

Digital Image Processing

Introduction

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Outline

- 1 Human Visual System
- 2 Light and the electromagnetic spectrum
- 3 Image representation
- 4 Image Enhancement (Point Processing)
 - Point Processing
 - Intensity Transformations

Agenda

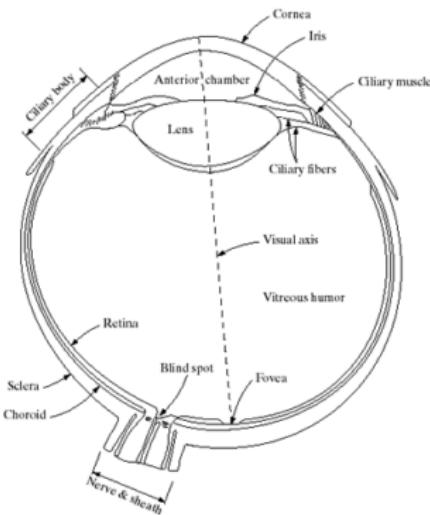
Today Discussion

- The human visual system
- Light and the electromagnetic spectrum
- Image representation
- Image sensing and acquisition
- Sampling, quantisation and resolution

Human Visual System

- The best vision model we have!
- Knowledge of how images form in the eye can help us with processing digital images
- We will take just a whirlwind tour of the human visual system

Structure Of The Human Eye



- The **lens** focuses light from objects onto the retina
- The **retina** is covered with light receptors called cones (6-7 million) and rods (75-150 million)
- **Cones** are concentrated around the fovea and are very sensitive to colour
- **Rods** are more spread out and are sensitive to low levels of illumination

Blind-Spot Experiment

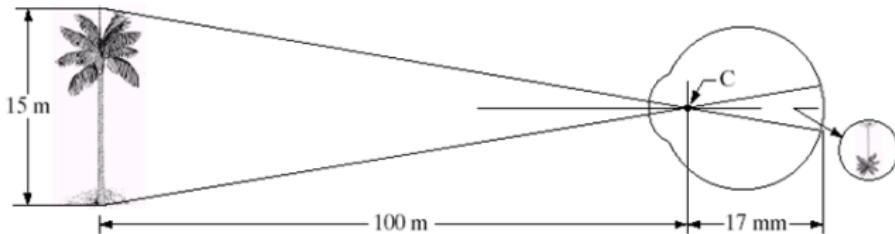
Draw an image similar to that below on a piece of paper (the dot and cross are about 6 inches apart)



- Close your right eye and focus on the cross with your left eye
- Hold the image about 20 inches away from your face and move it slowly towards you
- The dot should disappear!

Image Formation In The Eye

- Muscles within the eye can be used to change the shape of the lens allowing us focus on objects that are near or far away
- An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain



Brightness Adaptation & Discrimination

- The human visual system can perceive approximately 10^{10} different light intensity levels
- However, at any one time we can only discriminate between a much smaller number — brightness adaptation
- Similarly, the perceived intensity of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination

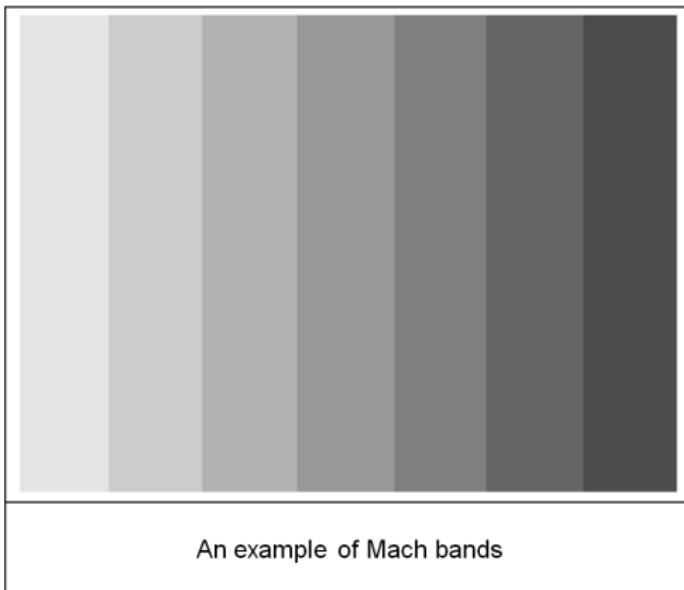
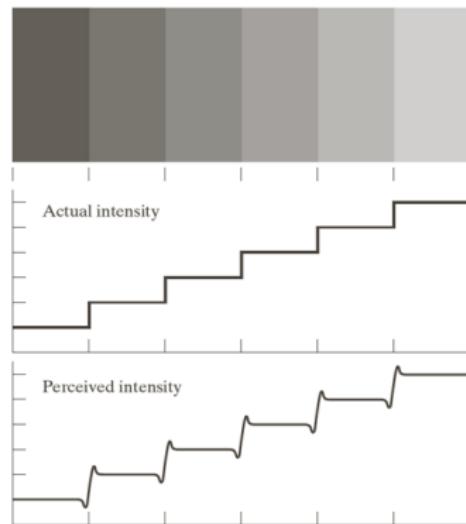
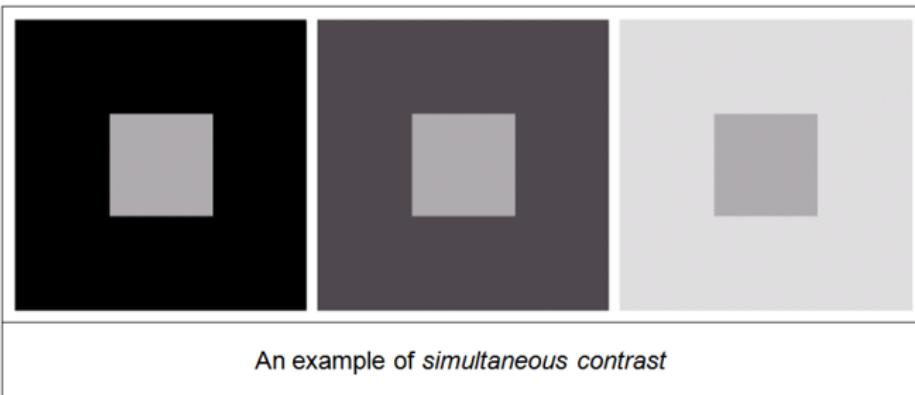


