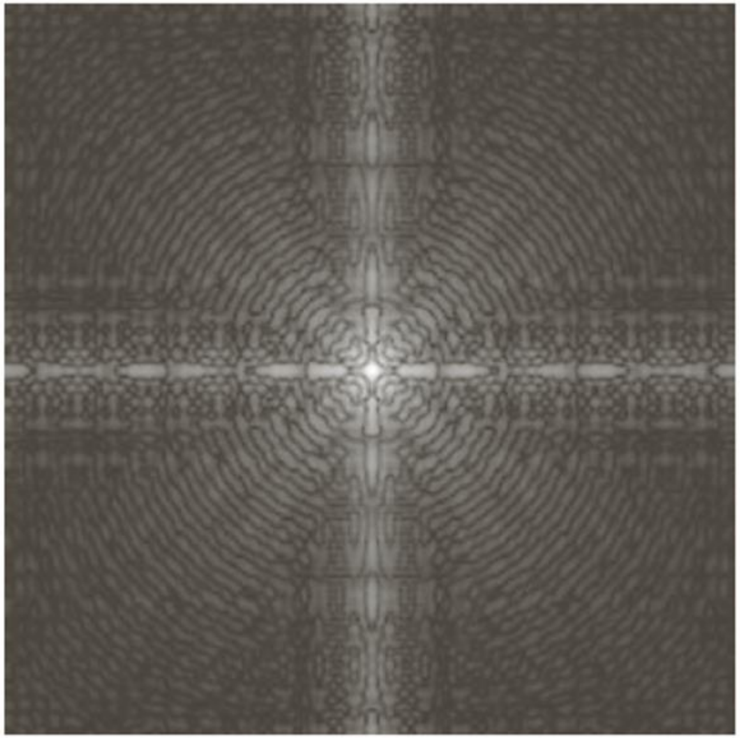


Input Fourier Spectrum, intensity range: $[0,\ 1.5\times10^{6}]$, scaled linearly to $[0,255]$ for display

Log Transform

s=c×log(1+r)

