10EC763
DIGITAL IMAGE PROCESSING: INTRODUCTION

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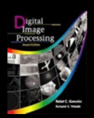
INTRODUCTION

- *"One picture is worth more than thousand words"*
  - Anonymous

REFERENCES

- **Text book:**
- **"Digital Image Processing", Rafael C. Gonzalez & Richard E. Woods, TMH, Second Edition 2010**
  - Much of the material that follows is taken from this book

- **"Fundamentals of Digital Image Processing"**, Anil K. Jain, Pearson Education, 2001.
- **"Digital Image Processing and Analysis"**, B. Chanda and D. Dutta Majumdar, PHI, 2003.

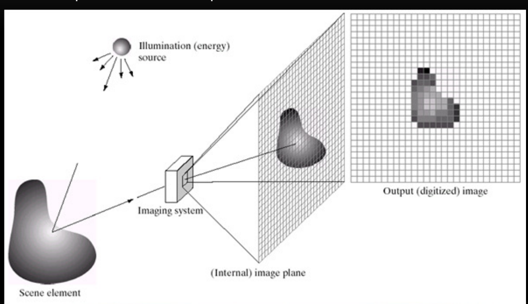


CONTENTS

- This lecture will cover:
  - What is a digital image?
  - What is digital image processing?
  - History of digital image processing
  - State of the art examples of digital image processing
  - Key stages in digital image processing

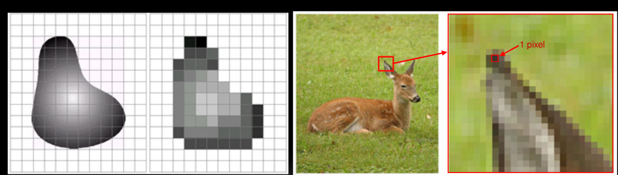
WHAT IS A DIGITAL IMAGE?

- A **digital image** is a representation of a two-dimensional image as a finite set of digital values, called picture elements or pixels



WHAT IS A DIGITAL IMAGE? (CONT…)

- Pixel values typically represent gray levels, colours, heights, opacities etc
- **Remember** *digitization* implies that a digital image is an *approximation* of a real scene



WHAT IS A DIGITAL IMAGE? (CONT…)

- Common image formats include:
  - 1 sample per point (B&W or Grayscale)
  - 3 samples per point (Red, Green, and Blue)
  - 4 samples per point (Red, Green, Blue, and "Alpha", a.k.a. Opacity)
  - For most of this course we will focus on grey-scale images

WHAT IS DIGITAL IMAGE PROCESSING?

- Digital image processing focuses on two major tasks
  - Improvement of pictorial information for human interpretation
  - Processing of image data for storage, transmission and representation for autonomous machine perception

WHAT IS DIP? (CONT…)

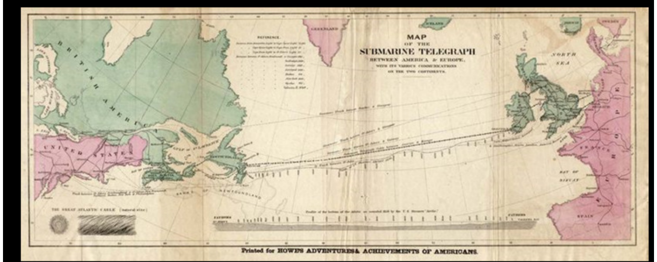
- The continuum from image processing to computer vision can be broken up into low-, mid- and high-level processes

Low Level Process	Mid Level Process	High Level Process
Input: Image **Output:** Image	**Input:** Image **Output:** Attributes	**Input:** Attributes **Output:** Understanding
Examples: Noise removal, image sharpening	**Examples:** Object recognition, segmentation	**Examples:** Scene understanding, autonomous navigation

In this course we will stop here

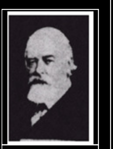
HISTORY OF DIGITAL IMAGE PROCESSING

- **Early 1920s:** One of the first applications of digital imaging was in the news- paper industry
  - The Bartlane cable picture transmission service
  - Images were transferred by submarine cable between London and New York



HISTORY OF DIP (CONT…)

- **Mid to late 1920s:** Improvements to the Bartlane system resulted in higher quality images
  - New reproduction processes based on photographic techniques
  - Increased number of tones in reproduced images



Improved digital image

Early 15 tone digital image

HISTORY OF DIP (CONT…)

- **1960s:** Improvements in computing technology and the onset of the ***space race*** led to a surge of work in digital image processing
  - **1964:** Computers used to improve the quality of images of the moon taken by the *Ranger 7* probe
  - Such techniques were used in other space missions including the Apollo landings

