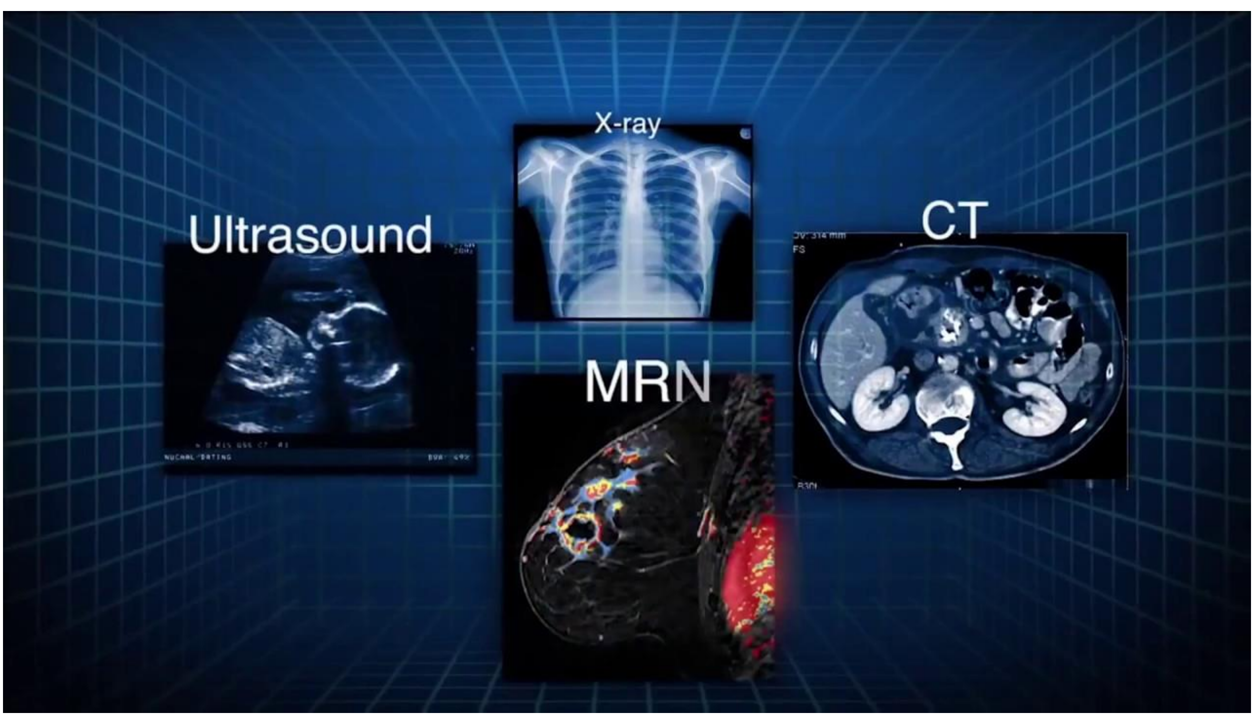
NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Eraj
Lecture: 1

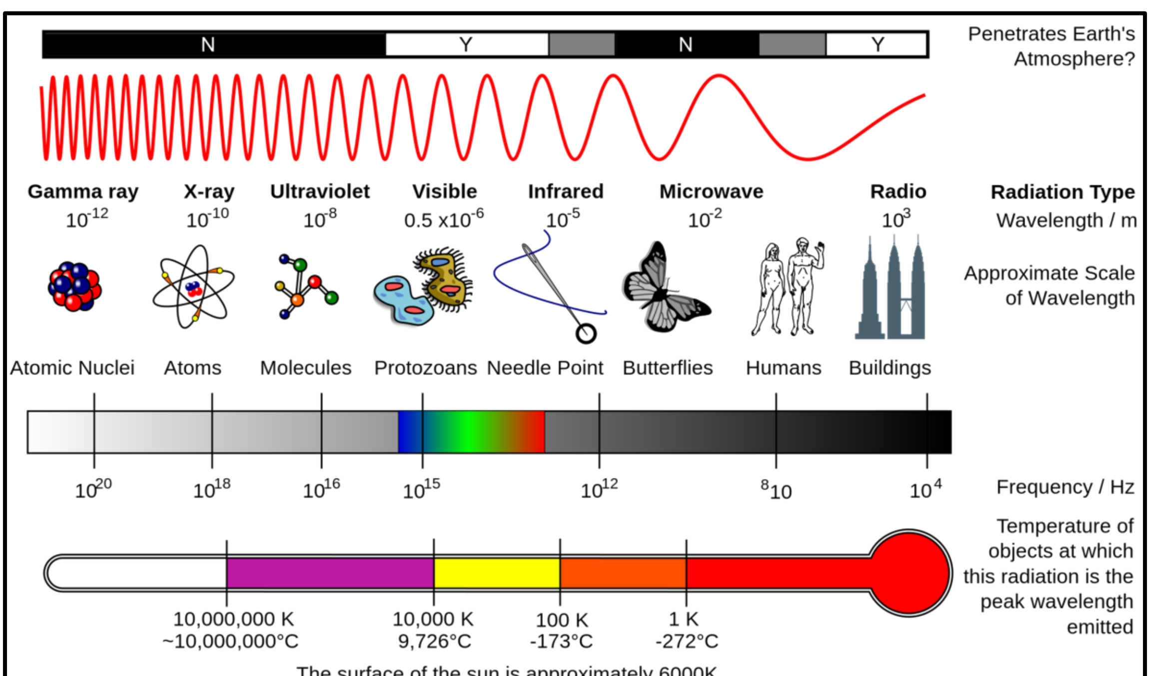


Imaging

- to get detailed information about the human body
- to diagnose everything from simple medical events to complex disease

What do you think of when you consider medical imaging?

- To most of you it is probably those large envelopes
- sheets of photographic film
- From local radiology centre back to your treating physician.



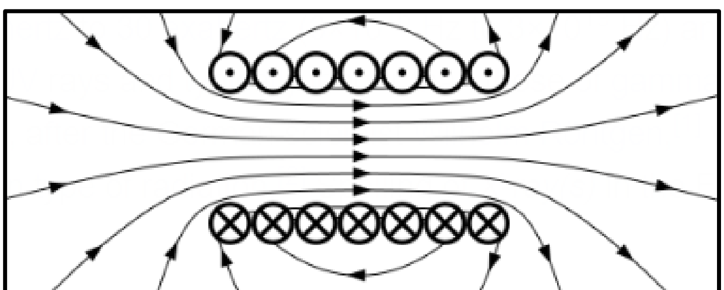
X-rays

Invented in the late 19th century

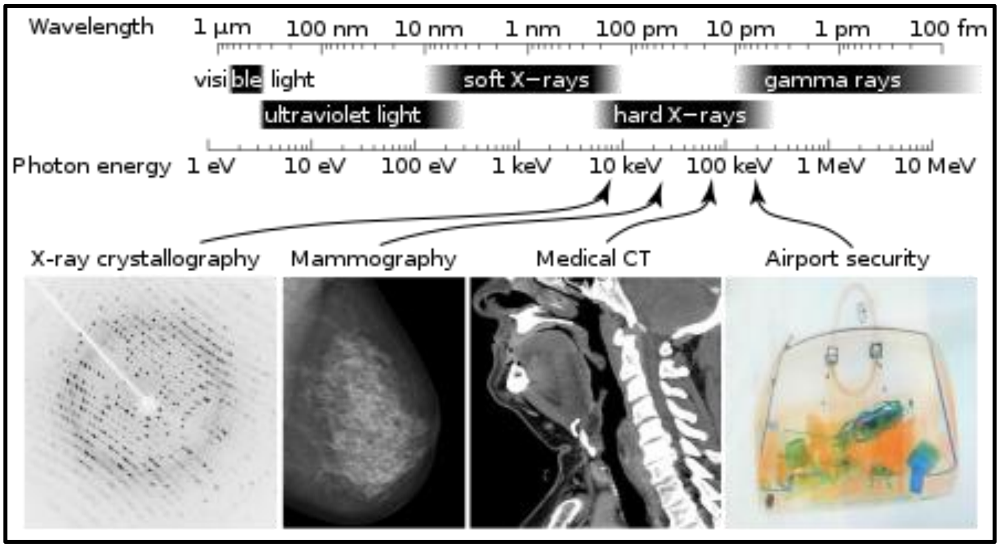
- German Physicist, Wilhelm Roentgen
- They are a form of electromagnetic radiation

The energy level of the photons is high enough to penetrate the body, but differential absorption by different tissue types produces contrast.

Hand with Rings: print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896.



In physics, **electromagnetic radiation** refers to the waves of the electromagnetic field, propagating (radiating) through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays.



By Ulflund - This figure is a compilation of different images from wikimedia commons.The graph at the top I have made myself, originaly uploaded as .Own workThe crystallography image is from File:Lysozym diffraction.png by user:Del45.The mammography image is from File:40F MLO DMMG.png by Nevit Dilmen (talk).The CT image is from File:Ct-workstation-neck.jpg by en:User:ChumpusRex.The luggage scanner image is from File:Luggage screening at VTBS.JPG by user User:Mattes., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=22545004

Image production is a projection of the object being imaged, a bit like a shadow.

Hand with Rings: print of Wilhelm Röntgen's first "medical" X-ray, of his wife's hand, taken on 22 December 1895 and presented to Ludwig Zehnder of the Physik Institut, University of Freiburg, on 1 January 1896.

Computed Tomography

CT imaging

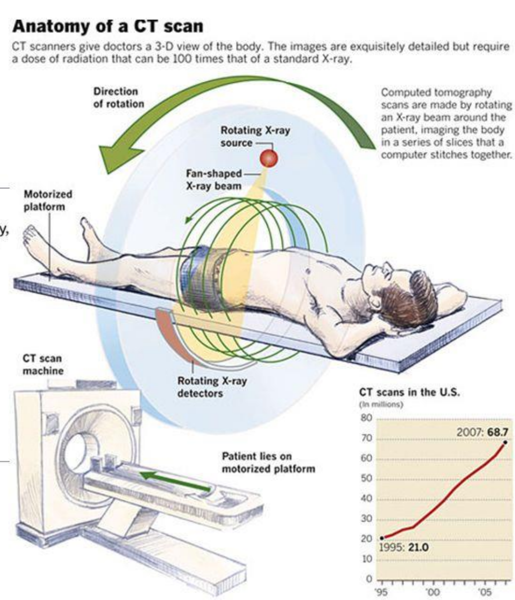
- also uses X-rays
- but provides far more detail
- because it is able to select thin slices of tissue

It uses many projections in different directions to build up an image.

CT can also be used to build a 3-dimensional image.

CT Imaging Overview

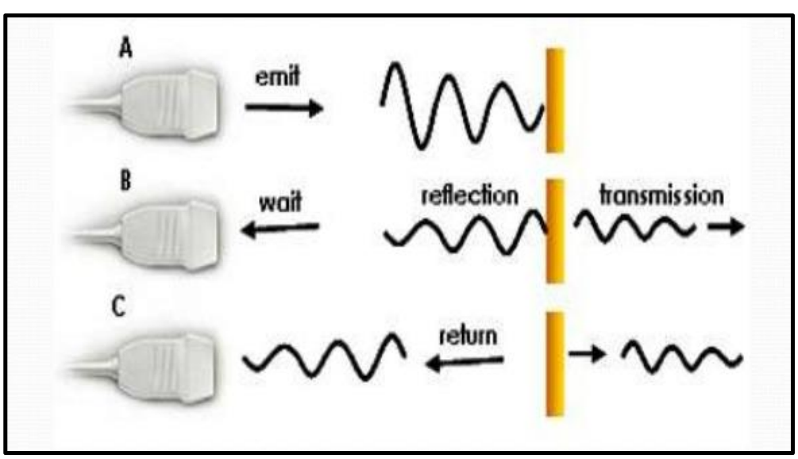
During a computerized tomography (CT) scan, a thin x-ray beam rotates around an area of the body, generating a 3-D image of the internal structures



Ultrasound

Many of you will have had an ultrasound, before you were born

The sonographer uses a transducer to transmit sound waves and then collect the signal that is reflected



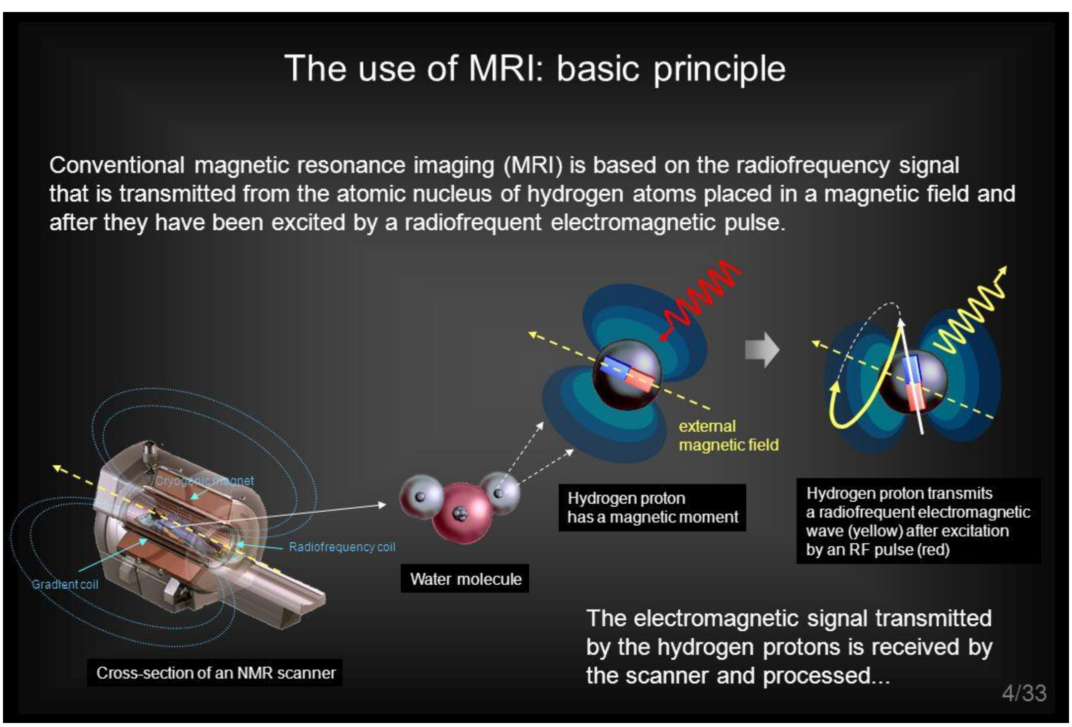
Magnetic Resonance Imaging

MRI

- relies on the fact that in your body the Hydrogen atoms produce a magnetic field which points in random directions

When Hydrogen atoms are put in a powerful magnet

- they line up in the same way as a magnetised needle in a compass lines up with the Earth's magnetic field.
- The image changes by simply altering the timing of the acquisition

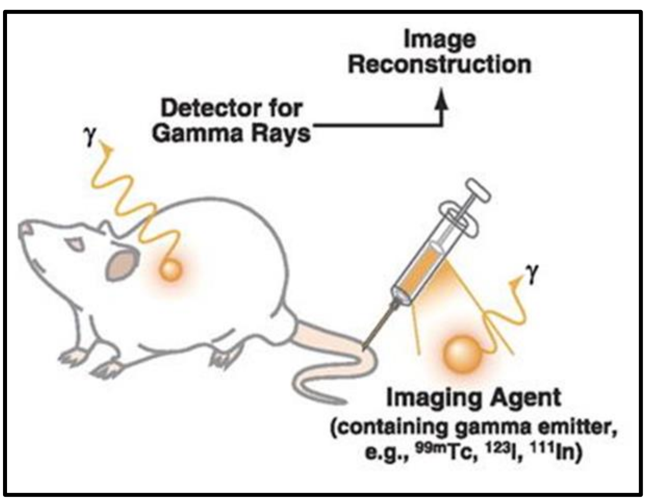


Molecular imaging

2 classes of molecular imaging

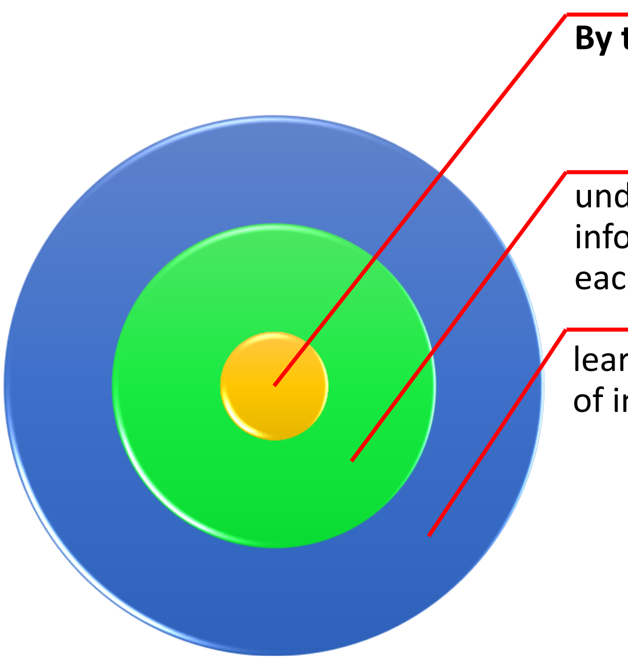
- Single Photon Emission Computed Tomography,abbreviated SPECT
- Positron Emission Tomography, or PET

Both use extremely small quantities of a molecule with a radioactive nucleus. The scanner detects the gamma-rays, another form of electromagnetic radiation, to build an image.



First, a targeted SPECT imaging agent (containing a γ emitting radioisotope) is administered to the subject and the gamma rays are detected via a gamma camera (rotated around the subject). The detected gamma rays are then reconstructed into tomographic images, providing information on the location of the imaging agent in the subject.

Do we need all these different types of imaging?



By the end of this course

understand different types of information that is obtained from each of these imaging modalities

learn the basic physics of each type of imaging modality

1. You are exposed to X-ray whenever you enter a room with an X-ray machine.
Explanation
False: the X-ray machine needs to be turned on, as it is an electronically generated radiation.
2. X-rays do not stay in the body after the radiation exposure.
Explanation
True. Therefore, you cannot become radioactive and expose other people to radiation from having an X-ray taken.
3. Pregnant women should never have an X-ray.
Explanation
False. In some cases, pregnant women can still be X-rayed but this is to be discussed at all times with the radiographer prior to the X-ray.
4. CT is like a computerised X-ray.
Explanation
True. Put it simply, it uses the principles of X-ray to generate digital images of a slice, or multiple slices, of tissue.
5. CT stands for Computed Tomography.
Explanation
True. Tomography is a technique for displaying a representation of a cross section through a human body or other solid object using X-rays or ultrasound.

6. CT is only used to diagnose cancer
Explanation
False. Although commonly used to diagnose cancers, it can also serve to diagnose heart diseases, neurological problems or even back problems involving the spinal cord for example.
7. Ultrasound machines use sound waves to produce an image.
Explanation
True. The sound reflects and echoes off parts of the tissue; this echo is recorded and displayed as an image to the operator.
8. Ultrasound images are always 2D.
Explanation
False. It can also show the anatomy of a three-dimensional region.
9. Ultrasound can be used to locate tumors.

Explanation
True. This is a new development of the use of ultrasound, currently at the pre-clinical stage.
10. Magnetic Resonance Imaging (MRI) uses ionising radiation to produce an image.
Explanation
False. It uses strong magnetic field and radio waves to form images of the body.

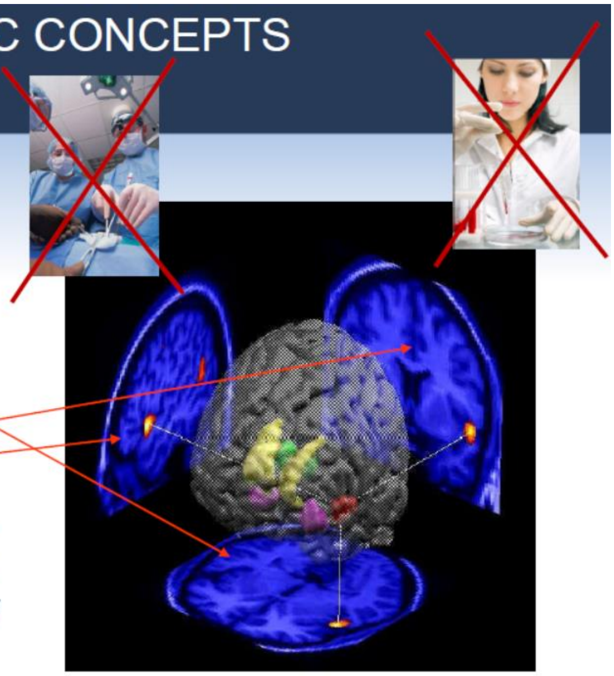
11. MRI is the safest imaging diagnostic tool for everyone.
Explanation
False. As MRI is a non-invasive technology, it is usually preferred to alternative options such as CT. However, patients with metal implants will not be able to undergo an MRI scan.
12. It is a good idea to leave all jewellery at home when you go for an MRI.
Explanation
True. Once in the room where the scanner is, the magnet attracts all metallic objects, which can become lethal projectiles if not removed. The radiographer will advise you prior to the scan.
13. A 3T MRI scanner, commonly used in clinical practice, has 60,000 times the force of the Earth's magnetic field.
Explanation
True.
14. If you get injected with a radiopharmaceutical for a PET scan, you become permanently radioactive.
Explanation
False. The radiopharmaceutical has a very short half-life and passes through the body quickly.
15. Nuclear medicine that uses PET and SPECT scanners is only used for oncology.
Explanation
False. Although nuclear medicine is widely used in oncology, it can also help to diagnose neurodegenerative diseases, movement disorders, inflammation, etc.

MEDICAL APPLICATION OF VARIOUS FIELDS

Field	Freq. (Hz)	Diagnostic applications	Therapeutic applications
Electromagnetic field			
Resistive current	0 - 10^5	ECG, EEG,…	Physical electrotherapy
Radiofields	- 10^{12}	MRI	Physical thermotherapy
Infrared radiation	- $4*10^{14}$	Thermal imaging	Laser therapy
Visible light	- $8*10^{14}$	Use of human eye	Light and laser therapy
UV light	- $3*10^{18}$		Skin therapy
X and γ radiation	- $3*10^{22}$	X-ray and nucl.imaging	Radiation therapy
Particle radiation *(electrons, protons, neutrons etc.)*			
	Secondary electromagn. radiation: 10^{21} - 10^{23}		Radiation therapy
Acoustic field: *sound waves*			
Ultrasound	10^6 - 10^7	CTG, US imaging	Physical US therapy

BASIC CONCEPTS

- Imaging is *non-invasive*, *in vivo* diagnostic method
- *Projection / tomographic* (imaging)
- Tomographic orientations:
  - A. Transverse=axial=transaxial
  - B. Coronal = frontal
  - C. Sagittal
- Digital 2D image is a matrix of picture elements = *pixels*
- Digital 3D image consists of volume elements=*voxels*



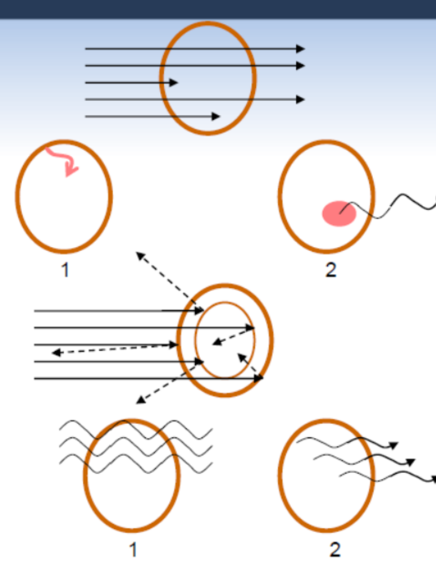
PHYSICAL PRINCIPLES OF CLINICAL IMAGING METHODS

X-ray: TRANSMISSION of X-rays

Nuclear Medicine: EMISSION of gamma rays

Ultrasound imaging: REFLECTION of ultrasound

MRI: RESPONSE to RF field



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The Need for Multimodality

Previously images

- provided structural and morphological information

now

- provides new information about function and molecular composition and interaction.

The use of imaging can reduce the need for invasive tests, such as biopsy.

Multimodality imaging

- different technologies to view the same tissue

molecular and functional information

- relating to disease specific processes, can be overlayed on a structural image

medical team can identify the precise location of any defects

first combinations

- PET-CT and SPECT-CT

whereby the molecular image information is superimposed on a structural CT X-ray

Recent

- MR-PET
- can combine structural and functional information

such as detailed fibre tracking of the nerves from MRI with the molecular and metabolic information from PET images *the technologies are synergistic*



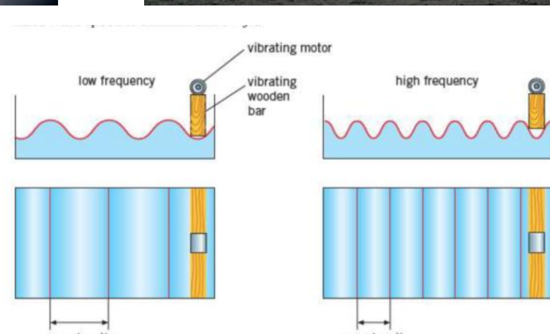


Figure 14.7 Ripple tank patterns for low- and high-frequency vibrations

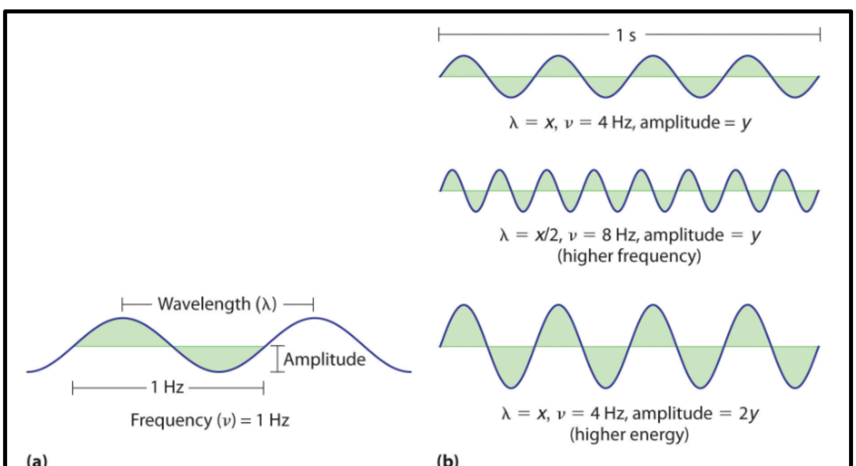
It is part of our everyday life

- visible light
- infra-red
- ultra-violet light
- radio waves
- X-rays
- gamma-rays

All types of electromagnetic radiation.

So, what is electromagnetic radiation?

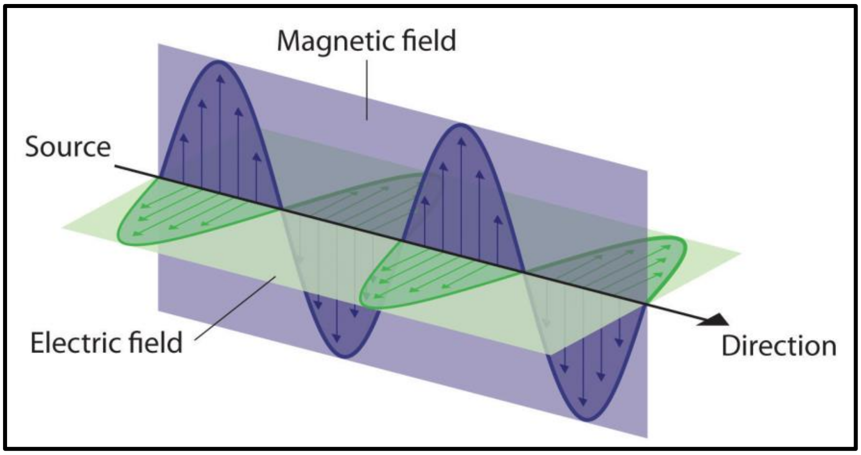
- It consists of two perpendicular fields: an electric field and a magnetic field.
- The two fields are sinusoidal and in phase, which means that as they oscillate, they both pass through zero at the same point in time.



The energy moves or propagates in the direction

- which is perpendicular to the two oscillating fields
- The wavelength is the distance required to complete one full cycle of the wave ➔ lambda λ

Important Properties of Waves (a) Wavelength (λ in meters), frequency (v, in Hz), and amplitude are indicated on this drawing of a wave. (b) The wave with the ***shortest wavelength has the greatest number of wavelengths*** *per unit time (i.e., the highest frequency). If two waves have the same frequency and speed, the one with the greater amplitude has the higher energy.*



The energy moves or propagates in the direction

- which is perpendicular to the two oscillating fields
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Electromagnetic radiation has an important property: it is self-propagating. Simply put, the oscillating magnetic field produces an oscillating electric field, and the oscillating electric field produces an oscillating magnetic field. This means, that it doesn't need the source to continue to add energy, **unlike other forms of EM Fields, such as magnetic fields or static electricity**.

These only occur close to the source.

once electromagnetic radiation has been produced

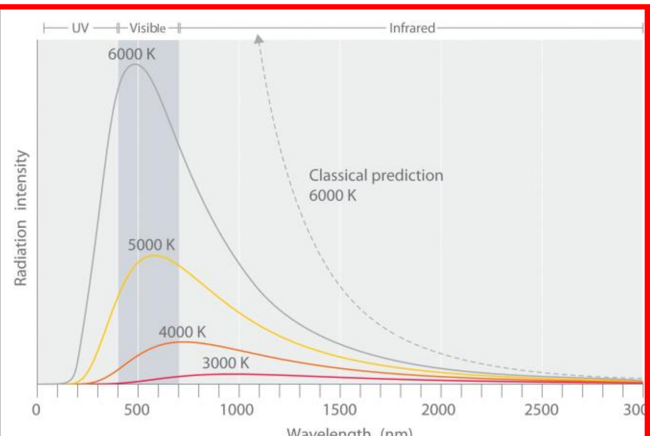
- transmitter can no longer influence it
- it will continue to move in a straight line unless it encounters something that can slow it down, stop it, or absorb it

history of the science surrounding EM radiation in just over 150 years

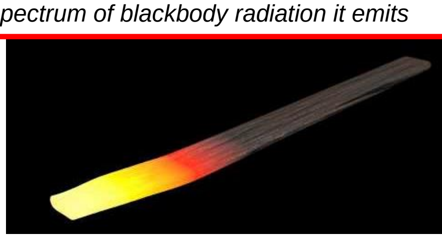
- 1865, Maxwell published "A Dynamical Theory of the Electromagnetic Field". He discovered that light is a wave.

In 1900, Max Planck proposed that the energy in light could only be emitted or absorbed in discrete amounts. That is the energy of light is quantized. It is not done in random amounts

This was the beginning of what we now call Quantum Theory.



Relationship between the temperature of an object and the spectrum of blackbody radiation it emits



low temperatures

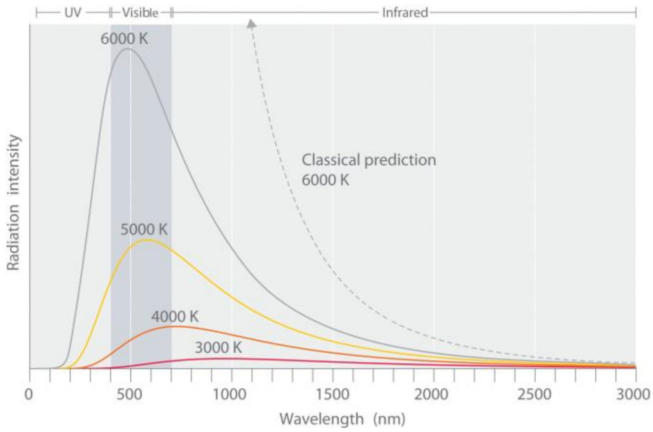
- *most radiation is emitted at wavelengths longer than 700 nm ➔ infrared*

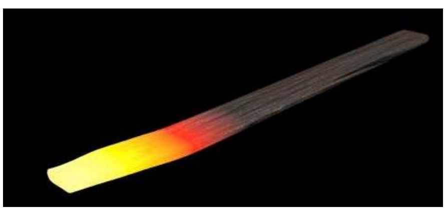
Temperature of the object increases

- *maximum intensity shifts to shorter wavelengths*
- *successively resulting in orange, yellow, and finally white light*

At high temperatures

- *all wavelengths of visible light are emitted with approximately equal intensities.*





The white light spectrum shown for an object at 6000 K closely approximates the spectrum of light emitted by the sun.

The sharp decrease

- *in the intensity of radiation emitted at wavelengths below 400 nm, which constituted the ultraviolet catastrophe*

The classical prediction fails to fit the experimental curves entirely and does not have a maximum intensity.

Importantly, Planck recognised

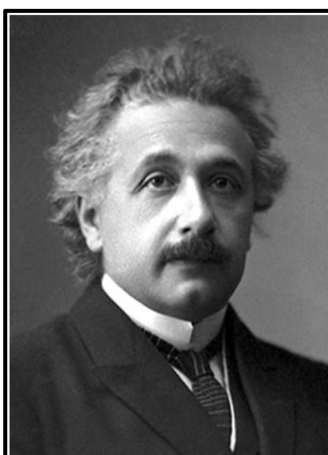
- the energy was related to the frequency of the light.
- Previously, it was the intensity of the light that determined how it interacted with matter

Planck's equation defines that relationship whereby the energy is directly proportional to the frequency, and the proportionality constant, h, is now called Planck's constant.

In 1905, Einstein went a step further

- light has mass and momentum
- demonstrated it through the Photoelectric effect

light could displace an electron and cause a current to flow. He postulated that light consisted of particles, just like electrons.

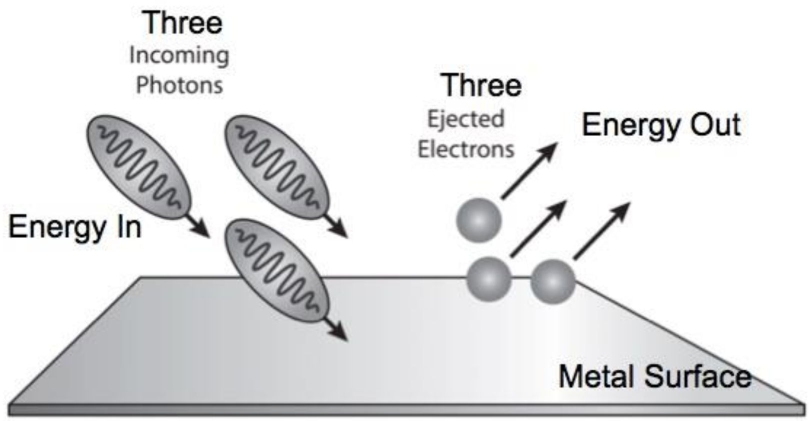


March, 1905: Twenty six year old Albert Einstein demonstrates the particle nature of light by explaining the photoelectric effect.

He won the Nobel Prize for that in 1921.

Photoelectric Effect

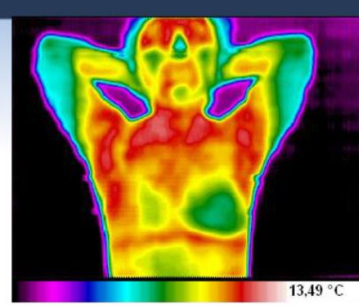
- Energy In > Energy Out   What absorbed the missing energy?

