APPM4058A: Digital Image Processing

Hairong Wang

School of Computer Science & Applied Mathematics
University of the Witwatersrand, Johannesburg

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What is a digital image anyway? (1)

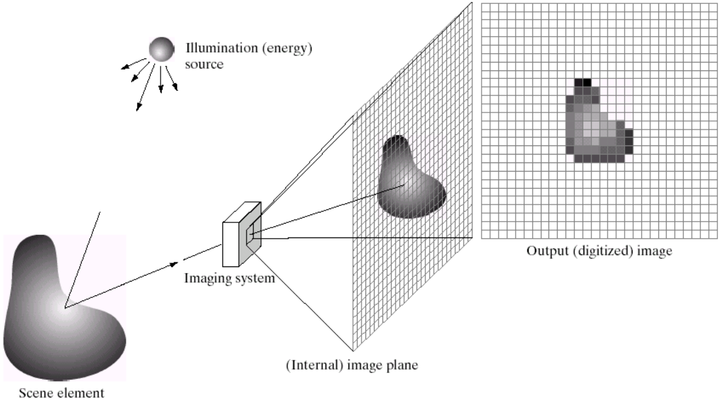

Figure: A digital image is a representation of a 2D image as a finite set of digital values, called picture elements or pixels.

What is a digital image anyway? (2)

- An image may be defined as a 2D function, $f(x, y)$,
  - x, y — spatial coordinates
  - the amplitude of f at (x, y) — intensity or gray level of the image at (x, y).
- When x, y and f are all finite, discrete quantities — the image is a digital image.
- A digital image consists of a finite number of pixels.
- At each pixel there is an attribute vector.
- Any image can be digitized.
- Digitization implies a digital image is an approximation of a real scene.

What is a digital image anyway? (3)

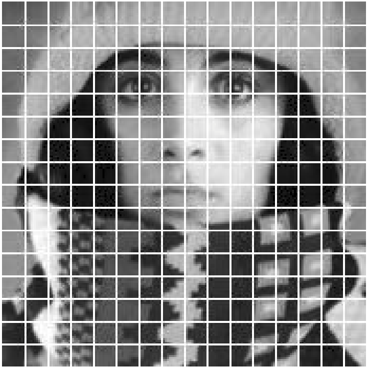

Figure: Digitization of a continuous image. The pixel at coordinates (3, 10) has the integer brightness value 110. This is the ATTRIBUTE vector.

What does a pixel value represent?

(a) (b)

Figure: (a) Image 'Lena'; (b) A zoomed sub image of 'Lena'.

Outline

1. Introduction
   - What Is a Digital Image Anyway?
   - The Scope of Digital Image Processing
   - The Application of Digital Image Processing
2. Piecewise Linear Transformation - Contrast Stretching
3. Human Visual Perception

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The scope of digital image processing

- Related areas include image analysis (or image understanding), computer vision.
- There is no clear cut in the continuum from image processing to computer vision.
- A useful paradigm is to consider three types of computerized processes in this continuum: low-, mid-, and high-level processes.
- For example, consider the problem of automated analyses of text.
- Two major tasks of digital image processing
  - Human interpretation —
  - Machine interpretation —

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The application of digital image processing (1)

Since early 1960s,

- Space application

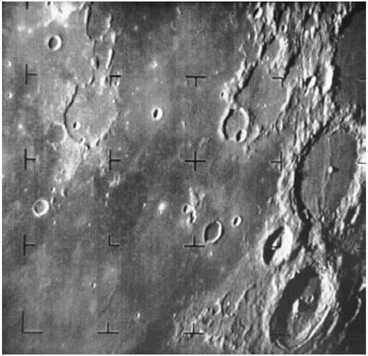

Figure: Ranger 7 took this image, the first picture of the moon by a U.S. spacecraft, on July 31, 1964 at 13:09 UT (9:09 AM EDT), about 17 minutes before impacting the lunar surface.