A picture of the moon taken by the Ranger 7 probe minutes before landing

HISTORY OF DIP (CONT…)

- **1970s:** Digital image processing begins to be used in medical applications
  - **1979:** Sir Godfrey N. Hounsfield & Prof. Allan M. Cormack share the Nobel Prize in medicine for the invention of tomography, the technology behind Computerised Axial Tomography (CAT) scans

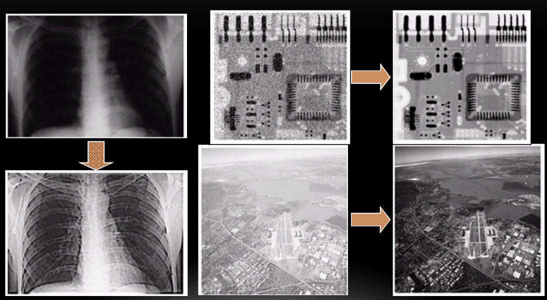
Typical head slice CAT image

HISTORY OF DIP (CONT…)

- **1980s - Today:** The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas
  - Image enhancement/restoration
  - Artistic effects
  - Medical visualisation
  - Industrial inspection
  - Law enforcement
  - Human computer interfaces

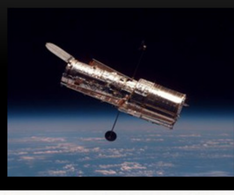
EXAMPLES: IMAGE ENHANCEMENT

- One of the most common uses of DIP techniques: improve quality, remove noise etc



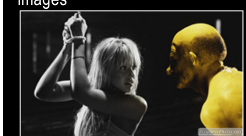
EXAMPLES: THE HUBBLE TELESCOPE

- Launched in 1990 the Hubble telescope can take images of very distant objects
- However, an incorrect mirror made many of Hubble's images useless
- Image processing techniques were used to fix this



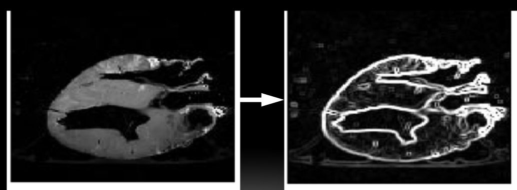
EXAMPLES: ARTISTIC EFFECTS

- Artistic effects are used to make images more visually appealing, to add special effects and to make composite images



EXAMPLES: MEDICINE

- Take slice from MRI scan of canine heart, and find boundaries between types of tissue
  - Image with gray levels representing tissue density
  - Use a suitable filter to highlight edges

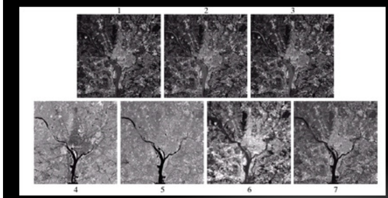


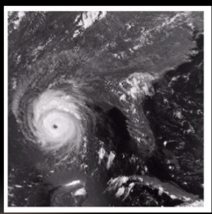
Original MRI Image of a Dog Heart

Edge Detection Image

EXAMPLES: GIS

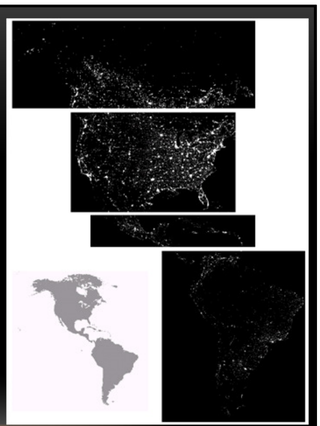
- Geographic Information Systems
  - Digital image processing techniques are used extensively to manipulate satellite imagery
  - Terrain classification
  - Meteorology





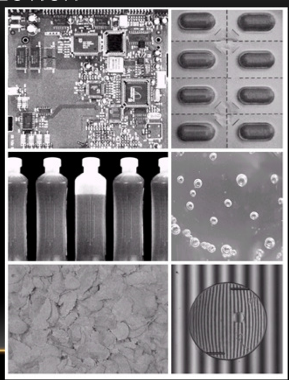
EXAMPLES: GIS (CONT…)

- *Night-Time Lights of the World* data set
  - Global inventory of human settlement
  - Not hard to imagine the kind of analysis that might be done using this data



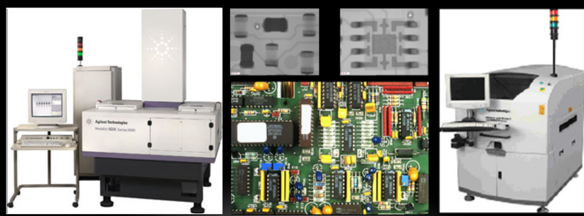
EXAMPLES: INDUSTRIAL INSPECTION

- Human operators are expensive, slow and unreliable
- Make machines do the job instead
- Industrial vision systems are used in all kinds of industries
- Can we trust them?