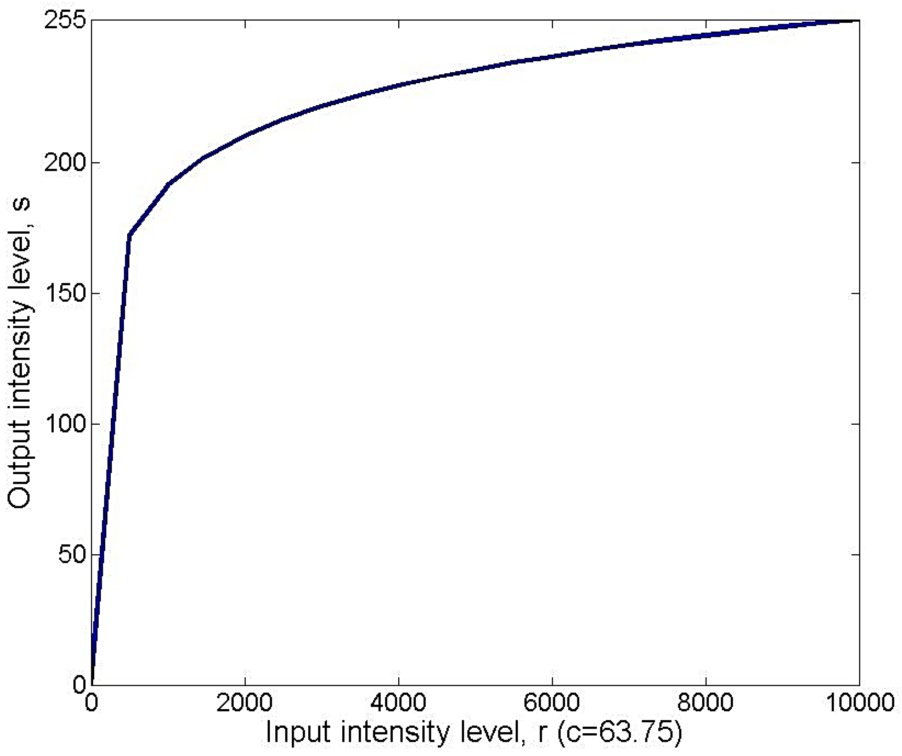
C = 1



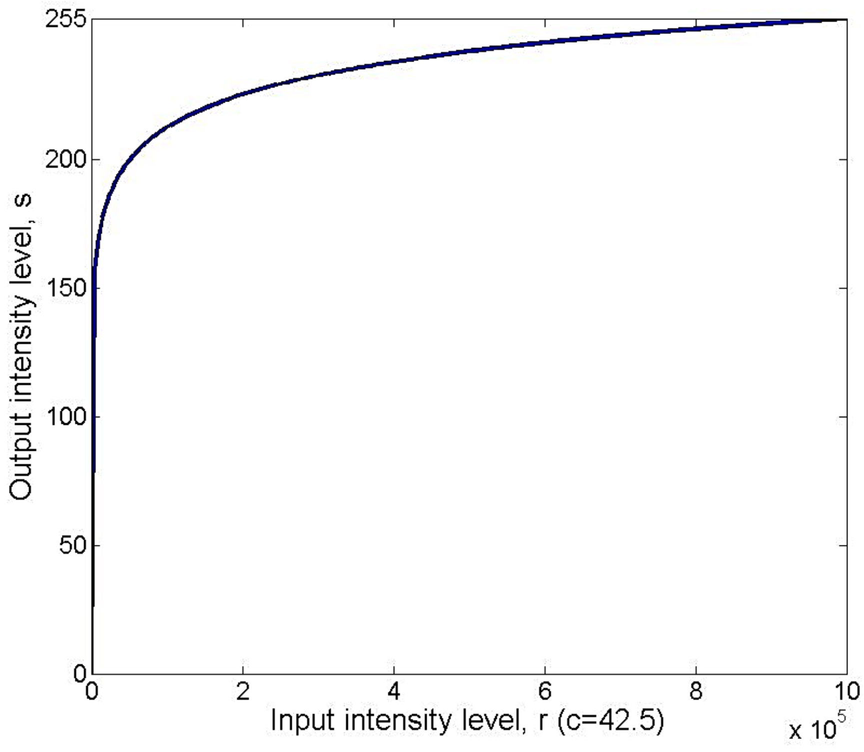
Output Fourier Spectrum

Log Transformation - example

r∈[0, 9999], c=63.75



r∈[0,10^6-1], c=42.5



During image processing in ***transform domain*** ,it is ***not unusual*** to encounter spectrum values that range from 0 to 10^6 or higher.

Inverse Log Transformation

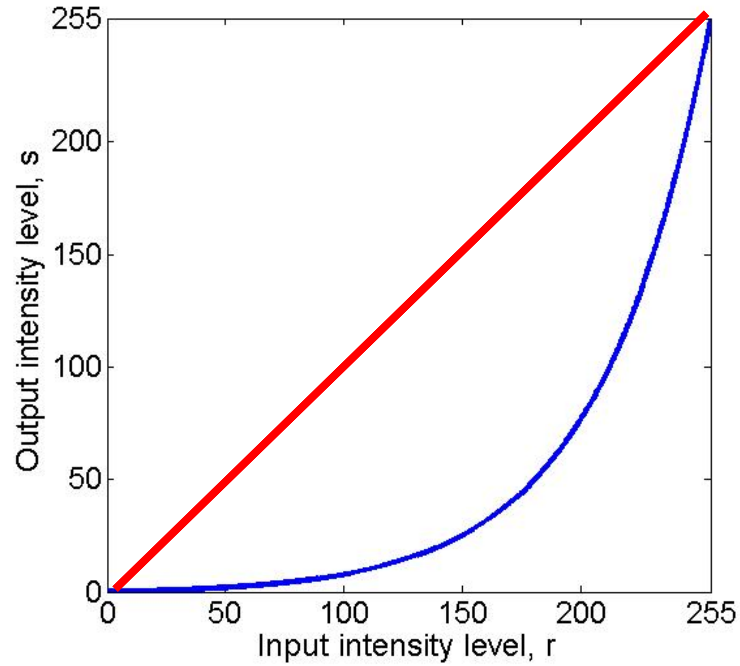
- Uses the transform:

  $$s = 10^{r/c} - 1$$

  where c is a constant and it is assumed that $r \geq 0$.

- Maps wider input intensity ranges to narrow output ranges for lower intensity values.

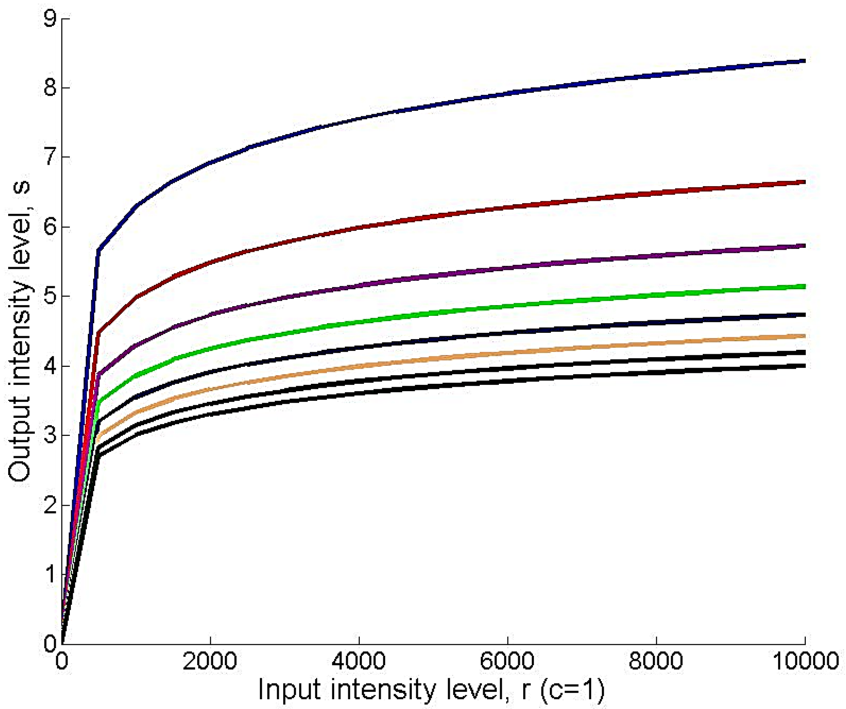
- Maps narrow input intensity ranges to wider output ranges for higher intensity values.