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The application of digital image processing (2)

- Medical imaging
- In physics and related fields, processing (enhancement etc.) the images of experiments in areas such as high-energy plasmas and electron microscopy.
- Similar successful applications of image processing concepts in astronomy, biology, nuclear medicine, remote sensing, law enforcement, defence, and industry.

The Electromagnetic Spectrum

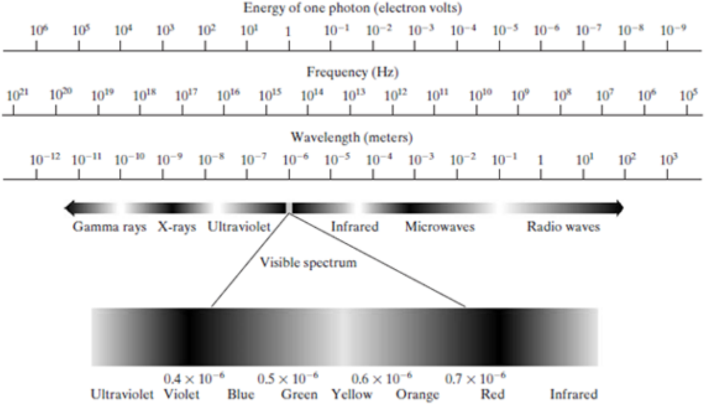

Figure: The EM spectrum

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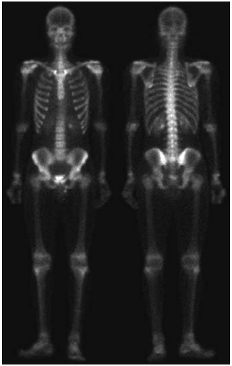
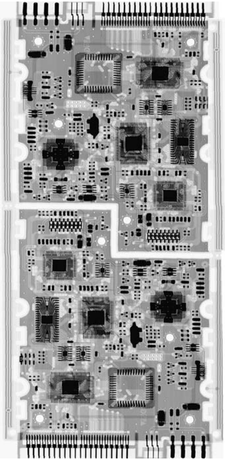
The application of digital image processing (3)

- Gamma-ray imaging: nuclear medicine and astronomical observation
- X-ray imaging: medicine, astronomy, and industry.
- Imaging in the ultraviolet band: lithography, industrial inspection, microscopy, lasers, biological imaging, and astronomical observation.
- Imaging in the visual and infrared bands: most popular. light microscopy, remote sensing, astronomy, industry, and law enforcement.
  - Multispectral imaging: LANDSAT,
  - Hyperspectral imaging: AVIRIS
- Imaging in the microwave band: Dominant applications are in radar. Some radar waves can penetrate clouds, and under certain condition can see through vegetation, ice, dry sand. In many cases, radar is the only way to explore inaccessible regions of the Earth's surface.
- Imaging in the radio band: medicine (magnetic resonance imaging (MRI) and astronomy.

The application of digital image processing (4)



(a) Gamma ray imaging - Bone scan



(b) X-ray imaging - Circuit

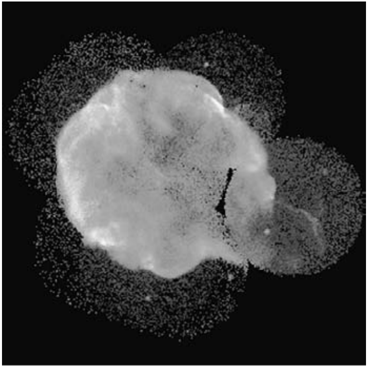
Figure: Examples of images based on imaging in EM

The application of digital image processing (5)

(c) X-ray imaging - Head scan

Figure: Examples of images based on imaging in EM

The application of digital image processing (6)

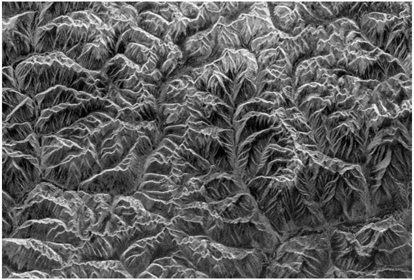


(e) X-ray imaging - Cygnus loop

(f) UV imaging - Cygnus loop

Figure: Examples of images based on imaging in EM

The application of digital image processing (7)