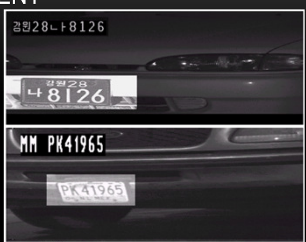
EXAMPLES: PCB INSPECTION

- Printed Circuit Board (PCB) inspection
  - Machine inspection is used to determine that all components are present and that all solder joints are acceptable
  - Both conventional imaging and x-ray imaging are used



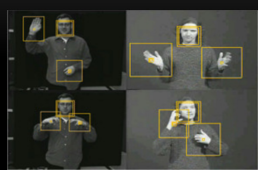
EXAMPLES: LAW ENFORCEMENT

- Image processing techniques are used extensively by law enforcers
  - Number plate recognition for speed cameras/automated toll systems
  - Fingerprint recognition
  - Enhancement of CCTV images



EXAMPLES: HCI

- Try to make human computer interfaces more natural
  - Face recognition
  - Gesture recognition
- Does anyone remember the user interface from "Minority Report"?
- These tasks can be extremely difficult



Energy Sources for Images

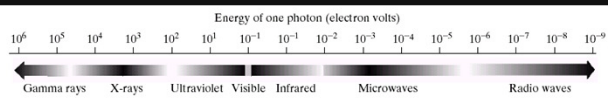


FIGURE 1.5 The electromagnetic spectrum arranged according to energy per photon.

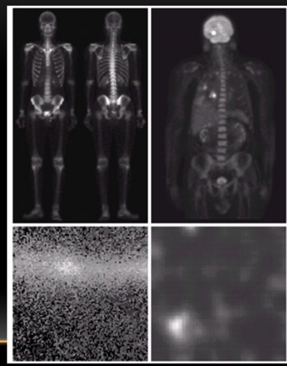
Main energy source
Electromagnetic wave

Other energy sources
- Sound
- Magnetic fields
- Electron
- others

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

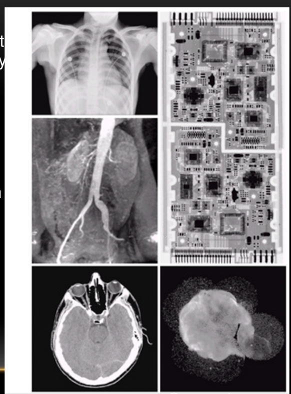
Gamma Ray

External source
Radioactive isotope decay
Internal Source
Positron emission
Star
Nuclear reaction



(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

X-Ray

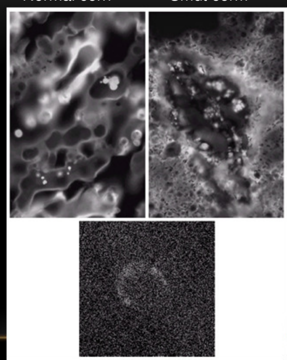


Source : X-Ray tube
Star
Nuclear reaction

(Images from Rafael C. Gonzalez and Richard E. Wood, Digital Image Processing, 2nd Edition.

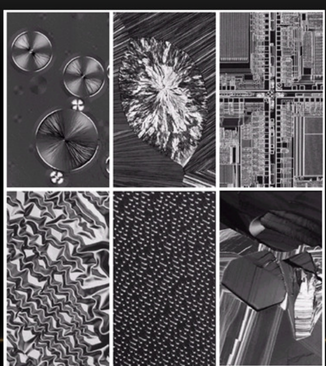
Ultraviolet

Fluorescence phenomenon



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Visible Light and Infrared

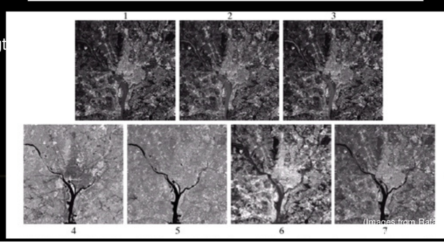


(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Visible Light and Infrared

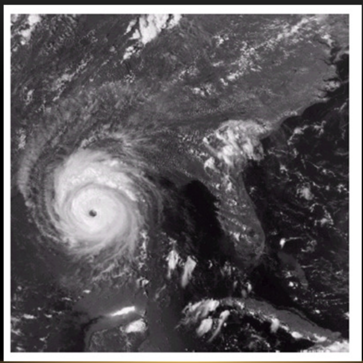
Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

Washington D.C.