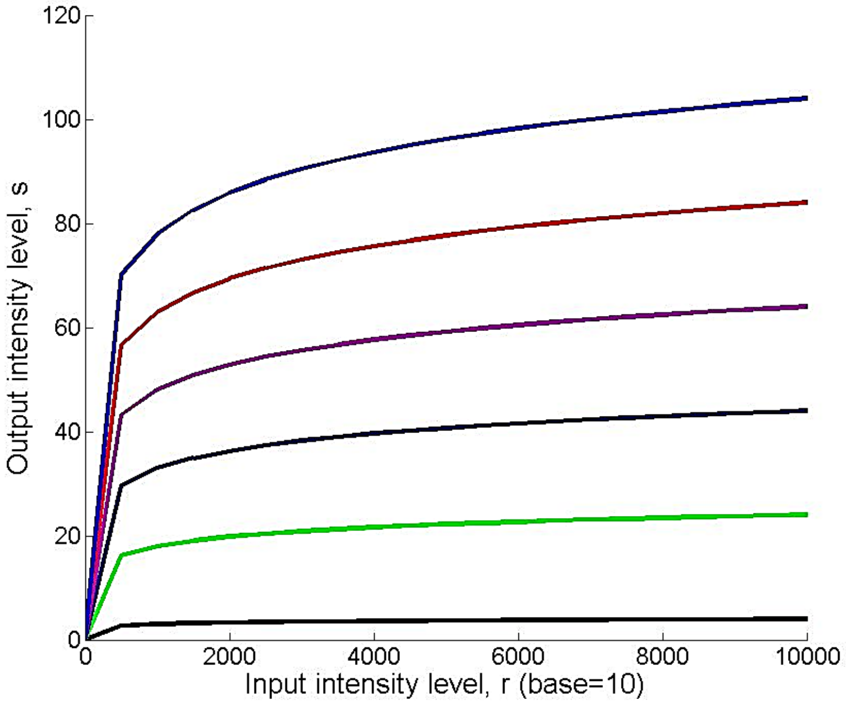
$c=105.8865$

- We use a transformation of this type to ***expand*** the ***dynamic range*** of images with very small variations in intensity values.

Log Transformations



Varying base



Varying c

$s = c \times \log_{10}(1+r)$ **$s = 10^{r/c}-1$**

Power-Law (Gamma-γ) Transformation

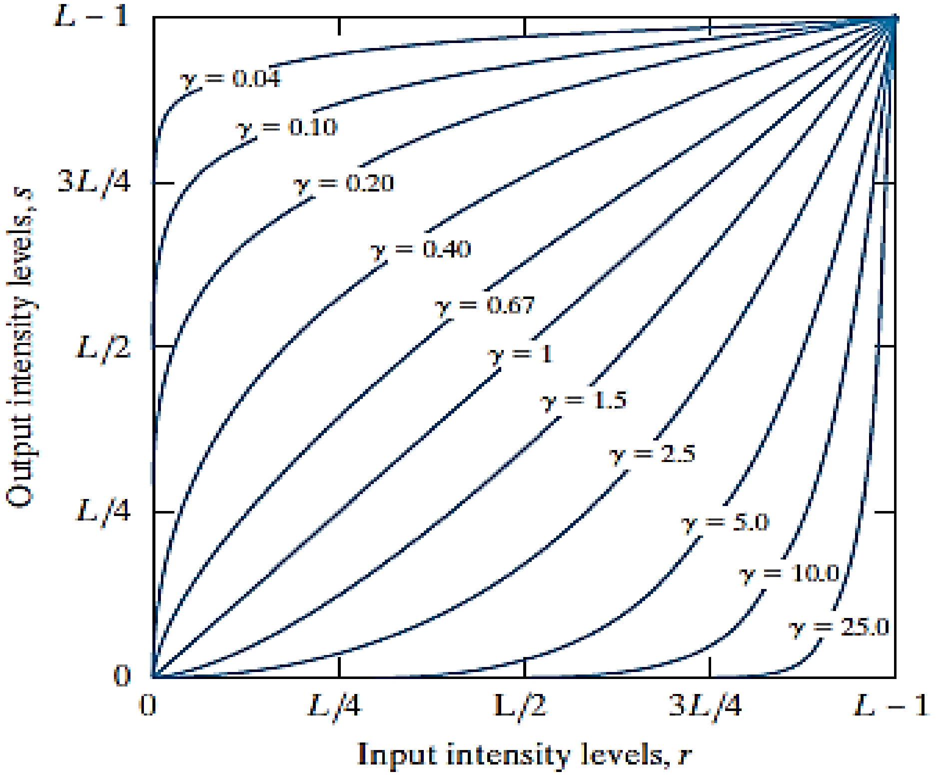
- Uses the transform:

  $s = c \times r^{\gamma}$

  OR

  $s = c \times (r+\varepsilon)^{\gamma}$ to account for output when input is zero.

  where c and γ are positive constants.



C = 1

- As with log transformations, power-law curves with ***fractional values*** of γ map a narrow range of dark input values into a wider range of output values, with the opposite being true for ***higher values*** of γ.