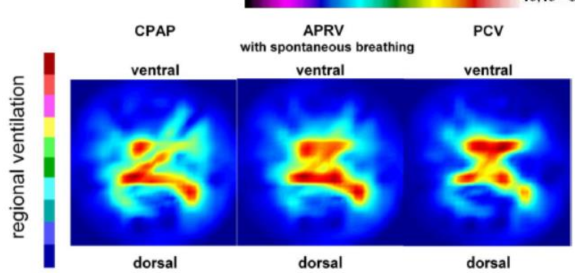


IMAGING METHODS IN PROGRESS

- Thermography
- Electrical impedance tomography
- Optical tomography

* (high-resolution EEG and MEG: signals, not images)

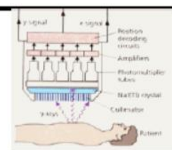


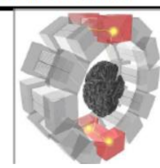


EVOLUTION OF IMAGING METHODS

A / D	METHOD	SINGLE DETECTOR	PLANAR IMAGING	TOMOGRAPHIC IMAGING
ANALOG	**X-ray**	-	projection radiography	X-ray tomography
	Scintigraphy	gamma counter	-	-
	Ultrasound	A-scan, M-scan, Doppler	-	B-scan
	MRI	NMR spectrometry	-	-
DIGITAL	**X-ray**	-	**digital radiography**	**CT**
	Scintigraphy	gamma counter	**digital scintigraphy**	**SPECT, PET**
	Ultrasound	A-scan, M-scan, Doppler	**digital US imaging**	-
	MRI	NMR spectrometry	-	**MRI scanner**

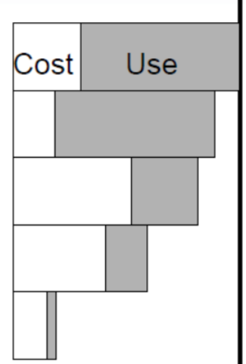
evolution



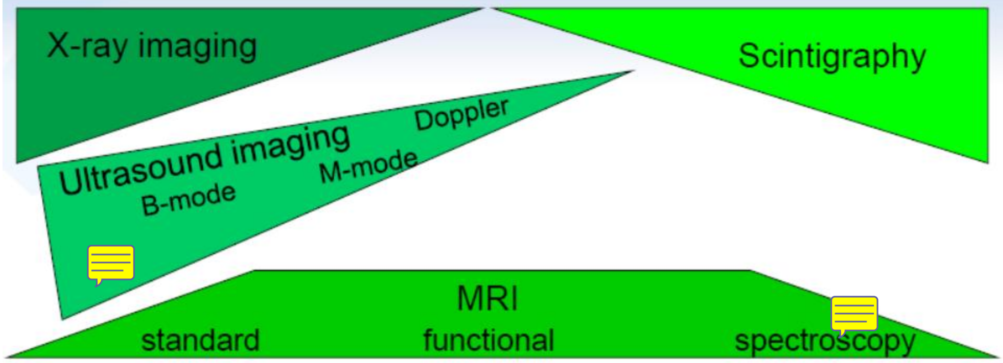


PROPERTIES OF IMAGING METHODS

METHOD	PRINCIPLE	ACTIVE IN IMAGING PROCESS	BENEFIT ANALYSIS
X-ray imaging	Transmission	Field / radiation	
Ultrasound			
MRI			
Scintigraphy			
Thermography	Emission	Tissue	



INFORMATION OF IMAGING METHODS



ANATOMY – FUNCTION – PHYSIOLOGY – METABOLY

GENERAL COMPARISON OF MEDICAL IMAGING METHODS

X-ray imaging

transmission, ionizing, high resolution,
especially for structure of hard tissues

Scintigraphy (Nuclear medicine, gamma imaging)

emission, ionizing, poor resolution,
for metaboly

Ultrasound imaging

reflection, non-ionizing, average resolution,
especially for function

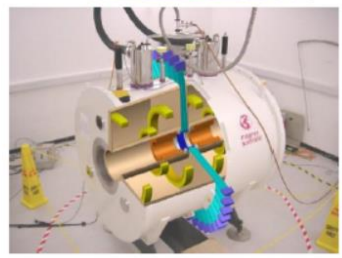
Magnetic resonance imaging

response, non-ionizing, high resolution,
especially for soft tissues

COMBINATION OF SCANNERS

PET-CT: Already in clinical use

PET-MRI: In progress



INVASIVE IMAGING

Interventional angiography: clinical routine for about 50 years

Interventional MRI: In progress

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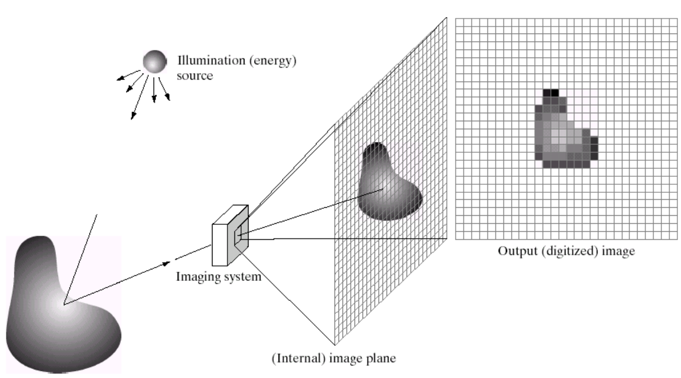
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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

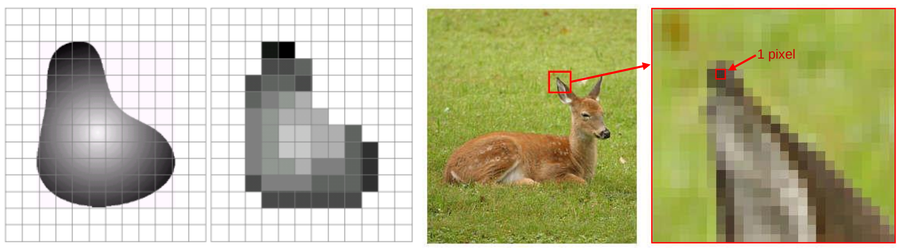


What is a Digital Image? (cont…)

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

•Pixel values typically represent gray levels, colours, heights, opacities etc

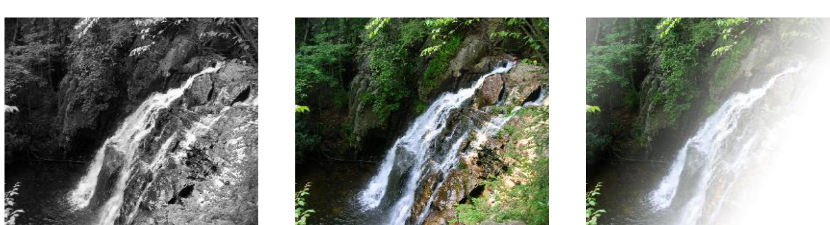
•**Remember** *digitization* implies that a digital image is an *approximation* of a real scene



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)



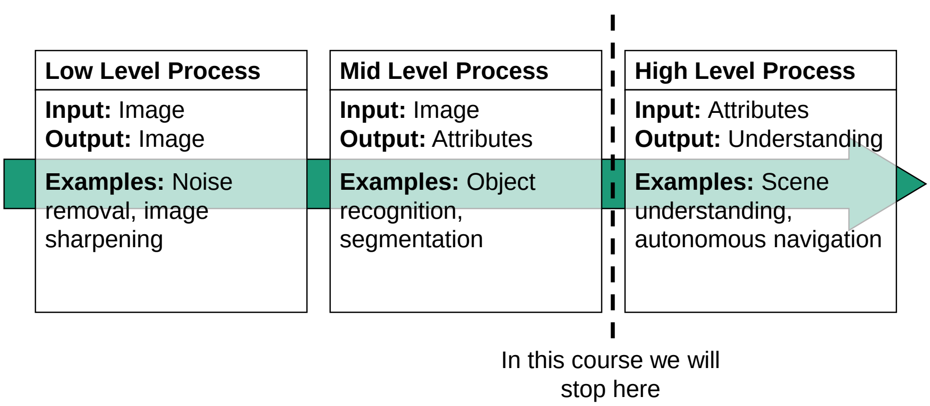
•For most of this course we will focus on grey-scale images

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
- Where image processing ends and fields such as image analysis and computer vision start?

What is DIP? (cont…)

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



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

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
- Pictures were **coded for cable transfer and reconstructed at the receiving end** on a telegraph printer

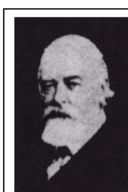
Early digital image

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

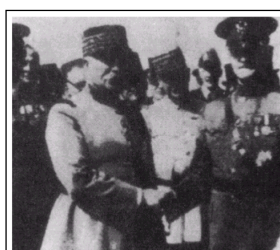
History of DIP (cont…)

•**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

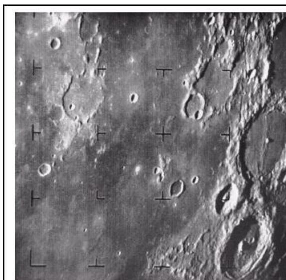


Early 15 tone digital image

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…)

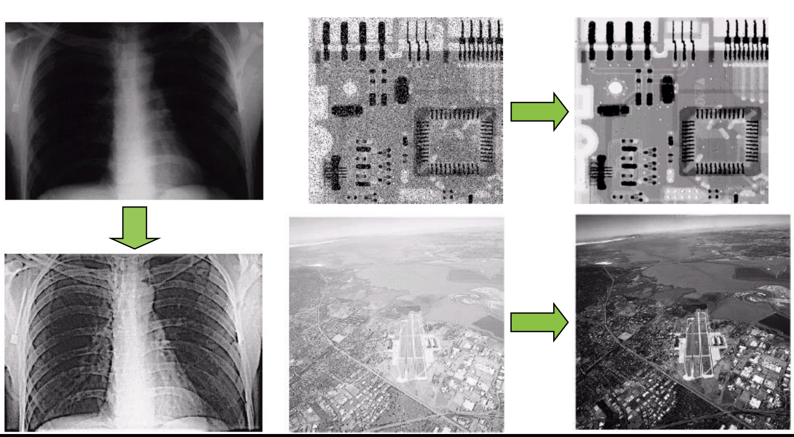
•**1980s - Today:** The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas

- Image enhancement/restoration
- Artistic effects
- Medical visualisation
- Industrial inspection
- Law enforcement
- Human computer interfaces

Examples: Image Enhancement

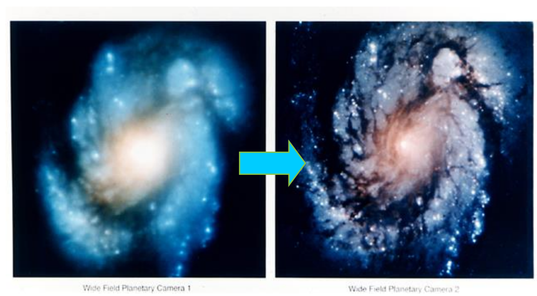
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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



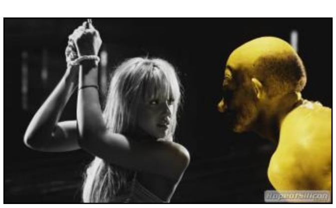
Examples: The Hubble Telescope

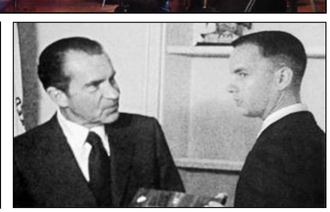
- Launched in 1990 the Hubble telescope can take images of very distant objects
- However, an incorrect mirror made many of Hubble's images useless
- Image processing techniques were used to fix this



Examples: Artistic Effects

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



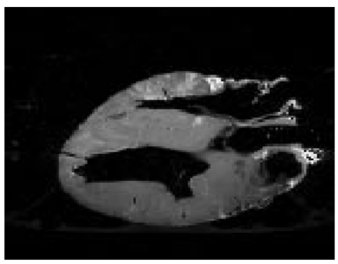


Examples: Medicine

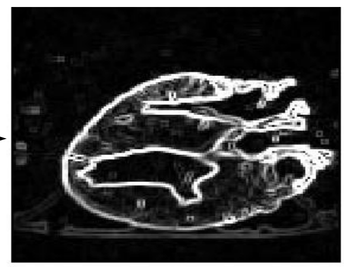
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

•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



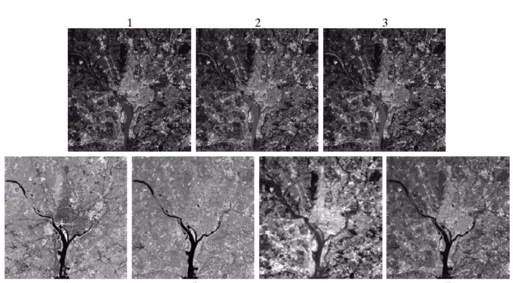
Edge Detection Image

Examples: GIS

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

•Geographic Information Systems

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



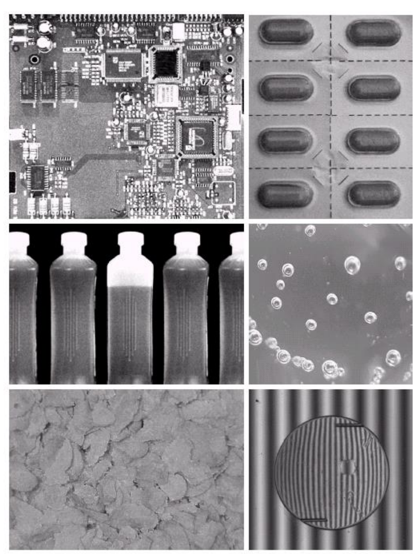
Examples: GIS (cont…)

- *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

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

Examples: Industrial Inspection

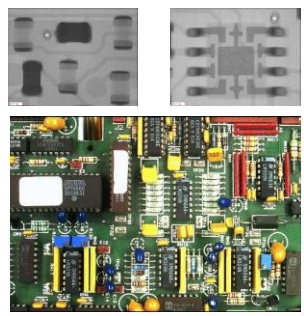
- Human operators are expensive, slow and unreliable
- Make machines do the job instead
- Industrial vision systems are used in all kinds of industries
- Can we trust them?



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

Examples: PCB Inspection

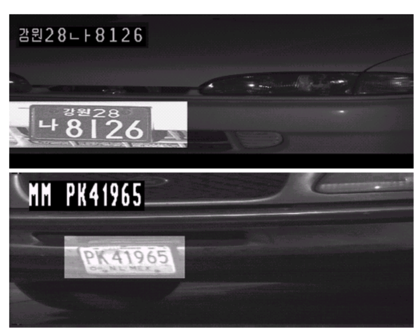
•Printed Circuit Board (PCB) inspection
- Machine inspection is used to determine that all components are present and that all solder joints are acceptable
- Both conventional imaging and x-ray imaging are used

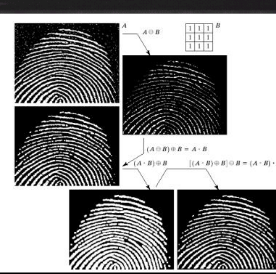


Examples: Law Enforcement

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

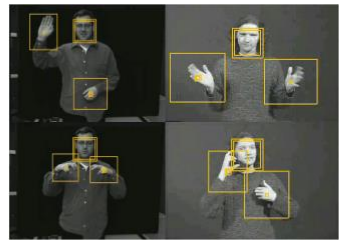
•Image processing techniques are used extensively by law enforcers
- Number plate recognition for speed cameras/automated toll systems
- Fingerprint recognition
- Enhancement of CCTV images



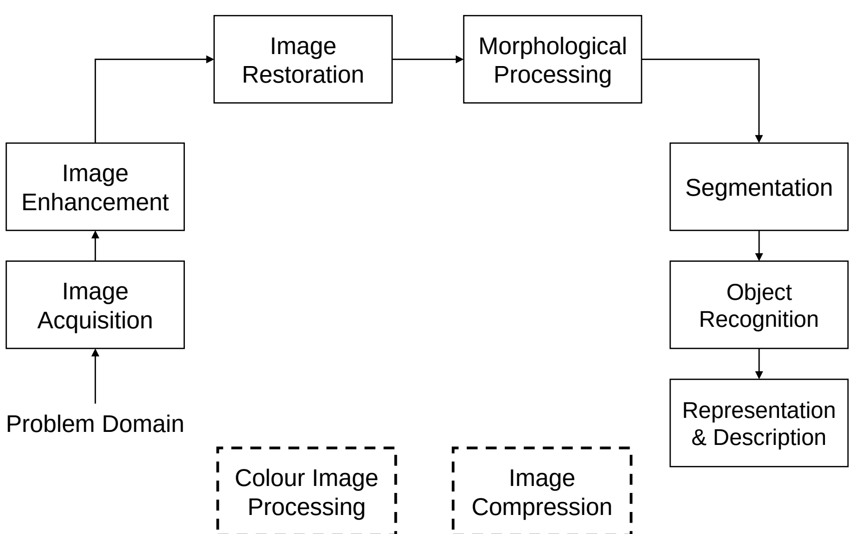


Examples: HCI

- 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

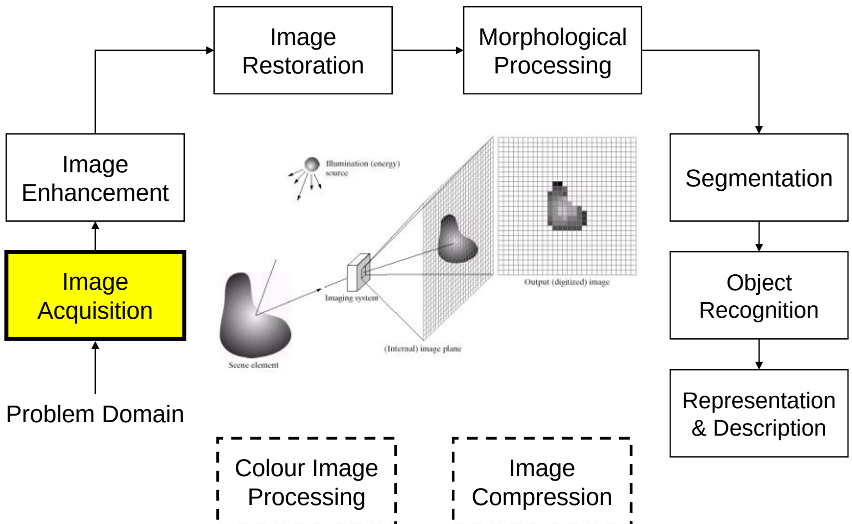


Key Stages in Digital Image Processing



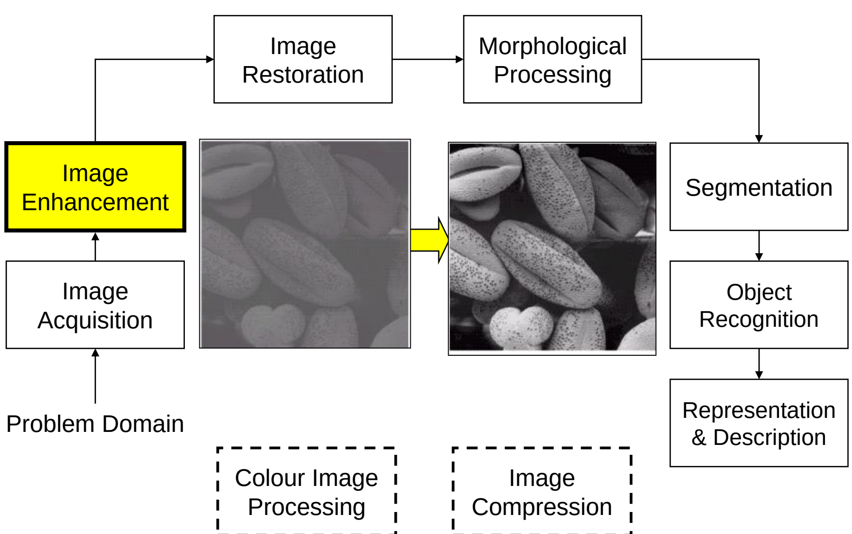
Key Stages in Digital Image Processing: Image Aquisition

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



Key Stages in Digital Image Processing: Image Enhancement

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



Key Stages in Digital Image Processing: Image Restoration

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

Image Restoration

Morphological Processing

Image Enhancement

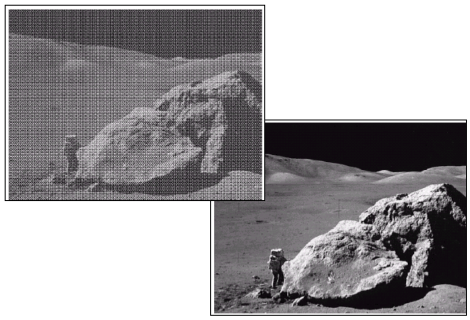
Segmentation

Image Acquisition

Object Recognition

Representation & Description

Problem Domain



Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Morphological Processing

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

Image Restoration

Morphological Processing

Image Enhancement

Segmentation

Image Acquisition

Object Recognition

Representation & Description

Problem Domain

Colour Image Processing

Image Compression

Key Stages in Digital Image Processing: Segmentation

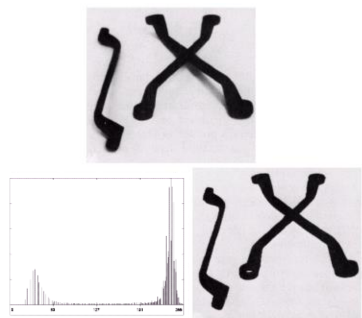
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration

Colour Image Processing

Image Compression



Key Stages in Digital Image Processing: Object Recognition

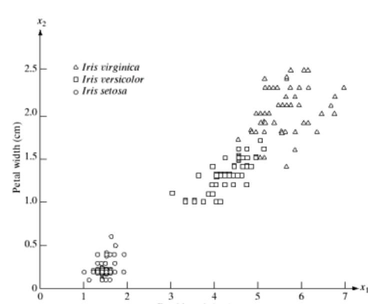
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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

Problem Domain → Image Acquisition → Image Enhancement → Image Restoration

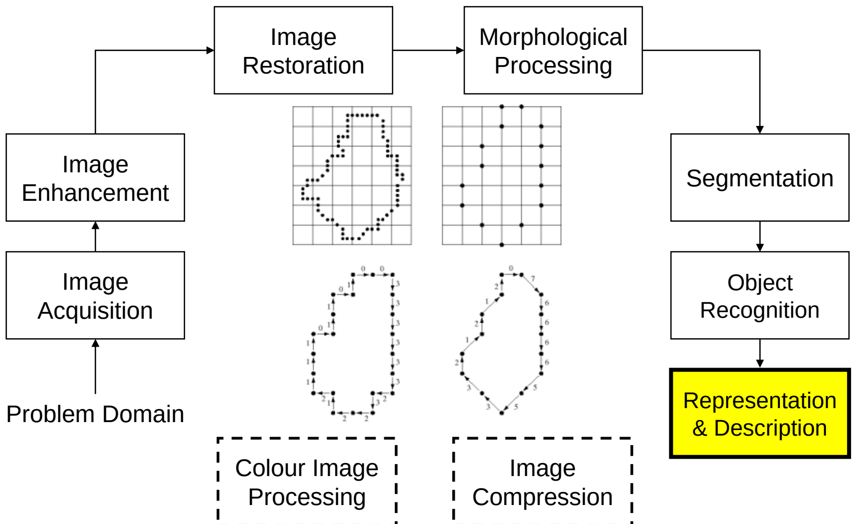
Colour Image Processing

Image Compression

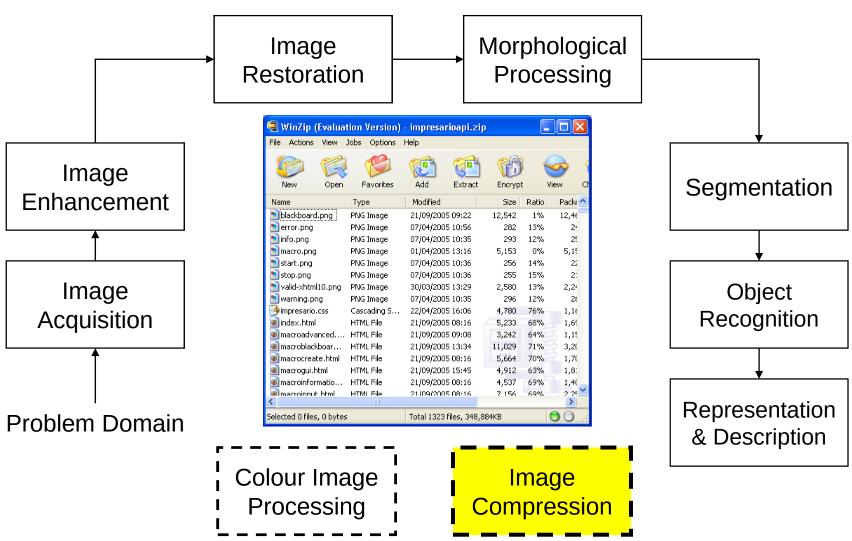


Key Stages in Digital Image Processing: Representation & Description

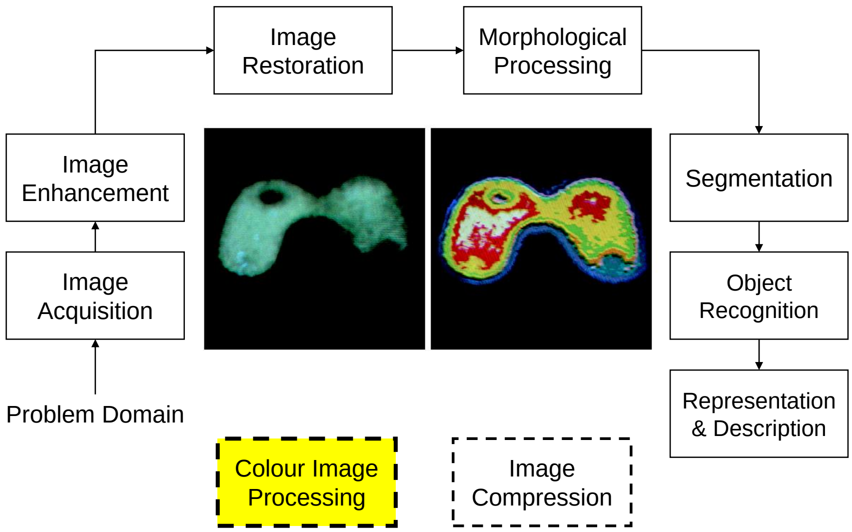
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Key Stages in Digital Image Processing: Image Compression



Key Stages in Digital Image Processing: Colour Image Processing



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 week we start to see how it all works…

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Eraj
Lecture: 4

Slides adopted from lectures of Dr. Brian Mac Namee

Contents

This lecture will cover:

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

Human Visual System

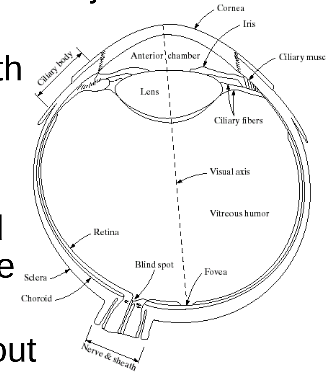
The best vision model we have!

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



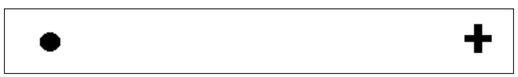
The retina is covered with light receptors called *cones* (6-7 million) and *rods* (75-150 million)

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

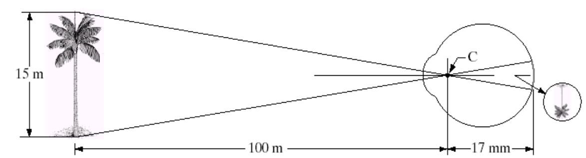
Hold the image about 20 inches away from your face and move it slowly towards you

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

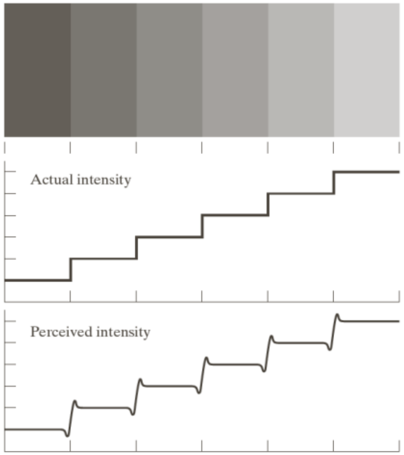
An image is focused onto the retina causing rods and cones to become excited which ultimately send signals to the brain



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 (cont…)



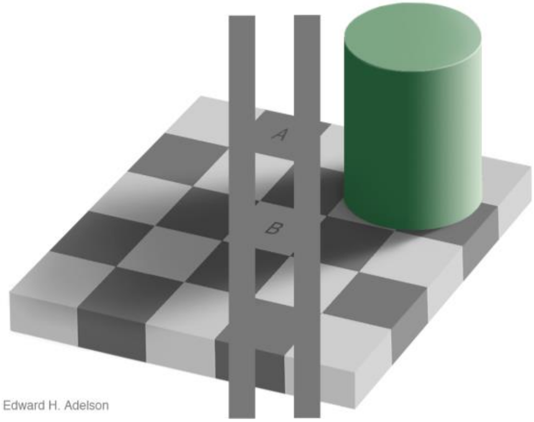
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

9 of 42 Brightness Adaptation & Discrimination (cont…)

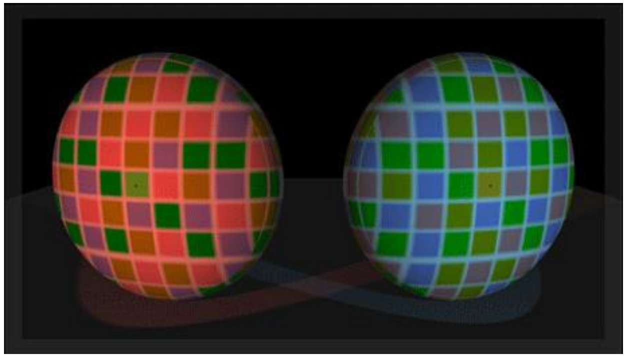
An example of *simultaneous contrast*

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

10 of 42 Brightness Adaptation & Discrimination (cont…)



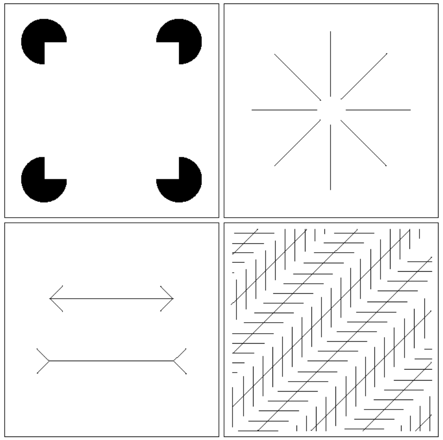
For more great illusion examples take a look at: http://web.mit.edu/persci/gaz/



Available here: http://www.lottolab.org/Visual%20Demos/Demo%2015.html

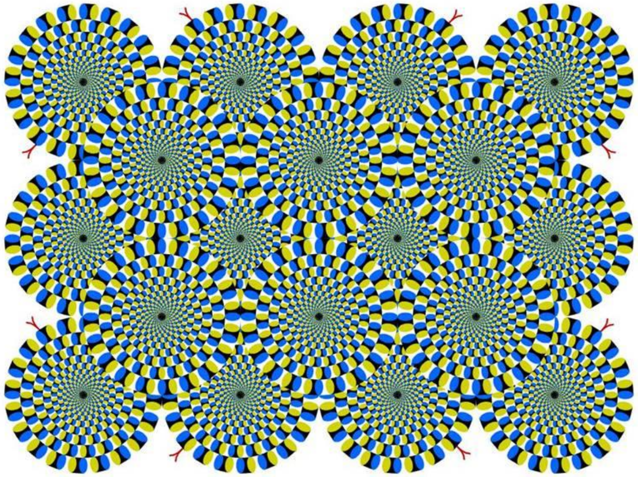
Optical Illusions

Our visual systems play lots of interesting tricks on us



13
of
42

If something's rotating – go home, you need a break! *g*



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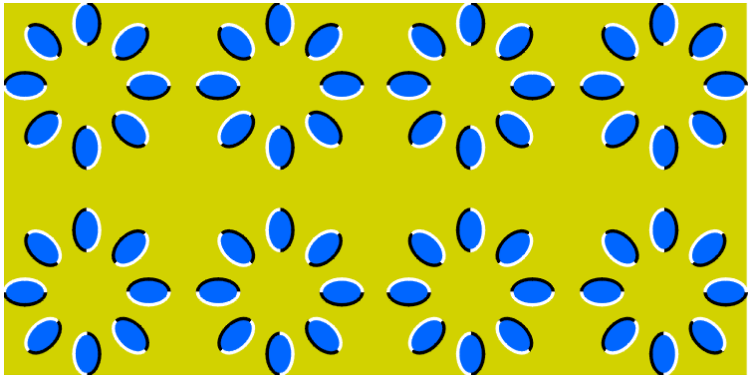
of
42

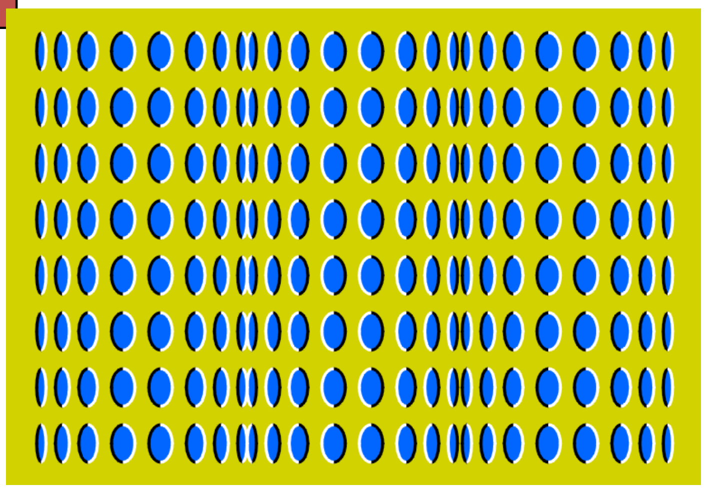
Optical Illusions and Visual Phenomena

Want to confuse your eyes and brain a bit?

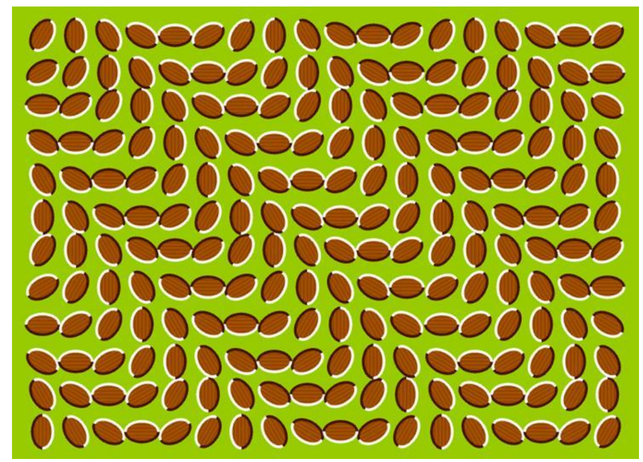
Yes? Then you might want to have a look at the following pics ..



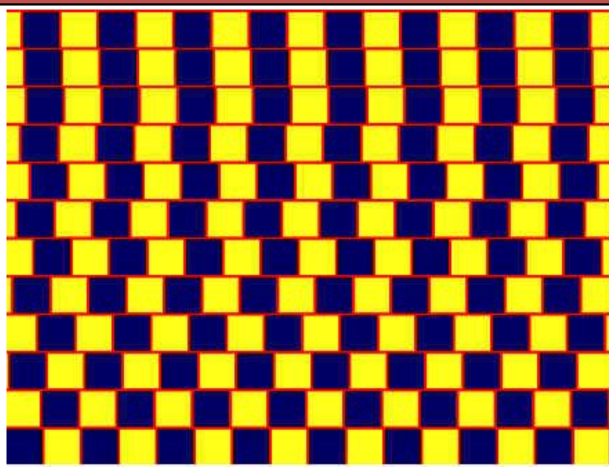
It …

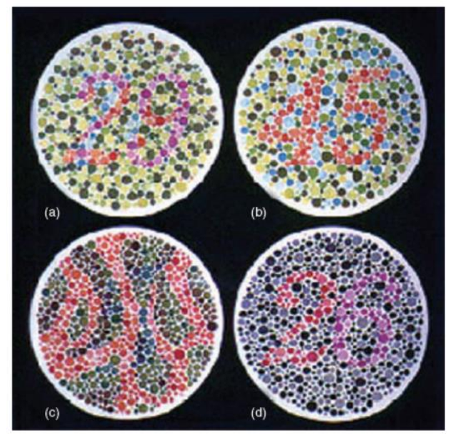


… doesn't move!