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

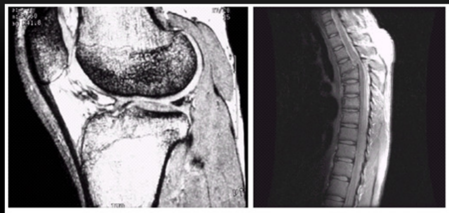
Multispectral Imaging



Hurricane Andrew

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Magnetic



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Multispectral images

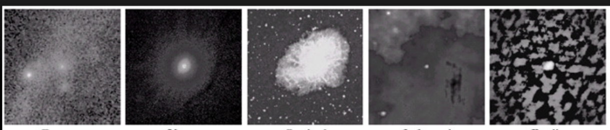
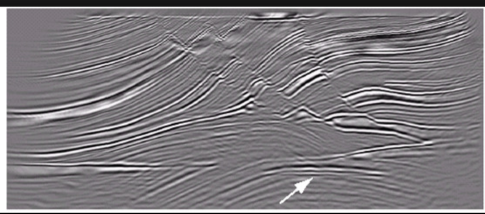


FIGURE 1.18 Images of the Crab Pulsar (in the center of images) covering the electromagnetic spectrum. (Courtesy of NASA.)

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

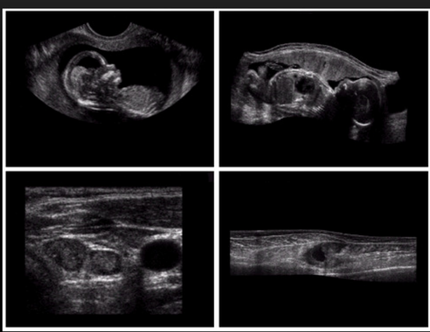
Seismic imaging

FIGURE 1.19 Cross-sectional image of a seismic model. The arrow points to a hydrocarbon (oil and/or gas) trap. (Courtesy of Dr. Curtis Ober, Sandia National Laboratories.)



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Ultrasound imaging

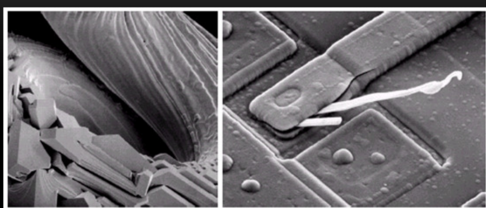


a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Electron Microscope Images

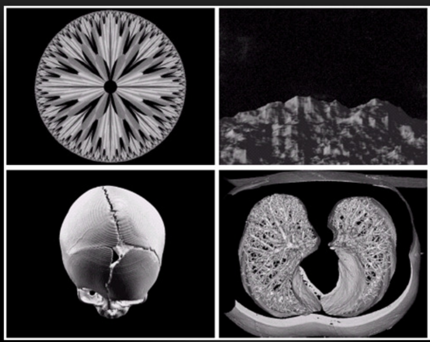


a b

FIGURE 1.21 (a) 250× SEM image of a tungsten filament following thermal failure. (b) 2500× SEM image of damaged integrated circuit. The white fibers are oxides resulting from thermal destruction. (Figure (a) courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene; (b) courtesy of Dr. J. M. Hudak, McMaster University, Hamilton, Ontario, Canada.)

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Synthesis Images

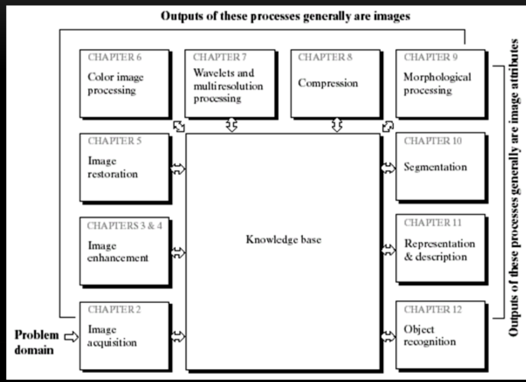


a b
c d

FIGURE 1.22 (a) and (b) Fractal images. (c) and (d) Images generated from 3-D computer models of the objects shown. (Figures (a) and (b) courtesy of Ms. Melissa D. Binde, Swarthmore College, (c) and (d) courtesy of NASA.)