Power-Law (Gamma) Correction

- The response of many devices used for image capture, printing, and display obey a power law:

$$\text{voltage} = c \times \text{intensity}^{\gamma}$$

Example: ($\gamma \in [1.8, 2.5]$) for CRT devices

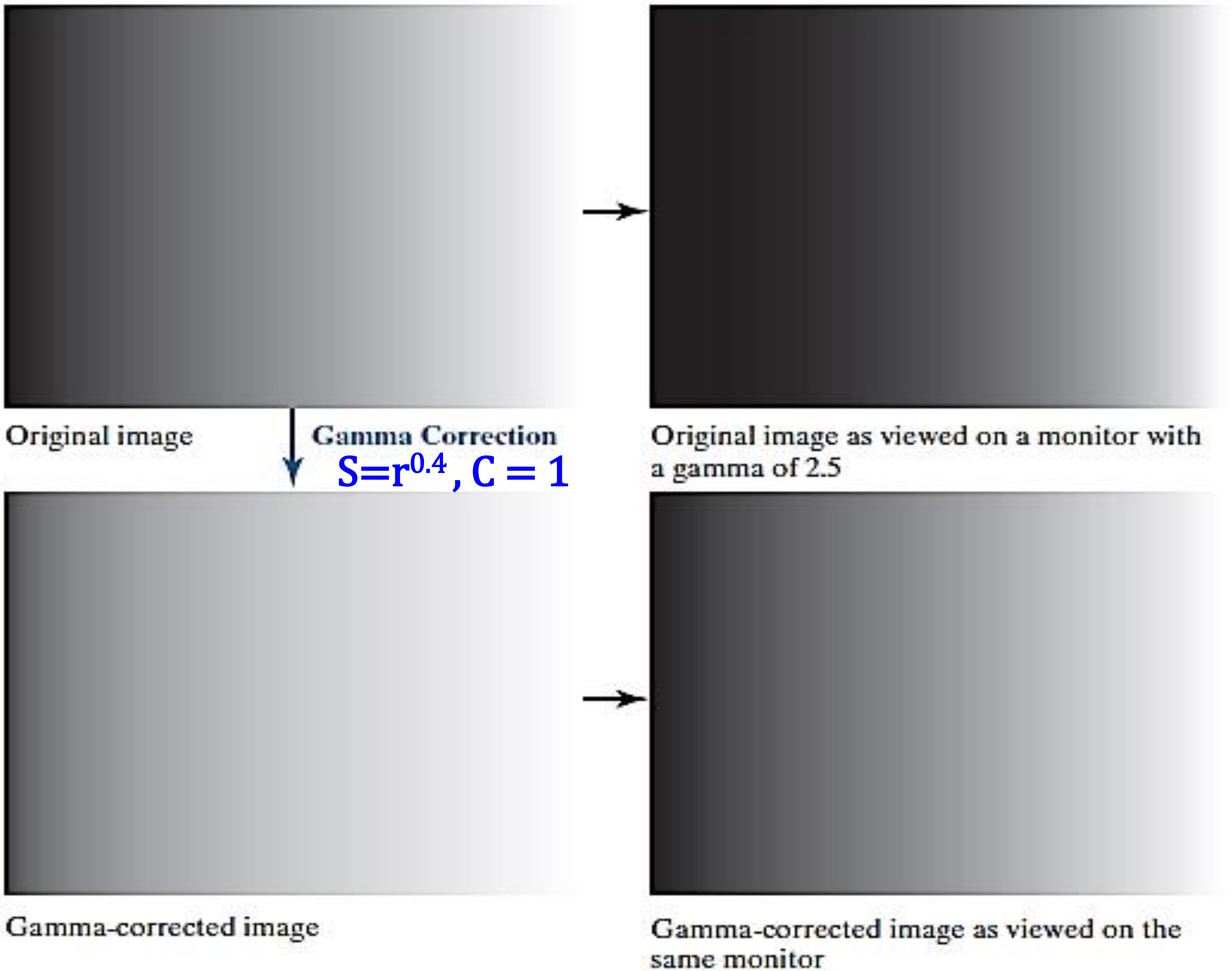
- The process used to correct these power-law response phenomena is called *gamma correction* or *gamma encoding*.

Gamma Correction

Original image

Original image as viewed on a monitor with a gamma (γ) = **2.5**

Gamma Correction



Power-Law (Gamma) Transformation

Contrast manipulation

MRI of an upper thoracic human spine with a fracture dislocation.

Power-Law (Gamma) Transformation

Contrast manipulation

Gamma Transformations

MRI of an upper thoracic human spine with a fracture dislocation and spinal cord impingement