(g) Microwave imaging - Radar image (Tibet)
(Mountains above sea level 5800m)

Figure: Examples of images based on imaging in EM

The application of digital image processing (8)

(h) Radio imaging - Hydrogen gas in M83 galaxy
A galaxy discovered in Cape Town 1752 (MeerKat)

Figure: Examples of images based on imaging in EM

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Outline

Binary image (1)

- Common image formats —

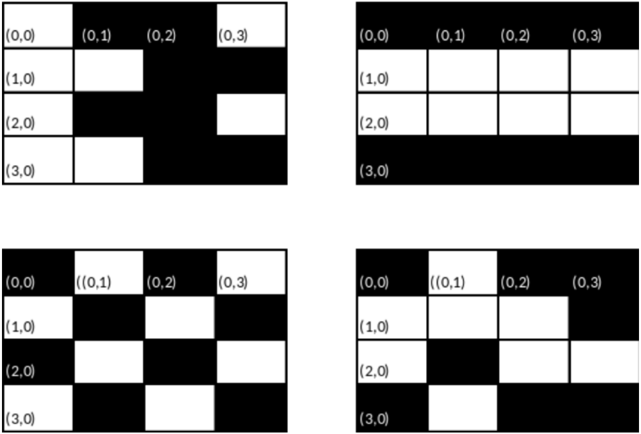

Figure: Patterns: Junction, Two bars, Chessboard?

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Binary image (2)

- Statistics: Mean = 0.5; Variance = 0.25
- The mean tells us about the number of black pixels vs the number of white pixels.
- What does the Variance tells us?

Gray scale images

- In a gray scale image, the attribute at each pixel is a number indicating the brightness level of that pixel.
- The number usually is an N-bit binary number i.e. lies between 0 and $2^N - 1$. This is called the full dynamic range of the image.

1	2	2	1
2	3	3	2
1	2	2	1
0	1	1	0

(a)

1	2	2	1
2	2	2	2
1	2	2	1
1	1	1	1

(b)

Figure: (a) mean = 1.5, var = 0.75; (b) mean = 1.5, var = 0.25.

Mean = Brightness; Variance = Contrast.

Dynamic range (1)

- In a gray scale image the values recorded for the pixel brightness range between 0 and $2^N - 1$.
- Thus the pixels can take on 2^N distinct brightness values in the full dynamic range.
- The dynamic range of the image is the actual range of values that occur.
- In Figure (a) it is 4, and in Figure (b) it is 2.

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Dynamic range (2)

5	8	8	6
0	0	0	0
7	9	9	6
0	0	0	0

142	227	227	170
0	0	0	0
198	255	255	170
0	0	0	0

- If 256 is the full dynamic range, then the first picture above will appear BLACK to a human observer. But it does have structure.
- In the second picture, the observer will see two white lines – even noting that they fade towards the ends.

Dynamic range (3)

- This technique is called CONTRAST STRETCHING.
- Since human observers are most sensitive to contrast, this is a valuable perception enhancer.
- The idea is to increase the dynamic range of the gray levels in the image.
- To achieve this, a simple piecewise linear transformation is used. Many IP packages apply this automatically.
- Matlab function `imadjust`.

Contrast stretching (1)

- Low contrast images can result from
  - poor illumination
  - Lack of dynamic range in the imaging sensor
  - Wrong setting of a lens aperture during image acquisition.
- A simple contrast stretch

$$b(x,y) = (2^N - 1) * \frac{a(x,y) - min(a)}{max(a) - min(a)} \tag{1}$$

- EXERCISE: Use this formula to construct the second image from the first in the previous example.

Contrast stretching (2)

- (1) is sensitive to outliers. One "noise" pixel could completely void the contrast stretch.
- The following formula is more robust.

$$\begin{cases} b(x,y) = 0, & a(x,y) \leq p_{low}; \\ b(x,y) = (2^N - 1) * \frac{a(x,y) - p_{low}}{p_{high} - p_{low}}, & p_{low} < a(x,y) < p_{high}; \\ b(x,y) = 2^N - 1, & a(x,y) \geq p_{high}. \end{cases} \quad (2)$$

- The values of p_{low} and p_{high} are usually chosen either so that they eliminate a certain percentage of pixels, or to eliminate a certain range of pixels.