(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

Fundamental Steps in Digital Image Processing



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

KEY STAGES IN DIGITAL IMAGE PROCESSING

Image Restoration → Morphological Processing → Segmentation → Object Recognition → Representation & Description

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration

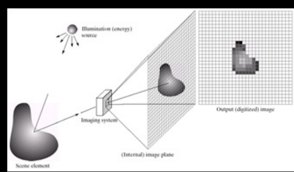
Colour Image Processing

Image Compression

KEY STAGES IN DIGITAL IMAGE PROCESSING: IMAGE AQUISITION

Image Restoration → Morphological Processing → Segmentation → Object Recognition → Representation & Description

Problem Domain → Image Acquisition → Image Enhancement



Colour Image Processing

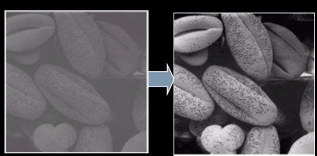
Image Compression

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

KEY STAGES IN DIGITAL IMAGE PROCESSING: IMAGE ENHANCEMENT

Image Restoration → Morphological Processing → Segmentation → Object Recognition → Representation & Description

Problem Domain → Image Acquisition → Image Enhancement



Colour Image Processing

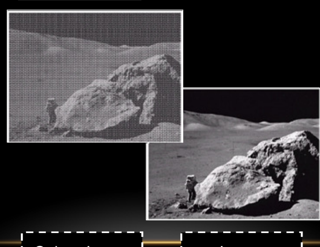
Image Compression

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

KEY STAGES IN DIGITAL IMAGE PROCESSING: IMAGE RESTORATION

Image Restoration → Morphological Processing → Segmentation → Object Recognition → Representation & Description

Problem Domain → Image Acquisition → Image Enhancement



Colour Image Processing

Image Compression

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image restoration vs. image enhancement

- Enhancement:
  - largely a subjective process
  - Priori knowledge about the degradation is not a must (sometimes no degradation is involved)
  - Procedures are heuristic and take advantage of the psychophysical aspects of human visual system
- Restoration:
  - more an objective process
  - Images are degraded
  - Tries to recover the images by using the knowledge about the degradation

KEY STAGES IN DIGITAL IMAGE PROCESSING: MORPHOLOGICAL PROCESSING

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration
Morphological Processing
Image Enhancement
Image Acquisition
Problem Domain
Segmentation
Object Recognition
Representation & Description
Colour Image Processing
Image Compression

KEY STAGES IN DIGITAL IMAGE PROCESSING: SEGMENTATION

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration
Morphological Processing
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Problem Domain
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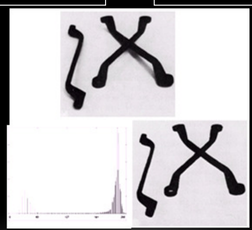
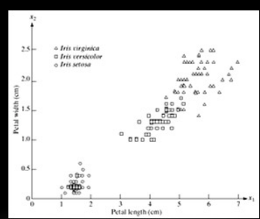
Representation & Description
Colour Image Processing
Image Compression



KEY STAGES IN DIGITAL IMAGE PROCESSING: OBJECT RECOGNITION

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

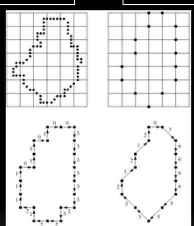
Image Restoration
Morphological Processing
Image Enhancement
Image Acquisition
Problem Domain
Segmentation
Object Recognition
Representation & Description
Colour Image Processing
Image Compression



KEY STAGES IN DIGITAL IMAGE PROCESSING: REPRESENTATION & DESCRIPTION

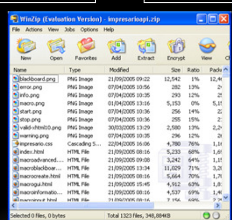
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Restoration
Morphological Processing
Image Enhancement
Image Acquisition
Problem Domain
Segmentation
Object Recognition
Representation & Description
Colour Image Processing
Image Compression

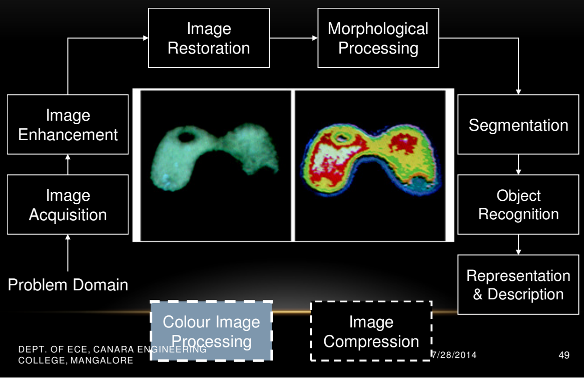


KEY STAGES IN DIGITAL IMAGE PROCESSING: IMAGE COMPRESSION

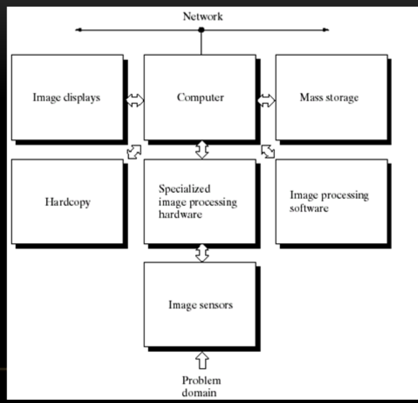
Image Restoration
Morphological Processing
Image Enhancement
Image Acquisition
Problem Domain
Segmentation
Object Recognition
Representation & Description
Colour Image Processing
Image Compression



KEY STAGES IN DIGITAL IMAGE PROCESSING: COLOUR IMAGE PROCESSING



Components of an Image Processing System



(Images from Rafael C. Gonzalez and Richard Wood, Digital Image Processing, 2nd Edition.