$s = r^{0.6}$

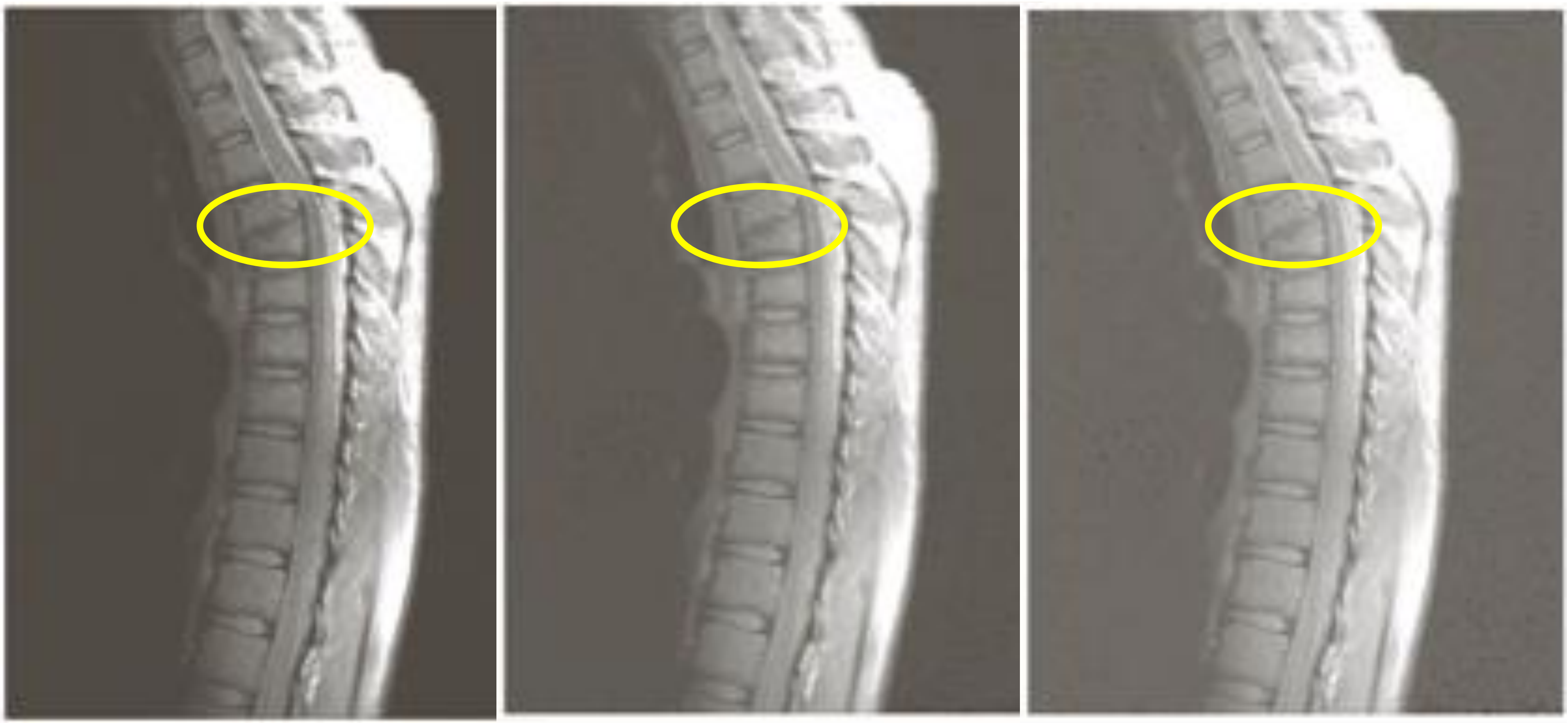
$s = r^{0.4}$

$s = r^{0.3}$

C = 1 in all the cases

Power-Law (Gamma) Transformation

Contrast manipulation



$\gamma=0.6$ $\gamma=0.4$ $\gamma=0.3$

Power-Law (Gamma) Transformation

Contrast manipulation

An aerial image with washed-out appearance

Power-Law (Gamma) Transformation

Contrast manipulation

Gamma Transformations

$s = r^3$

$s = r^4$

$s = r^5$

C = 1 in all the cases

Power-Law (Gamma) Transformation

Contrast manipulation

$\gamma=3$

$\gamma=4$

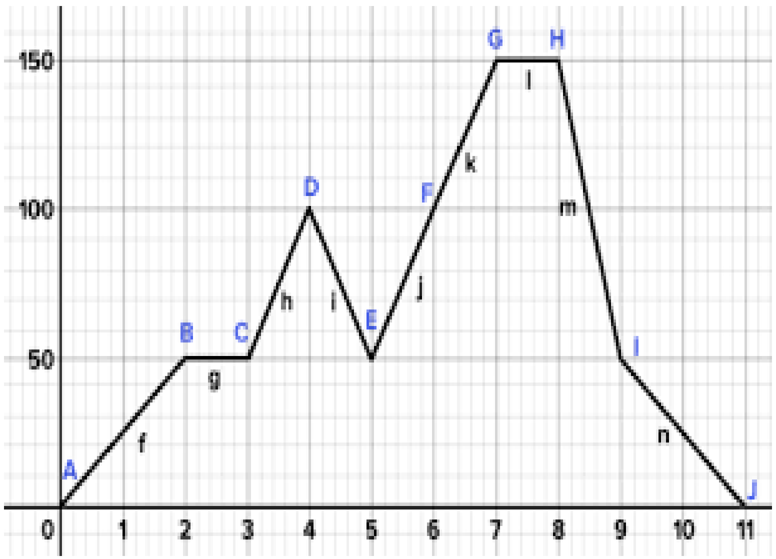
$\gamma=5$

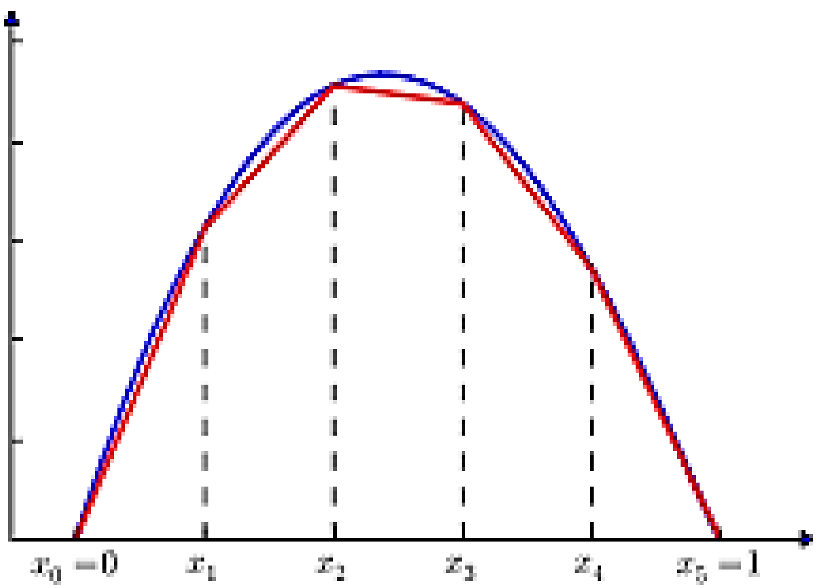
Intensity Transformation Functions

- Basic transformations
  - Image negative
  - Log transformations
  - Power-Law (Gamma) transformations