... parallel or not?





4 Sex-linked traits:

1. Normal color vision:
A: 29, B: 45, C: --, D: 26

2. Red-green color-blind:
A: 70, B: --, C: 5, D: --

3. Red color-blind:
A: 70, B: --, C: 5, D: 6

4. Green color-blind:
A: 70, B: --, C: 5, D: 2

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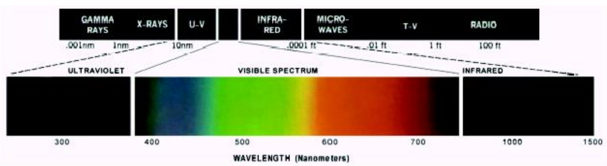
of
42

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



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of
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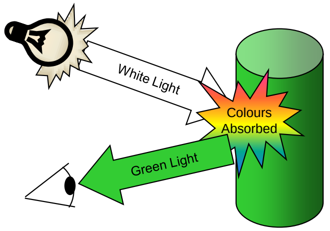
Reflected Light

- 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



Sampling, Quantisation And Resolution

In the following slides we will consider what is involved in capturing a digital image of a real-world scene

- Image sensing and representation
- Sampling and quantisation
- Resolution

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

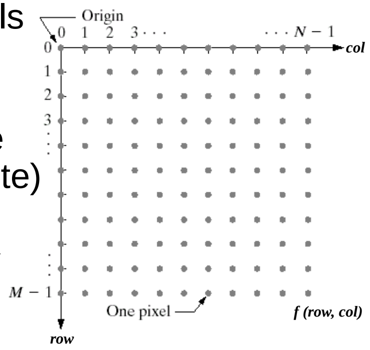
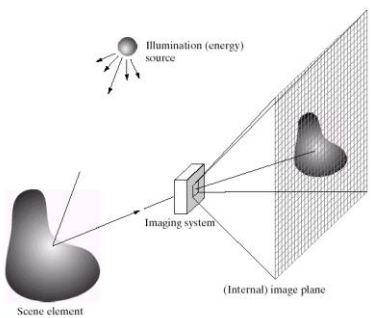


Image Acquisition

Images are typically generated by ***illuminating*** a *scene* and **absorbing the energy** reflected by the objects in that scene

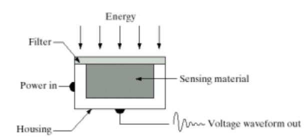


– Typical notions of illumination and scene can be way off:
  - X-rays of a skeleton
  - Ultrasound of an unborn baby
  - Electro-microscopic images of molecules

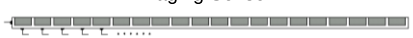
Image Sensing

Incoming energy lands on a sensor material responsive to that type of energy and this generates a voltage

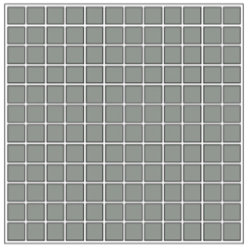
Collections of sensors are arranged to capture images



Imaging Sensor

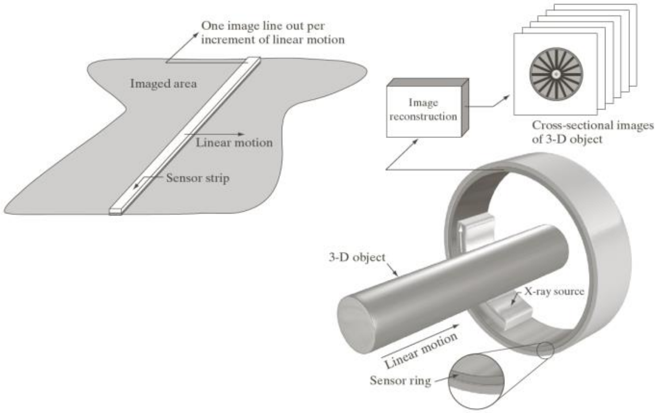


Line of Image Sensors



Array of Image Sensors

Image Sensing



Using Sensor Strips and Rings

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

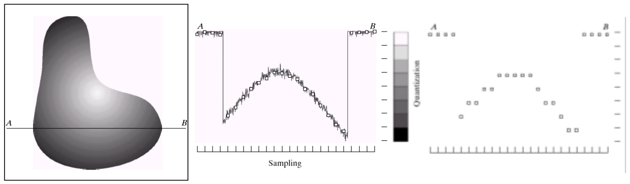


Image Sampling And Quantisation

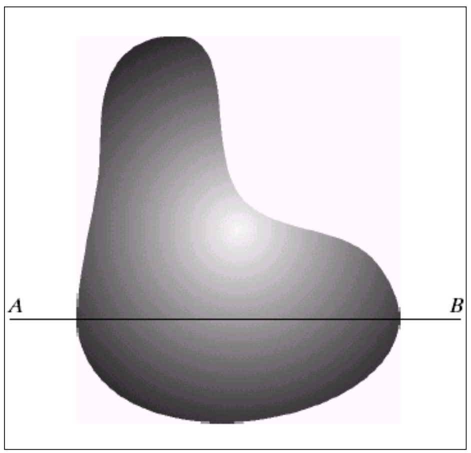
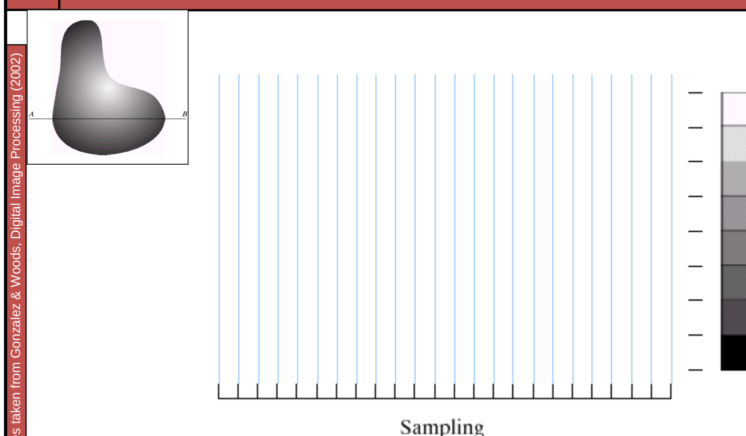


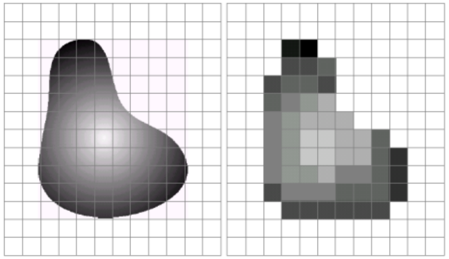
Image Sampling And Quantisation



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

Image Sampling And Quantisation (cont…)

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



Spatial Resolution

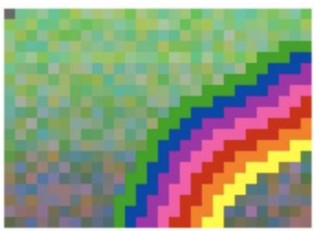
The spatial resolution of an image is determined by how sampling was carried out

Spatial resolution simply refers to the smallest discernable detail in an image

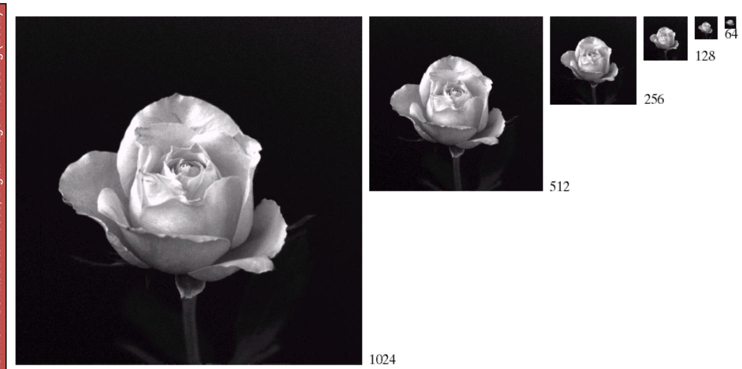
- Vision specialists will often talk about pixel size
- Graphic designers will talk about *dots per inch* (DPI)

PPI describes the **number of square pixels** that show up **in an inch** of digital screen (usually between 67-300).

DPI, on the other hand, is a printing term referring to the number of **physical dots** of ink in a printed document.

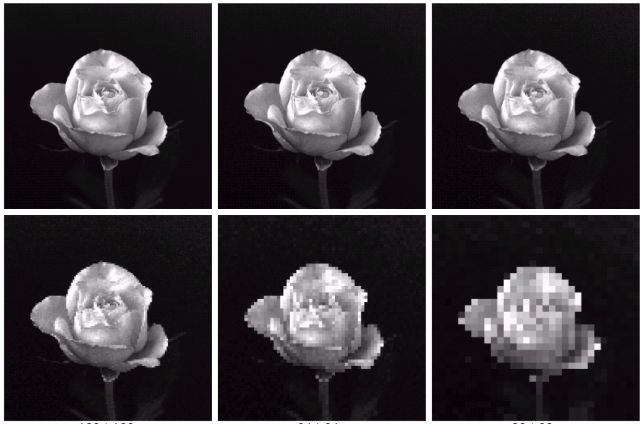


Spatial Resolution (cont…)



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

Spatial Resolution (cont…)



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

Intensity Level Resolution

Intensity level resolution refers to the number of intensity levels used to represent the image

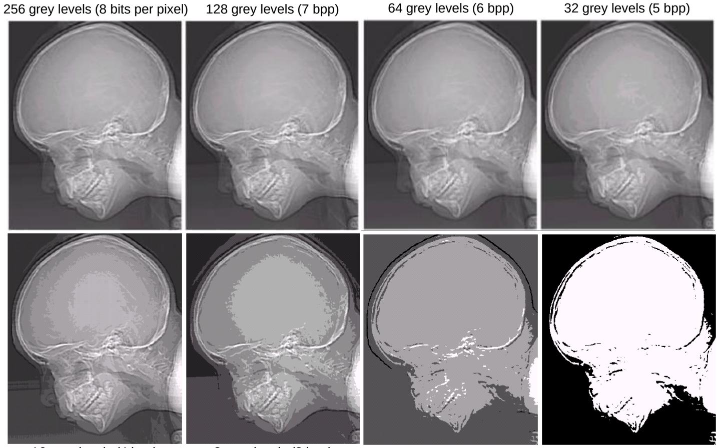
- The more intensity levels used, the finer the level of detail discernable in an image
- Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Intensity Level Resolution (cont…)

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

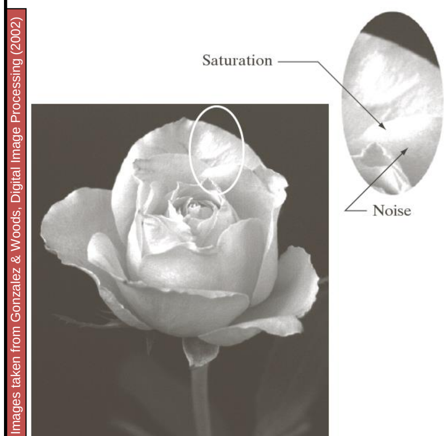
256 grey levels (8 bits per pixel) | 128 grey levels (7 bpp) | 64 grey levels (6 bpp) | 32 grey levels (5 bpp)



16 grey levels (4 bpp) | 8 grey levels (3 bpp) | 4 grey levels (2 bpp) | 2 grey levels (1 bpp)

Saturation & Noise

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

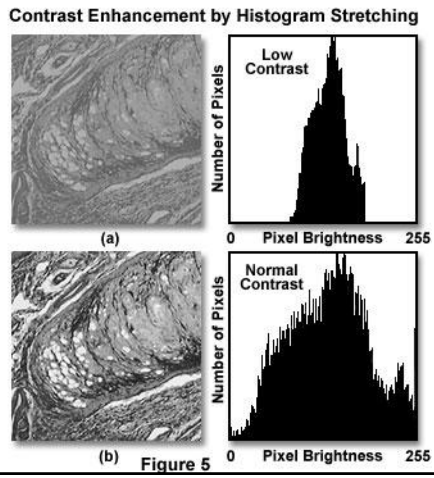


Saturation

- Highest value beyond which all intensity levels are clipped
- High contrast

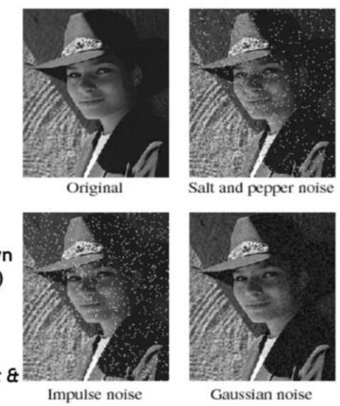
Noise

- Grainy texture patterns



Common Types of Noise

- Salt & pepper noise
  - Random occurrences of black and white pixels
- Impulse noise
  - Random occurrences of white pixels
- Gaussian noise
  - Variations in intensity drawn from a Gaussian ("Normal") distribution.
- *Basic Assumption*
  - *Noise is i.i.d. (independent & identically distributed)*



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? (cont…)

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

Intensity Level Resolution (cont…)

Low Detail | Medium Detail | High Detail

Summary

We have looked at:

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

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Eraj
Lecture: 5

Slides adopted from lectures of Dr. Brian Mac Namee

A Note About Grey Levels

So far when we have spoken about image grey level values we have said they are in the range [0, 255]

- Where 0 is black and 255 is white

There is no reason why we have to use this range

- The range [0,255] stems from display technologes

For many of the image processing operations in this lecture grey levels are assumed to be given in the range [0.0, 1.0]

What Is Image Enhancement?

Image enhancement is the process of making images more useful

The reasons for doing this include:

- Highlighting interesting detail in images
- Removing noise from images
- Making images more visually appealing

Image Enhancement Examples

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

Image Enhancement Examples (cont…)

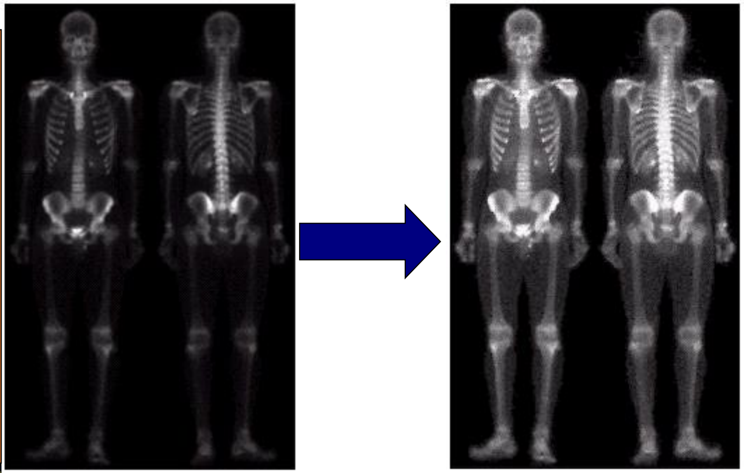


Image Enhancement Examples (cont…)

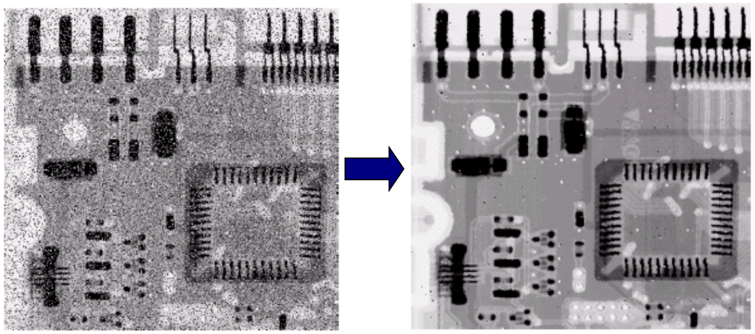


Image Enhancement Examples (cont…)

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

Spatial & Frequency Domains

There are two broad categories of image enhancement techniques

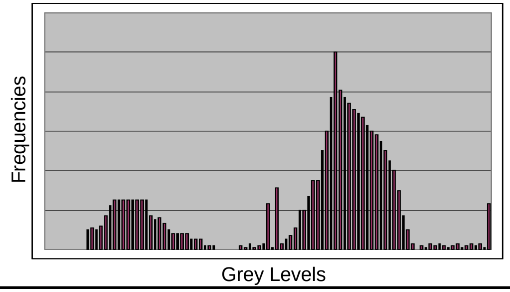
- Spatial domain techniques
  - Direct manipulation of image pixels
- Frequency domain techniques
  - Manipulation of Fourier transform or wavelet transform of an image

For the moment we will concentrate on techniques that operate in the spatial domain

Image Histograms

The histogram of an image shows us the distribution of grey levels in the image

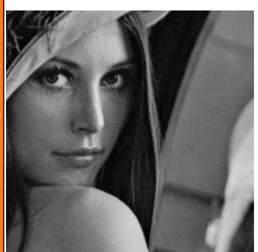
Massively useful in image processing, especially in segmentation

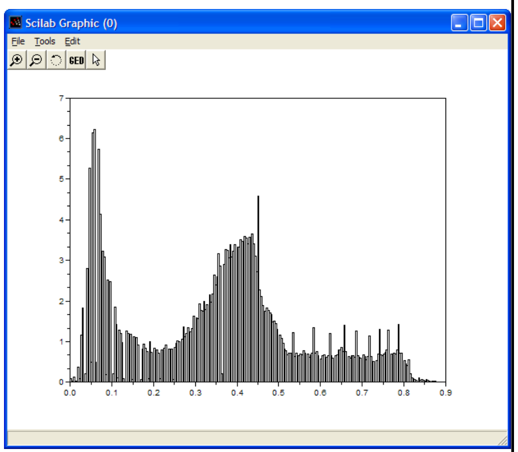


Histogram Examples

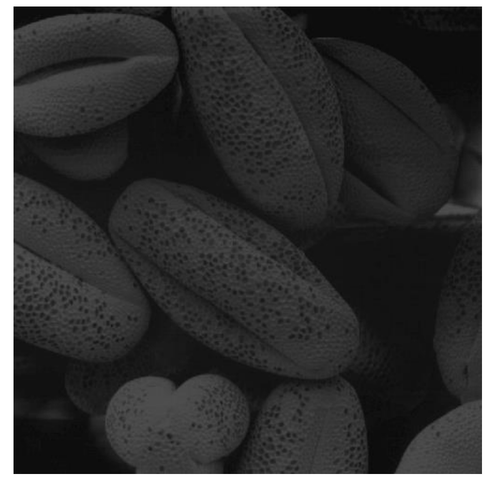
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Examples (cont…)

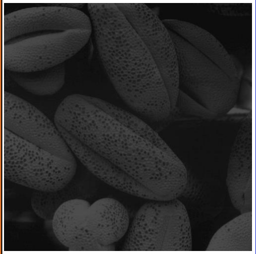


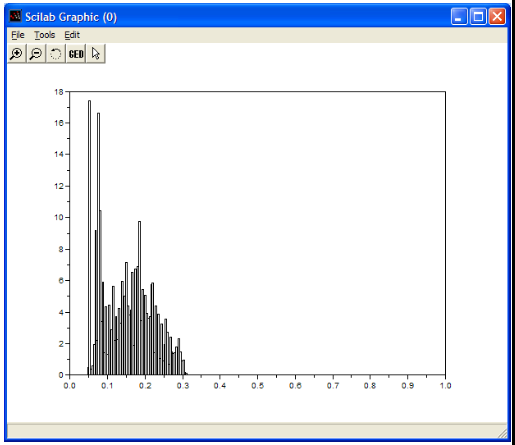


Histogram Examples (cont…)



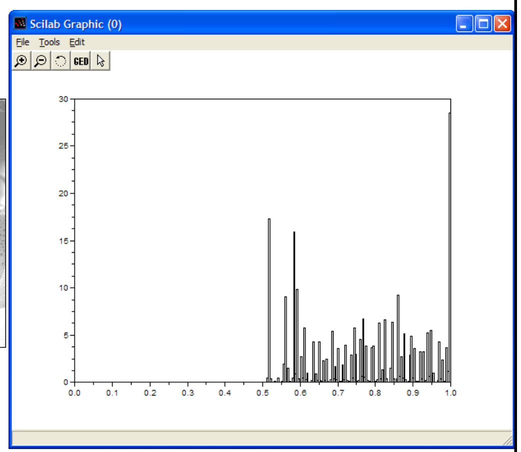
Histogram Examples (cont…)



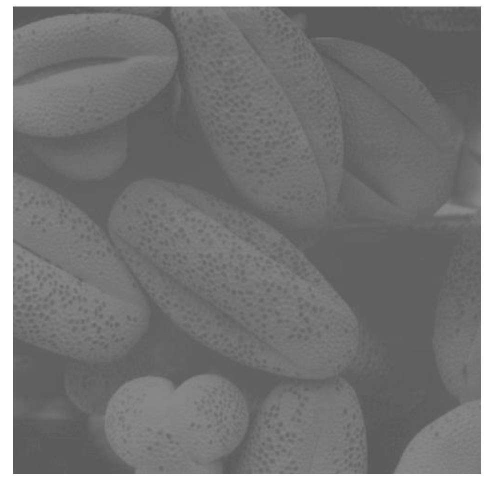


Histogram Examples (cont…)

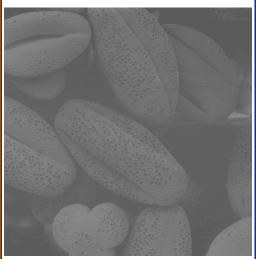
Histogram Examples (cont…)

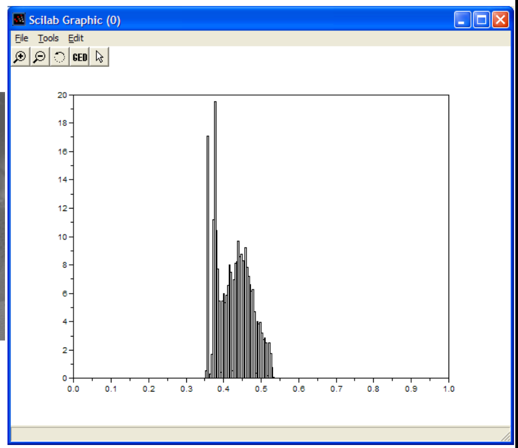


Histogram Examples (cont…)



Histogram Examples (cont…)



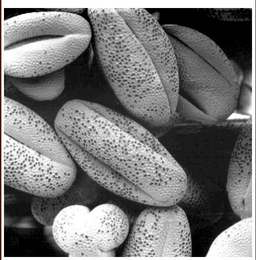


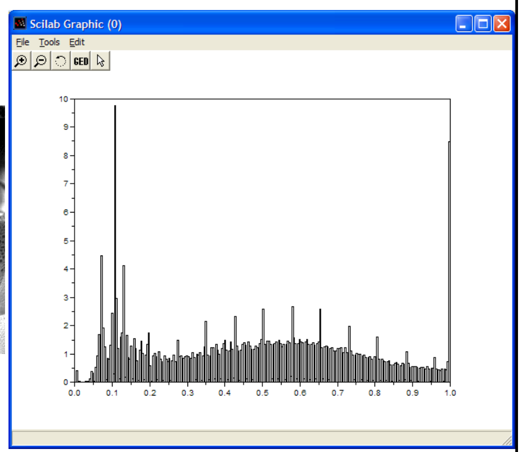
Histogram Examples (cont…)

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

Histogram Examples (cont…)

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





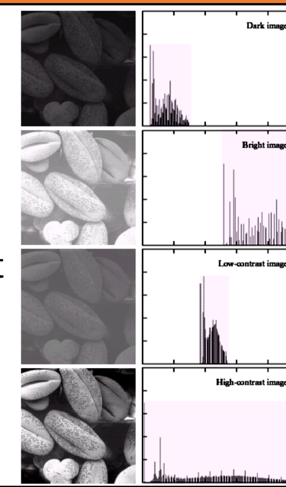
Histogram Examples (cont…)

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

A selection of images and their histograms

Notice the relationships between the images and their histograms

Note that the high contrast image has the most evenly spaced histogram



Contrast Stretching

We can fix images that have poor contrast by applying a pretty simple contrast specification

The interesting part is how do we decide on this transformation function?

Histogram Equalisation

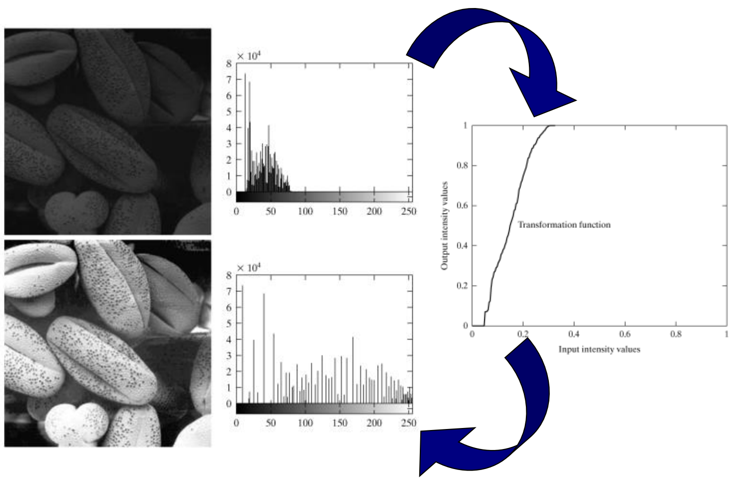
Spreading out the frequencies in an image (or equalising the image) is a simple way to improve dark or washed out images

The formula for histogram equalisation is given where

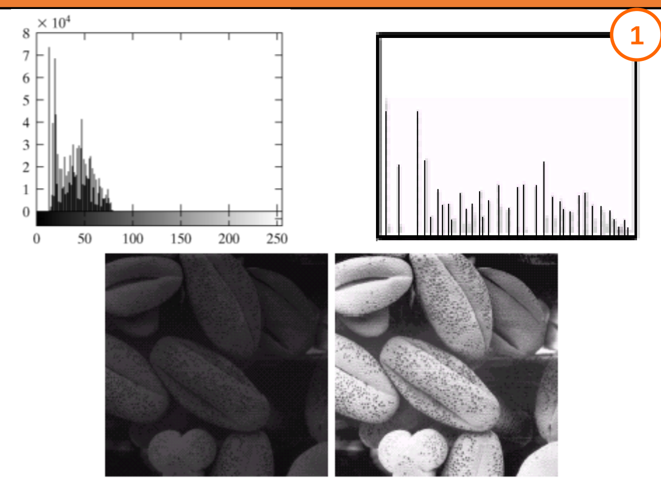
- r_k: input intensity
- s_k: processed intensity
- k: the intensity range (e.g 0.0 – 1.0)
- n_j: the frequency of intensity j
- n: the sum of all frequencies

$$\begin{aligned} s_k &= T(r_k) \\ &= \sum_{j=1}^{k} p_r(r_j) \\ &= \sum_{j=1}^{k} \frac{n_j}{n} \end{aligned}$$

Equalisation Transformation Function

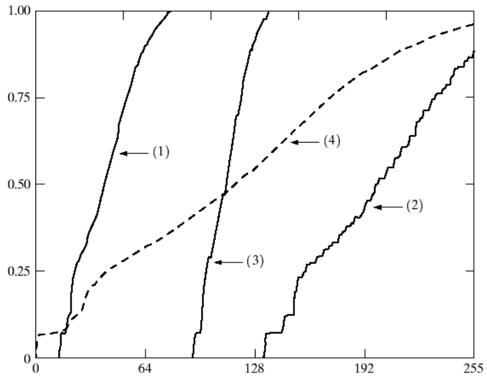


Equalisation Examples



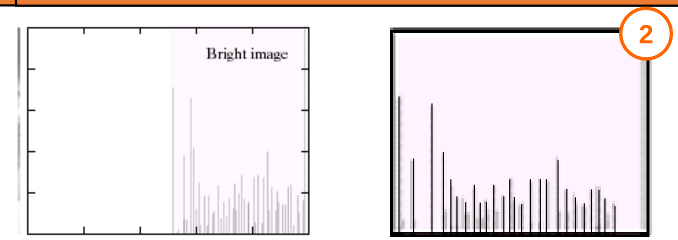
Equalisation Transformation Functions

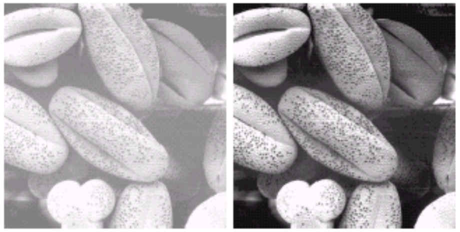
The functions used to equalise the images in the previous example



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

Equalisation Examples

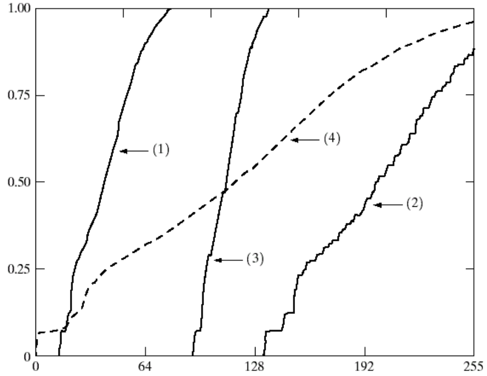




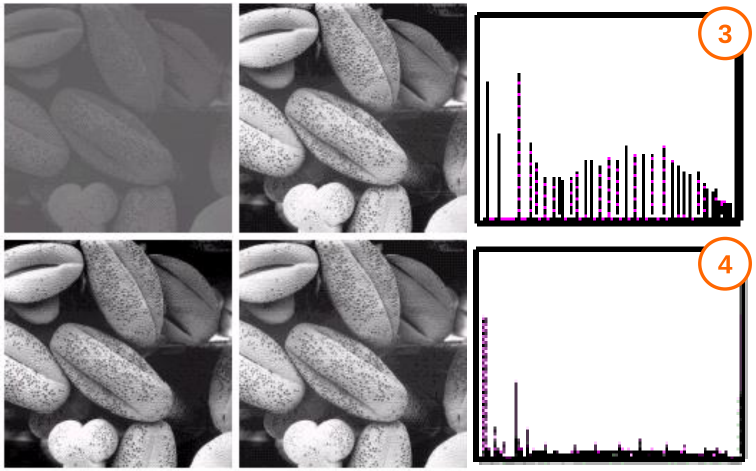
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Equalisation Transformation Functions

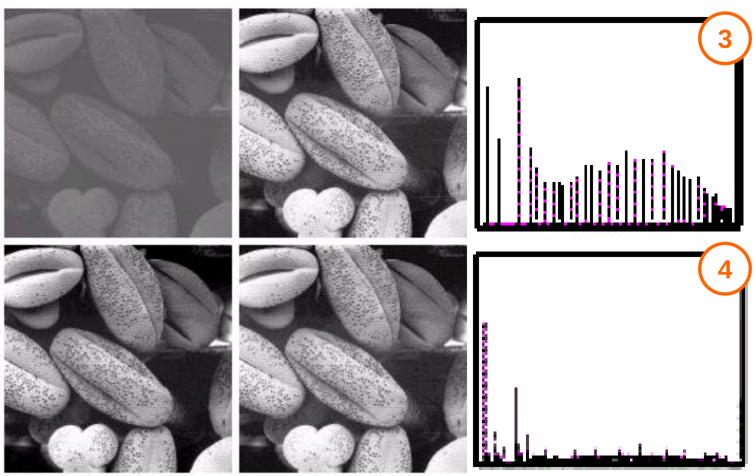
The functions used to equalise the images in the previous example



Equalisation Examples (cont…)

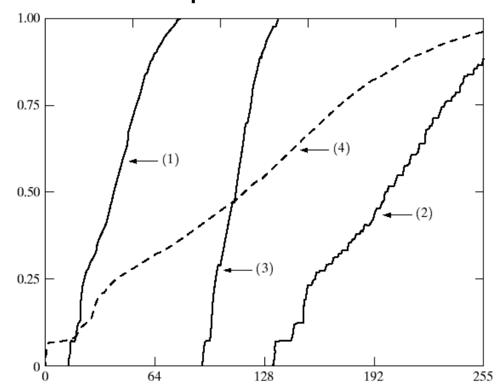


Equalisation Examples (cont…)



Equalisation Transformation Functions

The functions used to equalise the images in the previous examples



Summary

We have looked at:

- Different kinds of image enhancement
- Histograms
- Histogram equalisation

Next time we will start to look at point processing and some neighbourhood operations

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj Humayun Mirza
Lecture: 6

Slides adopted from lectures of Dr. Brian Mac Namee

Image Enhancement
(Point Processing)

Contents

In this lecture we will look at image enhancement point processing techniques:

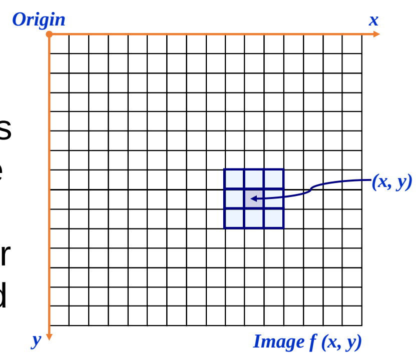
- What is point processing?
- Negative images
- Thresholding
- Logarithmic transformation
- Power law transforms
- Bit plane slicing

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

$$s = T(r)$$

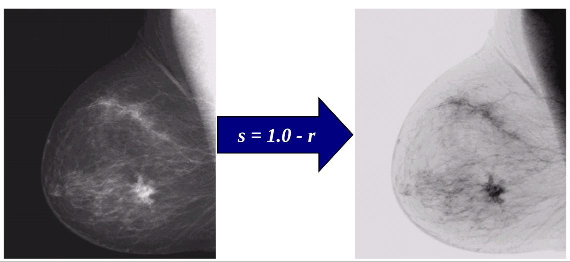
where s refers to the **processed image pixel value** and r **refers to the original image pixel value**

Point Processing Example: Negative Images

Negative images are useful for enhancing white or grey detail embedded in dark regions of an image

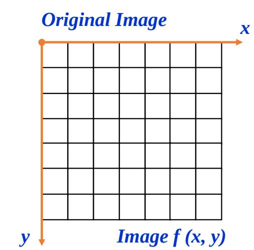
- Note how much clearer the tissue is in the negative image of the mammogram below

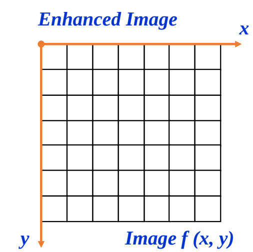
Original Image



Negative Image

Point Processing Example: Negative Images (cont…)



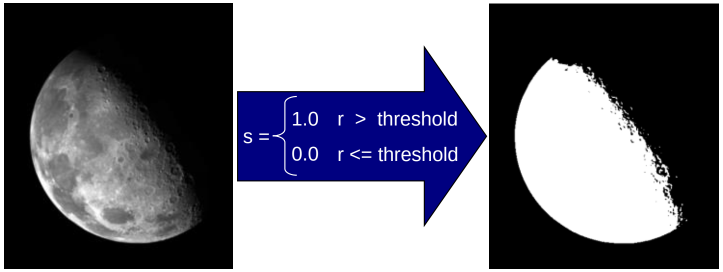


$$s = intensity_{max} - r$$

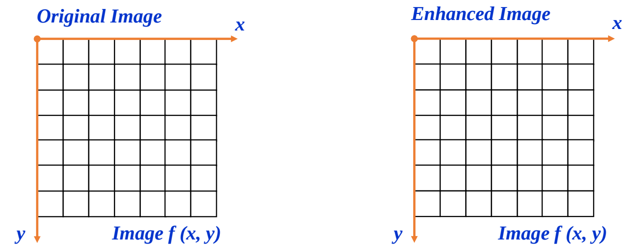
Point Processing Example: Thresholding

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

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



Point Processing Example: Thresholding (cont…)