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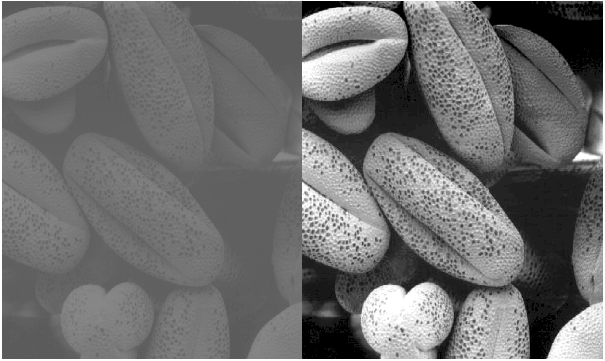
Contrast stretching example (1)



(a) (b)

Figure: (a) Low contrast image; (b) Result of contrast stretching.

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Contrast stretching (3)

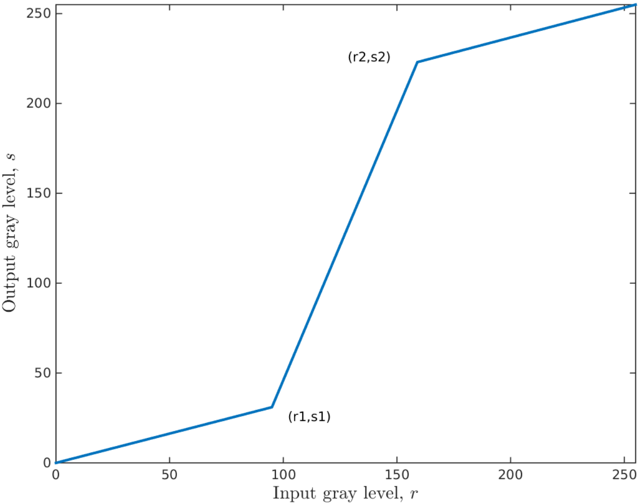
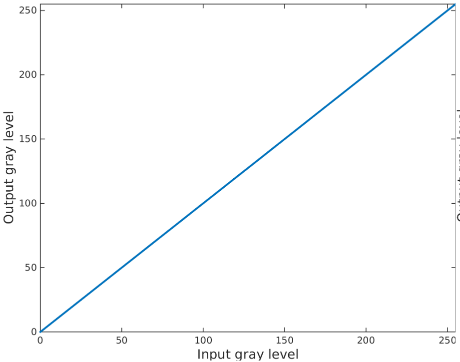


Figure: Form of contrast stretching transformation function

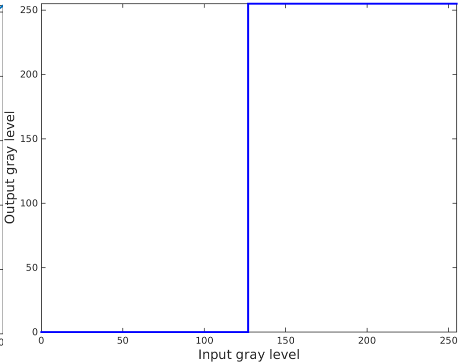
Contrast stretching (4)

- The location of points (r_1, s_1), (r_2, s_2) controls the shape of the transformation function.
- In general, $r_1 \leq r_2$ and $s_1 \leq s_2$.
- What if $r_1 = s_1$ and $r_2 = s_2$?
- $r_1 = r_2$, $s_1 = 0$ and $s_2 = L - 1$?

Contrast stretching Example (2)



(a)



(b)

Figure: What does these transformations do?