- Piecewise-linear Transformations
  - Contrast stretching
  - Intensity-level slicing
  - Bit-plane slicing

Piecewise-linear Transformations

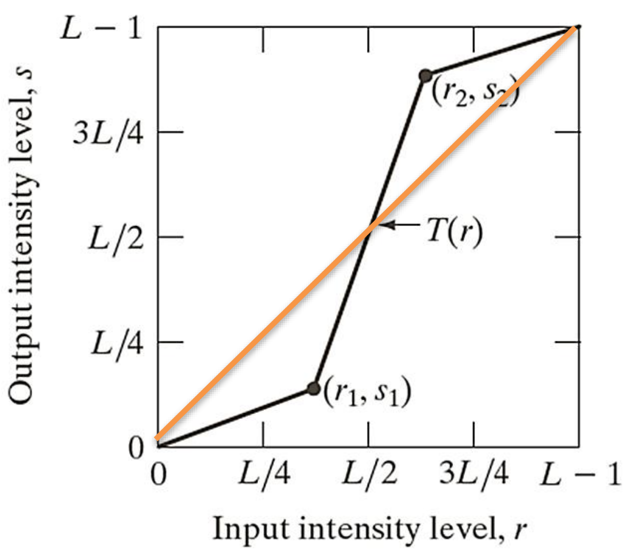
- A *piecewise linear function* is a function composed of some number of ***linear segments*** defined over an equal number of intervals, usually of equal size.





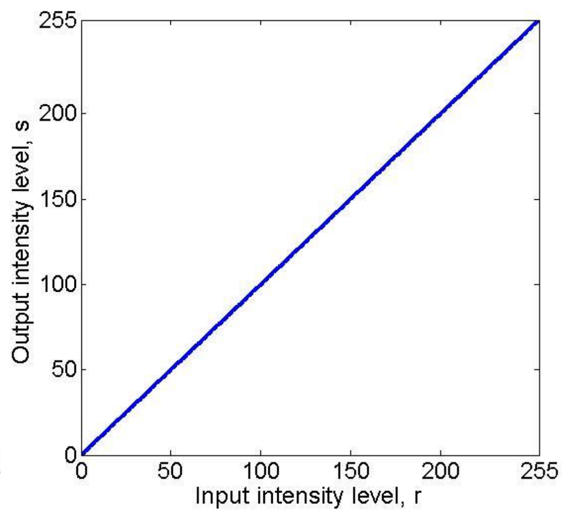
Contrast Stretching

- *Contrast stretching* expands the range of intensity levels in an image so that it spans the ideal full intensity range of the recording medium or display device.
- The locations of points (r_1, s_1) and (r_2, s_2) control the shape of the transformation function.



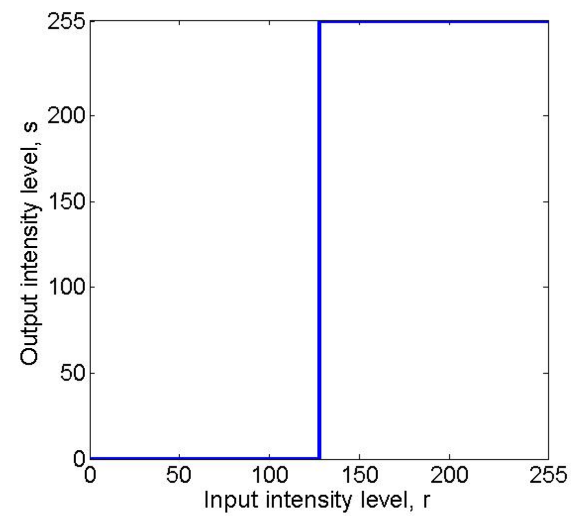
Typical function for contrast stretching $r_1 \le r_2$ and $s_1 \le s_2$