Figure: Mach bands were named after Ernst Mach who described the phenomenon in 1865

Human Eye Perception

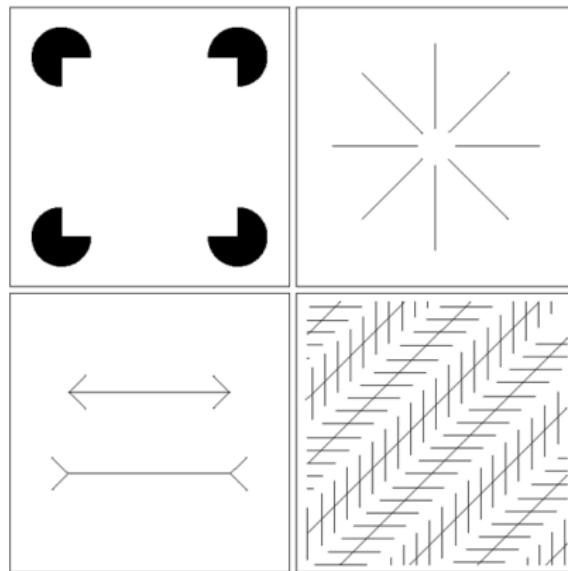


Simultaneous Contrast



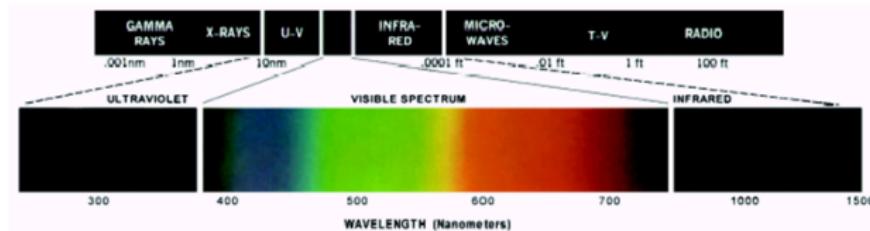
Optical Illusions

Our visual systems play lots of interesting tricks on us



Light And The Electromagnetic Spectrum

- Light is just a particular part of the electromagnetic spectrum that can be sensed by the human eye
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy the brain
- In 1666 Sir Isaac Newton discovered that light passed through a prism splits into a continuous spectrum of colours
- Many image applications use electromagnetic radiation that is far outside the visual spectrum, *i.e.*, x-ray images, infra-red images; we generate images of these images by mapping them to the visual spectrum



Reflected Light

- The colours that we perceive are determined by the nature of the light reflected from an object
- For example, if white light is shone onto a green object most wavelengths are absorbed, while green light is reflected from the object

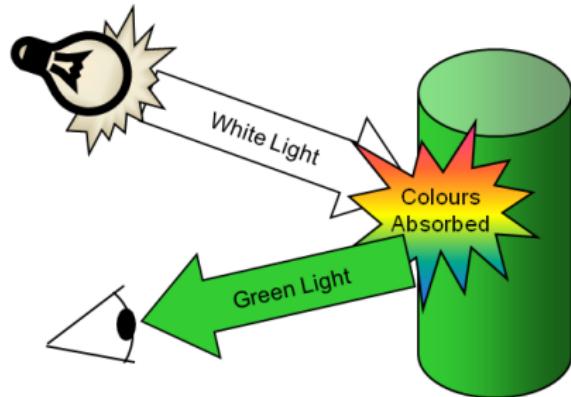


Image representation

- Before we discuss image acquisition recall that a digital image is composed of M rows and N columns of pixels each storing a value
- Pixel values are most often grey levels in the range 0-255(black-white)
- We will see later on that images can easily be represented as matrices