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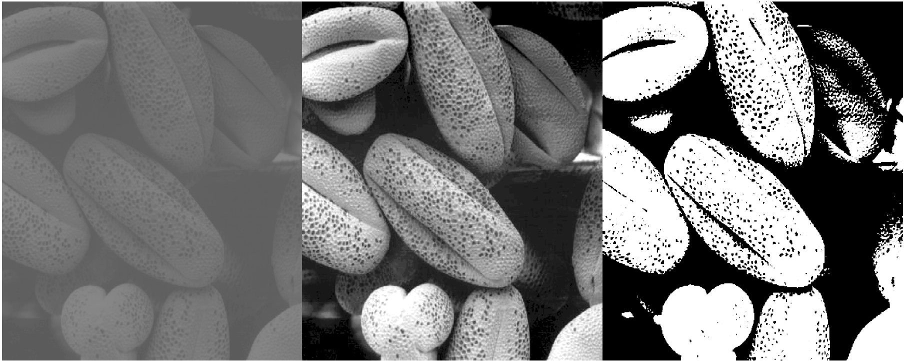
Contrast stretching example (3)



(a) (b) (c)

Figure: (a) Low contrast image; (b) Result of contrast stretching; (c) Result of thresholding.

Gray-level transformation example

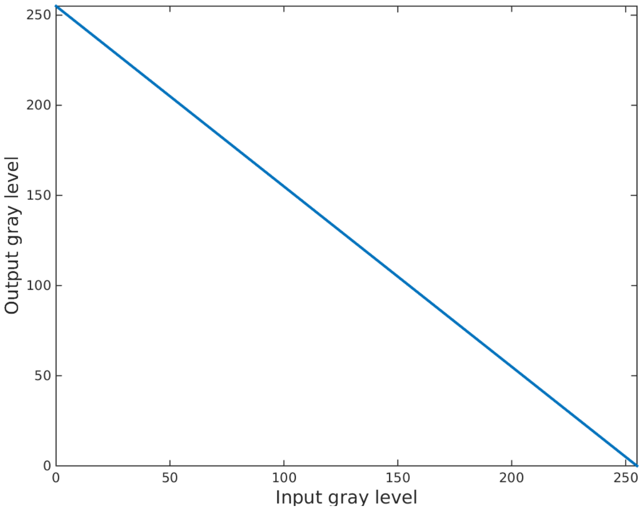


Figure: What does this transform do?

Outline

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Sensing systems – the human eye (1)

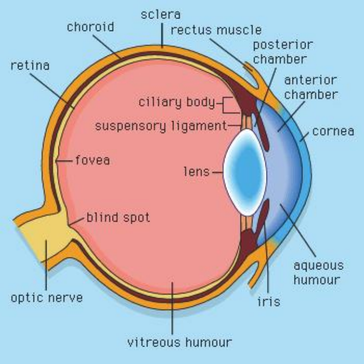

Figure: Simplified diagram of the eye, showing the lens, retina, fovea, optic nerve, etc..

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Sensing systems – the human eye (2)

- Retina - the innermost membrane of the eye
- Pattern vision is afforded by the distribution of discrete light receptors over the surface of the retina
- Two classes of receptors - cones and rods
  - Cones - 6-7 million; Located primarily in the central portion of the retina, called fovea; highly sensitive to colour; each connected to a nerve end; Cone vision - photopic or bright-light vision
  - Rod - 75 - 150 million; give general, overall picture of the field of view; not involved in color vision; sensitive to low levels of illumination; Rod vision - scotopic or dim-light vision.

Sensing systems – the human eye (3)

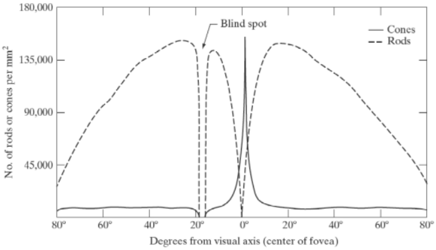

Figure: Distribution of rod and cones in the retina

Sensing systems – the human eye (4)

- Fovea - A circular indentation of the retina with highest density of cones, approximately 337000.
- Lens - absorbs approximately 8% of the visible light spectrum, with relatively higher at shorter wavelengths. Excessive clouding of lens caused by affliction referred to as cataracts.
- Choroid - contains a network of blood vessels that serve as the major source of nutrition to the eye. At its anterior extreme, it is divided into
  - ciliary body
  - iris diaphragm - contracts or expands to control the amount of light that enters the eye; the central opening - pupil.