$r_1 = s_1$ and $r_2 = s_2$



Identity function

$r_1 = r_2$, $s_1 = 0$ and $s_2 = L-1$

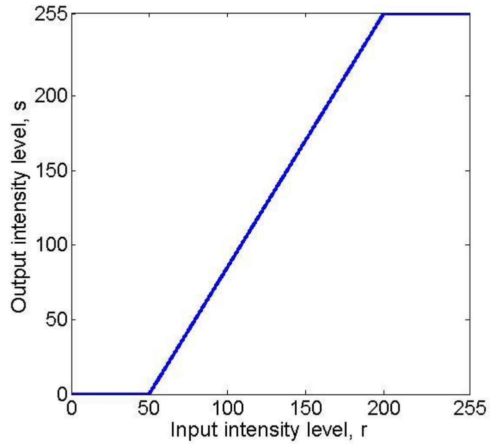


Thresholding function

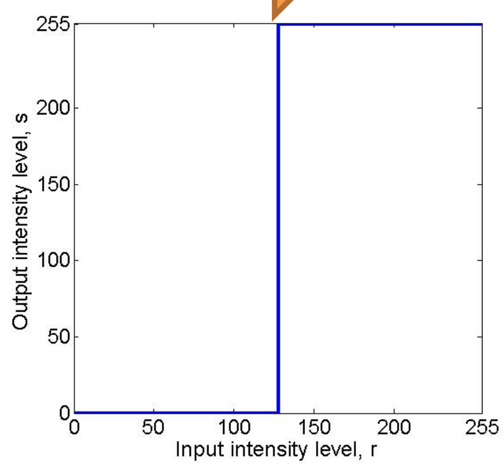
$$S = (r - f_{min})\left[\frac{max - min}{f_{max} - f_{min}}\right] + min$$

Contrast Stretching

Scanning electron microscope image of pollen, magnified ≈ 700 times



$(r_1,s_1)=(r_{min},0)$ and $(r_2,s_2)=(r_{max},L-1)$, where r_{min} and r_{max} denote the min & max intensity levels in the image

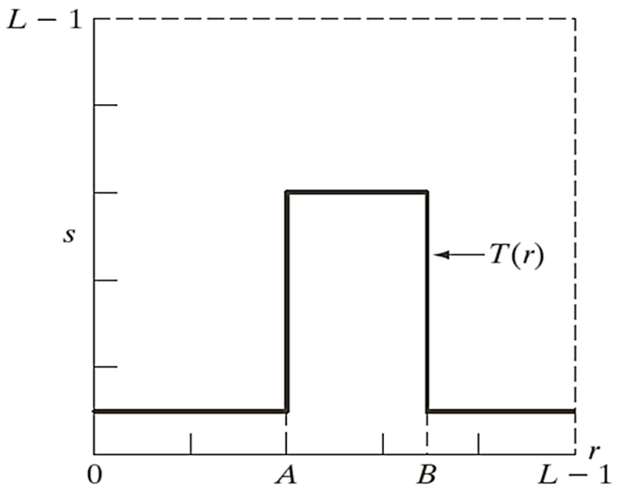


$(r_1,s_1)=(m,0)$ and $(r_2,s_2)=(m,L-1)$, where m is the mean intensity level in the image.

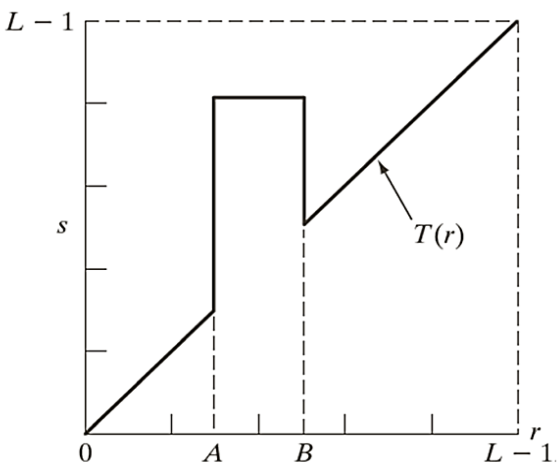
Intensity-Level Slicing

- These functions *highlight a specific range of intensities* in an image.

- What about the remaining intensities?
  - Set to default (lower) level, usually zero (fig. 1)
  - Preserve original values (fig. 2)



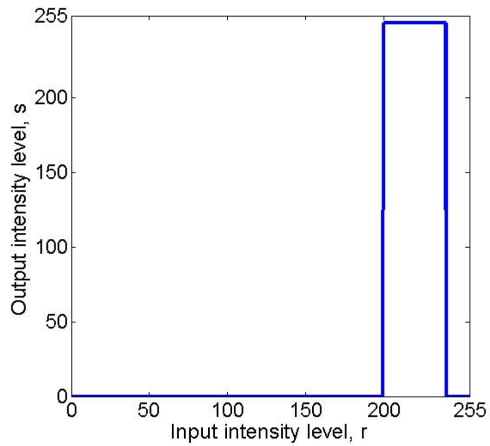
(fig. 1)

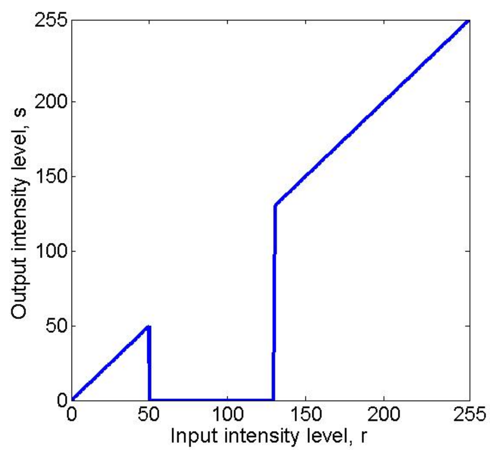


(fig. 2)