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

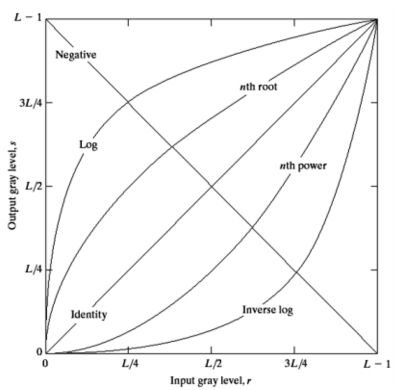
Basic Grey Level Transformations

Logarithmic 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

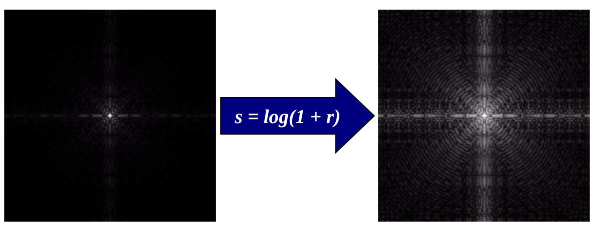
$$s = c * log(1 + r)$$

The log transformation maps a **narrow range of low input grey level values into a wider range** of output values

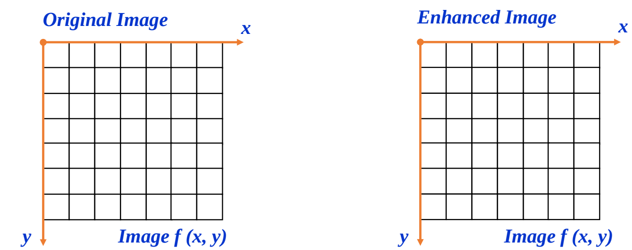
The inverse log transformation performs the opposite transformation

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



Logarithmic Transformations (cont…)



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

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

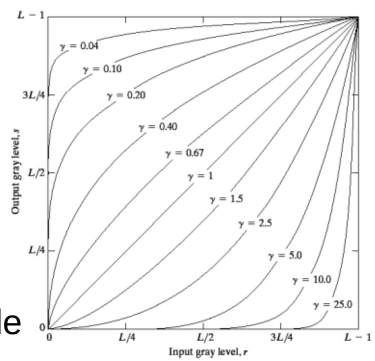
Power Law Transformations

Power law transformations have the following form

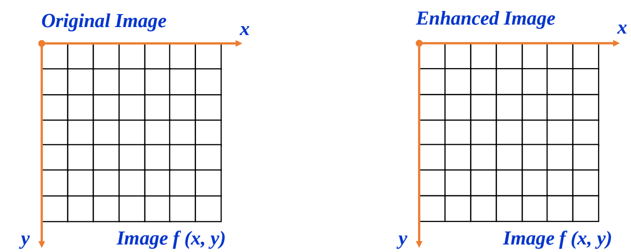
$$s = c * r^{\gamma}$$

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…)



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

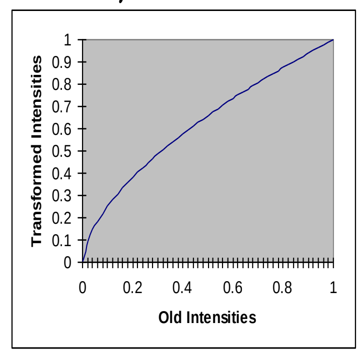
We usually set c to 1

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

Power Law Example

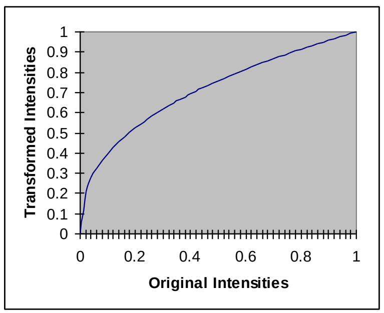
Power Law Example (cont…)

$\gamma = 0.6$



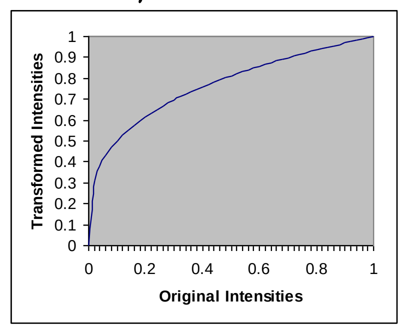
Power Law Example (cont…)

$\gamma = 0.4$



Power Law Example (cont…)

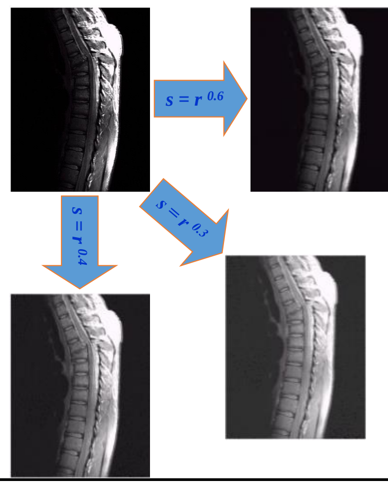
$\gamma = 0.3$



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

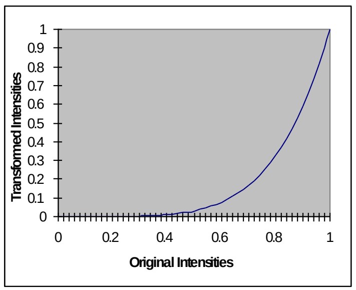


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Power Law Example

Power Law Example (cont…)

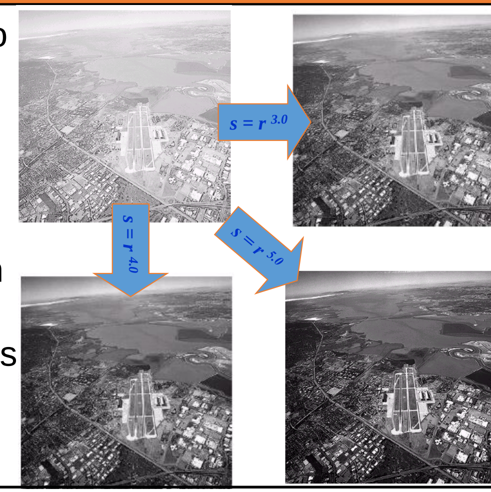
$\gamma = 5.0$



Power Law Transformations (cont…)

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

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



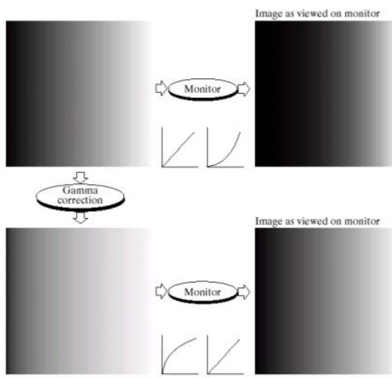
Gamma Correction

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

Many of you might be familiar with gamma correction of computer monitors

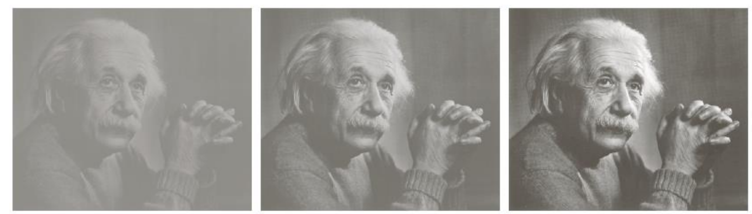
Problem is that display devices do not respond linearly to different intensities

Can be corrected using a log transform



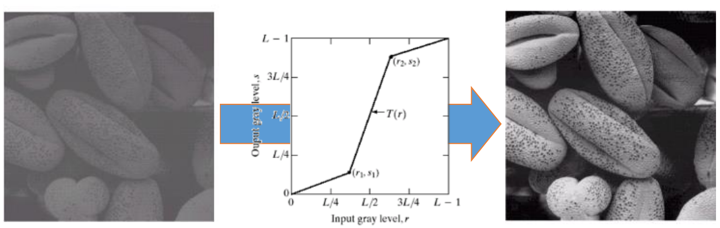
More Contrast Issues

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



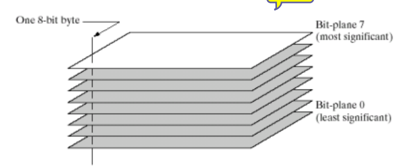
Piecewise Linear Transformation Functions

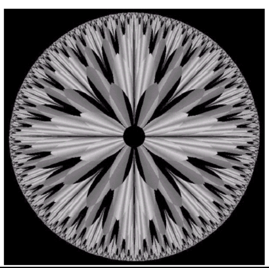
- Rather than using a well defined mathematical function we can use arbitrary user-defined transforms
- The images below show a contrast stretching linear transform to add contrast to a poor quality image



Bit Plane Slicing

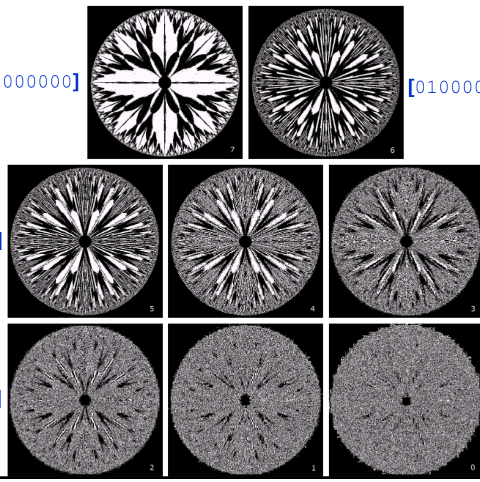
- Often by isolating particular bits of the pixel values in an image we can highlight interesting aspects of that image
  - Higher-order bits usually contain most of the significant visual information
  - Lower-order bits contain subtle details





Bit Plane Slicing (cont…)

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



[10000000] [01000000]

[00100000] [00001000]

[00000100] [00000001]

Summary

We have looked at different kinds of point processing image enhancement

Next time we will start to look at neighbourhood operations – in particular *filtering* and *convolution*

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj Humayun Mirza
Lecture: 7

Slides adopted from lectures of Dr. Brian Mac Namee

Image Enhancement
(Spatial Filtering 1)

Contents

In this lecture we will look at spatial filtering techniques:

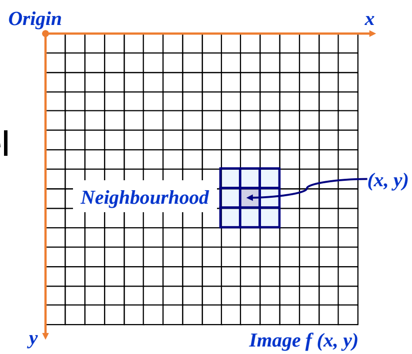
- Neighbourhood operations
- What is spatial filtering?
- Smoothing operations
- What happens at the edges?
- Correlation and convolution

Neighbourhood Operations

Neighbourhood operations simply operate on a larger neighbourhood of pixels than point operations

Neighbourhoods are mostly a rectangle around a central pixel

Any size rectangle and any shape filter are possible



Simple Neighbourhood Operations

Some simple neighbourhood operations include:

- **Min:** Set the pixel value to the minimum in the neighbourhood
- **Max:** Set the pixel value to the maximum in the neighbourhood
- **Median:** The median value of a set of numbers is the midpoint value in that set (e.g. from the set [1, 7, 15, 18, 24] 15 is the median). Sometimes the median works better than the average

Simple Neighbourhood Operations Example

Original Image *x*

123	127	128	119	115	130	•••
140	145	148	153	167	172	
133	154	183	192	194	191	
194	199	207	210	198	195	
164	170	175	162	173	151	
		⋮				

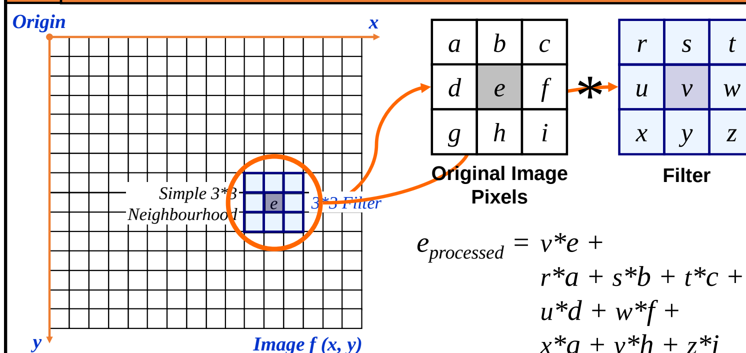
y

Enhanced Image *x*

						•••
		⋮				

y

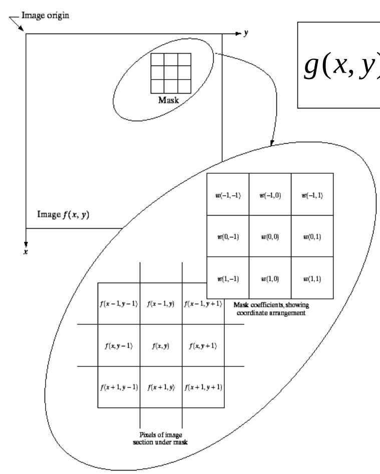
The Spatial Filtering Process



$$e_{processed} = v*e + r*a + s*b + t*c + u*d + w*f + x*g + y*h + z*i$$

The above is repeated for every pixel in the original image to generate the filtered image

Spatial Filtering: Equation Form



$$g(x,y) = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t) f(x+s, y+t)$$

Filtering can be given in equation form as shown above

Notations are based on the image shown to the left

Smoothing Spatial Filters

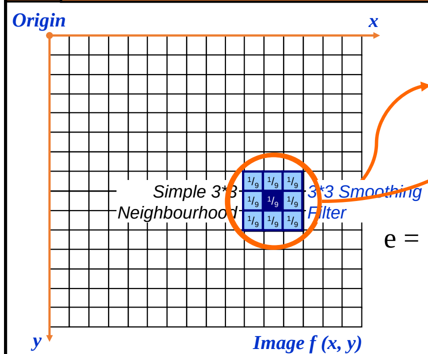
One of the simplest spatial filtering operations we can perform is a smoothing operation

- Simply average all of the pixels in a neighbourhood around a central value
- Especially useful in removing noise from images
- Also useful for highlighting gross detail

$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

Simple averaging filter

Smoothing Spatial Filtering



104	*100*	*108*
99	*106*	*98*
95	*90*	*85*

Original Image Pixels

*

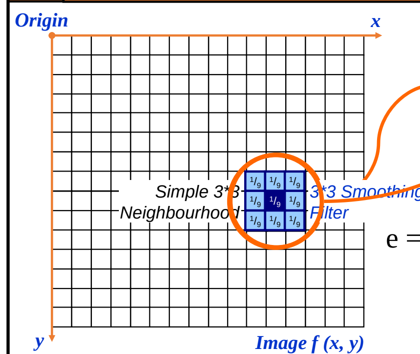
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

Filter

$$\begin{aligned} e = {} & ^1/_9*106 + \\ & ^1/_9*104 + {}^1/_9*100 + {}^1/_9*108 + \\ & ^1/_9*99 + {}^1/_9*98 + \\ & ^1/_9*95 + {}^1/_9*90 + {}^1/_9*85 \\ = {} & 98.3333 \end{aligned}$$

The above is repeated for every pixel in the original image to generate the smoothed image

Smoothing Spatial Filtering



104	*100*	*108*
99	*106*	*98*
95	*90*	*85*

Original Image Pixels

*

$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

Filter

$$\begin{aligned} e = {} & ^1/_9*\_\_\_\_ + \\ & ^1/_9*\_\_\_\_ + {}^1/_9*\_\_\_\_ + {}^1/_9*\_\_\_\_ + \\ & ^1/_9\_\_\_\_ + {}^1/_9*\_\_\_\_ + \\ & ^1/_9*\_\_\_\_ + {}^1/_9*\_\_\_\_ + {}^1/_9*\_\_\_\_ \\ = {} & \_\_\_\_\_\_ \end{aligned}$$

The above is repeated for every pixel in the original image to generate the smoothed image

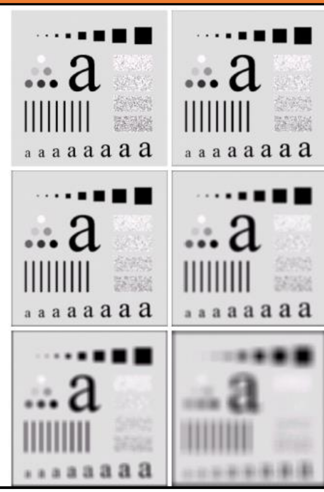
Image Smoothing Example

The image at the top left is an original image of size 500*500 pixels

The subsequent images show the image after filtering with an averaging filter of increasing sizes

– 3, 5, 9, 15 and 35

Notice how detail begins to disappear



Weighted Smoothing Filters

More effective smoothing filters can be generated by allowing different pixels in the neighbourhood different weights in the averaging function

– Pixels closer to the central pixel are more important

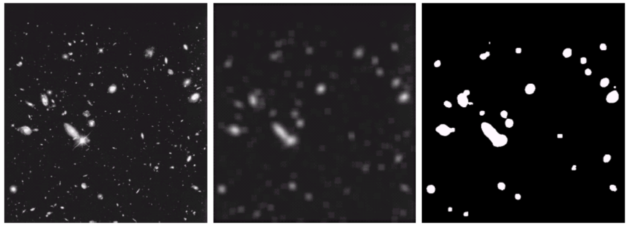
– Often referred to as a *weighted averaging*

$^{1}/_{16}$	$^{2}/_{16}$	$^{1}/_{16}$
$^{2}/_{16}$	$^{4}/_{16}$	$^{2}/_{16}$
$^{1}/_{16}$	$^{2}/_{16}$	$^{1}/_{16}$

Weighted averaging filter

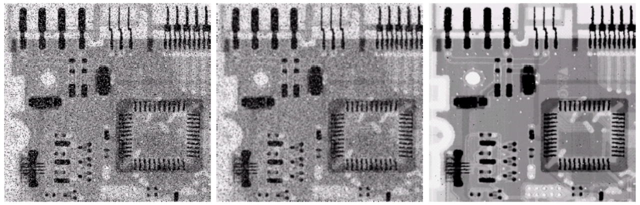
Another Smoothing Example

By smoothing the original image we get rid of lots of the finer detail which leaves only the gross features for thresholding



Original Image Smoothed Image Thresholded Image

Averaging Filter Vs. Median Filter Example



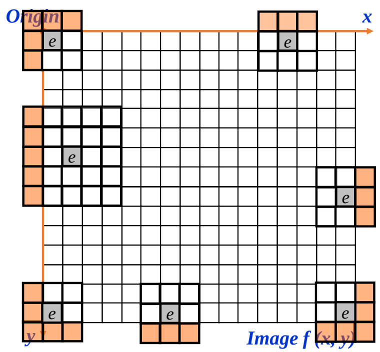
Original Image With Noise | Image After Averaging Filter | Image After Median Filter

Filtering is often used to remove noise from images

Sometimes a median filter works better than an averaging filter

Strange Things Happen At The Edges!

At the edges of an image we are missing pixels to form a neighbourhood

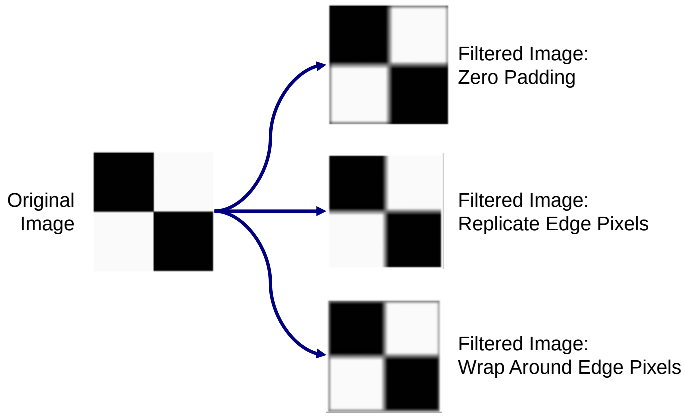


Strange Things Happen At The Edges! (cont…)

There are a few approaches to dealing with missing edge pixels:

- Omit missing pixels
  - Only works with some filters
  - Can add extra code and slow down processing
- Pad the image
  - Typically with either all white or all black pixels
- Replicate border pixels
- Truncate the image
- Allow pixels *wrap around* the image
  - Can cause some strange image artefacts

Strange Things Happen At The Edges! (cont…)



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

Correlation & Convolution

The filtering we have been talking about so far is referred to as *correlation* with the filter itself referred to as the *correlation kernel*

Convolution is a similar operation, with just one subtle difference

a	b	c
d	e	e
f	g	h

Original Image Pixels

$*$

r	s	t
u	v	w
x	y	z

Filter

$$e_{processed} = v*e + z*a + y*b + x*c + w*d + u*e + t*f + s*g + r*h$$

For symmetric filters it makes no difference

Summary

In this lecture we have looked at the idea of spatial filtering and in particular:

- Neighbourhood operations
- The filtering process
- Smoothing filters
- Dealing with problems at image edges when using filtering
- Correlation and convolution

Next time we will looking at sharpening filters and more on filtering and image enhancement

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-550
Instructor: Dr. Eraj Humayun Mirza
Lecture: 8

Slides adopted from lectures of Dr. Brian Mac Namee

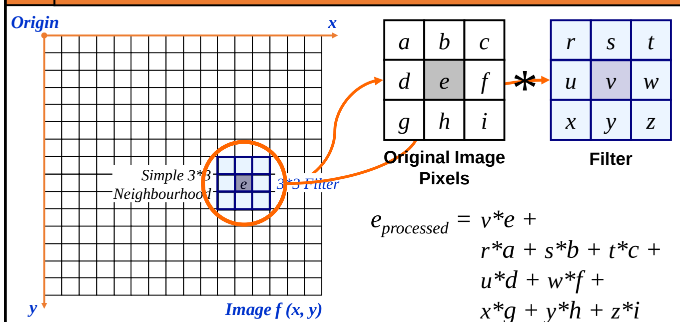
•Image Enhancement
(Spatial Filtering 2)

Contents

In this lecture we will look at more spatial filtering techniques

- Spatial filtering refresher
- Sharpening filters
  - 1^{st} derivative filters
  - 2^{nd} derivative filters
- Combining filtering techniques

Spatial Filtering Refresher



$$e_{processed} = v*e + r*a + s*b + t*c + u*d + w*f + x*g + y*h + z*i$$

The above is repeated for every pixel in the original image to generate the smoothed image

Sharpening Spatial Filters

Previously we have looked at smoothing filters which remove fine detail

Sharpening spatial filters seek to highlight fine detail

- Remove blurring from images
- Highlight edges

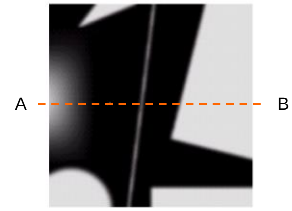
Sharpening filters are based on *spatial differentiation*

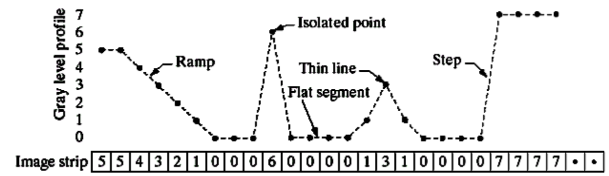
Spatial Differentiation

Differentiation measures the *rate of change* of a function

Let's consider a simple 1 dimensional example

Spatial Differentiation





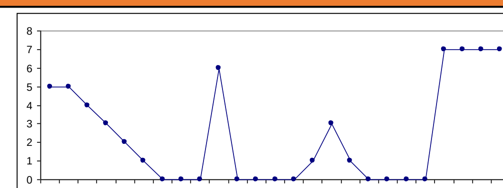
1st Derivative

The formula for the 1st derivative of a function is as follows:

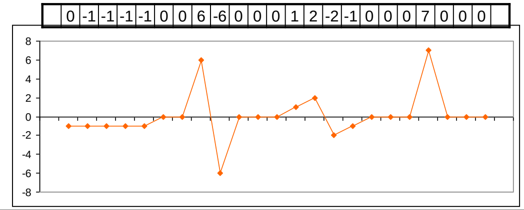
$$\frac{\partial f}{\partial x} = f(x+1) - f(x)$$

It's just the difference between subsequent values and measures the rate of change of the function

1st Derivative (cont…)



5	5	4	3	2	1	0	0	0	6	0	0	0	0	1	3	1	0	0	0	0	7	7	7	7
	0	-1	-1	-1	-1	0	0	6	-6	0	0	0	1	2	-2	-1	0	0	0	7	0	0	0	



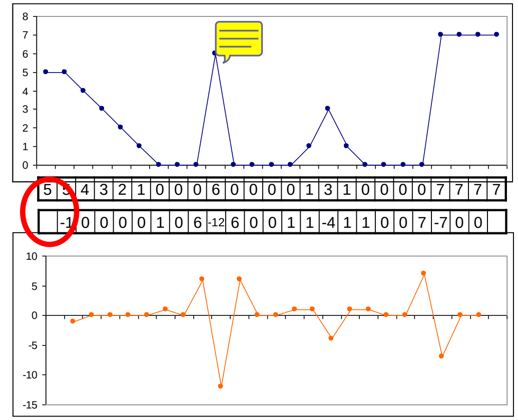
2nd Derivative

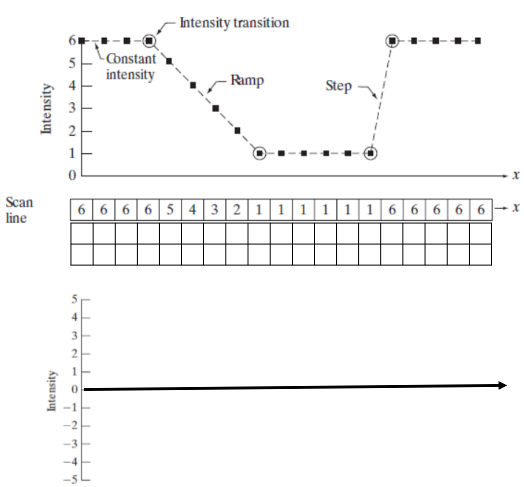
The formula for the 2nd derivative of a function is as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1) + f(x-1) - 2f(x)$$

Simply takes into account the values both before and after the current value

2nd Derivative (cont…)





Using Second Derivatives For Image Enhancement

The 2nd derivative is more useful for image enhancement than the 1st derivative

- Stronger response to fine detail
- Simpler implementation

The first sharpening filter we will look at is the *Laplacian*

- Isotropic
- One of the simplest sharpening filters
- We will look at a digital implementation

The Laplacian

The Laplacian is defined as follows:

$$\nabla^2 f = \frac{\partial^2 f}{\partial^2 x} + \frac{\partial^2 f}{\partial^2 y}$$

where the partial 1st order derivative in the x direction is defined as follows:

$$\frac{\partial^2 f}{\partial^2 x} = f(x+1, y) + f(x-1, y) - 2f(x, y)$$

and in the y direction as follows:

$$\frac{\partial^2 f}{\partial^2 y} = f(x, y+1) + f(x, y-1) - 2f(x, y)$$

The Laplacian (cont…)

So, the Laplacian can be given as follows:

$$\nabla^2 f = [f(x+1, y) + f(x-1, y) + f(x, y+1) + f(x, y-1)] - 4f(x, y)$$

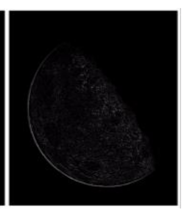
We can easily build a filter based on this

0	1	0
1	-4	1
0	1	0

The Laplacian (cont…)

Applying the Laplacian to an image we get a new image that highlights edges and other discontinuities

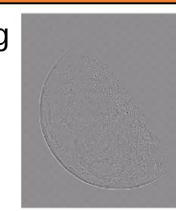

Original Image


Laplacian Filtered Image


Laplacian Filtered Image Scaled for Display

But That Is Not Very Enhanced!

- The result of a Laplacian filtering is not an enhanced image
- We have to do more work in order to get our final image
- Subtract the Laplacian result from the original image to generate our final sharpened enhanced image


Laplacian Filtered Image Scaled for Display

$$g(x, y) = f(x, y) - \nabla^2 f$$

Laplacian Image Enhancement

Original
Image

-

Laplacian
Filtered Image

=

Sharpened
Image

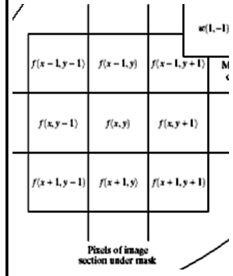
In the final sharpened image edges and fine detail are much more obvious

Laplacian Image Enhancement

Simplified Image Enhancement

The entire enhancement can be combined into a single filtering operation

$$
\begin{aligned}
g(x,y) &= f(x,y) - \nabla^2 f \\
&= f(x,y) - [f(x+1,y) + f(x-1,y) \\
&\qquad + f(x,y+1) + f(x,y-1) \\
&\qquad - 4f(x,y)] \\
&= 5f(x,y) - f(x+1,y) - f(x-1,y) \\
&\qquad - f(x,y+1) - f(x,y-1)
\end{aligned}
$$



0	1	0
1	−4	1
0	1	0

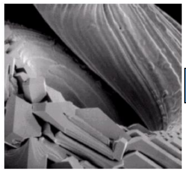
1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

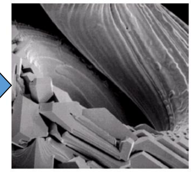
−1	−1	−1
−1	8	−1
−1	−1	−1

Simplified Image Enhancement (cont…)

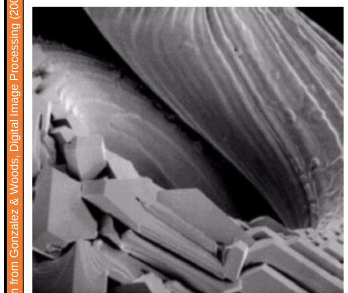
This gives us a new filter which does the whole job for us in one step

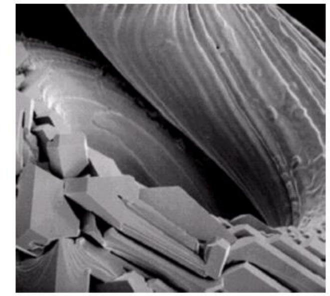


0	-1	0
-1	5	-1
0	-1	0



Simplified Image Enhancement (cont…)





Variants On The Simple Laplacian

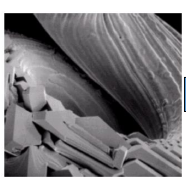
There are lots of slightly different versions of the Laplacian that can be used:

0	1	0
1	-4	1
0	1	0

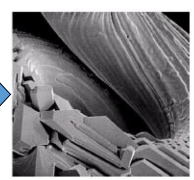
Simple Laplacian

1	1	1
1	-8	1
1	1	1

Variant of Laplacian



-1	-1	-1
-1	9	-1
-1	-1	-1



1st Derivative Filtering

Implementing 1st derivative filters is difficult in practice

For a function $f(x, y)$ the gradient of f at coordinates (x, y) is given as the column vector:

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix}$$

1^{st} Derivative Filtering (cont…)

The magnitude of this vector is given by:

$$\begin{aligned}\nabla f &= mag(\nabla \mathrm{f}) \\ &= \left[G_x^2 + G_y^2\right]^{1/2} \\ &= \left[\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2\right]^{1/2}\end{aligned}$$

For practical reasons this can be simplified as:

$$\nabla f \approx |G_x| + |G_y|$$

Sobel Operators

Based on the previous equations we can derive the *Sobel Operators*

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

To filter an image it is filtered using both operators the results of which are added together

1^{st} Derivative Filtering (cont…)

There is some debate as to how best to calculate these gradients but we will use:

$$\begin{aligned}\nabla f \approx\ & \left|(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)\right| \\ & + \left|(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)\right|\end{aligned}$$

which is based on these coordinates

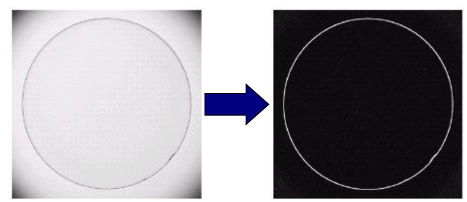
z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

-1	-2	-1
0	0	0
1	2	1

-1	0	1
-2	0	2
-1	0	1

Sobel Example

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



An image of a contact lens which is enhanced in order to make defects (at four and five o'clock in the image) more obvious

Sobel filters are typically used for edge detection

1^{st} & 2^{nd} Derivatives

Comparing the 1^{st} and 2^{nd} derivatives we can conclude the following:

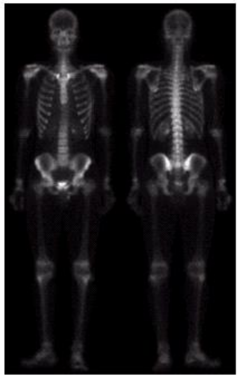
- 1^{st} order derivatives generally produce thicker edges
- 2^{nd} order derivatives have a stronger response to fine detail e.g. thin lines
- 1^{st} order derivatives have stronger response to grey level step
- 2^{nd} order derivatives produce a double response at step changes in grey level

Combining Spatial Enhancement Methods

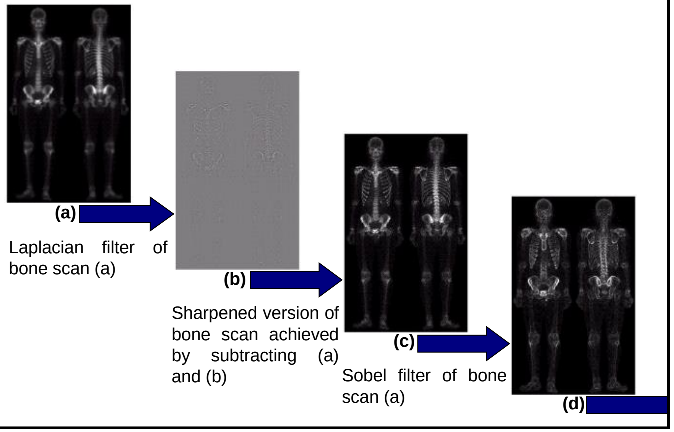
Successful image enhancement is typically not achieved using a single operation

Rather we combine a range of techniques in order to achieve a final result

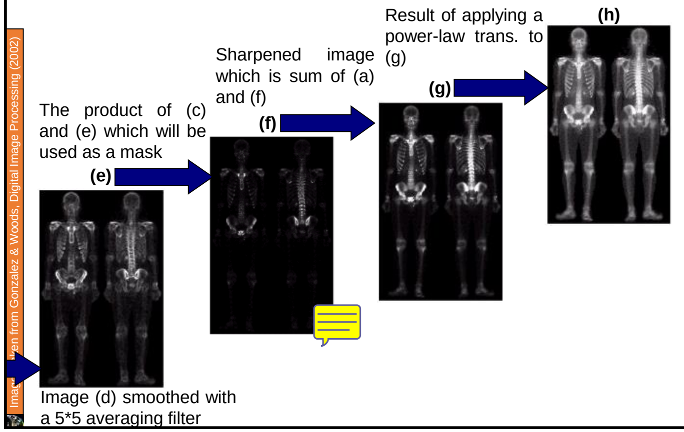
This example will focus on enhancing the bone scan to the right



Combining Spatial Enhancement Methods (cont…)



Combining Spatial Enhancement Methods (cont…)



Combining Spatial Enhancement Methods (cont…)

Compare the original and final images

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj Humayun Mirza
Lecture: 9

Slides adopted from lectures of Dr. Brian Mac Namee

Image Enhancement:
Filtering in the Frequency Domain

Contents

In this lecture we will look at image enhancement in the frequency domain

- Jean Baptiste Joseph Fourier
- The Fourier series & the Fourier transform
- Image Processing in the frequency domain
  - Image smoothing
  - Image sharpening
- Fast Fourier Transform

Jean Baptiste Joseph Fourier

Fourier was born in Auxerre, France in 1768

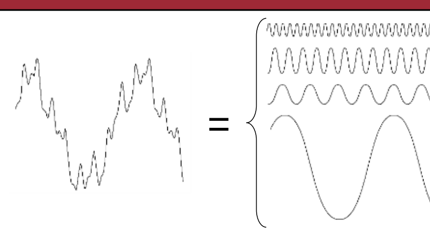
- Most famous for his work *"La Théorie Analitique de la Chaleur"* published in 1822
- Translated into English in 1878: *"The Analytic Theory of Heat"*

Nobody paid much attention when the work was first published

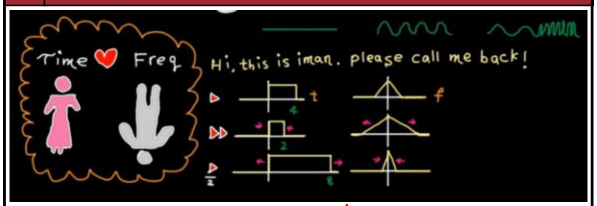
One of the most important mathematical theories in modern engineering

The Big Idea

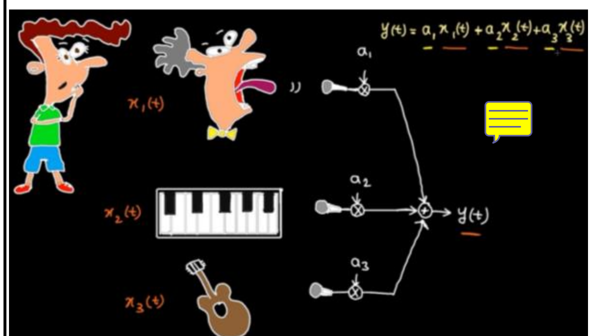
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



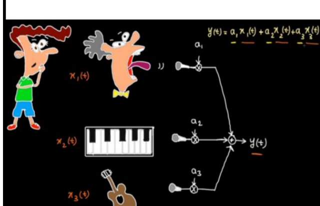
Any function that periodically repeats itself can be expressed as a sum of sines and cosines of different frequencies each multiplied by a different coefficient – a *Fourier series*

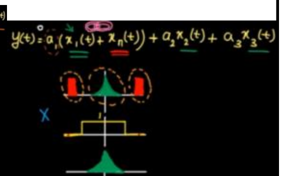


Time
Freq
Hi, this is iman. please call me back!
t
f

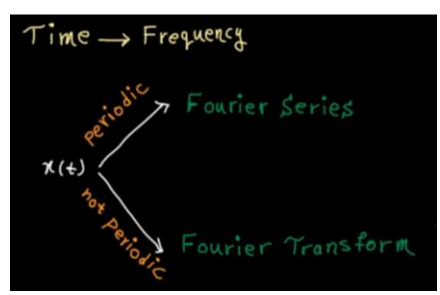


$y(t) = a_1x_1(t) + a_2x_2(t) + a_3x_3(t)$
a_1
$x_1(t)$
a_2
$x_2(t)$
$y(t)$
a_3
$x_3(t)$



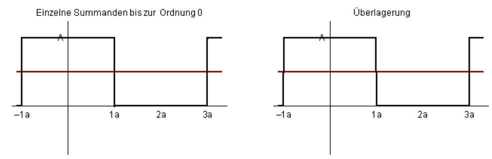


$y(t) = a_1(x_1(t) + x_n(t)) + a_2x_2(t) + a_3x_3(t)$



Time → Frequency
periodic
Fourier Series
x(t)
not periodic
Fourier Transform

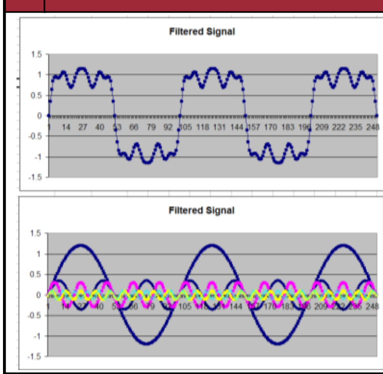
The Big Idea (cont…)



Notice how we get closer and closer to the original function as we add more and more frequencies

Taken from www.tfh-berlin.de/~schwenk/hobby/fourier/Welcome.html

The Big Idea (cont…)



Frequency domain signal processing example in Excel

The Discrete Fourier Transform (DFT)

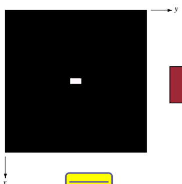
The *Discrete Fourier Transform* of $f(x, y)$, for x = 0, 1, 2…M-1 and y = 0,1,2…N-1, denoted by $F(u, v)$, is given by the equation:

$$F(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)}$$

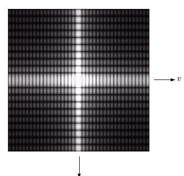
for u = 0, 1, 2…M-1 and v = 0, 1, 2…N-1.