Sensing systems – the human eye (5)

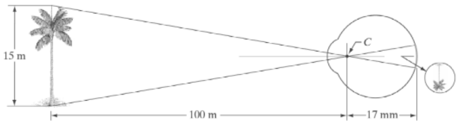

Figure: Image formation in the eye. Point C is the optical center of the lens.

Sensing systems – the human eye (6)

- Spectral Resolution: $0.4 - 0.7\mu m$
- Spatial Resolution: approximate $1 - 3cm$ at 20m
- Radiometric Resolution: approximate $16 - 32$ shades B/W or approximate 100 colours
- Two classes of light receptors – cones and rods. 75 to 150 million rods, 6 to 7 million cones, and 1 million optic axons
  - Cones – colour sensitive, form sharp images, require many photons
  - Rods – intensity, but not colour sensitive, and form blurred images
  - Birds – big eyes, more cones, “faster” eye muscles, more support, and best vision (8 times better than ours)
  - Nocturnal animals have big eyes, and more rods/fewer cones

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Brightness adaptation and discrimination

- The range of light intensity levels to which the human visual system can adapt is enormous – the order of 10^{10}.
- The subjective brightness is a logarithmic function of the light intensity incident on the eye.

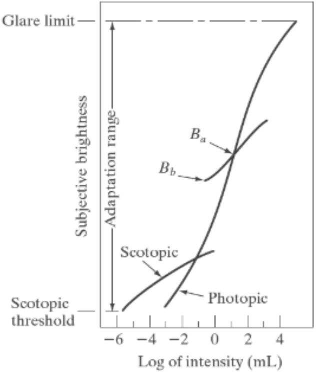

Figure: A plot of light intensity versus subjective brightness.

Human perception

- Human perception of colour, brightness and contrast is NOT uniform or even linear.
- This means that the way in which we DISPLAY images makes a difference.
- It is necessary to use the most appropriate display to provide the observer with the maximum amount of information from the image.

Brightness and contrast (1)

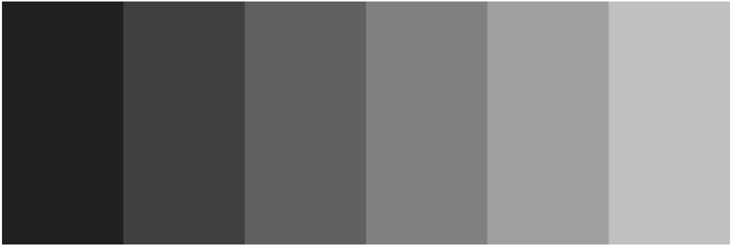

Figure: Note the Mach band effect which emphasises contrast at edges. Perceived intensity is not a simple function of actual intensity.

Brightness and contrast (2)

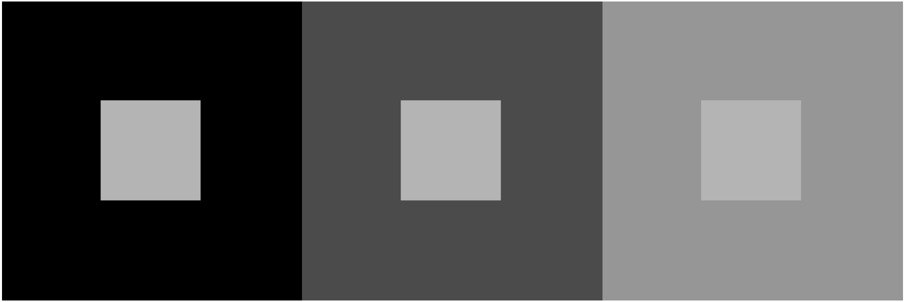

Figure: The phenomenon - simultaneous contrast - a region's brightness is not simply dependent on its intensity. All the centre squares have the same intensity. However, they appear to the eye become darker when the background become lighter.