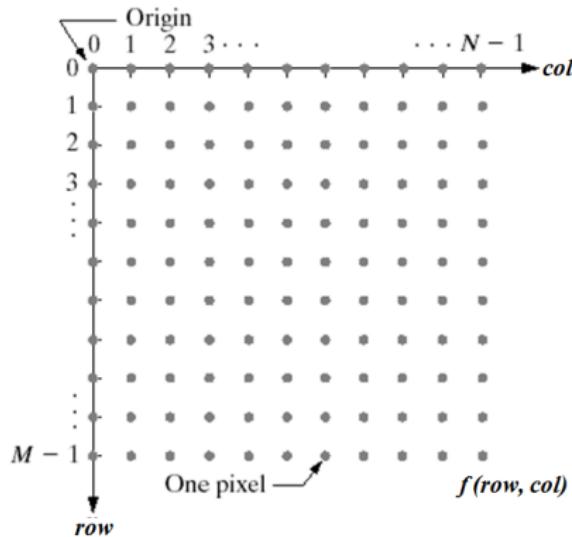
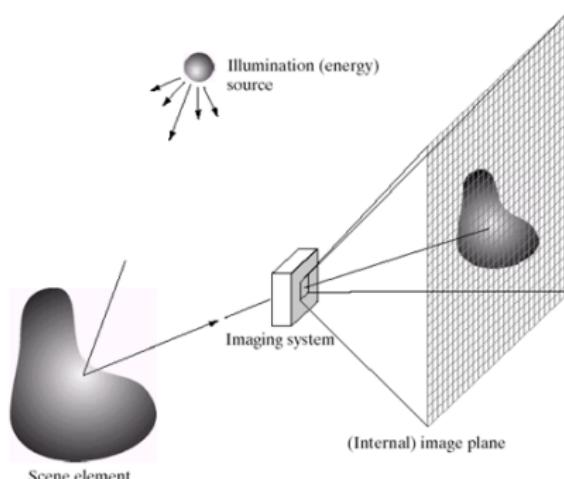


Image Acquisition

- Images are typically generated by illuminating a scene and absorbing the energy reflected by the objects in that scene
- Typical notions of illumination and scene can be way off:
 - X-rays of a skeleton
 - Ultrasound of an unborn baby
 - Electro-microscopic images of molecules



Conversion of analog signal to digital signal

- Why we need digital signal?
- sampling
- quantization
- convert both of its axis (x,y) into a digital format.



Image Sampling And Quantisation

- A digital sensor can only measure a limited number of samples at a discrete set of energy levels
- Quantisation is the process of converting a continuous analogue signal into a digital representation of this signal

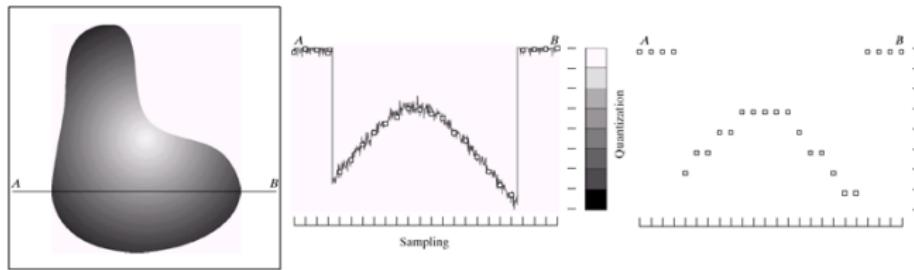
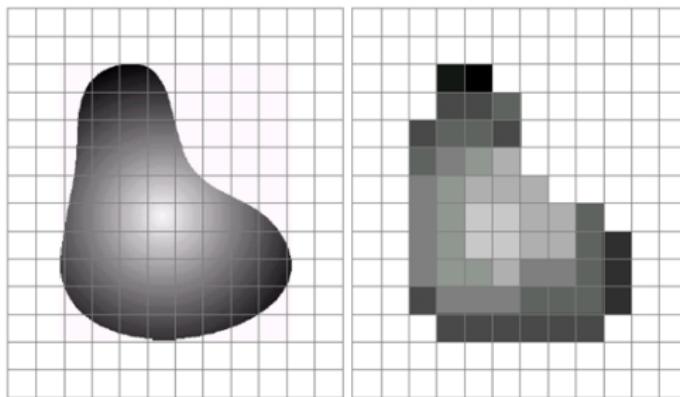


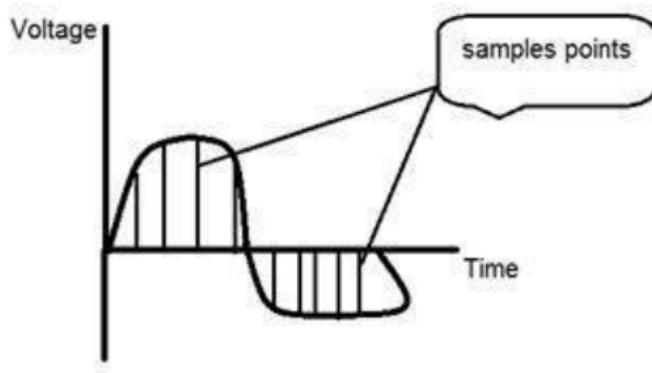
Image Sampling And Quantisation

Remember that a digital image is always only an approximation of a real world scene



Sampling

- The term refers to take samples
- We digitize x axis *i.e.*, independent variable
- In case of equation $y = \sin(x)$, it is done on x variable



- Up sampling and down sampling
- How much samples are needed?
- effect of noise?

Pixels and Zooming

- Smallest element of an image.
- Pixel can store a value proportional to the light intensity at that particular location.
- Pixels = total no of rows * total no of columns.
- increase quantity of pixels, so that when you zoom an image , you will see more detail.
- Oversampling
- difference between zooming and sampling?

Resolution

Pixel Resolution

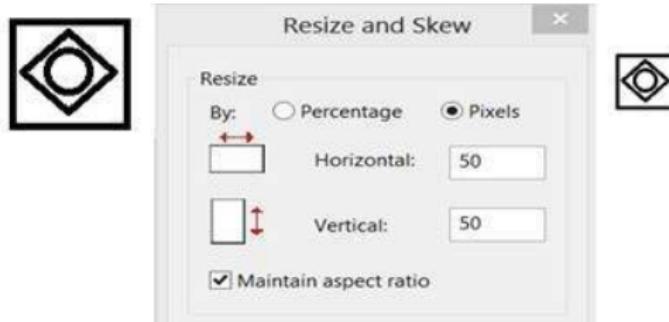
- Pixel resolution , spatial resolution , temporal resolution , spectral resolution
- Monitor resolution of 800×600 , 640×480 etc.
- Pixel resolution:** total number of count of pixels in an digital image. e.g., $M \times N$.
- Two numbers; width of the picture, or the pixels across columns. Second number is height of picture, or the pixels across its width.