SUMMARY

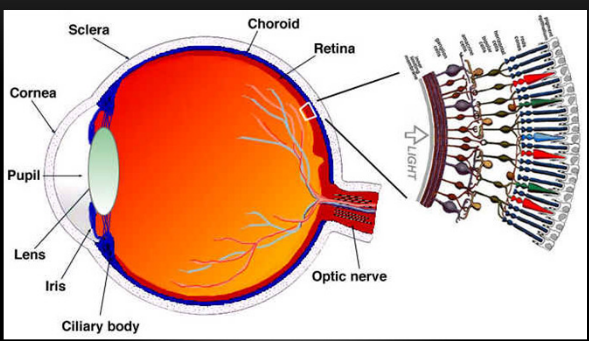
- We have looked at:
  - What is a digital image?
  - What is digital image processing?
  - History of digital image processing
  - State of the art examples of digital image processing
  - Key stages in digital image processing
- Next time we will start to see how it all works…

CONTENTS

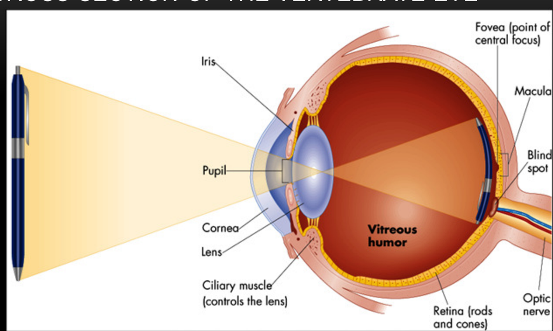
- This lecture will cover:
  - The human visual system
  - Light and the electromagnetic spectrum
  - Image representation

2nd Unit topics
- Image sensing and acquisition
- Sampling, quantisation and resolution

STRUCTURE OF THE HUMAN EYE…

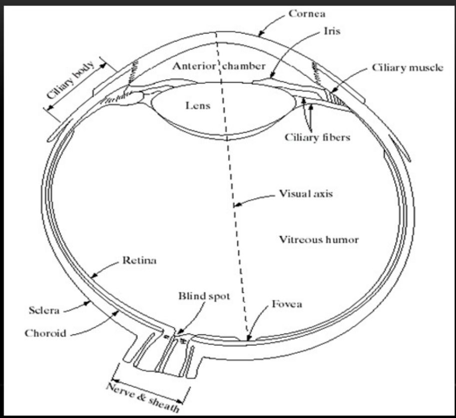


CROSS SECTION OF THE VERTEBRATE EYE

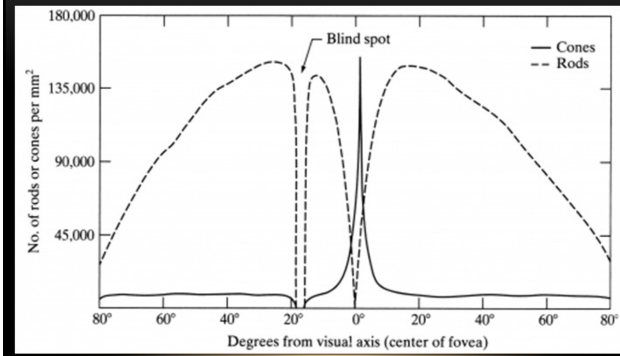


Note how an object in the visual field produces an inverted image on the retina.

STRUCTURE OF THE HUMAN EYE



DISTRIBUTION OF THE CONES AND RODS IN THE RETINA



STRUCTURE OF THE HUMAN EYE…

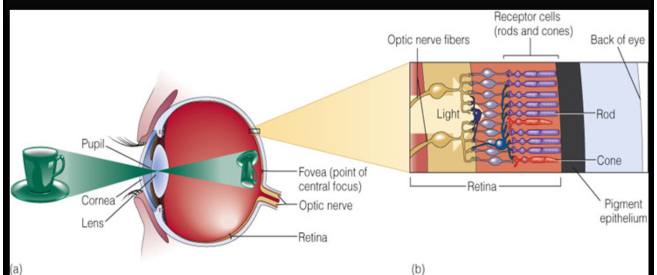
- The lens focuses light from objects onto the retina
- The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million)
- Cones are concentrated around the fovea

  and are very sensitive to colour
- Humans can resolve fine details with these cones largely because each one is connected to its own nerve end.
- Muscles controlling the eye rotate the eyeball until the image of an object of interest falls on the fovea
- Cone vision is called Photopic or bright-light vision