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Optical illusions

- Optical illusions, in which the eye fills in nonexisting information or wrongly perceives geometrical properties of objects.

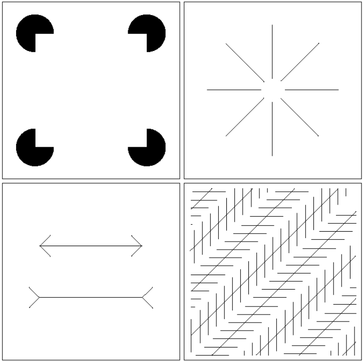

Figure: Some optical illusions

More optical illusions at https://michaelbach.de/ot/ and http://www.ritsumei.ac.jp/%7Eakitaoka/index-e.html

Colour images

- All colours can be obtained as a combination of the three colours: Red, Green, Blue.
- Thus when we represent a colour digital image, we have a three dimensional attribute vector (R, G, B) associated with every point.
- Each component is treated exactly like a grey scale image. Indeed that is what it is.

Contrast in colour images

- Problem with RGB format is that applying processing routines to each band separately could change the colour.
- Really we want to process the intensity of the image without changing the colour space.
- This motivates a number of different ways of representing colour images.

Hue, Saturation, Intensity (HSI) representation (1)

- An approach that provides a means for color definition, and corresponds to the operation of hardware or directly to human vision
- Hue - color
- Saturation - the amount of color that is present
- Intensity - lightness
- The HSI color space can be pictured as a double cone

HSI color space (2)

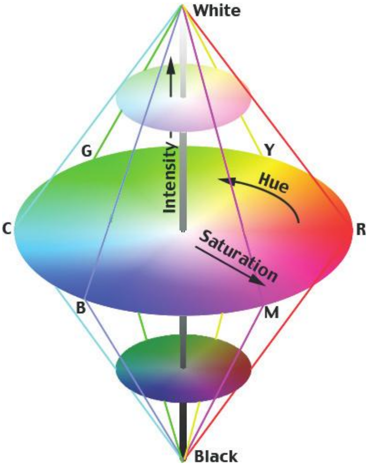

Figure: Bi-conic representation of Hue-Saturation-Intensity Space. Grays lie along the central axis. Distance from the axis gives the Saturation, while direction (angle) specifies the Hue.

HSI color space (3)

- Separate the colour information in ways that correspond to the human visual system's response
- Advantageous for image processing. For example, avoid color shift
- Approximated by geometrically simpler spaces, such as Lab
- L - luminance, a and b are orthogonal axis together define color and saturation.
- Conversion between RGB and Lab

Coversion between RGB and Lab

$$\begin{bmatrix} L \\ a \\ b \end{bmatrix} = \begin{bmatrix} 1/3 & 1/3 & 1/3 \\ -\sqrt{2}/6 & -\sqrt{2}/6 & 2\sqrt{2}/6 \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 1/2 & 1/3 \\ 1 & -1/2 & 1/3 \\ 1 & 0 & -2/3 \end{bmatrix} \times \begin{bmatrix} L \\ a \\ b \end{bmatrix} \tag{4}$$

$$H = tan^{-1}(\frac{b}{a}) \tag{5}$$

$$S = \sqrt{a^2 + b^2} \tag{6}$$

Summary

- A basic definition of digital image
- The breadth and practical scope of image processing
- A brief introduction to human visual system
- A basic image enhancement technique for intensity or gray-level transformation

The materials are from [Gonzalez and Woods, 2008, Chapters 1, 2, 3], [Gonzalez et al., 2009, Chapter 3] [Russ, 2011, Chapters 1, 2]

Gonzalez, R. C. and Woods, R. E. (2008). *Digital Image Processing*. Pearson Prentice Hall, Upper Saddle River, NJ 07458, third edition.

Gonzalez, R. C., Woods, R. E., and Eddins, S. L. (2009). *Digital Imageage Processing using MATLAB*. Gatesmark Publishing.

Russ, J. C. (2011). *The image processing handbook*. CRC press.

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