MegaPixel

- Column pixels (width) X row pixels (height) / 1 Million.
- Size = pixel resolution X bpp (bits per pixel)
- For an image of dimension: 2500×3192 .
- Its pixel resolution = $2500 * 3192 = 7982350$ bytes.
- Dividing it by 1 million = $7.9 = 8$ mega pixel (approximately).

Aspect Ratio

- Ratio between width of an image and the height of an image. e.g., 1.33:1, 2.00:1, etc.
- Advantages?



- You are given an image with aspect ratio of 6:2 of an image of pixel resolution of 480000 pixels given the image is a gray scale image.
 - Resolve pixel resolution to calculate the dimensions of image
 - Calculate the size of the image

Solution

- Aspect ratio: $c:r = 6:2$
- Pixel resolution: $c * r = 480000$
- Bits per pixel: grayscale image = 8bpp
- Number of rows, cols = ?

$$\text{Equation 1. } c:r = 6:2 \rightarrow c = 6r / 2$$

$$\text{Equation 2. } c = 480000/r$$

$$\text{Comparing both equations } \frac{6r}{2} = \frac{480000}{r}$$
$$r^2 = \sqrt{\frac{480000*2}{6}}$$

That gives $r = 400.$

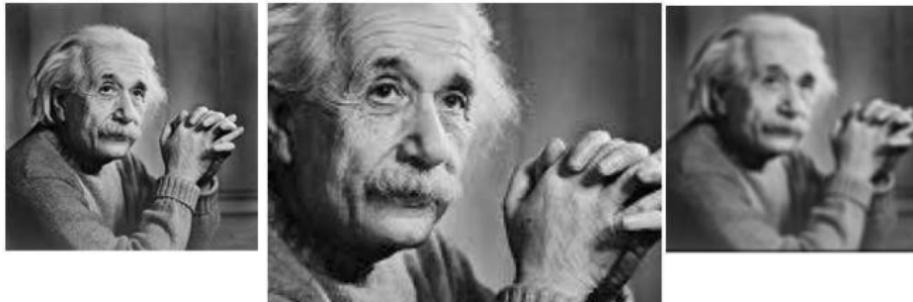
Put r in equation 1, we get $\rightarrow c = 1200.$

So rows = 400 cols = 1200.

- Size = rows * cols * bpp = $400 * 1200 * 8 = 3840000$ bits
- Size of image in bytes = 480000 bytes; 48 kb (approx).

Spatial Resolution

- Clarity of an image cannot be determined by the pixel resolution. The number of pixels in an image does not matter.
- Definition:** Smallest discernible detail in an image. *i.e.*, number of independent pixels values per inch.



Spatial Resolution

- The spatial resolution of an image is determined by how sampling was carried out
- Spatial resolution simply refers to the smallest discernible detail in an image
 - Vision specialists will often talk about pixel size
 - Graphic designers will talk about dots per inch (DPI)
 - Dots per inch or DPI is usually used in monitors.
 - Lines per inch or LPI is usually used in laser printers.
 - Pixel per inch or PPI is measure for different devices such as tablets , Mobile phones etc.

Pixels per inch

- Samsung galaxy s4 has PPI or pixel density of 441
Diagonal resolution:

$$c = \sqrt{a^2 + b^2} \quad (1)$$

- Where a and b are height and width resolutions in pixel:
1080 x 1920 pixels: $C = 2202.90717$;
- $\text{PPI} = c / \text{diagonal size in inches}$
- The diagonal size in inches of Samsun galaxy s4 is 5.0 inches.
- $\text{PPI} = 2202.90717/5.0 = \text{PPI} = 440.58 = \text{PPI} = 441 \text{ (approx)}$

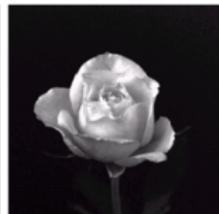
Dots per inch

- DPI or dots per inch is a measure of spatial resolution of printers.
- DPI means that how many dots of ink are printed per inch when an image get printed out from the printer.
- Remember , it is not necessary that each Pixel per inch is printed by one dot per inch. There may be many dots per inch used for printing one pixel. The reason behind this that most of the color printers uses CMYK model. The colors are limited. Printer has to choose from these colors to make the color of the pixel whereas within pc , you have hundreds of thousands of colors.
- The higher is the dpi of the printer , the higher is the quality of the printed document or image on paper.
- Usually some of the laser printers have dpi of 300 and some have 600 or more.