DFT & Images

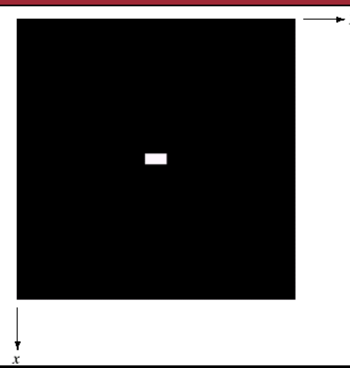
The DFT of a two dimensional image can be visualised by showing the spectrum of the images component frequencies



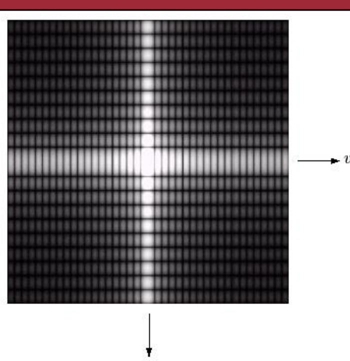
DFT



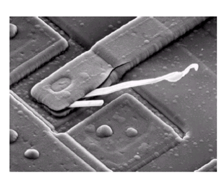
DFT & Images



DFT & Images

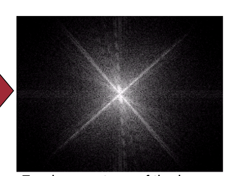


DFT & Images (cont…)



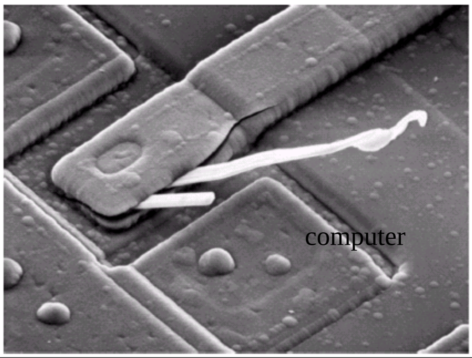
Scanning electron microscope image of an integrated circuit magnified ~2500 times

DFT

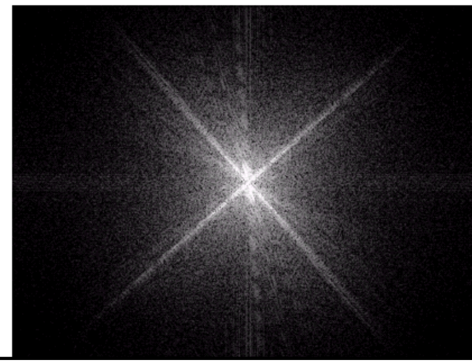


Fourier spectrum of the image

DFT & Images (cont…)



DFT & Images (cont…)



The Inverse DFT

It is really important to note that the Fourier transform is completely **reversible**

The inverse DFT is given by:

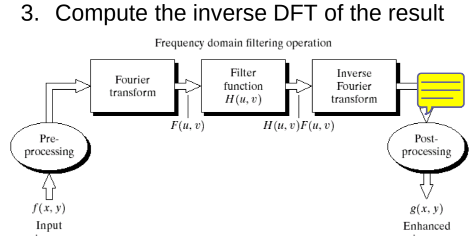
$$f(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} F(u,v)e^{j2\pi(ux/M+vy/N)}$$

for x = 0, 1, 2…M-1 and y = 0, 1, 2…N-1

The DFT and Image Processing

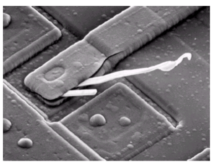
To filter an image in the frequency domain:

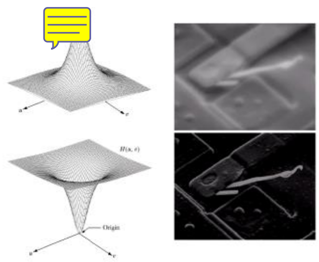
1. Compute $F(u,v)$ the DFT of the image
2. Multiply $F(u,v)$ by a filter function $H(u,v)$
3. Compute the inverse DFT of the result



Some Basic Frequency Domain Filters

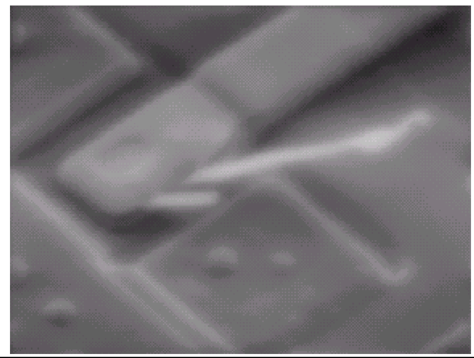
Low Pass Filter



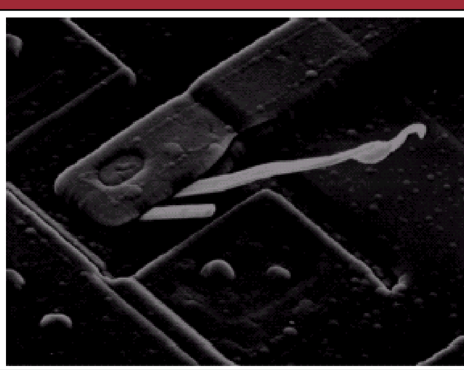


High Pass Filter

Some Basic Frequency Domain Filters



Some Basic Frequency Domain Filters



Smoothing Frequency Domain Filters

Smoothing is **achieved** in the frequency domain by **dropping out the high frequency** components

The basic model for filtering is:

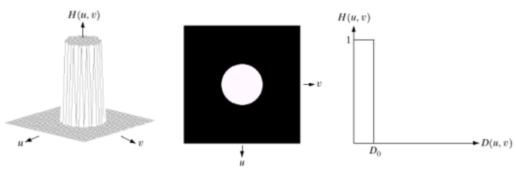
$$G(u,v) = H(u,v)F(u,v)$$

where $F(u,v)$ is the **Fourier transform** of the image being filtered and $H(u,v)$ is the **filter** transform function

Low pass filters – only pass the low frequencies, drop the high ones

Ideal Low Pass Filter

Simply cut off all high frequency components that are a specified distance D_0 from the origin of the transform



changing the distance changes the behaviour of the filter

Ideal Low Pass Filter (cont…)

The transfer function for the ideal low pass filter can be given as:

$$H(u,v) = \begin{cases} 1 & \text{if } D(u,v) \leq D_0 \\ 0 & \text{if } D(u,v) > D_0 \end{cases}$$

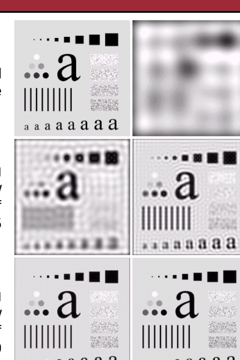
where $D(u,v)$ is given as:

$$D(u,v) = [(u - M/2)^2 + (v - N/2)^2]^{1/2}$$

Ideal Low Pass Filter (cont…)

Above we show an image, it's Fourier spectrum and a series of ideal low pass filters of radius 5, 15, 30, 80 and 230 superimposed on top of it

Ideal Low Pass Filter (cont…)



Original image

Result of filtering with ideal low pass filter of radius 5

Result of filtering with ideal low pass filter of radius 15

Result of filtering with ideal low pass filter of radius 30

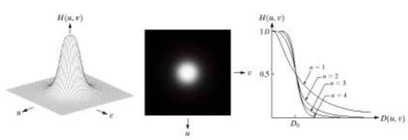
Result of filtering with ideal low pass filter of radius 80

Result of filtering with ideal low pass filter of radius 230

Butterworth Lowpass Filters

The transfer function of a Butterworth lowpass filter of order n with cutoff frequency at distance D_0 from the origin is defined as:

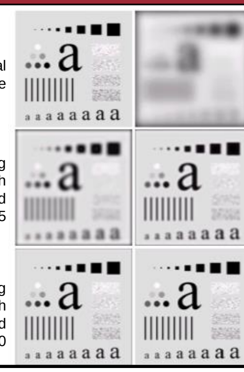
$$H(u,v) = \frac{1}{1+[D(u,v)/D_0]^{2n}}$$



Butterworth Lowpass Filter (cont…)

Original image

Result of filtering with Butterworth filter of order 2 and cutoff radius 5



Result of filtering with Butterworth filter of order 2 and cutoff radius 15

Result of filtering with Butterworth filter of order 2 and cutoff radius 30

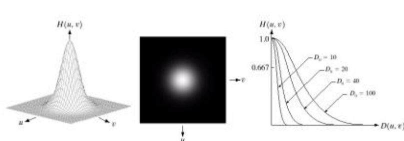
Result of filtering with Butterworth filter of order 2 and cutoff radius 80

Result of filtering with Butterworth filter of order 2 and cutoff radius 230

Gaussian Lowpass Filters

The transfer function of a Gaussian lowpass filter is defined as:

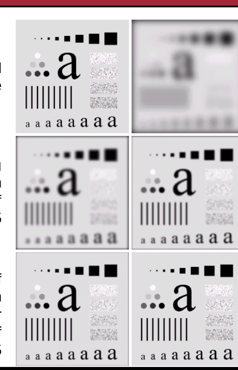
$$H(u,v) = e^{-D^2(u,v)/2D_0^{\,2}}$$



Gaussian Lowpass Filters (cont…)

Original image

Result of filtering with Gaussian filter with cutoff radius 5



Result of filtering with Gaussian filter with cutoff radius 15

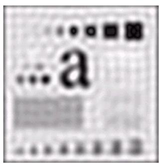
Result of filtering with Gaussian filter with cutoff radius 30

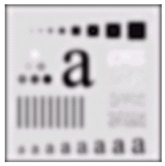
Result of filtering with Gaussian filter with cutoff radius 85

Result of filtering with Gaussian filter with cutoff radius 230

Lowpass Filters Compared

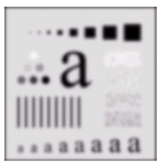
Result of filtering with ideal low pass filter of radius 15





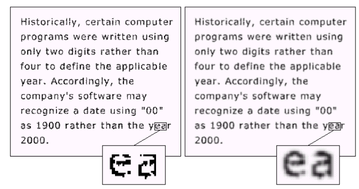
Result of filtering with Butterworth filter of order 2 and cutoff radius 15

Result of filtering with Gaussian filter with cutoff radius 15

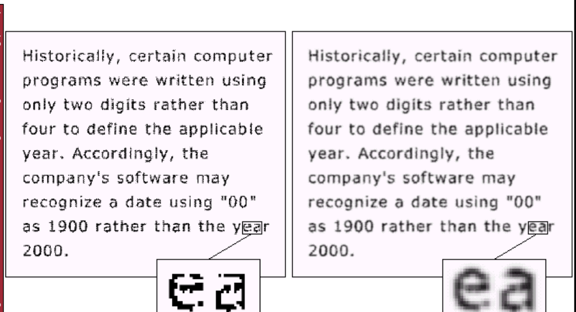


Lowpass Filtering Examples

A low pass Gaussian filter is used to connect broken text



Lowpass Filtering Examples

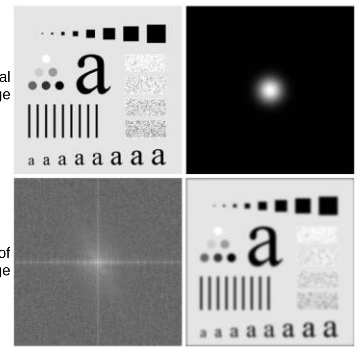


Lowpass Filtering Examples (cont…)

Different lowpass Gaussian filters used to remove blemishes in a photograph

Lowpass Filtering Examples (cont…)

Lowpass Filtering Examples (cont…)



Sharpening in the Frequency Domain

Edges and fine detail in images are associated with **high frequency components**

High pass filters – only pass the high frequencies, drop the low ones

High pass frequencies are precisely the **reverse of low pass filters**, so:

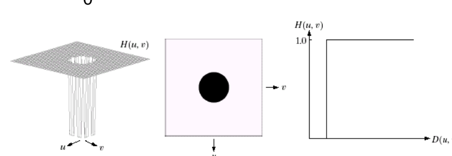
$$H_{hp}(u, v) = 1 - H_{lp}(u, v)$$

Ideal High Pass Filters

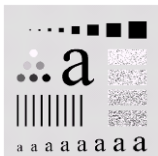
The ideal high pass filter is given as:

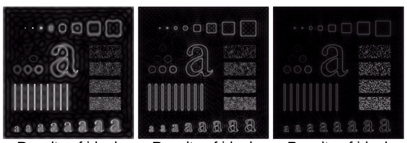
$$H(u,v) = \begin{cases} 0 & \text{if } D(u,v) \le D_0 \\ 1 & \text{if } D(u,v) > D_0 \end{cases}$$

where D_0 is the cut off distance as before



Ideal High Pass Filters (cont…)





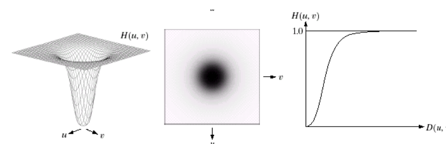
Results of ideal high pass filtering with $D_0 = 15$ | Results of ideal high pass filtering with $D_0 = 30$ | Results of ideal high pass filtering with $D_0 = 80$

Butterworth High Pass Filters

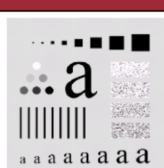
The Butterworth high pass filter is given as:

$$H(u,v) = \frac{1}{1 + [D_0 / D(u,v)]^{2n}}$$

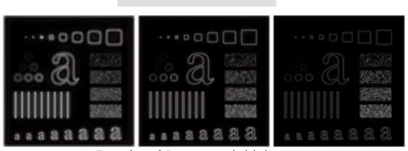
where n is the order and D_0 is the cut off distance as before



Butterworth High Pass Filters (cont…)



Results of Butterworth high pass filtering of order 2 with $D_0 = 15$



Results of Butterworth high pass filtering of order 2 with $D_0 = 80$

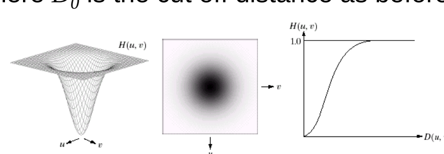
Results of Butterworth high pass filtering of order 2 with $D_0 = 30$

Gaussian High Pass Filters

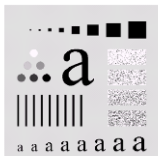
The Gaussian high pass filter is given as:

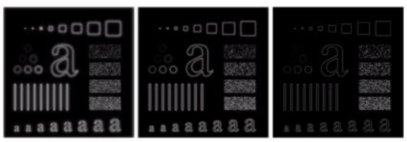
$$H(u,v) = 1 - e^{-D^2(u,v)/2D_0^{\,2}}$$

where D_0 is the cut off distance as before



Gaussian High Pass Filters (cont…)



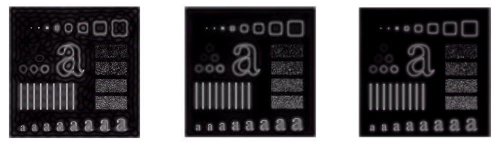


Results of Gaussian high pass filtering with D_0 = 15

Results of Gaussian high pass filtering with D_0 = 30

Results of Gaussian high pass filtering with D_0 = 80

Highpass Filter Comparison



Results of ideal high pass filtering with D_0 = 15

Results of Butterworth high pass filtering of order 2 with D_0 = 15

Results of Gaussian high pass filtering with D_0 = 15

Highpass Filtering Example

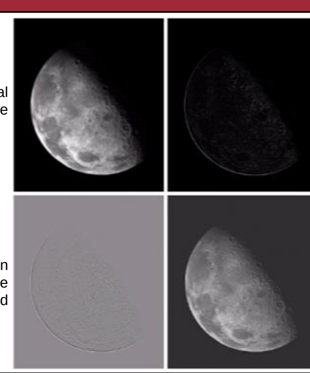
Original image

Highpass filtering result

High frequency emphasis result

After histogram equalisation

Frequency Domain Laplacian Example



Original image

Laplacian filtered image

Laplacian image scaled

Enhanced image

Fast Fourier Transform

The reason that Fourier based techniques have become so **popular** is the development of the ***Fast Fourier Transform (FFT)*** algorithm

Allows the Fourier transform to be carried out in a reasonable amount of time

Reduces the amount of time required to perform a Fourier transform by a factor of 100 – 600 times!

Frequency Domain Filtering & Spatial Domain Filtering

Similar jobs can be done in the spatial and frequency domains

Filtering in the **spatial domain** can be **easier to understand**

Filtering in the **frequency domain** can be much **faster** – especially for large images

Summary

In this lecture we examined image enhancement in the frequency domain

- The Fourier series & the Fourier transform
- Image Processing in the frequency domain
  - Image smoothing
  - Image sharpening
- Fast Fourier Transform

Next time we will begin to examine image restoration using the spatial and frequency based techniques we have been looking at

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj Humayun Mirza
Lecture: 10

Slides adopted from lectures of Dr. Brian Mac Namee

Image Restoration

Contents

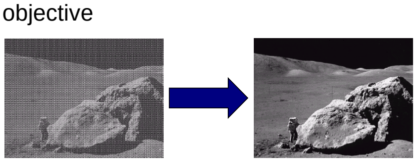
In this lecture we will look at image restoration techniques used for noise removal

- What is image restoration?
- Noise and images
- Noise models
- Noise removal using spatial domain filtering
- Periodic noise
- Noise removal using frequency domain filtering

What is Image Restoration?

Image restoration attempts to restore images that have been degraded

- Identify the degradation process and attempt to reverse it
- Similar to image enhancement, but more objective



Noise and Images

The sources of noise in digital images arise during image acquisition (digitization) and transmission

- Imaging sensors can be affected by ambient conditions
- Interference can be added to an image during transmission

Noise Model

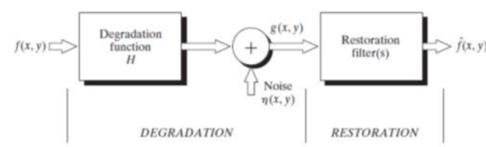
We can consider a noisy image to be modelled as follows:

$$g(x, y) = f(x, y) + \eta(x, y)$$

where $f(x, y)$ is the original image pixel, $\eta(x, y)$ is the noise term and $g(x, y)$ is the resulting noisy pixel

If we can estimate the model the noise in an image is based on this will help us to figure out how to restore the image

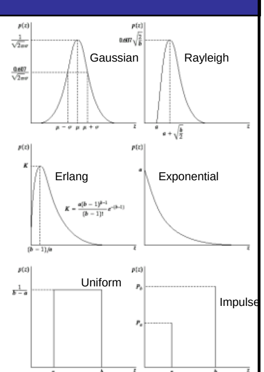
Noise Corruption



Noise Models

There are many different models for the image noise term $\eta(x, y)$:

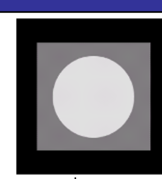
- Gaussian
  - Most common model
- Rayleigh
- Erlang
- Exponential
- Uniform
- Impulse
  - *Salt and pepper* noise



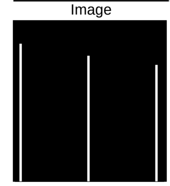
Noise Example

The test pattern to the right is ideal for demonstrating the addition of noise

The following slides will show the result of adding noise based on various models to this image

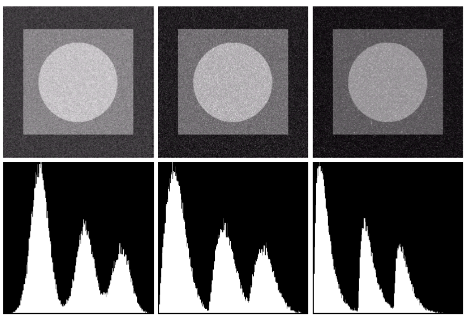


Image



Histogram

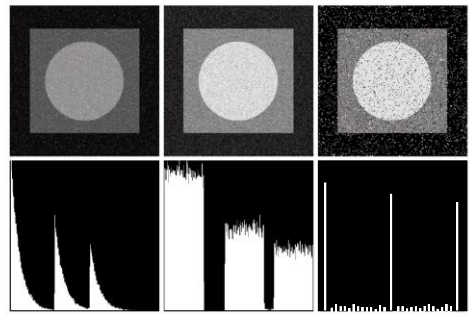
Noise Example (cont…)



Gaussian Rayleigh Erlang

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

Noise Example (cont…)



Exponential Uniform Impulse

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

Filtering to Remove Noise

We can use spatial filters of different kinds to remove different kinds of noise

The *arithmetic mean* filter is a very simple one and is calculated as follows:

$$\hat{f}(x,y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} g(s,t)$$

$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$
$^1/_9$	$^1/_9$	$^1/_9$

This is implemented as the simple smoothing filter

Blurs the image to remove noise

Noise Removal Example

Original Image

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
148	154	157	160	163	167	170
151	155	159	162	165	169	172

Image f (x, y)

Filtered Image

Image f (x, y)

Other Means

There are different kinds of mean filters all of which exhibit slightly different behaviour:

- Geometric Mean
- Harmonic Mean
- Contraharmonic Mean

Other Means (cont…)

There are other variants on the mean which can give different performance

Geometric Mean:

$$\hat{f}(x,y) = \left[\prod_{(s,t)\in S_{xy}} g(s,t) \right]^{\frac{1}{mn}}$$

Achieves similar smoothing to the arithmetic mean, but tends to lose less image detail

Noise Removal Example

Original Image

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
148	154	157	160	163	167	170
151	155	159	162	165	169	172

Image f (x, y)

Filtered Image

Image f (x, y)

Other Means (cont…)

Harmonic Mean:

$$\hat{f}(x,y) = \frac{mn}{\sum_{(s,t)\in S_{xy}} \frac{1}{g(s,t)}}$$

The reciprocal of the arithmetic mean of the reciprocals.

Works well for salt noise, but fails for pepper noise

Also does well for other kinds of noise such as Gaussian noise

Noise Corruption Example

Original Image

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

x *y* *Image f (x, y)*

Filtered Image

x *y* *Image f (x, y)*

Other Means (cont…)

Contraharmonic Mean:

$$\hat{f}(x,y) = \frac{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q+1}}{\sum_{(s,t)\in S_{xy}} g(s,t)^{Q}}$$

Q is the *order* of the filter and adjusting its value changes the filter's behaviour

Positive values of Q eliminate pepper noise

Negative values of Q eliminate salt noise

Noise Corruption Example

Original Image

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

x *y* *Image f (x, y)*

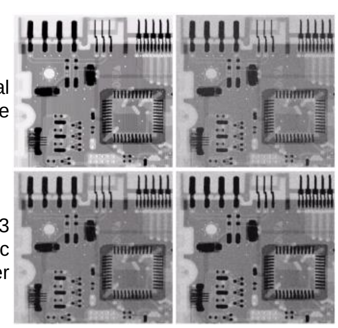
Filtered Image

x *y* *Image f (x, y)*

Noise Removal Examples

Original Image

Image Corrupted By Gaussian Noise

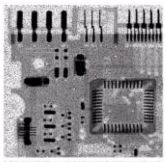


After A 3*3 Arithmetic Mean Filter

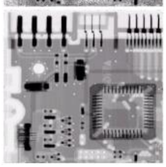
After A 3*3 Geometric Mean Filter

Noise Removal Examples (cont…)

Image Corrupted By Pepper Noise



Result of Filtering Above With 3*3 Contraharmonic Q=1.5



Noise Removal Examples (cont…)

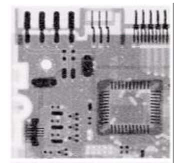
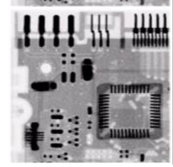


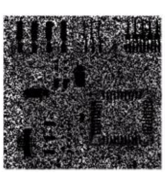
Image Corrupted By Salt Noise

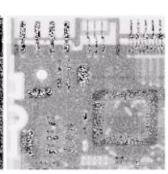


Result of Filtering Above With 3*3 Contraharmonic Q=-1.5

Contraharmonic Filter: Here Be Dragons

Choosing the wrong value for Q when using the contraharmonic filter can have drastic results





Order Statistics Filters

Spatial filters that are based on ordering the pixel values that make up the neighbourhood operated on by the filter

Useful spatial filters include

- Median filter
- Max and min filter
- Midpoint filter
- Alpha trimmed mean filter

Median Filter

Median Filter:

$$\hat{f}(x, y) = \underset{(s,t)\in S_{xy}}{median}\{g(s,t)\}$$

Excellent at noise removal, **without the smoothing** effects that can occur with other smoothing filters

Particularly **good when salt and pepper** noise is present

Noise Corruption Example

Original Image x

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

Image f (x, y) y

Filtered Image x

Image f (x, y) y

Max and Min Filter

Max Filter:

$$\hat{f}(x, y) = \max_{(s,t)\in S_{xy}}\{g(s,t)\}$$

Min Filter:

$$\hat{f}(x, y) = \min_{(s,t)\in S_{xy}}\{g(s,t)\}$$

Max filter is good for pepper noise and min is good for salt noise

Noise Corruption Example

Original Image x

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

Image f (x, y) y

Filtered Image x

Image f (x, y) y

Midpoint Filter

Midpoint Filter:

$$\hat{f}(x,y) = \frac{1}{2}\left[\max_{(s,t)\in S_{xy}}\{g(s,t)\} + \min_{(s,t)\in S_{xy}}\{g(s,t)\}\right]$$

Good for random Gaussian and uniform noise

Noise Corruption Example

Original Image x

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

y *Image f (x, y)*

Filtered Image x

y *Image f (x, y)*

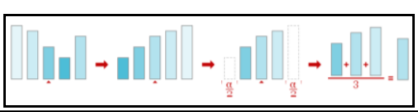
Alpha-Trimmed Mean Filter

Alpha-Trimmed Mean Filter:

$$\hat{f}(x,y) = \frac{1}{mn-d}\sum_{(s,t)\in S_{xy}} g_r(s,t)$$

We can delete the $d/2$ lowest and $d/2$ highest grey levels

So $g_r(s, t)$ represents the remaining $mn - d$ pixels



Noise Corruption Example

Original Image x

54	52	57	55	56	52	51
50	49	51	50	52	53	58
51	204	52	52	0	57	60
48	50	51	49	53	59	63
49	51	52	55	58	64	67
50	54	57	60	63	67	70
51	55	59	62	65	69	72

y *Image f (x, y)*

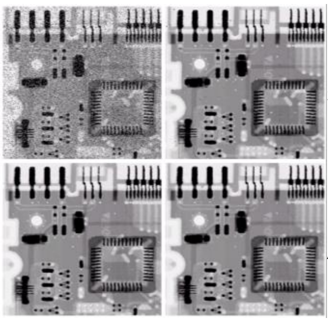
Filtered Image x

y *Image f (x, y)*

Noise Removal Examples

Image Corrupted By Salt And Pepper Noise

Result of 1 Pass With A 3*3 Median Filter



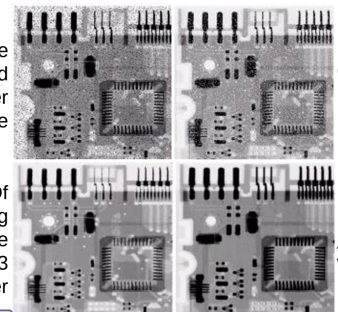
Result of 2 Passes With A 3*3 Median Filter

Result of 3 Passes With A 3*3 Median Filter

Noise Removal Examples (cont…)

Image Corrupted By Pepper Noise

Image Corrupted By Salt Noise



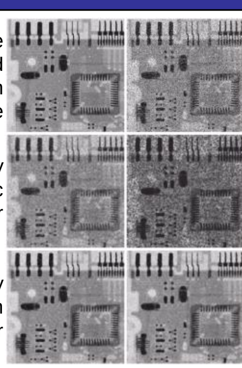
Result Of Filtering Above With A 3*3 Max Filter

Result Of Filtering Above With A 3*3 Min Filter

Noise Removal Examples (cont…)

Image Corrupted By Uniform Noise

Image Further Corrupted By Salt and Pepper Noise



Filtered By 5*5 Arithmetic Mean Filter

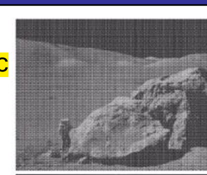
Filtered By 5*5 Geometric Mean Filter

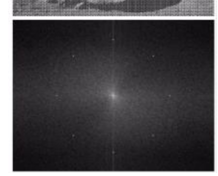
Filtered By 5*5 Median Filter

Filtered By 5*5 Alpha-Trimmed Mean Filter

Periodic Noise

- Typically arises due to electrical or electromagnetic interference
- Gives rise to regular noise patterns in an image
- Frequency domain techniques in the Fourier domain are most effective at removing periodic noise





Band Reject Filters

Removing periodic noise form an image involves removing a particular range of frequencies from that image

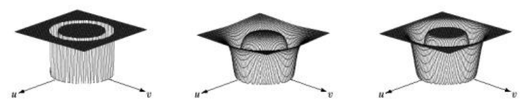
Band reject filters can be used for this purpose

An ideal band reject filter is given as follows:

$$H(u,v) = \begin{cases} 1 & if\ D(u,v) < D_0 - \frac{W}{2} \\ 0 & if\ D_0 - \frac{W}{2} \leq D(u,v) \leq D_0 + \frac{W}{2} \\ 1 & if\ D(u,v) > D_0 + \frac{W}{2} \end{cases}$$

Band Reject Filters (cont…)

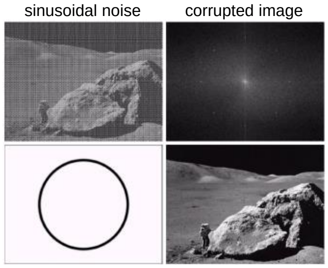
The ideal band reject filter is shown below, along with Butterworth and Gaussian versions of the filter



Ideal Band Reject Filter | Butterworth Band Reject Filter (of order 1) | Gaussian Band Reject Filter

Band Reject Filter Example

Image corrupted by sinusoidal noise | Fourier spectrum of corrupted image



Butterworth band reject filter | Filtered image

Summary

In this lecture we will look at image restoration for noise removal

Restoration is slightly more objective than enhancement

Spatial domain techniques are particularly useful for removing random noise

Frequency domain techniques are particularly useful for removing periodic noise

Adaptive Filters

The filters discussed so far are applied to an entire image without any regard for how image characteristics vary from one point to another

The behaviour of **adaptive filters** changes depending on the characteristics of the image inside the filter region

We will take a look at the **adaptive median filter**

Adaptive Median Filtering

The median filter performs relatively well on impulse noise as long as the spatial density of the impulse noise is not large

The adaptive median filter can handle much more spatially dense impulse noise, and also performs some smoothing for non-impulse noise

The key insight in the adaptive median filter is that the filter size changes depending on the characteristics of the image

Adaptive Median Filtering (cont…)

Remember that filtering looks at each original pixel image in turn and generates a new filtered pixel

First examine the following notation:

- z_{min} = minimum grey level in S_{xy}
- z_{max} = maximum grey level in S_{xy}
- z_{med} = median of grey levels in S_{xy}
- z_{xy} = grey level at coordinates (x, y)
- S_{max} =maximum allowed size of S_{xy}

Adaptive Median Filtering (cont…)

Level A: $A1 = z_{med} - z_{min}$
$A2 = z_{med} - z_{max}$
If $A1 > 0$ and $A2 < 0$, Go to level B
Else increase the window size
If window size $\leq$ repeat S_{max} level A
Else output z_{med}

Level B: $B1 = z_{xy} - z_{min}$
$B2 = z_{xy} - z_{max}$
If $B1 > 0$ and $B2 < 0$, output z_{xy}
Else output z_{med}

Adaptive Median Filtering (cont…)

The key to understanding the algorithm is to remember that the adaptive median filter has three purposes:

- Remove impulse noise
- Provide smoothing of other noise
- Reduce distortion

Adaptive Filtering Example

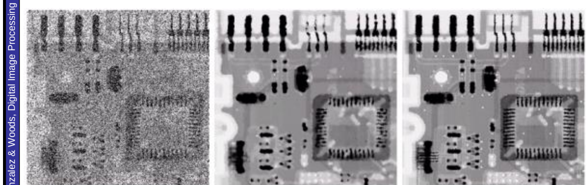


Image corrupted by salt and pepper noise with probabilities $P_a = P_b=0.25$

Result of filtering with a 7 * 7 median filter

Result of adaptive median filtering with i = 7

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj Humayun Mirza
Lecture: 11

Slides adopted from lectures of Dr. Brian Mac Namee

Image Segmentation: Thresholding

Contents

So far we have been considering image processing techniques used to transform images for human interpretation

Today we will begin looking at automated image analysis by examining the thorny issue of image segmentation:

- The segmentation problem
- Finding points, lines and edges

The Segmentation Problem

Segmentation attempts to partition the pixels of an image into groups that strongly correlate with the objects in an image

Typically the first step in any automated computer vision application

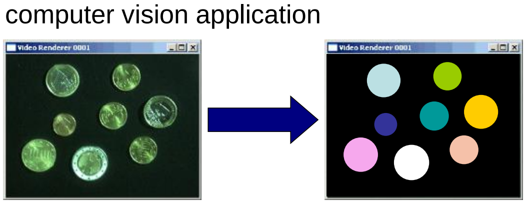
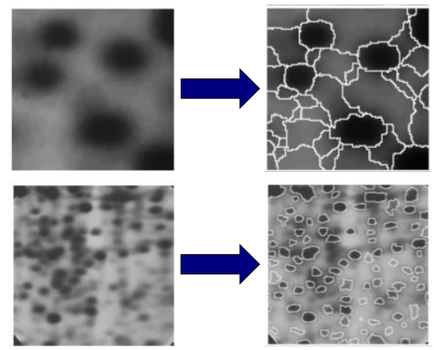


Figure 10.1(a) shows an image of a region of constant intensity superimposed on a darker background, also of constant intensity. These two regions comprise the overall image region. Figure 10.1(b) shows the result of computing the boundary of the inner region based on intensity discontinuities. Points on the inside and outside of the boundary are black (zero) because there are no discontinuities in intensity in those regions. To segment the image, we assign one level (say, white) to the pixels on, or interior to, the boundary and another level (say, black) to all points exterior to the boundary. Figure 10.1(c) shows the result of such a procedure.