STRUCTURE OF THE HUMAN EYE…

- Rods are more spread out and are sensitive to low levels of illumination
- Rods serve to give a general, overall picture of the field of view
- Not involved in color vision and are sensitive to low levels of illumination.
- Example: Objects appearing brightly coloured in day light appear colourless in moon light because only the rods are stimulated.
  - This phenomenon is known as Scotopic or dim-light vision

Cones and Rods



The eye works like a camera, using a lens to focus light onto a photo-sensitive surface at the back of a sealed structure.

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!

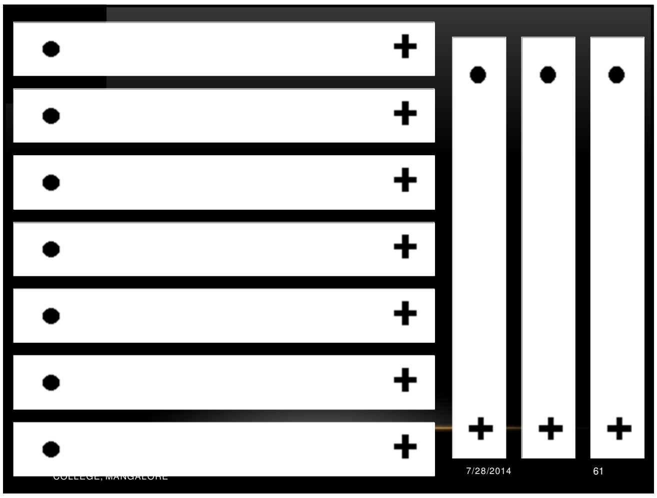
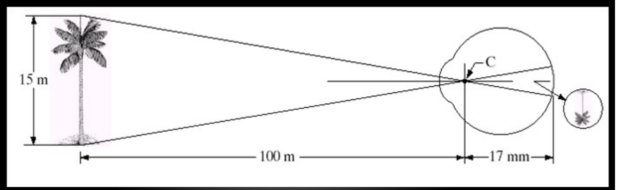
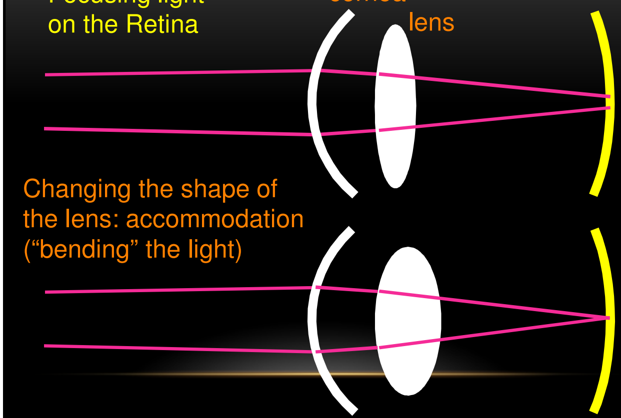


IMAGE FORMATION IN THE EYE

- 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



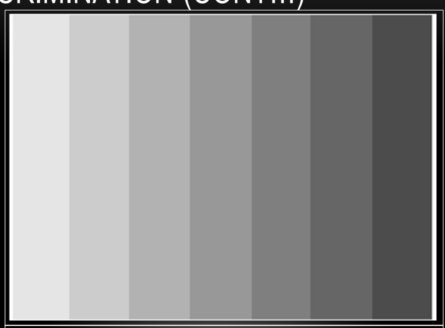


BRIGHTNESS ADAPTATION & DISCRIMINATION

- 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 (CONT…)

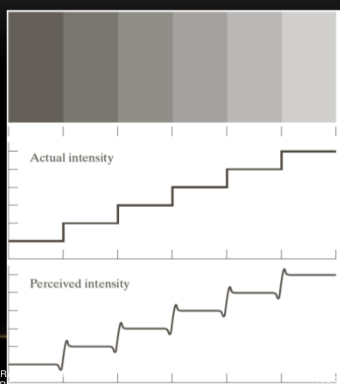
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



An example of Mach bands

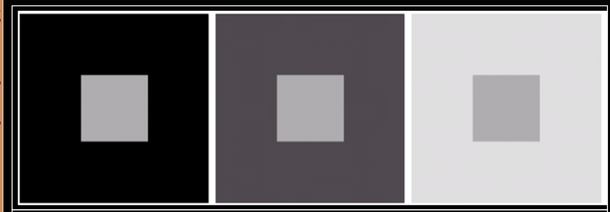
BRIGHTNESS ADAPTATION & DISCRIMINATION (CONT…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)