Spatial Resolution



1024



512



1



32



256

Spatial Resolution

Spatial Resolution: **1024**



Spatial Resolution

Spatial Resolution: 512



Spatial Resolution

Spatial Resolution: **256**



Spatial Resolution

Spatial Resolution: **128**



Spatial Resolution

Spatial Resolution: **64**



Spatial Resolution

Spatial Resolution: **32**

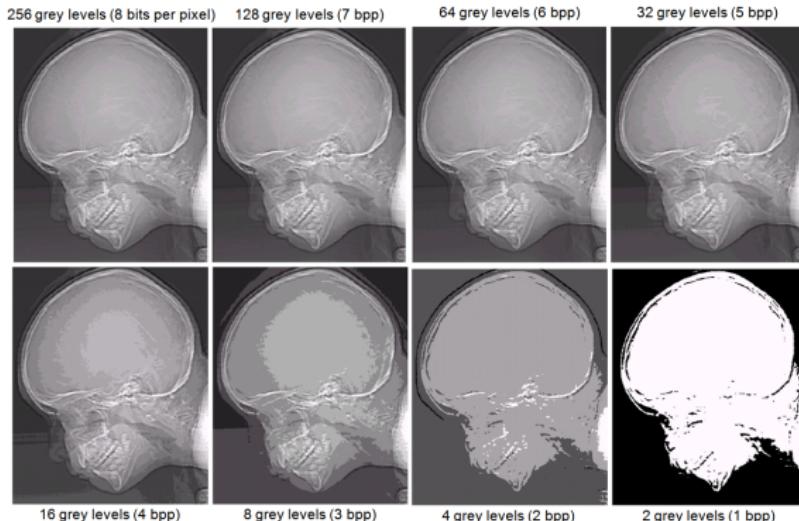


Intensity Level Resolution

- Intensity level resolution refers to the number of intensity levels used to represent the image
 - The more intensity levels used, the finer the level of detail discernable in an image
 - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Bits	Intensity Levels	Examples
1	2	(0, 1)
2	4	(00, 01, 10, 11)
4	16	(0000, 0101, 1111)
8	256	(00110011, 01010101)
16	65536	(1010101010101010)

Intensity Level Resolution



Resolution: How Much Is Enough?

- The big question with resolution is always how much is enough?
 - This all depends on what is in the image and what you would like to do with it
 - Key questions include
 - Does the image look aesthetically pleasing?
 - Can you see what you need to see within the image?

Resolution: How Much Is Enough?



Figure: The picture on the right is fine for counting the number of cars, but not for reading the number plate

Resolution: How Much Is Enough?



Figure: The picture on the right is fine for counting the number of cars, but not for reading the number plate

Resolution: How Much Is Enough?



Low Detail



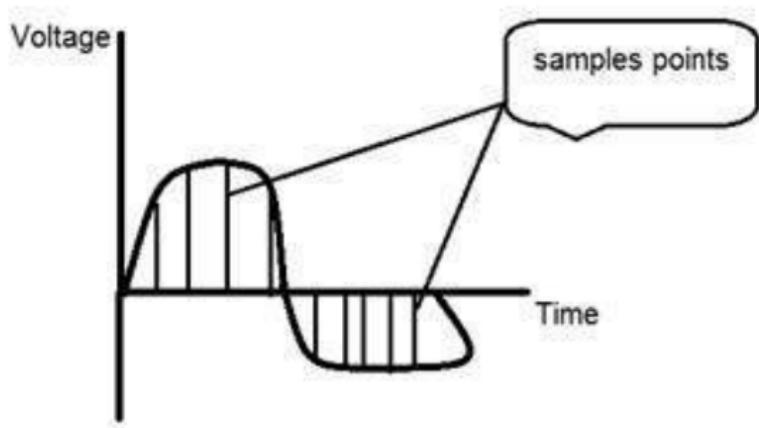
Medium Detail



High Detail

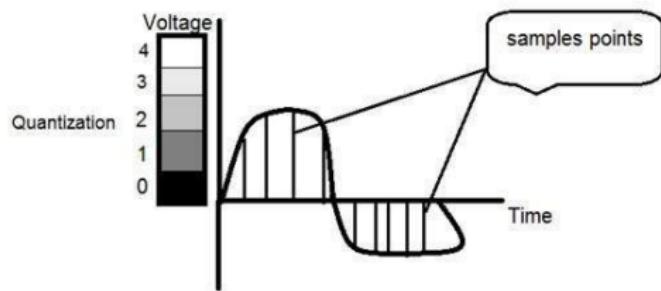
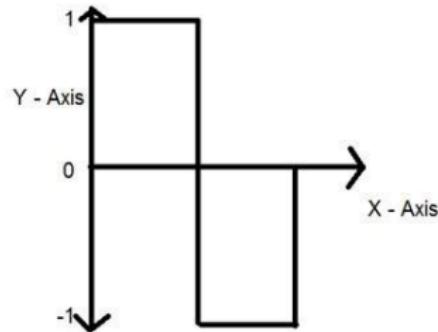
Quantization

- Gray level resolution is found on the y axis of the signal.
- Sampling is done on x axis. And quantization is done in Y axis. So that means digitizing the gray level resolution of an image is done in quantization.

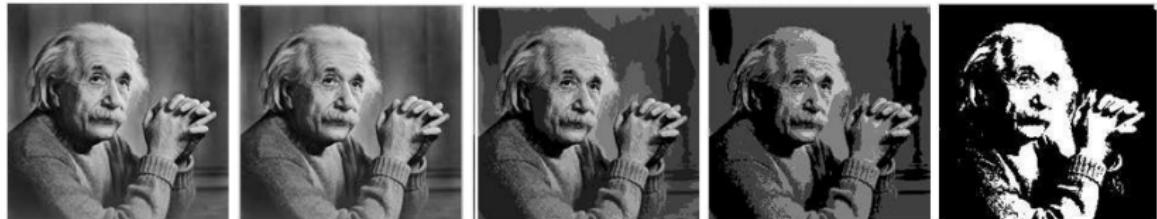


Quantization

Dividing a signal into quanta(partitions).