Segmentation Examples

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



Detection Of Discontinuities

There are three basic types of grey level discontinuities that we tend to look for in digital images:

- Points
- Lines
- Edges

We typically find discontinuities using masks and correlation

Point, Line, and Edge Detection

- The focus in this section is on segmentation methods that are based on detecting sharp, local changes in intensity.
- The three types of image features in which we are interested are isolated points, lines, and edges.
- Edge pixels are pixels at which the intensity of an image function changes abruptly (suddenly), and edges or edge segments are sets of connected edge pixels. Edge detectors are local image processing methods designed to detect edge pixels.
- A line may be viewed as an edge segment in which the intensity of the background on either side of the line is either much higher or much lower than the intensity of the line pixels.

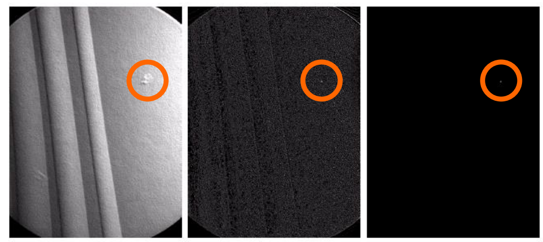
Point Detection

Point detection can be achieved simply using the mask below:

−1	−1	−1
−1	8	−1
−1	−1	−1

Points are detected at those pixels in the subsequent filtered image that are above a set threshold

Point Detection (cont…)



X-ray image of a turbine blade | Result of point detection | Result of thresholding

Line Detection

The next level of complexity is to try to detect lines

The masks below will extract lines that are one pixel thick and running in a particular direction

Horizontal

−1	−1	−1
2	2	2
−1	−1	−1

+45°

−1	−1	2
−1	2	−1
2	−1	−1

Vertical

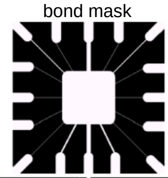
−1	2	−1
−1	2	−1
−1	2	−1

−45°

2	−1	−1
−1	2	−1
−1	−1	2

Line Detection (cont…)

Binary image of a wire bond mask

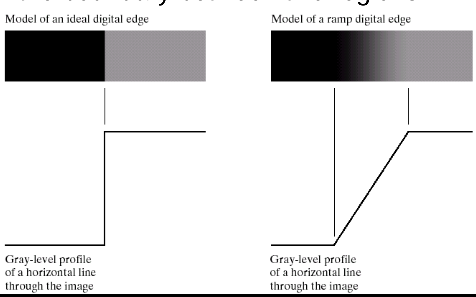


After processing with -45° line detector

Result of thresholding filtering result

Edge Detection

An edge is a set of connected pixels that lie on the boundary between two regions

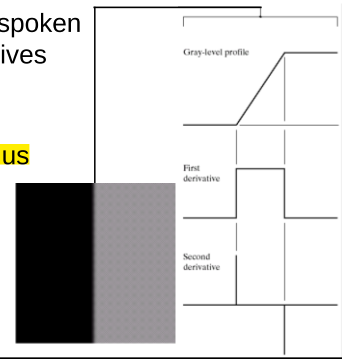


Edges & Derivatives

We have already spoken about how derivatives are used to find discontinuities

1st derivative tells us where an edge is

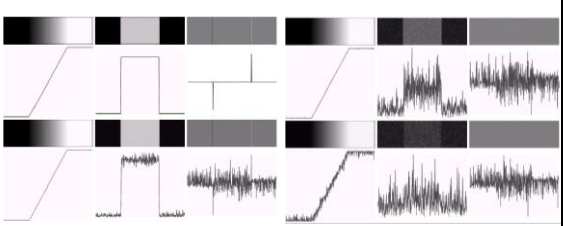
2nd derivative can be used to show edge direction



Derivatives & Noise

Derivative based edge detectors are extremely sensitive to noise

We need to keep this in mind



Common Edge Detectors

Given a 3*3 region of an image the following edge detection filters can be used

z_1	z_2	z_3
z_4	z_5	z_6
z_7	z_8	z_9

Roberts

−1	0
0	1

0	−1
1	0

Prewitt

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

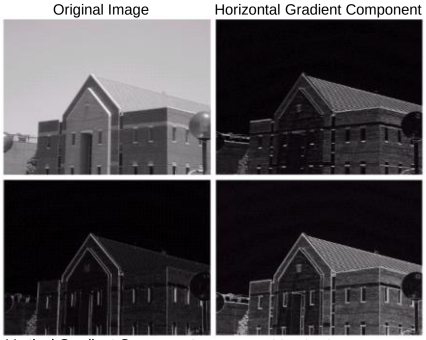
Sobel

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Edge Detection Example

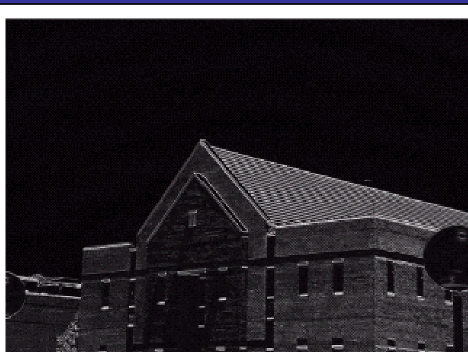
Original Image | Horizontal Gradient Component



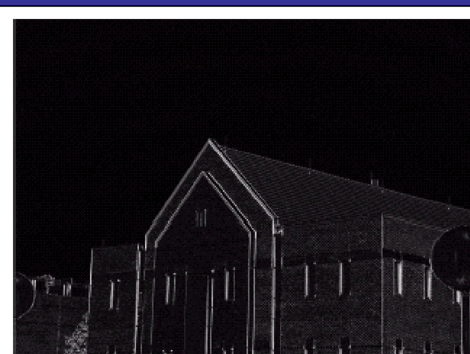
Vertical Gradient Component | Combined Edge Image

Edge Detection Example

Edge Detection Example



Edge Detection Example



Edge Detection Example

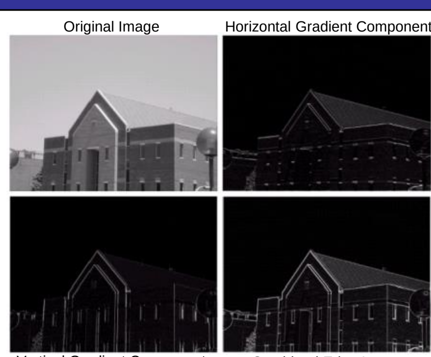
Edge Detection Problems

Often, problems arise in edge detection in that there is **too much detail**

For example, the brickwork he previous example

One way to overcome this is to **smooth images prior to edge detection**

Edge Detection Example With Smoothing



Laplacian Edge Detection

We encountered the 2nd-order derivative based Laplacian filter already

0	−1	0
−1	4	−1
0	−1	0

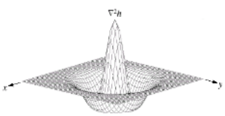
−1	−1	−1
−1	8	−1
−1	−1	−1

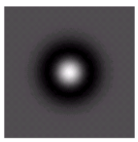
The Laplacian is typically not used by itself as it is too sensitive to noise

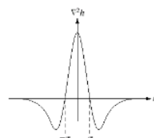
Usually when used for edge detection the Laplacian is combined with a smoothing Gaussian filter

Laplacian Of Gaussian

The Laplacian of Gaussian (or Mexican hat) filter uses the Gaussian for noise removal and the Laplacian for edge detection

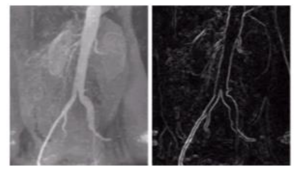


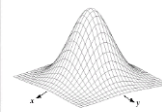




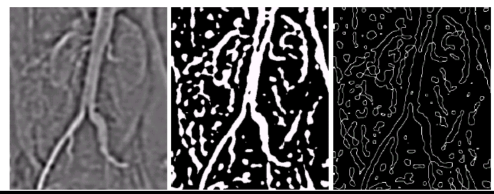
0	0	−1	0	0
0	−1	−2	−1	0
−1	−2	16	−2	−1
0	−1	−2	−1	0
0	0	−1	0	0

Laplacian Of Gaussian Example





−1	−1	−1
−1	8	−1
−1	−1	−1



Summary

In this lecture we have begun looking at segmentation, and in particular edge detection

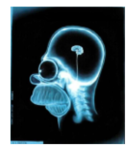
Edge detection is massively important as it is in many cases the first step to object recognition

NED University of Engineering and Technology

Course: Biomedical Imaging
Code: BM-406
Instructor: Dr. Eraj
Lecture: 12

Lecture Overview

- 1.X-ray imaging principles
- 2.Invention of X-ray imaging
- 3.Production of X-rays

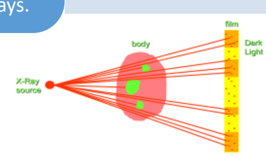


1. X-RAY IMAGING PRINCIPLES

- *Conventional cassette imaging*
- *Fluoroscopy*
- *Linear tomography*
- Digital radiography
- CT (computed tomography)

It is based on the fact that various anatomical structures of the body have different densities for the X-rays.

- When X-rays from a point source penetrate a section of the body, the Internal body structures absorb varying amount of the radiation.



The X-ray intensity distribution is **visualized by** a suitable device like a **photographic film**.

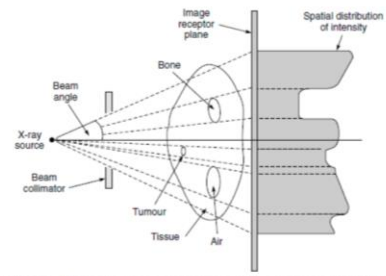
- A **shadow image** is generated that **corresponds to the X-ray density of the organs** in the body section.

features

The examination technique varies according to the clinical problem. The main **properties of X-rays**, which make them suitable for the purposes of medical diagnosis, are their:

- **Capability to penetrate** matter coupled with differential absorption observed in various marterials; and
- **Ability to produce luminescence** and its effect on photographic emulsions.

The **X-ray picture is called a radiograph**, which is a shadow picture produced by X-rays eman[...]m a point source.



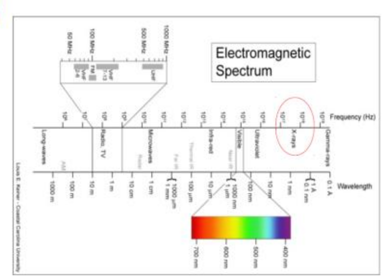
➤ Fig. 19.1 *Basic set-up for a diagnostic radiology image formation process*

X-rays are electromagnetic radiation

- located at the **low wavelength end** of the electromagnetic spectrum.
- The X-rays in the **medical diagnostic** region have wavelength of the order of **10e10m**.
- They propagate with a speed of **3x10e10 cm/s** and are unaffected by electric and magnetic fields.

According to the quantum theory, electromagnetic radiation **consists of photons**, which are

- conceived as **'packets' of energy**
- Their **interaction with matter involves an energy exchange**
- the **relation between the wavelength and the photon** is given by = ?



Short wavelength and extremely **high energy**

- X-rays are able to **penetrate through materials** which readily absorb and reflect visible light
- This forms the basis for the use of X-rays for radiography
- even for their **potential danger**

X-rays are absorbed when passing through matter

- The **extent of absorption** depends upon the **density of the matter**.

X-rays produce **secondary radiation in all matter** through which they pass

This secondary radiation is composed of:

- Scattered radiation
- Characteristic radiation
- Electrons

In **diagnostic radiology**, it is **scattered radiation** which is of practical importance.

The ionizing property

- used in the construction of **radiation-measuring instruments=?**

X-rays also **produce fluorescence in certain materials** to help them emit light.

- **Fluoroscopic screens and intensifying screens** have been constructed on the basis of this property

X-rays **affect photographic film** in the same way as ordinary visible light

International Commission on Radiological Units and Measurements (ICRUM)

- *Rontgen* as a **measure of the quantity** of x-radiation
- This unit is based on the **ability** of radiation to **produce ionization**
- abbreviated ‘R’

One R is the amount of x-radiation which will produce 2.08xl0e9 ion pairs per cubic centimetre of air at standard temperature (0°C) and pressure (760 mmHg at sea level and latitude 45°)

2. INVENTION OF X-RAY IMAGING

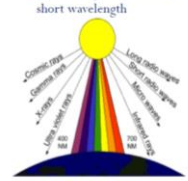
Roentgen's first X-ray

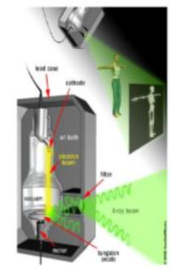
1895: X-rays -> +photography

->January 1896: X-ray imaging

Basic Concepts

- What is an X-Ray?
  - Electromagnetic Radiation - short wavelength





One description of radiography

- An x-ray is a picture a special doctor takes to see the bones inside your body.
- The picture can see hard things like bones
- The dentist can x-ray your teeth to look for cavities
- It doesn't hurt at all when the doctor x-rays you

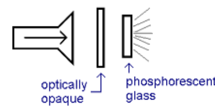
CHAPTER 1: INTRODUCTION

X-rays were discovered in **1895** when **Wilhelm Conrad Roentgen** observed that a screen coated with a barium salt fluoresced when placed near a cathode ray tube. Roentgen concluded that a form of penetrating radiation was being emitted by the cathode ray tube and called the unknown rays, **X-rays**.

What are X-rays?

- X rays are the ionizing *electromagnetic radiation* emitted from a highly evacuated high-voltage tube. Inner orbital electrons in the target anode are stimulated to emit x-radiation via bombardment by a stream of electrons from a heated cathode.
- X-rays, like gamma rays, are penetrating and carry enough energy to ionize atoms in their path. Nearly identical to gamma rays, x-rays require shielding to reduce their intensity and minimize the danger of tissue damage to personnel. Mishaps with x-rays can cause severe radiation burns and deep tissue damage and can lead to various cancers.

Röntgen's Setup



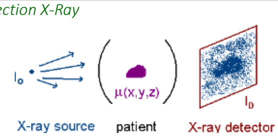
Röntgen detected:

- No reflection
- No refraction
- Unresponsive to mirrors or lenses

His conclusions:

- X-rays are not an EM wave
- Dominated by corpuscular behavior

Projection X-Ray



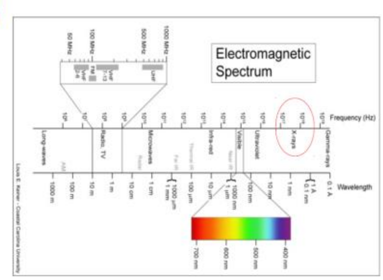
attenuation coefficient $\mu(x, y, z) = f(\text{electron density}, Z)$

$I_D =$ … $\mu(x, y$ … Measures line integrals of attenuation

…s intensity as a negative (dark areas, high x-ray detection

Disadvantage: Depth information lost

Advantage: Cheap, simple



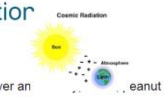
What is Radiation?

·Radiation is energy in the form of waves or particles.

·Radiation which is high enough in energy to cause ionization is called ionizing radiation. It includes particles and rays given off by radioactive material and high-voltage equipment. Ionizing radiation includes x-rays, gamma-rays, beta particles, alpha particles, and neutrons.

·Without the use of monitoring equipment, humans are not able to "find" ionizing radiation. In contrast to heat, light, odors and noise, humans are not able to see, feel, taste, smell, or hear ionizing radiation.

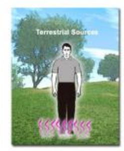
Sources of Radiation

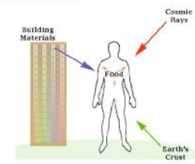


mic: altitude and latitude

strial: geographically

(pCi): brazil nuts; cereals; teas; liver an eanut butter; chocolates; biscuits; cheese; vegetables





Units of Radiation Exposure and Dose

- Exposure (Roentgens)
- Absorbed dose (Gray)
- Dose Equivalence (Sievert)
  elative biological effectiveness of different types of ionising radiation
- The Effective Dose Rate (Sievert)

Dose

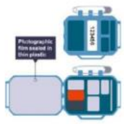
International Commission on Radiological Protection (ICRP)
Prescribed Limits per annum

- **Members of public**
  - 1 mSv per annum above background
  - 5 mSv to eye
  - 20 mSv to hands
- **Radiation workers**
  - 20 mSv per annum above background
  - 150 mSv to eye
  - 500 mSv to hands

·Pregnant women must receive no more than 2mSv per annum

PERSONNEL MONITORING

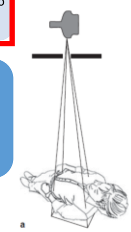
- X-ray devices users must wear personnel radiation monitoring devices (dosimeters / film badges). Dosimeters measure and document accrued dose to operators.



X-rays pass through the patient

- Detected using a **solid-state flat panel detector** which is placed just **below the patient**
- The detected X-ray **energy** is first **converted** into **light,** then into a **voltage and finally is digitized**

The **digital image represents a two-dimensional projection** of the tissues lying between the X-ray source and the detector.



In addition to being absorbed, **X-rays can also be scattered** as they pass through the body

- This gives rise to a background signal which **reduces the image contrast**
  - Therefore, an **'anti-scatter grid'** is used to ensure that only X-rays that pass directly through the body from source-to-detector are recorded.

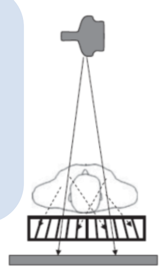


Figure 2.12

Images showing the effects of an anti-scatter grid on the CNR of a planar X-ray image. The images are produced from a pelvic phantom, which simulates the absorption properties of the human pelvis. (a) No anti-scatter grid: there is a large background signal from Compton-scattered X-rays which reduces the CNR of the image. (b) With an anti-scatter grid in place the overall signal intensity of the image is reduced, but the CNR is improved significantly.

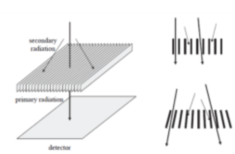


Figure 2.13

(left) Basic design of an anti-scatter grid, with thin lead septa aligned in either a parallel (top right) or slightly diverging (bottom right) geometry. The thick arrows show primary radiation which passes through the anti-scatter grid, and the thin arrows correspond to secondary Compton-scattered radiation which is stopped by the grid.

Principle components of x-ray tube:

- Source of electrons
- Target
- Evacuated envelope
- High-voltage source

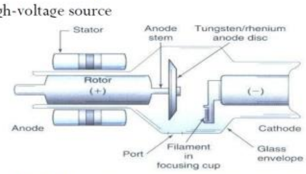


FIGURE 2-5 Structure of a typical x-ray tube, including the major operational parts.

The X-ray tube parts:

- Cathode (-)
  - Filament made of tungsten
- Anode (+) target
  - Tungsten disc that turns on a rotor
- Stator
  - motor that turns the rotor
- Port
  - Exit for the x-rays

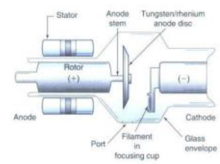


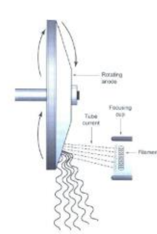
FIGURE 2-5 Structure of a typical x-ray tube, including the major operational parts.

X-ray Production

- X-rays are produced when high velocity electrons are decelerated during interactions with a high atomic number material, such as the tungsten target in an X-ray tube.
- An electrically heated filament within the X-ray tube generates electrons that are then accelerated from the filament to hit the tungsten target by the application of a high voltage to the tube.
- The electron speed can exceed half the speed of light before being rapidly decelerated in the target.

X-ray production

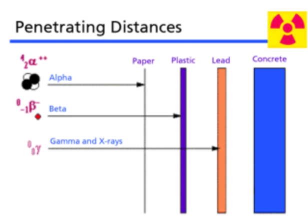
- Push the "rotor" or "prep" button
  - Charges the filament – causes thermionic emission (e- cloud)
  - Begins rotating the anode.
- Push the "exposure" or "x-ray" button
  - e-'s move toward anode target to produce x-rays



X-rays characteristics

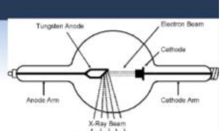
- Highly penetrating, invisible rays
- Electrically neutral
- Travel in straight lines.
- Travel with the speed of light in vaccum:
  300, 000 km/sec or 186, 400 miles/sec.
- Ionize matter by removing orbital electrons
- Induce fluorescense in some substances. Fluorescent screen glow after being stricken with photons.
- Can't be focused by lenses nor by collimators.

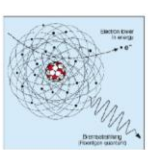
Penetrating Distances

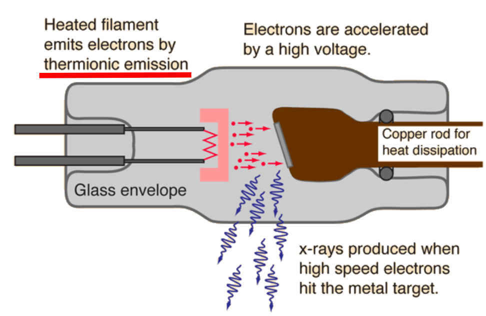


3. PRODUCTION OF X-RAYS

- vacuum tube
- filament is heated: free electrons
- electrons are accelerated by a high DC voltage between anode and cathode
- electrons hit the anode producing mostly bremsstrahlung: X-ray beam







The components of the X-ray system

The components of the X-ray system

- contained within an evacuated vessel
- The evacuated vessel is surrounded by oil for both cooling and electrical isolation

filament

The whole assembly is surrounded by a lead shield with a glass window, through which the X-ray beam is emitted.

- X-rays are produced by a beam of high energy electrons striking the surface of a metal target
- A negatively-charged cathode acts as the source of these electrons, and consists of a small helix of thin tungsten wire, through which an electric current is passed

When the temperature of the wire reaches ~2200 C

- Electrons have sufficient energy to leave the metal surface. In order to produce a tight beam of electrons

A large positive voltage is applied to a metal target, which thus forms an anode

- A potential difference between the anode and cathode of between 25 and 140 kV (depending upon the particular type of clinical study) is applied, such that the

electrons produced at the cathode are attracted to the anode, striking it at high velocities. This potential difference is known as the accelerating voltage, or kVp.

When the high energy electrons strike the anode surface

- part of their kinetic energy is converted into X-rays

The metal anode must be able to produce X-rays efficiently, and also be able to

- withstand the very high temperatures generated.

In terms of efficiency

- the higher the atomic number of the metal in the target, the higher the efficiency of X-ray production

The most commonly used metal is tungsten

- which has a high atomic number, 74, and a melting point of 3370 C
- In addition it has good thermal conductivity and a low vapour pressure, which allows a strong vacuum to be established within the X-ray tube, thus providing the electrons with an unimpeded path between cathode and anode

Even with the high efficiency of tungsten only ~1% of the energy of the electrons is converted into X-rays: the remainder is dissipated in heat.

In order to produce a narrow beam of electrons

- a negatively-charged focusing cup is constructed around the cathode filament
- In fact, many X-ray tubes contain two cathode filaments of different length, each with a focusing cup, as shown in

In order to achieve a well-defined small area in which the X-rays are created

The anode is bevelled at an angle between 8 and 17, with 12–15 being the usual

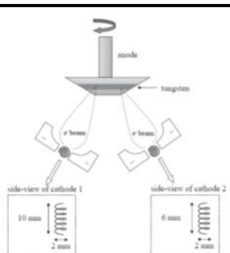


Figure 2.4

Top view showing the effect of the focusing cup on the shape of the electron beam striking the rotating anode. There are two cathodes (expanded in the side-views) which produce a wider or narrower beam depending upon the particular application. The direction of the X-ray beam produced is out-of-the-page towards the reader.

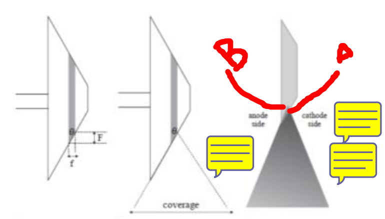


Figure 2.5

(a) The effect of the bevel angle θ on the effective focal spot size (f) as a function of the width of the electron beam (F). (b) Corresponding diagram for the effect of θ on the coverage of the X-ray beam. (c) Illustration of the Heel effect, in which the X-ray intensity is higher on the 'cathode side' of the beam than on the 'anode side', since the X-rays on the anode side have to travel further through the anode itself before leaving the tube, and are therefore more highly attenuated.

Three parameters that can be chosen by the operator for X-ray imaging:

- the accelerating voltage (kVp)
- the tube current (mA)
- the exposure time

The current that passes from the cathode to the anode is typically between 50 and 400 mA for planar radiography, and up to 1000 mA for CT. The value of the kVp varies from ~25 kV for digital mammography to ~140 kV for bone and chest applications.

Accelerate electrons towards anode. Three types of events can happen.

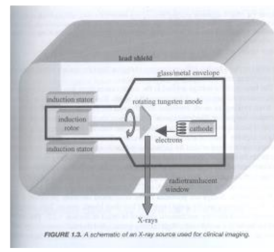


FIGURE 1.3 A schematic of an X-ray source used for clinical imaging.

1. Collision events -> heat
2. Photoelectric effect
3. Braking of electron b[y] nucleus creates an x-ray (Bremstrahlung effect)

Typically Tungsten Target
High melting point
High atomic number

When the electrons from the cathode are accelerated at high voltage to the anode:

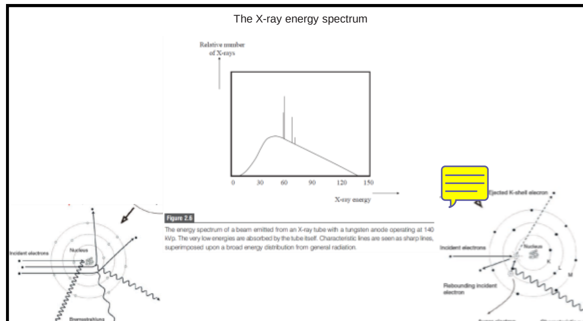
- 99% of the energy is dissipated as heat

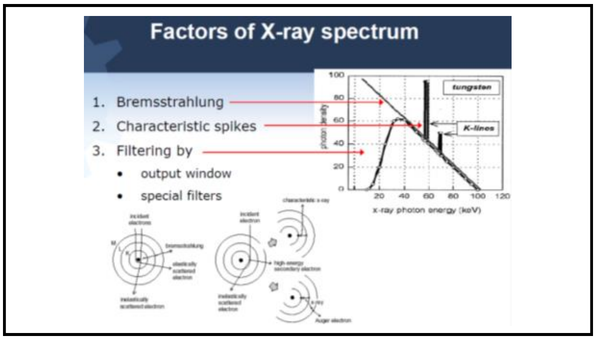
(anode materials are selected to withstand the high temperatures they are able to withstand)

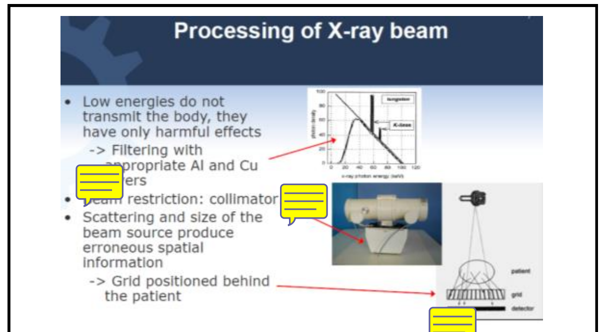
1% is given off as x-rays.

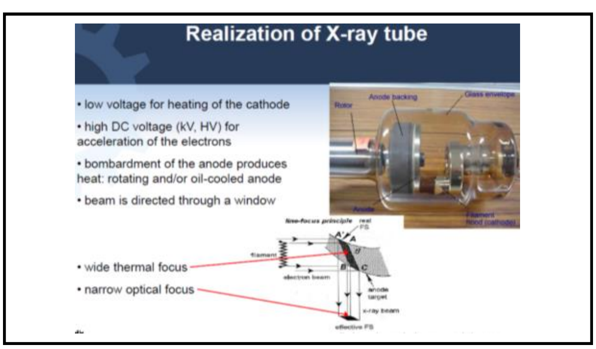
- The energy of the x-rays (keV) is determined by the voltage applied (kVp) while,
- The amount of x-rays is determined by the current (mA).

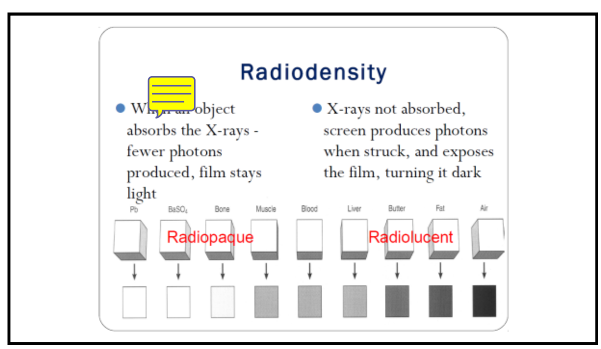
The X-ray energy spectrum

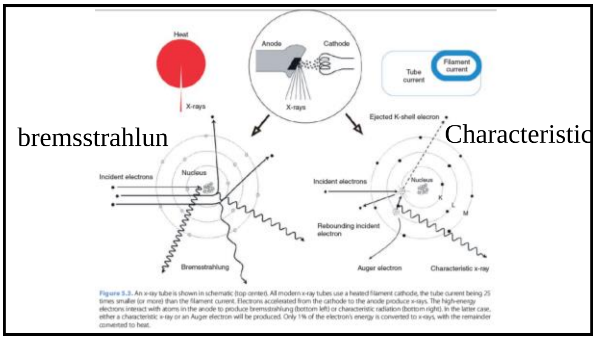



Factors of X-ray spectrum
1. Bremsstrahlung
2. Characteristic spikes
3. Filtering by
• output window
• special filters
tungsten
K-lines
photon density
x-ray photon energy (keV)
100
80
60
40
20
0
20 40 60 80 100 120


Processing of X-ray beam
• Low energies do not transmit the body, they have only harmful effects
-> Filtering with appropriate Al and Cu ers
• beam restriction: collimator
• Scattering and size of the beam source produce erroneous spatial information
-> Grid positioned behind the patient
patient
grid
detector

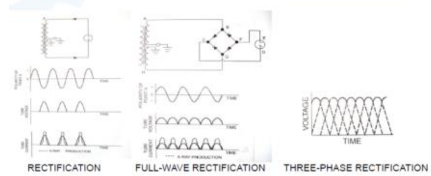

Realization of X-ray tube
• low voltage for heating of the cathode
• high DC voltage (kV, HV) for acceleration of the electrons
• bombardment of the anode produces heat: rotating and/or oil-cooled anode
• beam is directed through a window
• wide thermal focus
• narrow optical focus
Anode backing
Glass envelope
Rotor
Anode
line-focus principle
real FS
filament
electron beam
anode target
x-ray beam
effective FS


Radiodensity
• When an object absorbs the X-rays - fewer photons produced, film stays light
• X-rays not absorbed, screen produces photons when struck, and exposes the film, turning it dark
Pb
BaSO4
Bone
Muscle
Blood
Liver
Butter
Fat
Air
Radiopaque
Radiolucent



HV (kV) production

- high DC voltages are hard to produce
- Processed by transforming AC to high voltages and rectification
- x-rays appear mostly at highest voltage values



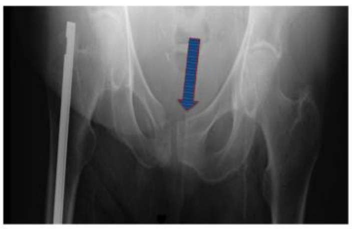
X-ray tube housing

- material: steel or aluminium alloy
- electrically grounded
- oil filling serves electrical insulation and cooling:
  - direct cooling for fixed anode
  - active cooling for rotating anode: oil circulated through water
- radiation protection: internal lead shield of 3-4 mm
- exit window covered with Al filtering

A-B-C-D

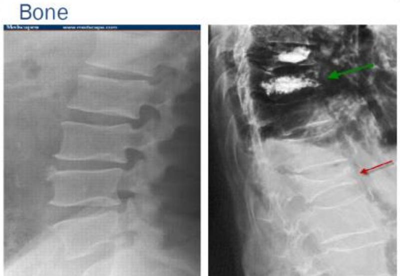
- A- Alignment- is the bone in good general alignment
- B- Bone- general bone density
- C- Cartilage- sufficient cartilage space
- D- Dee other stuff??
  - Muscles, fat pads and lines, joint capsules, miscellaneous soft-tissue findings, bullets

Alignment



Alignment

Bone



Bone

Cartilage

The role of imaging is to confirm the infection and show extent. Radiography will show the infection, however usually late. Radiography has a high specificity but low sensitivity.