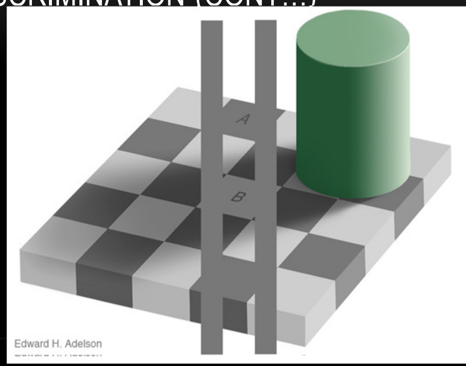
BRIGHTNESS ADAPTATION & DISCRIMINATION (CONT…)

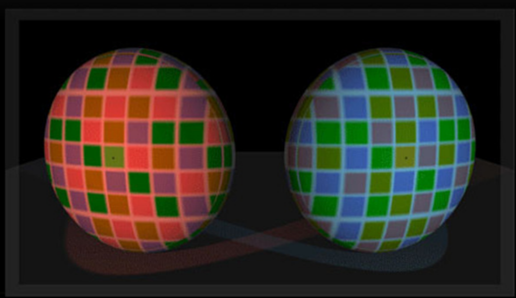
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



An example of *simultaneous contrast*

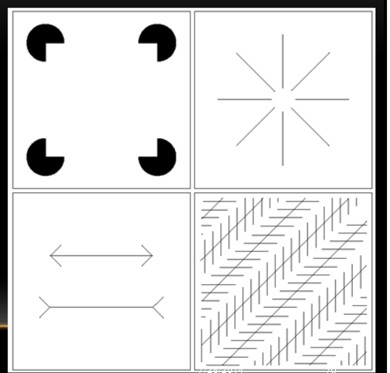
BRIGHTNESS ADAPTATION & DISCRIMINATION (CONT…)



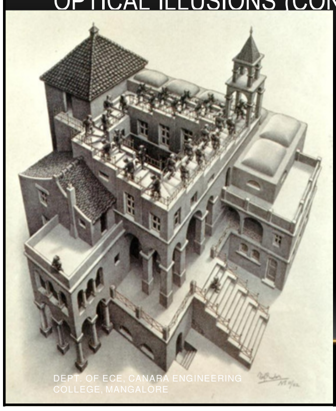


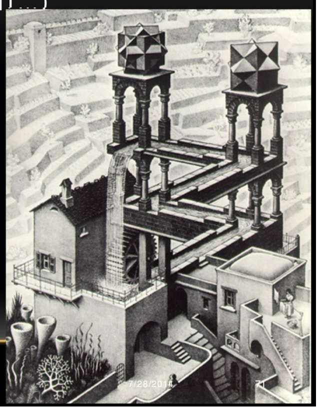
OPTICAL ILLUSIONS

- Our visual systems play lots of interesting tricks on us

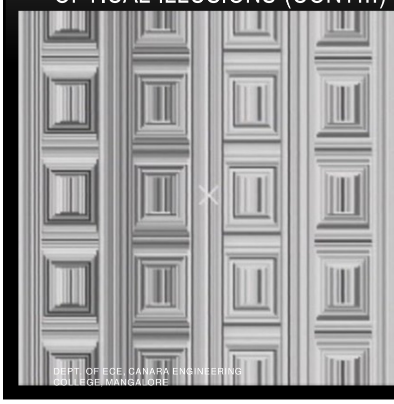


OPTICAL ILLUSIONS (CONT…)





OPTICAL ILLUSIONS (CONT…)



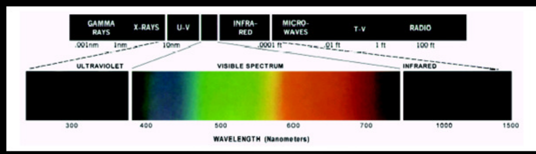
Stare at the cross in the middle of the image and think circles

BRIGHTNESS ADAPTION AND DISCRIMINATION…

- The human eye can adapt to a wide range ($\approx 10^{10}$) of intensity levels.
- The brightness that we perceive (subjective brightness) is not a simple function of the intensity.
- In fact the subjective brightness is a logarithmic function of the light intensity incident on the eye.
- The HVS(Human Visual System) mechanisms adapt to different lighting conditions.
- The sensitivity level for a given lighting condition is called as the **brightness adaption level**.
- As the lighting condition changes, our visual sensory mechanism will adapt by changing its sensitivity.
- The human eye cannot respond to the entire range of intensity levels at a given level of sensitivity.

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



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