Quantization

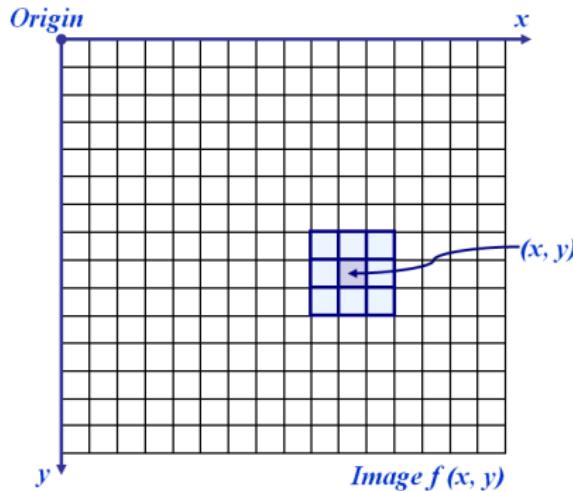


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 - Intensity Transformations

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

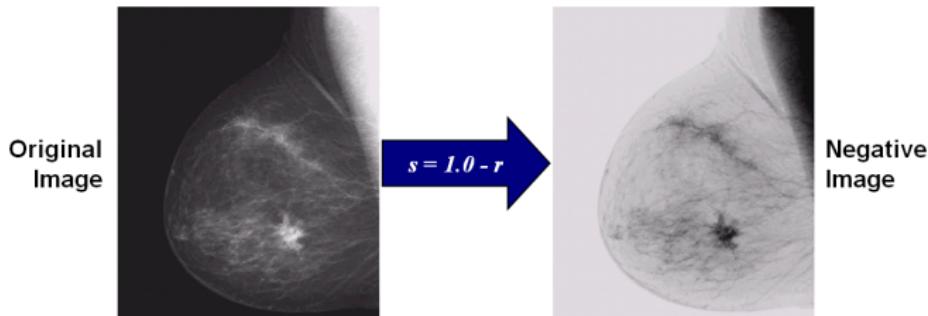
- The simplest spatial domain operations occur when the neighbourhood is simply the pixel itself
- In this case T is referred to as a grey level transformation function or a point processing operation
 - Point processing operations take the form

$$s = T(r) \quad (2)$$

where s refers to the processed image pixel value and r refers to the original image pixel value

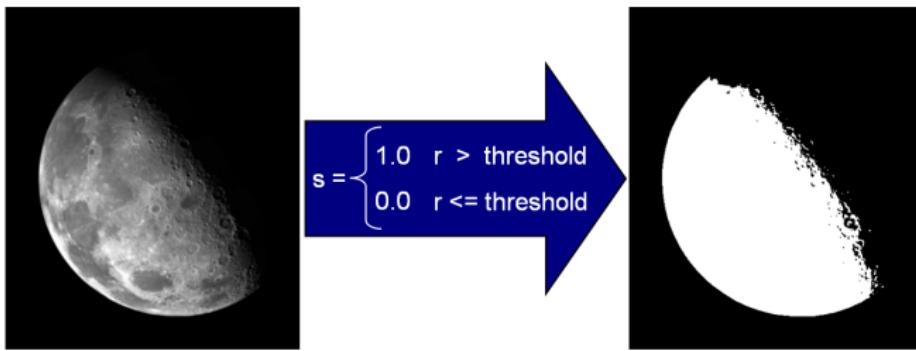
Point Processing Example: Negative Image

- 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



Point Processing Example: Thresholding

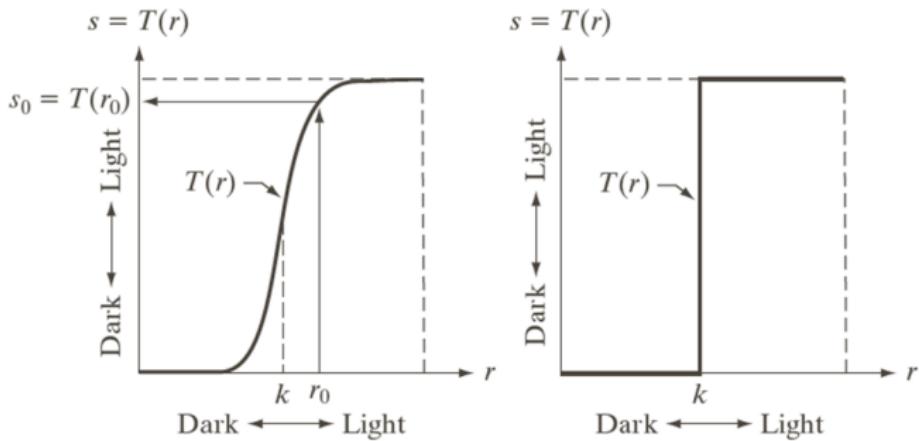
- Thresholding transformations are particularly useful for segmentation in which we want to isolate an object of interest from a background



Outline

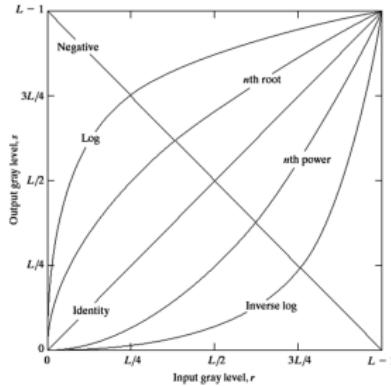
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Intensity Transformations