Specifications for anode material

- High M
- High heat conductivity
- Easy to machine

W and W alloys

wolfram

Anode constructions

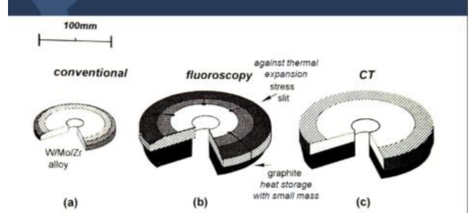
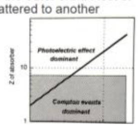


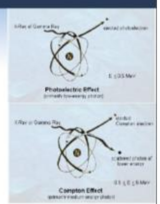
Figure 4.11 Anode designs for **(a)** conventional 100mm diameter anode made from a molybdenum/tungsten/zirconium composite with a rhenium/tungsten target, **(b)** an anode designed for a fluoroscopy system with stress slits and **(c)** a CT anode sometimes has a flat anode.

Interaction of X-rays with the tissue

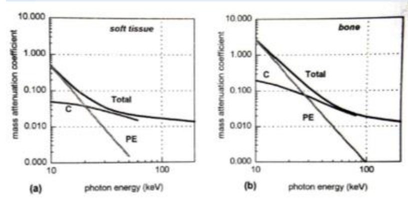
Photoelectric effect (absorption): X-ray photon releases all energy. Binding (dissolving) energy is given to the atom and rest to the electron as kinetic energy

Compton effect (scattering): part of the X-ray photon energy is used for dissolving an electron from the outer orbit. Rest of the energy is scattered to another direction





Total effect of interaction processes



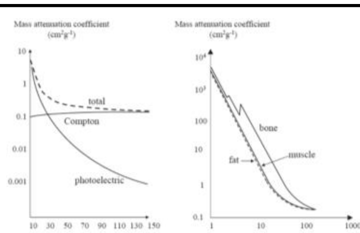


Figure 2.11

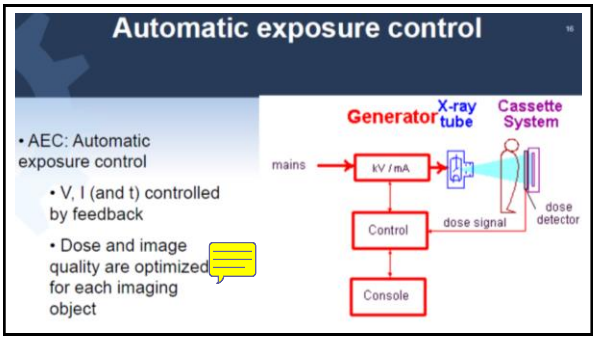
(left) The individual contributions from photoelectric attenuation and Compton scatter add together to give a net tissue linear attenuation coefficient (the specific data are shown for water). The contribution from the photoelectric effect dominates at low X-ray energies, but Compton scatter is the more important term at high energies. (right) The mass attenuation coefficient of lipid, muscle and bone as a function of X-ray energy.

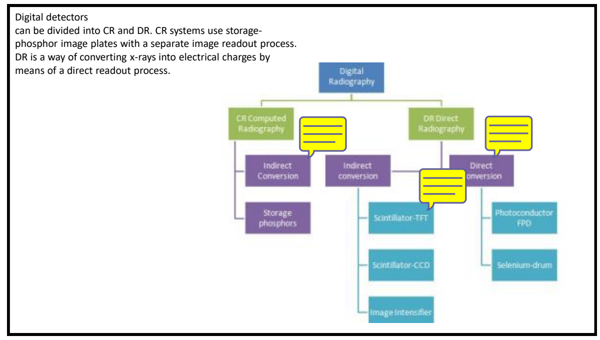
Tissue contrast in X-ray imaging

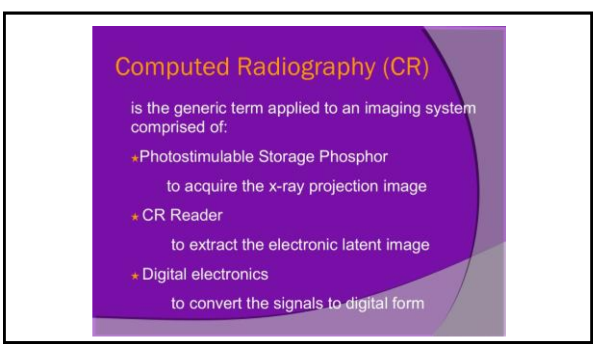
- Information of X-ray images: "Hard tissues" attenuate the radiation more effectively than soft ones

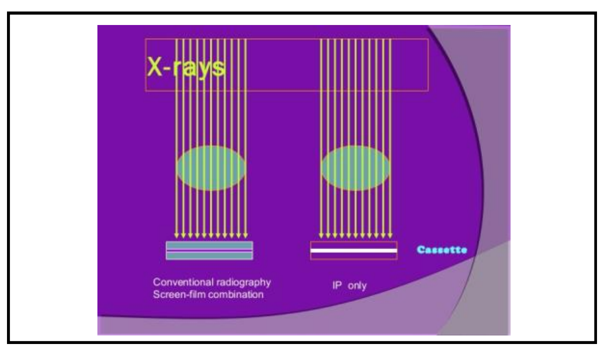
$I = I_0 e^{-\mu x}$, μ = attenuation coefficient and x = thickness of the tissue

- Contrast depends on energy
- Contrast can be altered by contrast media
- Both density and thickness of the tissue increase the attenuation


Automatic exposure control
• AEC: Automatic exposure control
• V, I (and t) controlled by feedback
• Dose and image quality are optimized for each imaging object
Generator
X-ray tube
Cassette System
mains
kV / mA
Control
dose signal
dose detector
Console


Digital detectors
can be divided into CR and DR. CR systems use storage-phosphor image plates with a separate image readout process.
DR is a way of converting x-rays into electrical charges by means of a direct readout process.
Digital Radiography
CR Computed Radiography
DR Direct Radiography
Indirect Conversion
Indirect conversion
Direct onversion
Storage phosphors
Scintillator-TFT
Scintillator-CCD
Image Intensifier
Photoconductor FPD
Selenium-drum


Computed Radiography (CR)
is the generic term applied to an imaging system comprised of:
Photostimulable Storage Phosphor
to acquire the x-ray projection image
CR Reader
to extract the electronic latent image
Digital electronics
to convert the signals to digital form

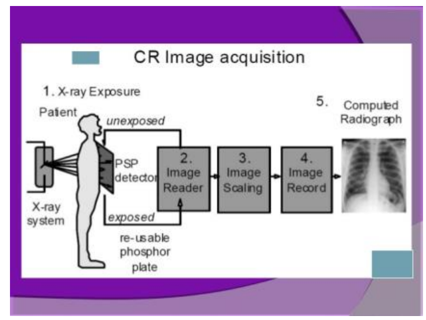

X-rays
Cassette
Conventional radiography
Screen-film combination
IP only

Computed radiography

- Consist detector plate and a CR reader

CR reader digitizes the plate after the X-ray image has been acquired

CR plate consists of a thin layer of phosphor crystals(barium fluorohalide) activated with europium ions (BaFX:Eu2+)



The plates can be categorized

either high resolution (HR)

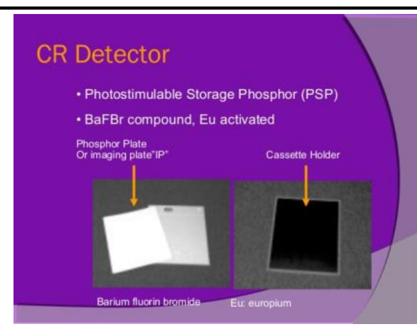
- mammography

Standard

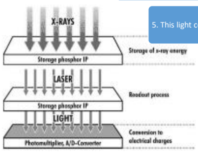
- for general applications

Note that HR plates have a thinner phosphor layer (~140 um) compared to standard plates (230 um), and the phosphor crystals are physically smaller.

The CR plates convert the X-rays which pass through the patient and the antiscatter



1. During exposure, x-ray energy is absorbed and temporarily stored by these crystals by bringing electrons to higher energy levels.
2. X-ray energy can be stored for several hours, depending on the specific physical properties of the phosphor crystals used.
3. The readout process should start immediately after exposure because the amount of stored energy decreases over time.
4. The readout process is a separate step that follows exposure of the image plate. When the detective layer is scanned pixel by pixel with a high-energy laser beam of a specific wave length, stored energy is set free as emitted light having a wave length different from that of the laser beam.
5. This light collected by photodiodes and converted digitally into an image.



The whole readout process for a 14x17-inch image plates takes about 30-40 seconds.

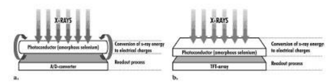
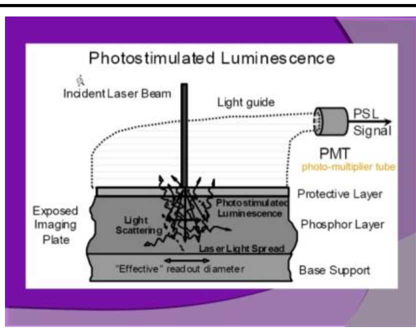
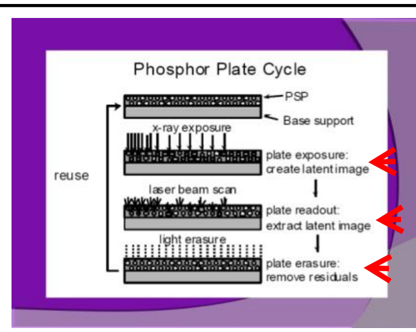
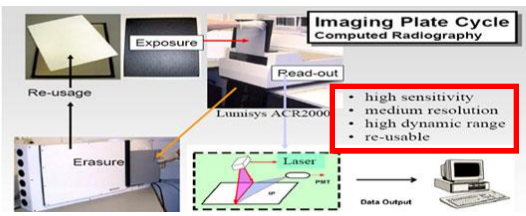


Figure 4: Amorphous selenium-based direct conversion DR systems. (a) Drawing illustrates a selenium drum-based system. A rotating selenium-dotted drum with a positive electrical surface charge is exposed to x-rays. Alteration of the charge pattern of the drum surface is proportional to the incident x-rays. The charge pattern is then converted into a digital image by an analog-digital converter(ADC). (b) Drawing illustrates a selenium-based flat-panel detector systems. Incident x-ray energy is directly converted into electrical charges within the fixed photo-conductor layer and read out by a linked TFT array beneath the defective layer.







Computed Radiography (CR)

The Pros

•CR costs significantly less than DR in every aspect. From equipment, install, and ongoing servicing.
•CR units are compatible with many different X-Ray devices; they are quite versatile in that they're able to convert many analog units.
•CR's can render an image digitally in less than a minute, [illegible]e it is done, storage [illegible] and space efficient.
[illegible]abor intensive of X-R[illegible]sions.

The Cons

•Much slower than DR.
•Not able to have instant gratification when it comes to image quality.

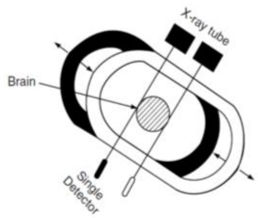
Digital Radiography (DR)

The Pros

•Digital is replacing analog at an exponentially fast rate, and eventually, it will be harder for those with analog systems to find parts and to find people that are trained to use them.
•If you replace your analog with DR, you most likely won't even need to remodel your X-Ray space.
•DR's can render an image in about 5 seconds.
•New systems sometimes come with software that is far more advanced than analog.

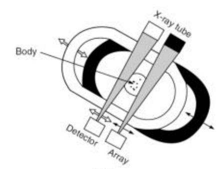
The Cons

•Far more expensive than CR.
•Labor intensive, meaning that install can take up to four days to complete.



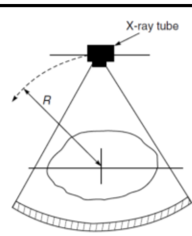
(a)

Scanning arrangement of the early CT machines. They made a linear traverse before taking a 1° rotation. The system employed single-source and single-detector system. It took long measuring times



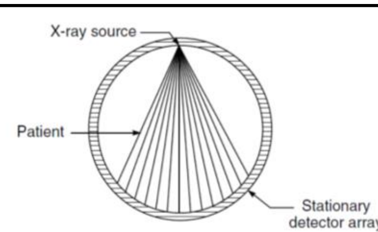
(b)

Using a fan-shaped beam and an array of detectors, larger steps can be taken and the scanning process speeded up



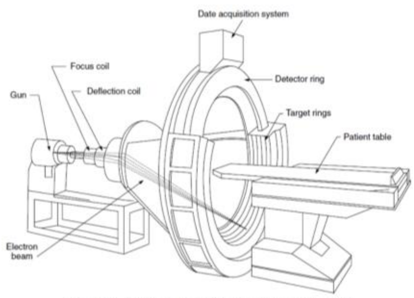
(c)

If the fan-beam is large, no traverse motion is needed. Only rotational movement of the scanning frame is required, thus offering considerable improvement in measuring time

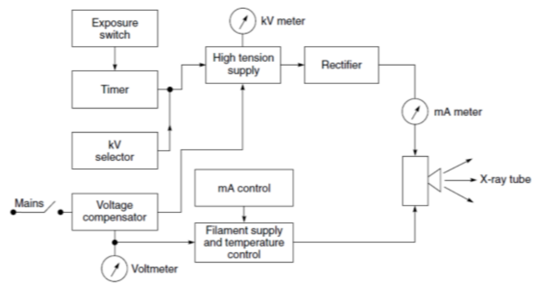


(d)

The x-ray tube rotates while detectors remain stationary. This arrangement overcomes many problems of pure rotational systems



➤ Fig. 20.7 *Schematic of ultrafast electron beam CT scanner*



➤ Fig. 19.5 *Block diagram of an X-ray machine*

NED University of Engineering and Technology

Course:	**Biomedical Imaging**
Code:	**BM-406**
Instructor:	**Dr. Eraj**
Lecture:	**13**

What is General Ultrasound Imaging?

- Ultrasound imaging, also called sonography, involves exposing part of the body to high-frequency sound waves to produce pictures of the inside of the body.
- Ultrasound examinations do not use ionizing radiation (as used in x-rays).
- Because ultrasound images are captured in real-time, they can show the structure and movement of the body's internal organs, as well as blood flowing through blood vessels.

Why Ultrasound

- Ultrasound (US) is the *most widely used* imaging technology worldwide
- Popular due to *availability, speed, low cost, patient-friendliness* (no radiation)
- Applied in obstetrics, cardiology, inner medicine, urology,...
- Ongoing research to improve image quality, speed and new application areas such a intra-operative navigation, tumour therapy,...

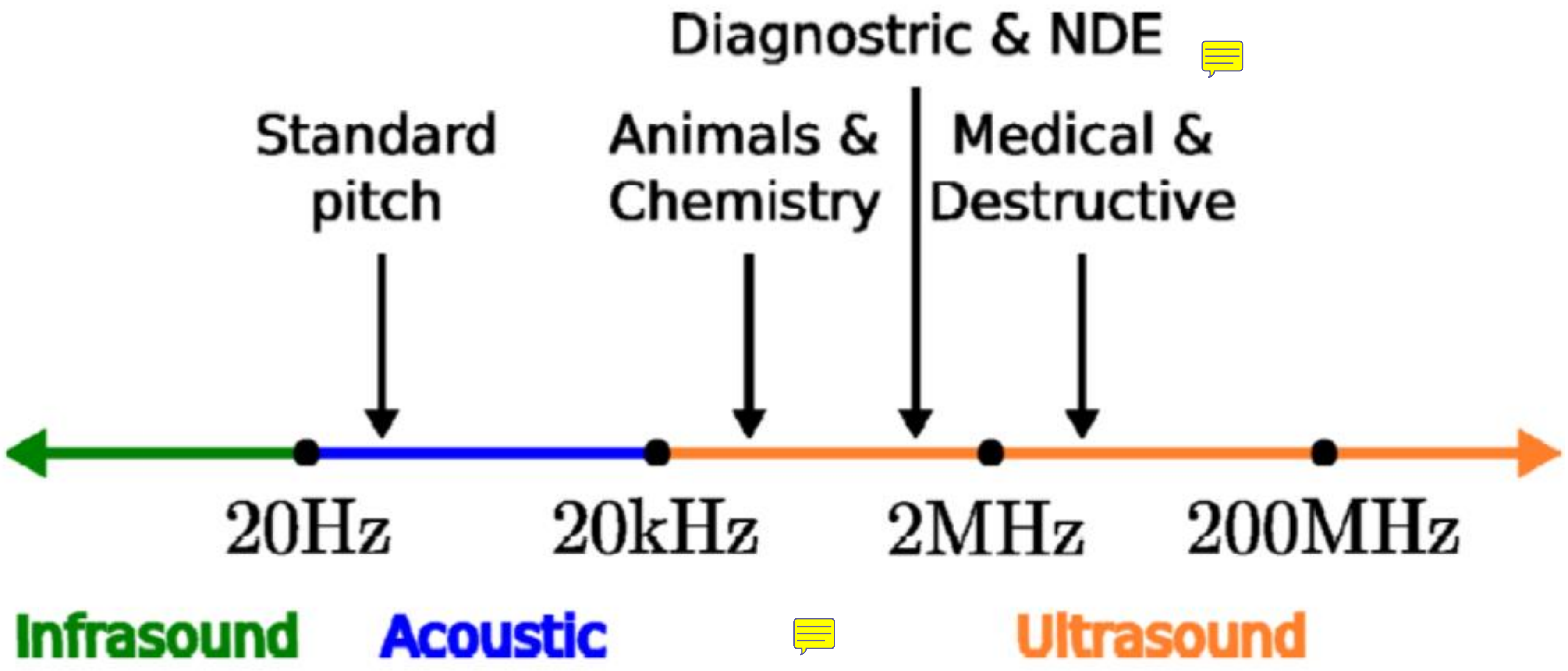
What are some common uses of the procedure?

1. Ultrasound examinations can help to diagnose a variety of conditions and to assess organ damage following illness.
2. Ultrasound is used to help physicians evaluate symptoms such as:

- pain
- swelling
- infection
- hematuria (blood in urine)

Properties of Ultrasound

The frequencies of medical Ultrasound waves are several magnitudes higher than the upper limit of → human hearing.



Approximate frequency ranges of sound

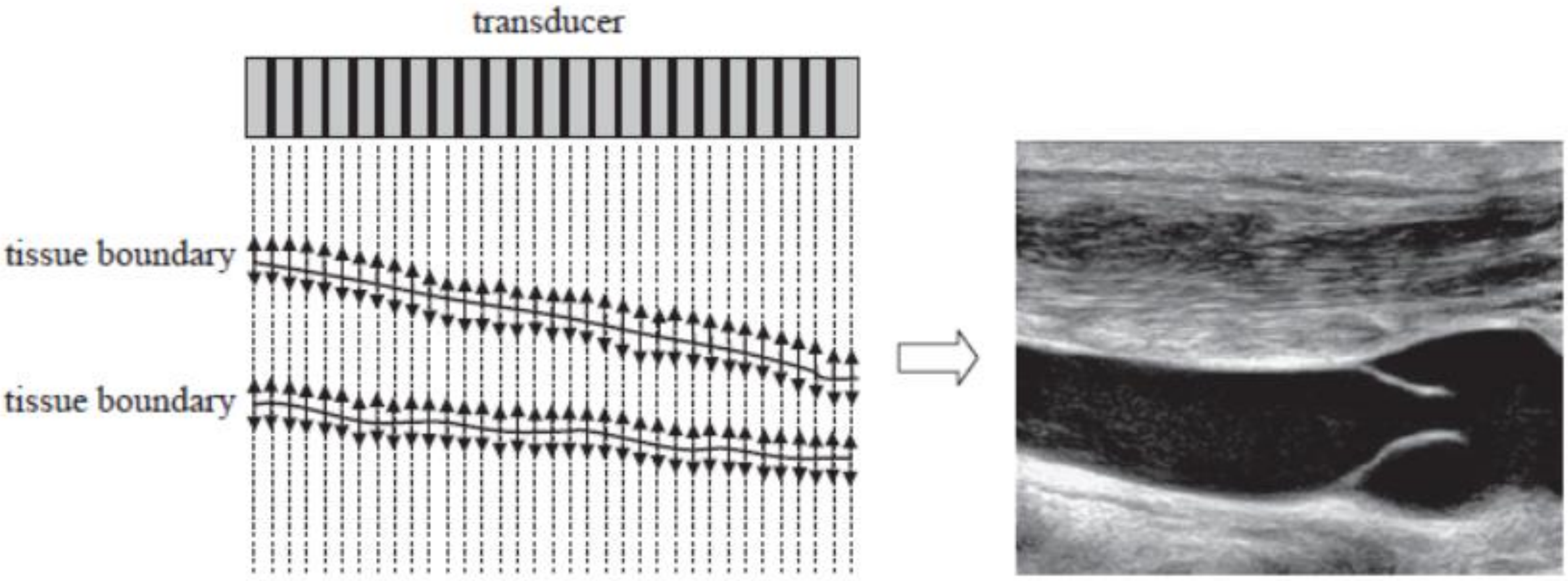


Figure 4.1

(left) Basic principle of ultrasound imaging. A transducer sends a series of pressure waves through the tissue. At boundaries between tissues, a small fraction of the energy is backscattered towards the transducer where it is detected. Using the speed of sound through tissue, the depth of the tissue boundary can be determined. Electronic steering of the beam across the sample builds up successive lines which form the image. (right) The intensity of each pixel in the image is proportional to the strength of the detected signal reflected from that point.

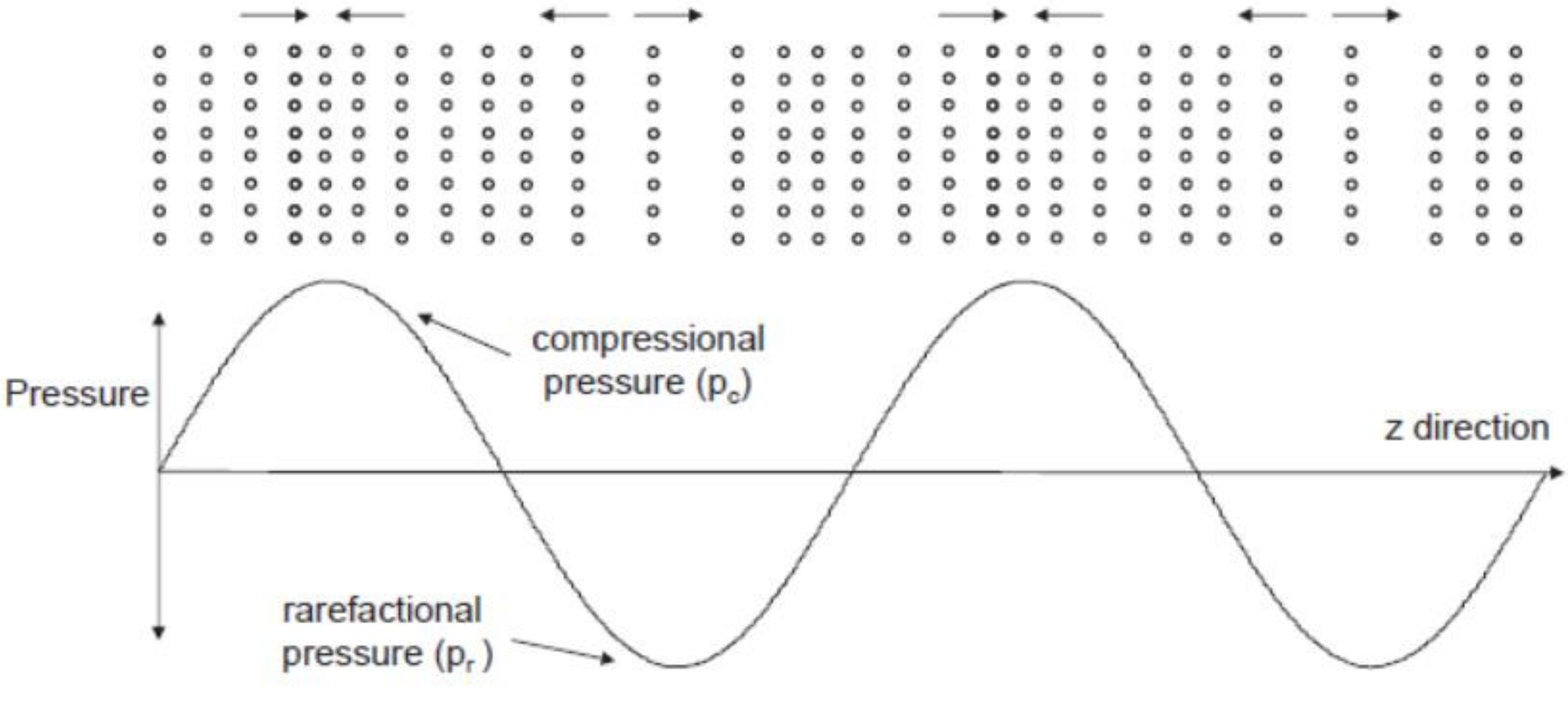


Figure 4.2

The effect of the passage of an ultrasound wave on the displacement of the molecules within tissue. The maximum positive pressure of the wave corresponds to the maximum compressional force, pushing the molecules together. The corresponding maximum negative pressure represents a rarefactional force.

	f	**Examples**
Infrasound	$0 \ldots 16\,\mathrm{Hz}$	Seismic waves
Audible sound	$16\,\mathrm{Hz} \ldots 20\,\mathrm{kHz}$	Music Human Speech
Ultrasound	$> 20\,\mathrm{kHz}$	Bat, Dolphin, and Whale Sounds Acoustic Microscopy Ultrasound Imaging

Table 11.1: Acoustic spectrum.

Table 4.1: Acoustic properties of biological tissues

	$Z \times 10^5$ ($g\ cm^{-2}\ s^{-1}$)	Speed of sound ($m\ s^{-1}$)	Density (gm^{-3})	Compressibility $x10^{11}$ ($cm\ g^{-1}\ s^2$)
Air	0.00043	330	1.3	70 000
Blood	1.59	1570	1060	4.0
Bone	7.8	4000	1908	0.3
Fat	1.38	1450	925	5.0
Brain	1.58	1540	1025	4.2
Muscle	1.7	1590	1075	3.7
Liver	1.65	1570	1050	3.9
Kidney	1.62	1560	1040	4.0

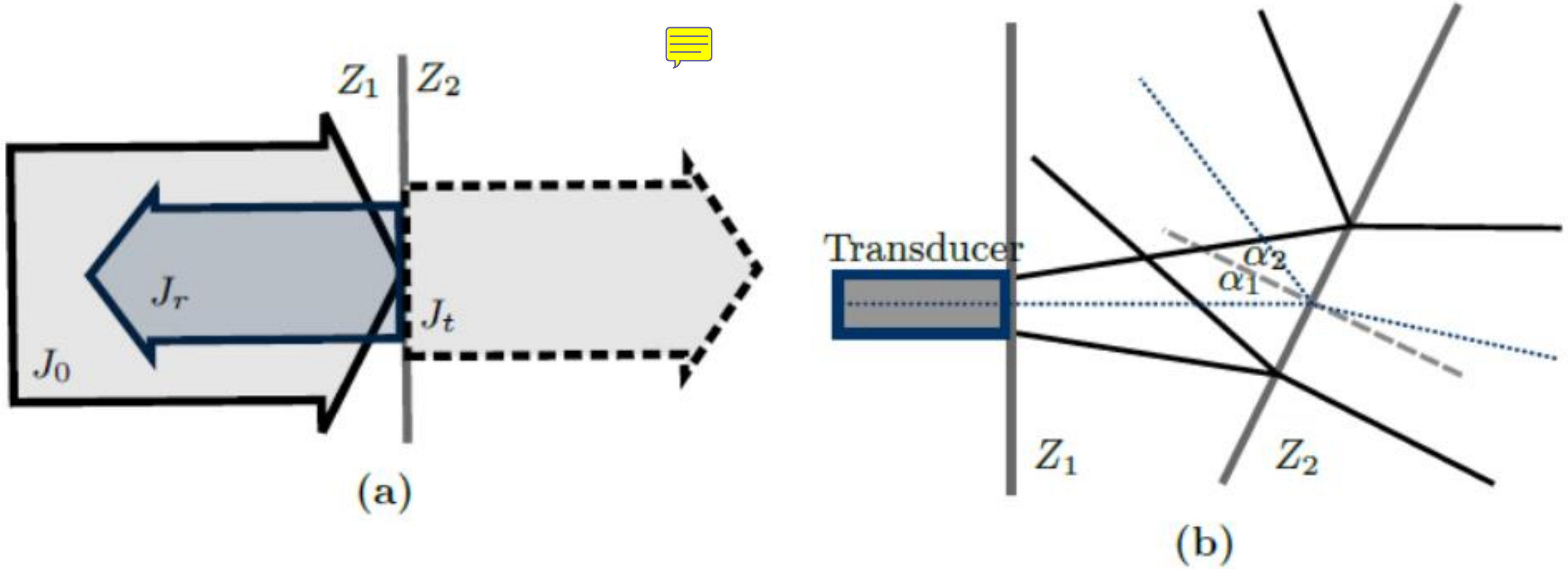


Figure 11.2: (a) Reflected J_r and transmitted J_t wave intensity at border between two different materials with impedance Z_1 and Z_2, respectively. (b) Reflection of sound waves at smooth surfaces ($\alpha_1 = \alpha_2$).

Material 1	**Material 2**	**Reflected**
Brain	Skull bone	43.5%
Fat	Muscle	1%
Fat	Kidney	0.6%
Muscle	Blood	0.1%
Soft tissue	Water	0.25%
Soft tissue	Air	99.9%

Table 11.3: Reflectivity at boundaries between two materials.

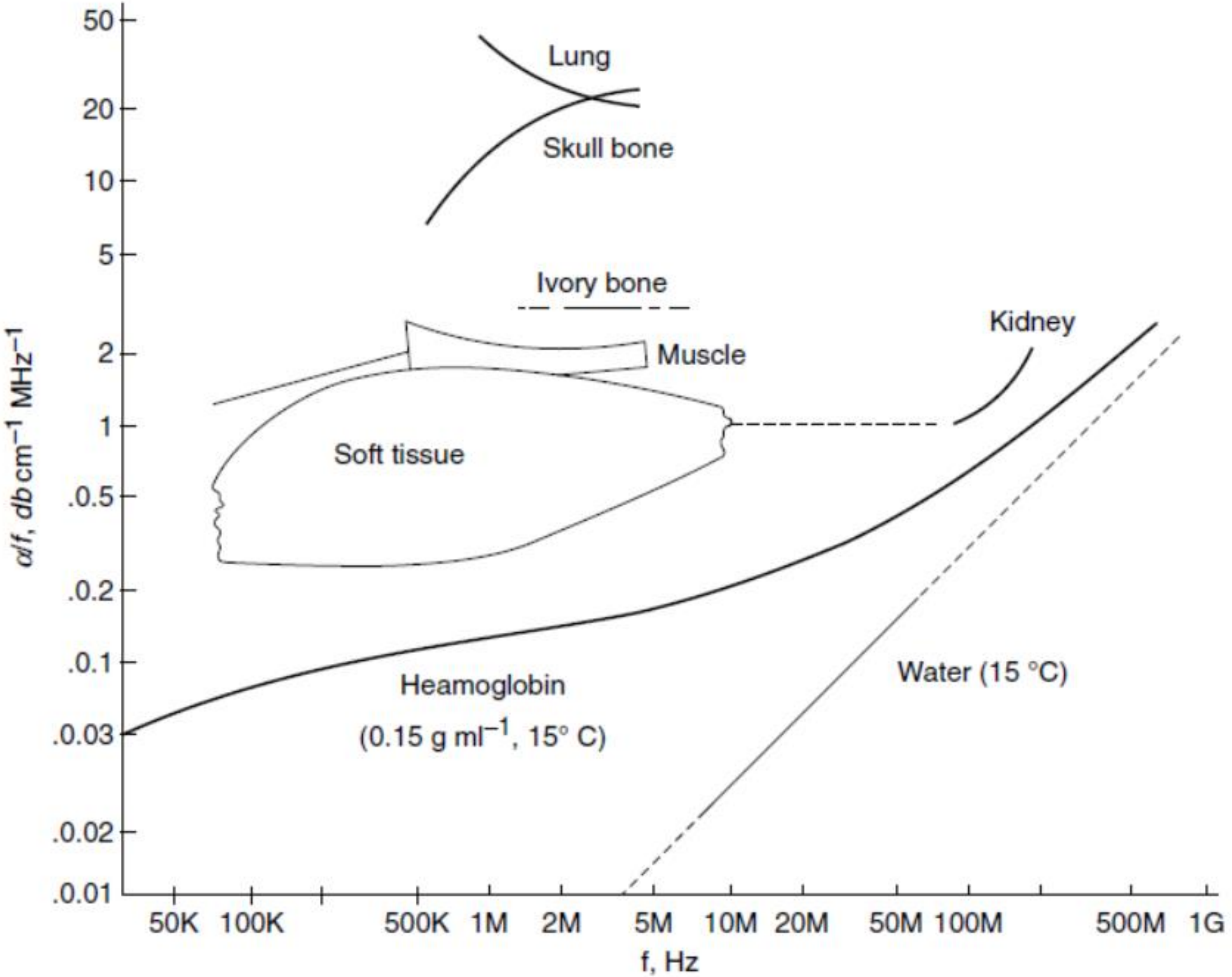


Fig. 23.3 *Attenuation of ultrasound in various biological materials (Adapted from P.N.T. Wells, Biomedical Ultrasound, Academic Press, London)*

ξ [MHz]	$d_{\max}$ [cm]	**Typical Applications**
1.0	50	*n/a*
3.5	15	Fetus, liver, heart, kidney
5.0	10	Brain
7.5	7	Prostate
10	5	Pancreas (intraoperative)
20	1.2	Eye, skin
40	0.6	Intravascular

Table 11.4: Maximum penetration depth $d_{\max}$ for various frequencies f.

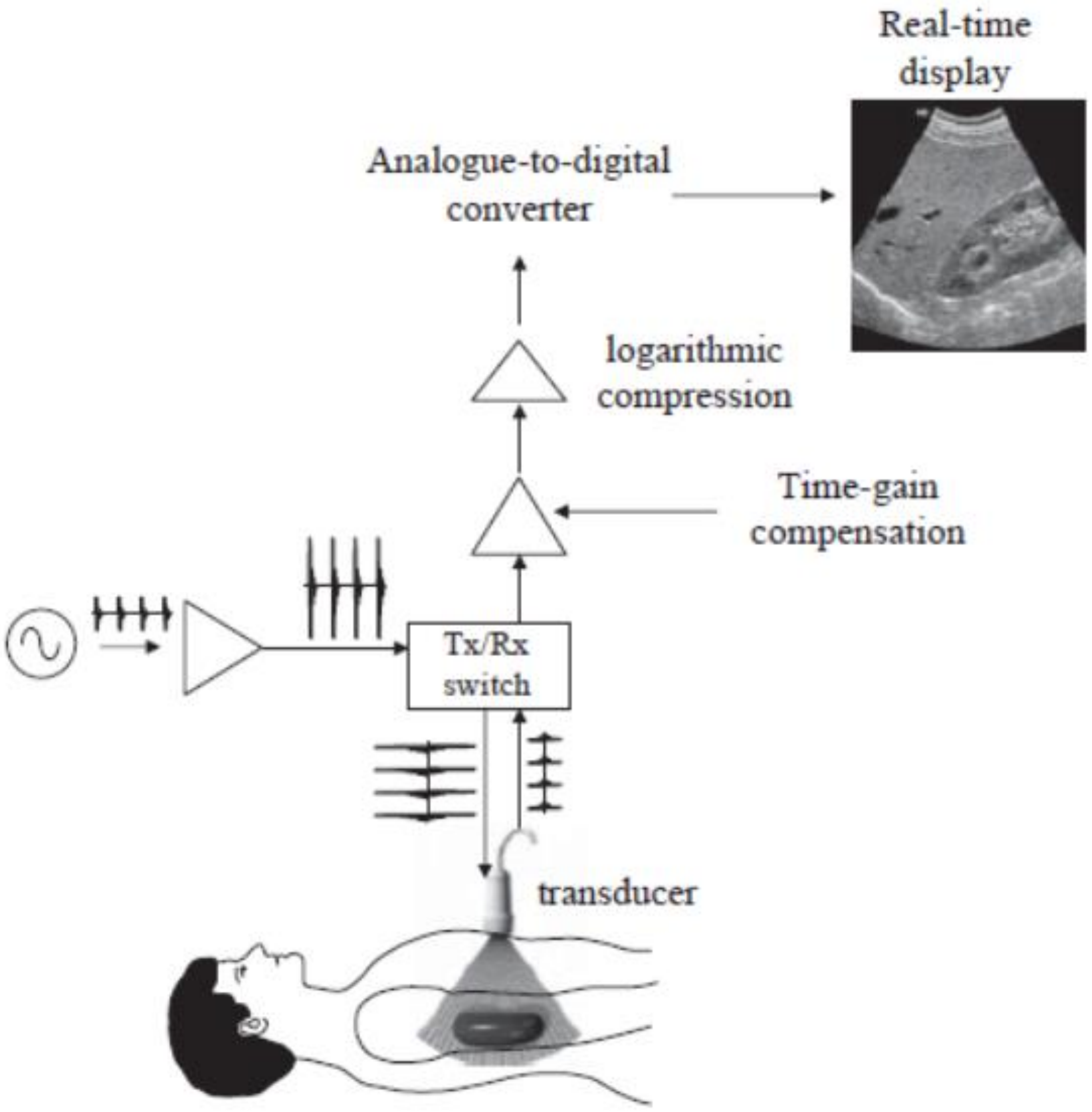


Figure 4.6

The major elements of a basic ultrasound imaging system.