Intensity-Level Slicing

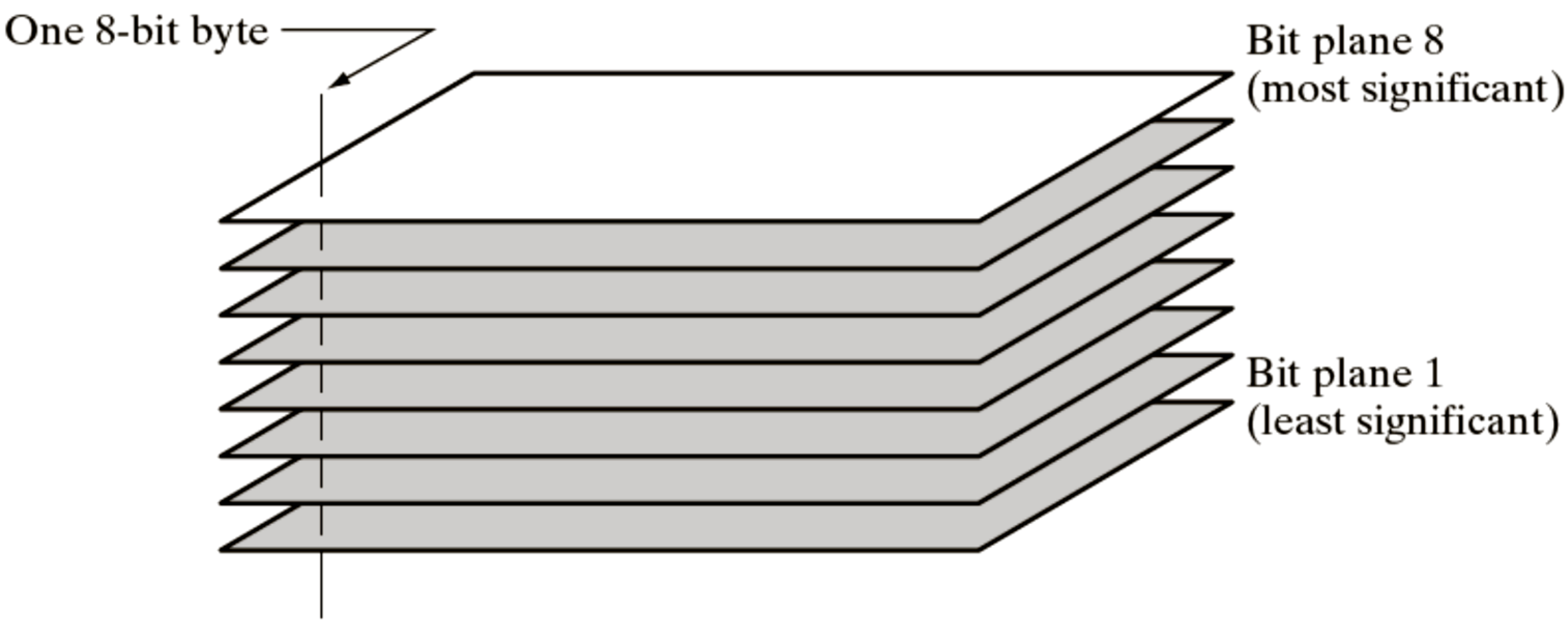
Aortic angiogram near the kidney area





Bit-Plane Slicing

- Pixels intensities are stored as binary numbers.
- Each bit position represents a level-of-detail.



Bit-Plane Slicing

Given image

Different Bit planes

bit-8

bit-7

bit-6

bit-5

bit-4

bit-3

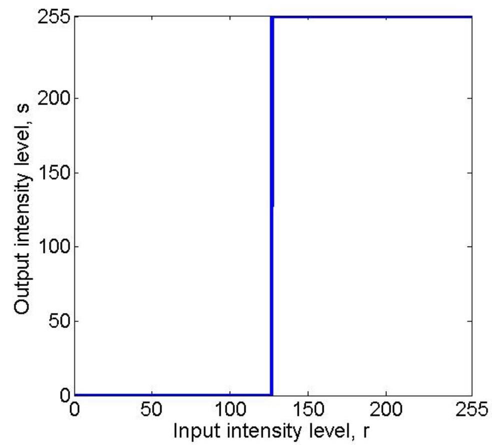
bit-2

bit-1

The intensity of the boarder is $\mathbf{194_{10}}$, which is $\mathbf{11000010_2}$

How to obtain each bit plane from the original image?

Bit-Plane Slicing - example



maps to **0** intensity values between 0 and 127, and maps to **1** values between 128 and 255.

$128_{10} = 10000000_2$

bit-8

How about the rest?

$64_{10} = 01000000_2$
$32_{10} = 00100000_2$
$16_{10} = 00010000_2$
$8_{10} = 00001000_2$
$4_{10} = 00000100_2$
$2_{10} = 00000010_2$
$1_{10} = 00000001_2$

Bit-Plane Slicing – applications

- Analyze the relative importance of each bit in the image.
- Determine the adequacy of the number of bits used to quantize the image.
- Useful in modelling image compression, in which fewer number of planes are used in reconstructing an image.

Bit-plane Slicing – image decomposition

All bits

bit 8,7

bit 8,7,6,5

bit 8,7,6

Next Lecture

- What is a Histogram?
- Histogram Normalization
- What is Random variable
- Histogram Equalization