Basic Grey Level Transformations

- There are many different kinds of grey level transformations
- Three of the most common are shown here
 - 1 Linear
 - Negative/Identity
 - 2 Logarithmic
 - Log/Inverse log
 - 3 Power law
 - n th power/ n th root



Logarithmic Transformations

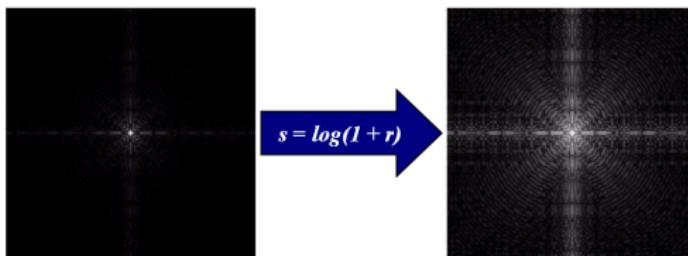
- The general form of the log transformation is

$$s = c * \log(1 + r) \quad (3)$$

- 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

- 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

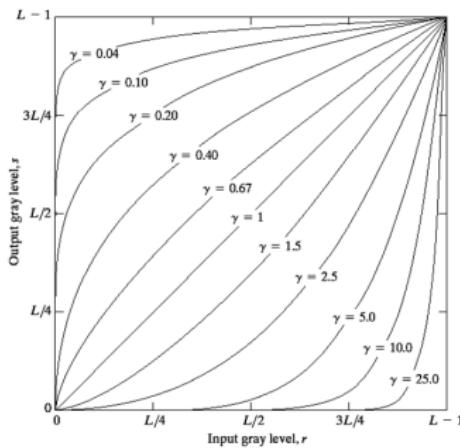


Power Law Transformations

- Power law transformations have the following form

$$s = c * r^\gamma \quad (4)$$

- 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

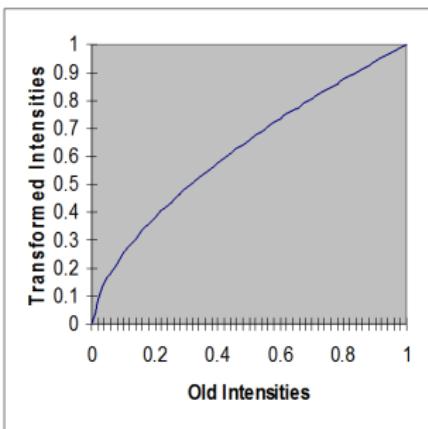


Power Law Example



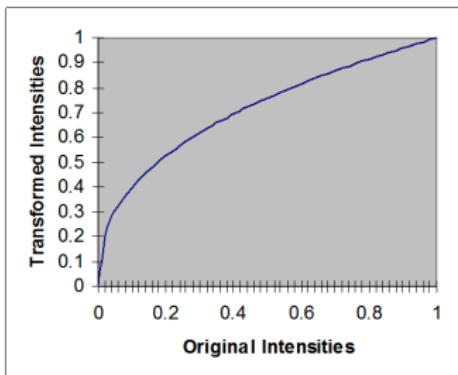
Power Law Example

$$\gamma = 0.6$$



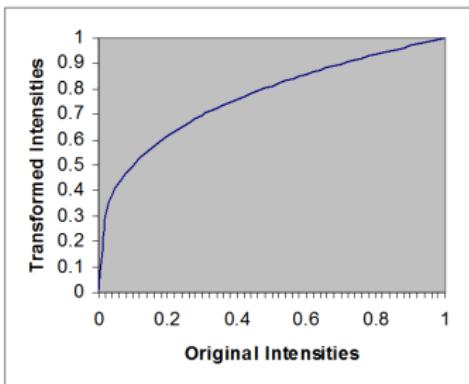
Power Law Example

$$\gamma = 0.4$$



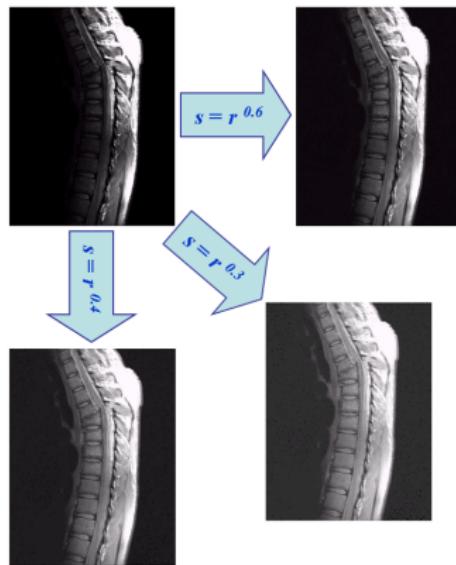
Power Law Example

$$\gamma = 0.3$$



Power Law Example

Magnetic Resonance (MR) image of a fractured human spine.
Different curves highlight different details.

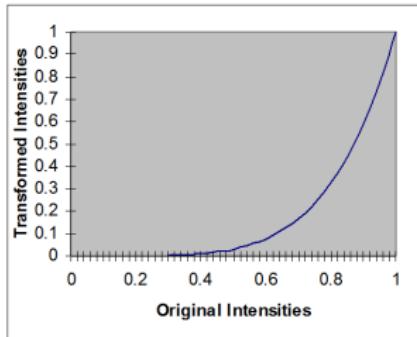


Power Law Example



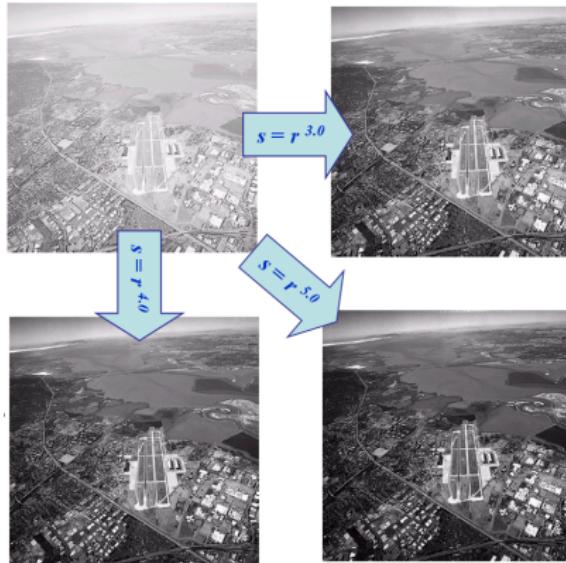
Power Law Example

$$\gamma = 5.0$$



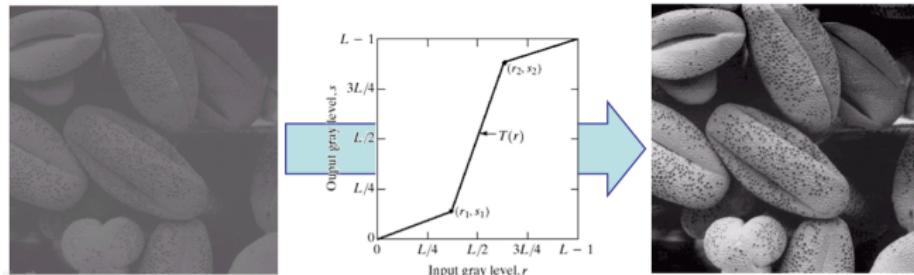
Power Law Example

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



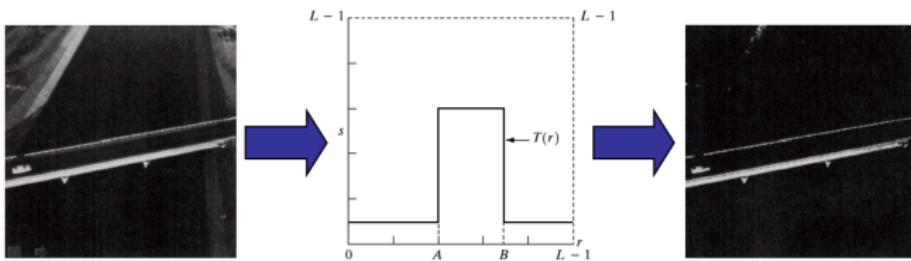
Piecewise Linear Transformation Functions

- 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



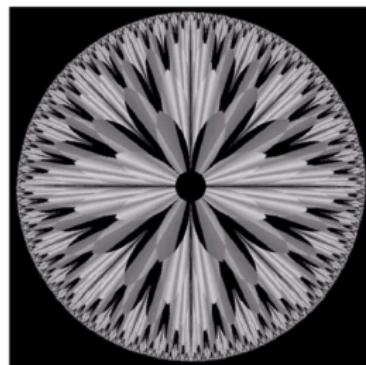
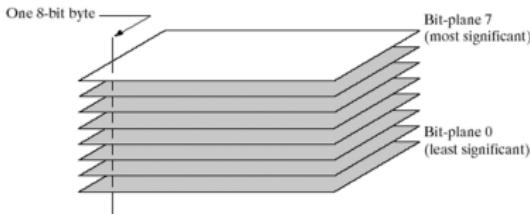
Piecewise Linear Transformation Functions

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

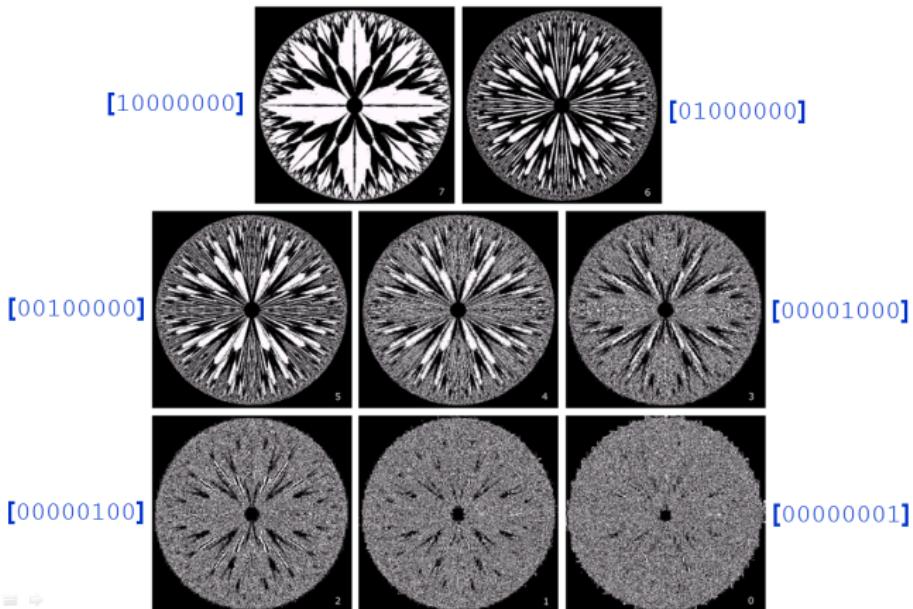


Bit Plane Slicing

- 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



Bit Plane Slicing



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.