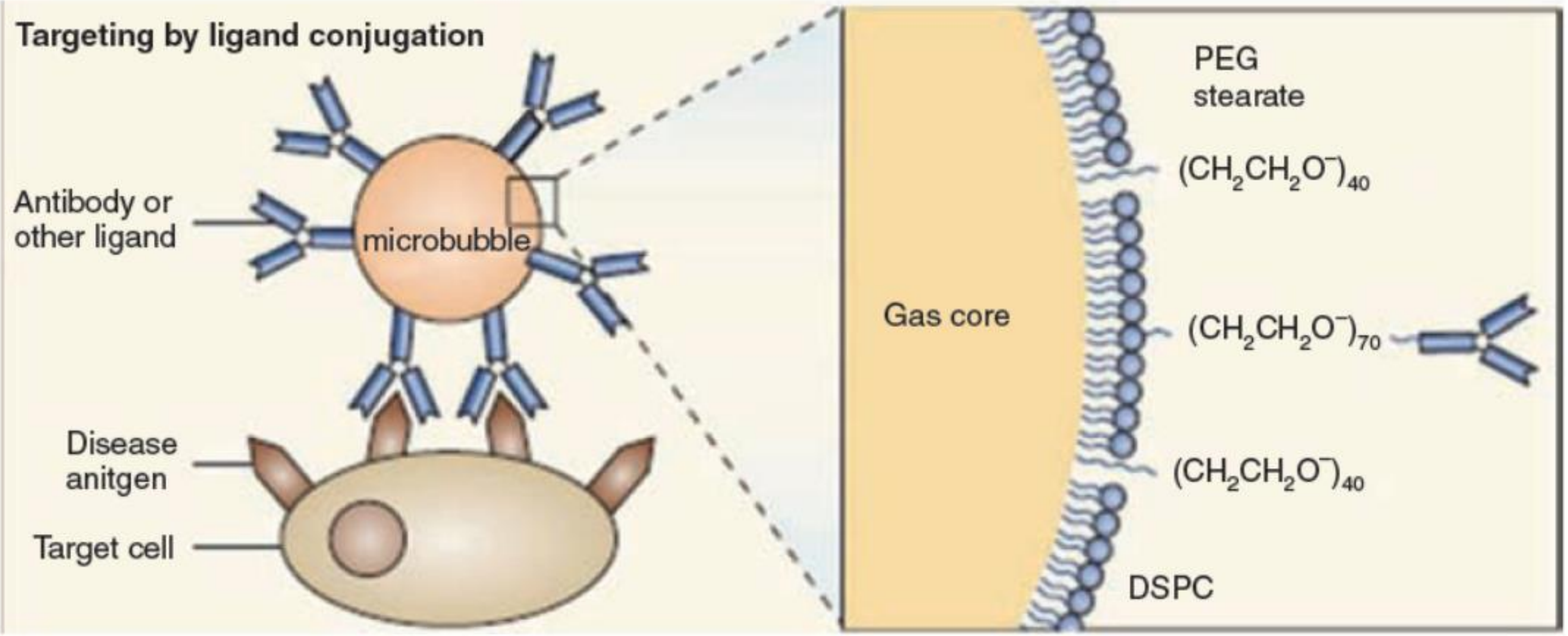
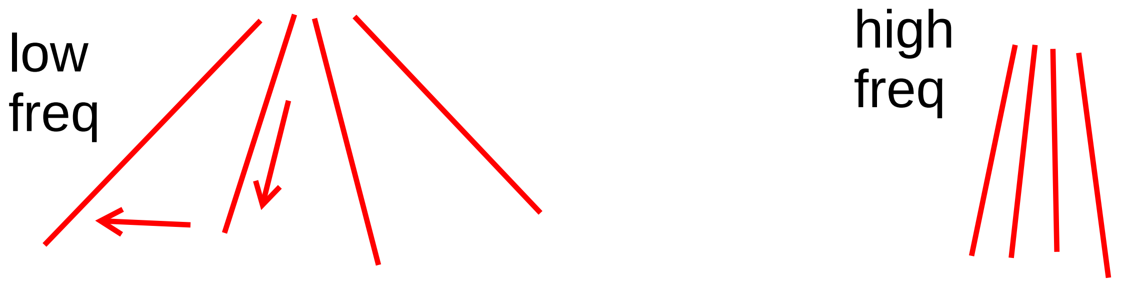


Figure 6.8. Molecular imaging by microbubble targeted contrast agent. The conjugated assemblies of microbubbles and ligands or antibodies attached to disease-specific antigens can be visualized by ultrasound imaging. (Adapted from Lindner, *Nat Rev Drug Discov* 2004; **3**: 527–32 [4].)

Frequency: With increase in frequency, the sound beam becomes more directional and the axial resolution improves.
However, due to attenuation of higher frequency ultrasound waves in the tissues, the penetration decreases.
For most abdominal ultrasound examinations, the frequencies used are in the range of 1-5 MHz, whereas the wavelength is in the range of 1 mm.
Higher frequencies (10-15 MHz) are used for superficial organs, such as the eye, where deep penetration is not required and where advantage may be taken of the 0.1 mm wavelength to improve geometrical resolution.



The following are general rules which apply to frequency:

↑ Frequency ↑ Axial Resolution ↑ Lateral Resolution ↓ Penetration

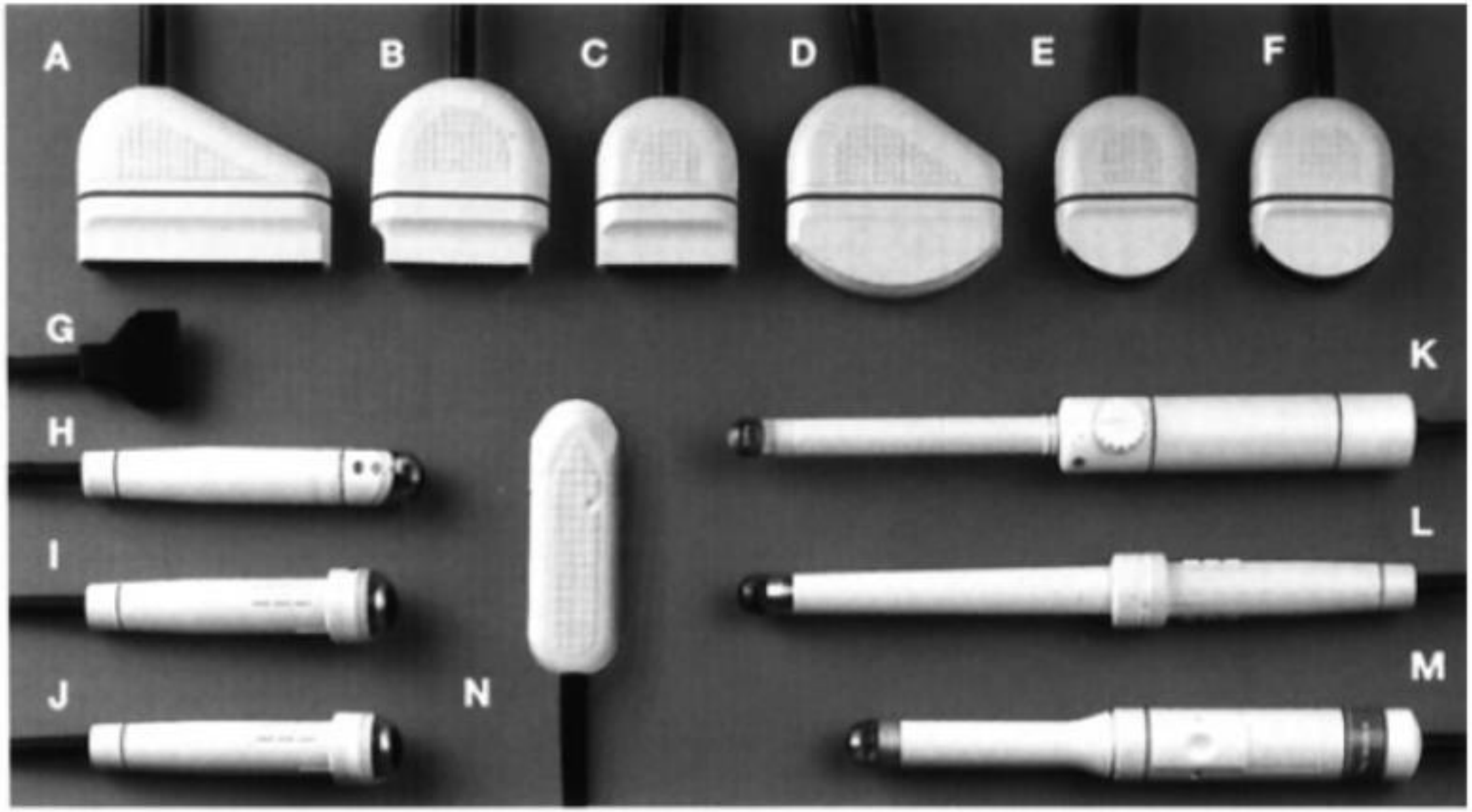
↓ Frequency ↓ Axial Resolution ↓ Lateral Resolution ↑ Penetration

Frequency also influences lateral resolution by affecting beam divergence. The following rule applies, assuming all other factors remain constant.

↑ Frequency ↓ Beam divergence ↑ Lateral Resolution

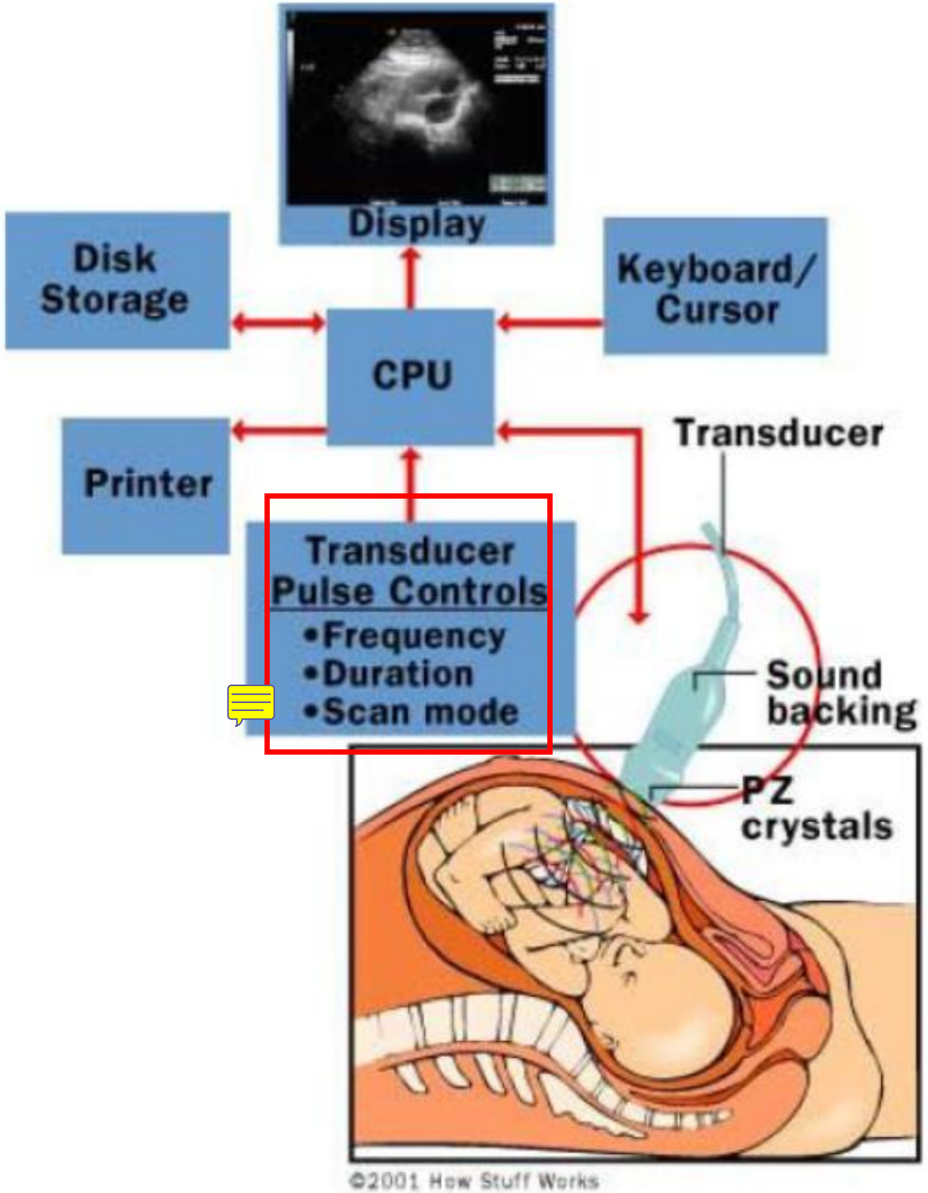
Probes

A Linear Array probe 3.5 and 3.5/5.0 MHz, 12 cm
B Linear Array probe 5.0/7.5 MHz, 7.4 cm
C Linear Array probe 7.5 MHZ, 6 cm
D Curved Array probe 3.5/5.0 MHz, R75
E Curved Array probe 3.5 and 3.5/5.0 MHz, R40
F Curved Array probe 5.0 MHz, R40
G Linear Array probe 7.5 MHz, 4 cm
H Multi-angle sector probe 5.0/7.5 MHz
I Annular Array sector probe 3.5 MHz
J Annular Array sector probe 5.0 MHz
K Multi-plane endorectal probe 5.0/7.5 MHz
L Endovaginal probe 5.0/7.5 MHz
M Multi-plane endovaginal probe 5.0/7.5 MHz
N Curved Array probe 5.0/7.5 MHz, R17



➤ **Fig. 23.21** *Various types of ultrasound probes used for real time scanning*

Ultrasound Parts



Safety Aspects

Ultrasound imaging offers many benefits over other imaging techniques, including:

- Non-invasiveness (no injections or needles in most cases) and mostly painless.
- Image acquisition is fast and relatively easy to learn.
- No ionizing radiation (contrary to X-ray/CT).
- Large number of potential applications: ultrasound can visualize structure, movement, and function of the body's organs and blood vessels.

However, ultrasound waves can harm the body:

- through heating, proportional to absorbed acoustic intensity, or
- through cavitation, which means gas bubbles that emerge in the low pressure phases of sound waves and collapse at high pressure phases.

This lecture comprises of 20 slides.

Elastography
BM-406

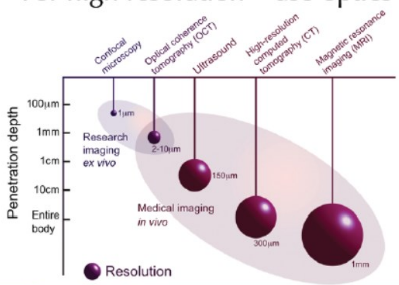
DR. ENGR. ERAJ HUMAYUN MIRZA

Overview

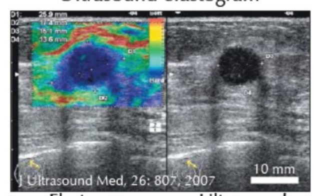
- Background
- What is elastography
- Features
- Types
- Analysis
- Applications
- Our Research
- Publications

Elastography

- Elastography – imaging of tissue mechanical properties
- Based on imaging modality – Ultrasound or MRI or…
- For high resolution – use optics

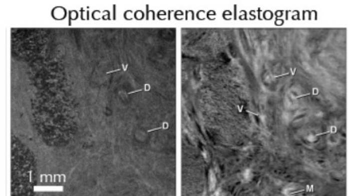


Ultrasound elastogram



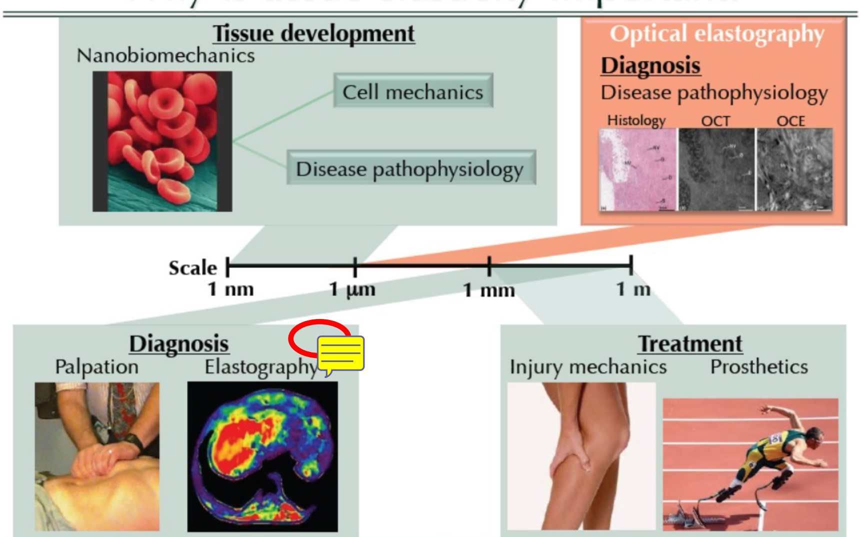
Elastogram Ultrasound

Optical coherence elastogram



OCT Elastogram

Why is tissue elasticity important?



Background

- 17^{th} century B.C. → Palpation
- Currently used the same way.
- Superficial detection of inflamed area only.
- Limited capability to locate deep inflammation or a tumor.
- Limited to accessible organs only.
- Interpretation of information is subjective.

Background

- non-invasive technique that comprises concepts of US, mathematics and physics to image a tissue.
- Mechanical properties of a tissue that is sensed via palpation and elastography are both associated with elastic restoring forces present in the tissue that respond to a mechanical deformation more generally called shear.
- Elastography use US to measure tissue deformations as a result of force applied.

Background

- Elastogram
  - Direct detection and display of tissue deformation.
  - Calculation and display of tissue strain due to deformation as a result of applied force.
  - Recording of propagation of shear waves data, that is used to calculate either:
    - Regional values of speed of waves without presenting images
    - Documenting images of the speed.

What is Elastography

- Elastography is an imaging technique to **measure the stiffness of tissues**.
- Images are acquired **before and after soft compression** of tissues and the deformation is evaluated.
- Initially elastography used **manual compression and was only qualitative**, now some methods appears to apply a non operator dependant compression.

Elastography

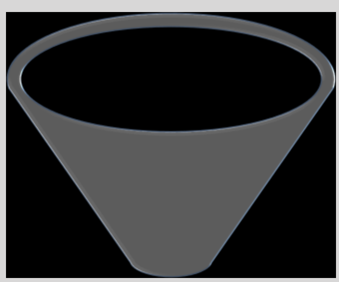
- Three step approach:
  - **Organs mechanically stressed** by either external or internal forces.
  - Measurement of **tissues movement** induced.
  - **Qualitative or quantitative** evaluation of tissue elastic properties from the measured displacement of tissues.

Elastography

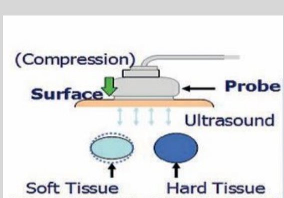
- Manual compression by operator using the transducer (static elastography).
- Organ compression by heartbeat or vascular pulsations.
- Push pulse waves compression.
- Supersonic shear waves.

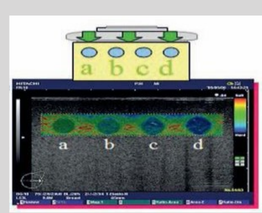
A comparison of radiofrequency signal captured before and after application of force creates an elastogram image

ELASTOGRAPHY



ELASTOGRAPHY



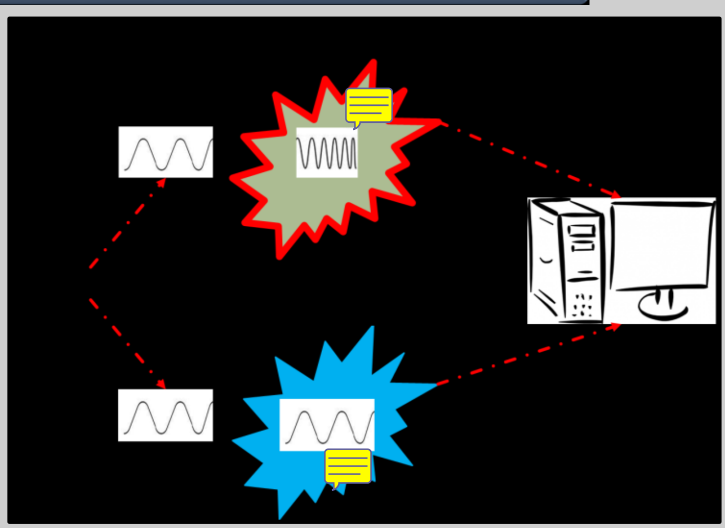


Features of ELASTOGRAPHY

BASIC FEATURES

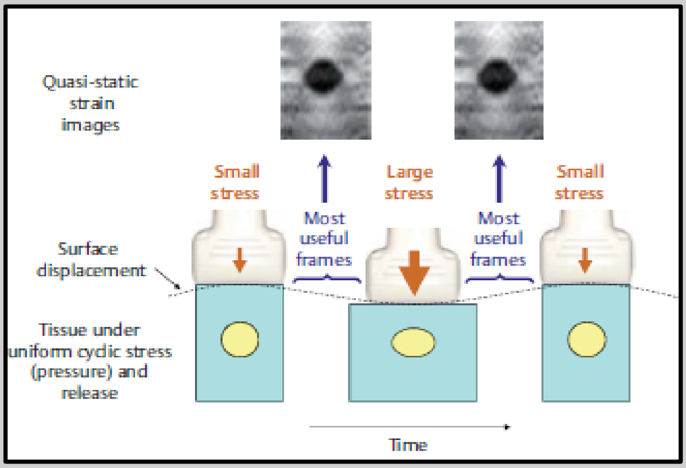
- NON – INVASIVE IMAGING
- DETECTION OF TUMORS BASED ON STIFNESS OF TISSUE
- CHANGES IN ELASTICITY RELATES TO DISEASED CONDITION

Shear-Wave Elastography Concept



Schematic of Shear-Wave Elastography Technique

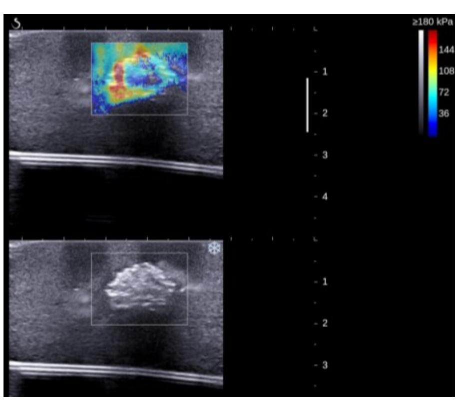
Strain Elastography Concept

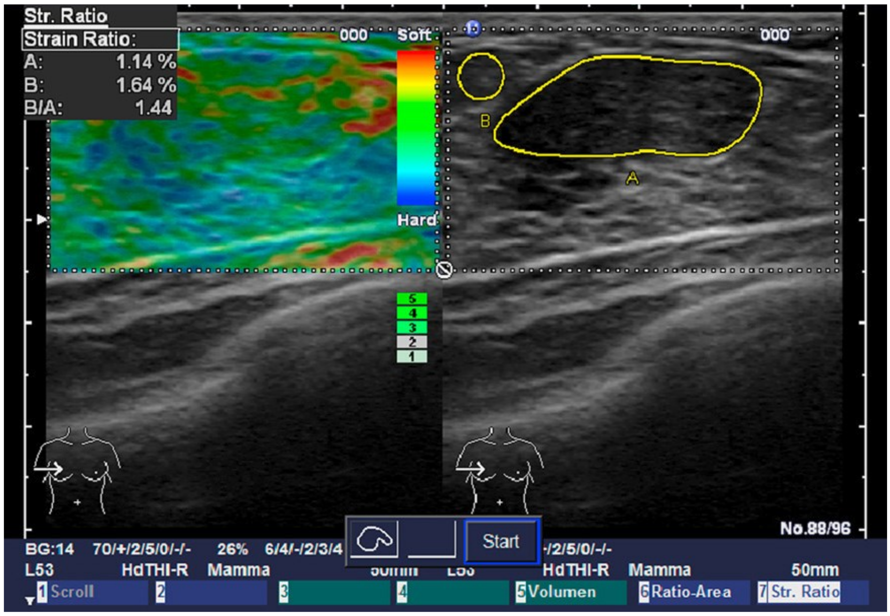


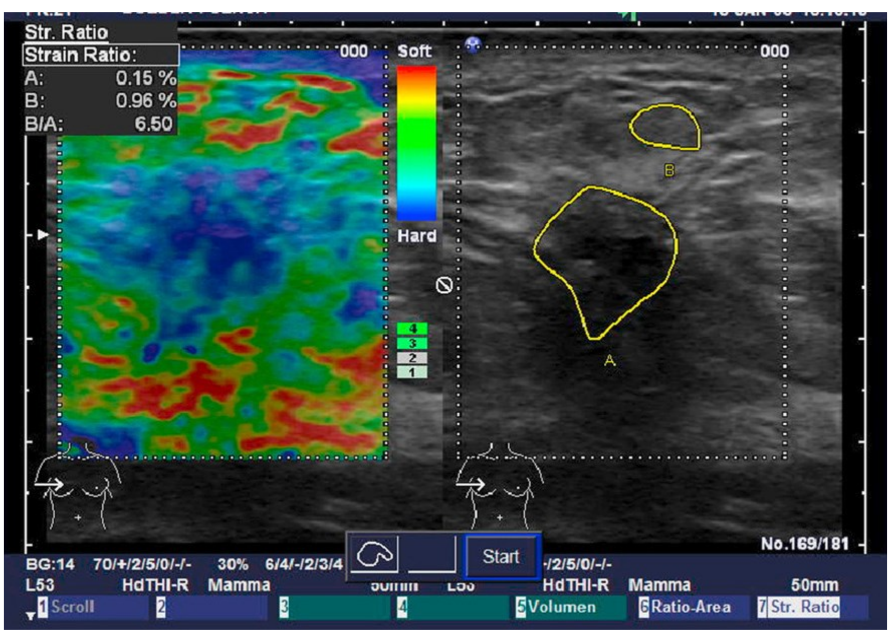
Schematic of Strain Elastography Technique

Shear-Wave

Strain

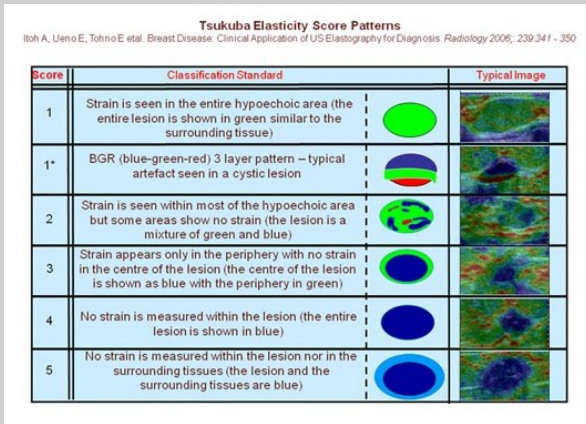



Str. Ratio
Strain Ratio:
A: 1.14 %
B: 1.64 %
B/A: 1.44
Soft
Hard
A
B
No.88/96
Start
BG:14 70/+/2/5/0/-/- 26% 6/4/-/2/3/4
-/2/5/0/-/-
L53 HdTHI-R Mamma
HdTHI-R Mamma 50mm
1 Scroll
5 Volumen
6 Ratio-Area
7 Str. Ratio


Str. Ratio
Strain Ratio:
A: 0.15 %
B: 0.96 %
B/A: 6.50
Soft
Hard
A
B
No.169/181
Start
BG:14 70/+/2/5/0/-/- 30% 6/4/-/2/3/4
-/2/5/0/-/-
L53 HdTHI-R Mamma
HdTHI-R Mamma 50mm
1 Scroll
5 Volumen
6 Ratio-Area
7 Str. Ratio

Analysis

- Analysing the Images

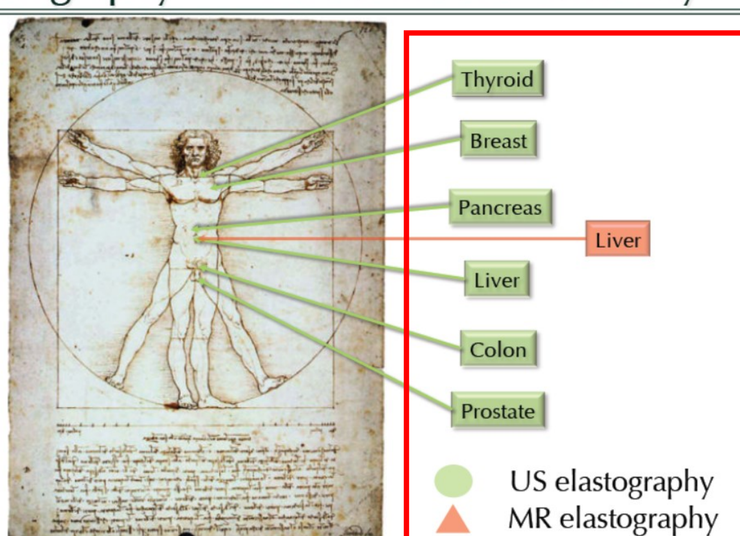


Tsukuba Elasticity Score Patterns

Itoh A, Ueno E, Tohno E et al. Breast Disease: Clinical Application of US Elastography for Diagnosis. *Radiology 2006; 239:341 - 350*

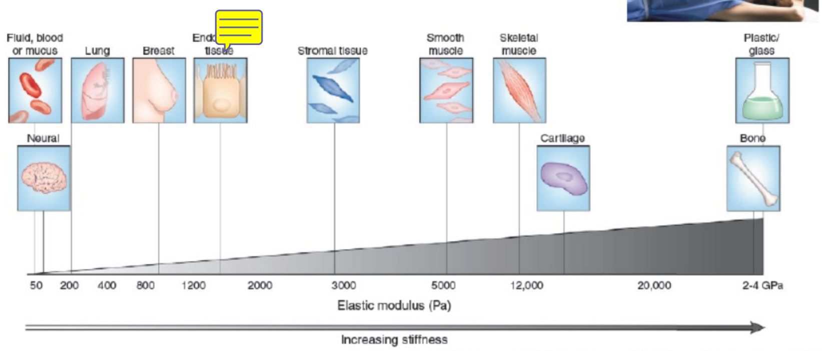
Score	Classification Standard	Typical Image
1	Strain is seen in the entire hypoechoic area (the entire lesion is shown in green similar to the surrounding tissue)	
1*	BGR (blue-green-red) 3 layer pattern – typical artefact seen in a cystic lesion	
2	Strain is seen within most of the hypoechoic area but some areas show no strain (the lesion is a mixture of green and blue)	
3	Strain appears only in the periphery with no strain in the centre of the lesion (the centre of the lesion is shown as blue with the periphery in green)	
4	No strain is measured within the lesion (the entire lesion is shown in blue)	
5	No strain is measured within the lesion nor in the surrounding tissues (the lesion and the surrounding tissues are blue)	

Elastography – where is it used clinically?



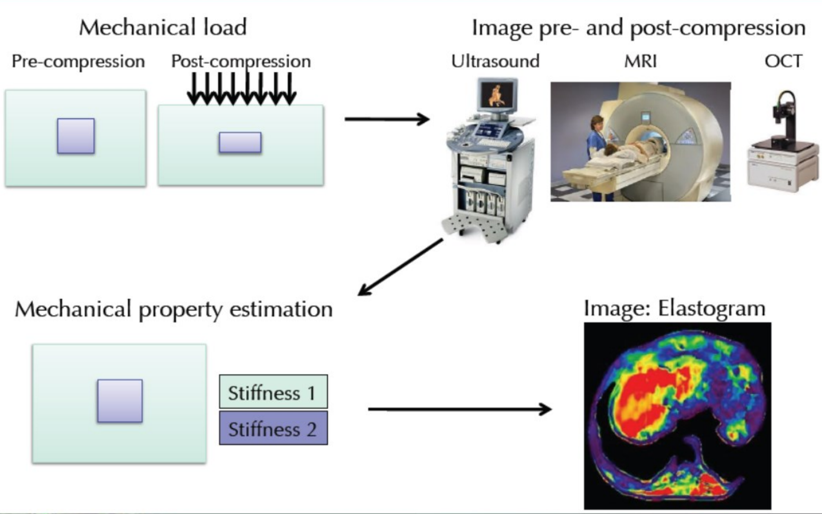
What elastic property do we care about for tissue?

- **Elastic modulus:** describes resistance to axial deformation
- This is the "stiffness" sensed by palpation



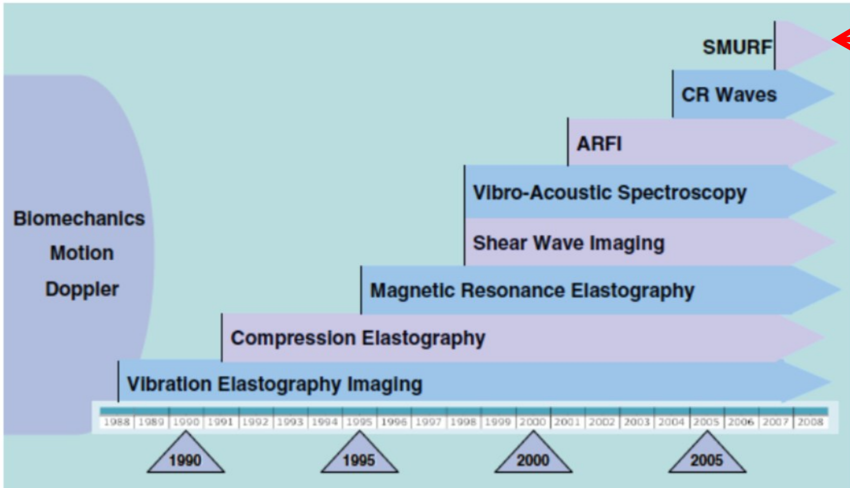
T.R. Cox and J.T. Erler, Disease Models and Mechanisms, 2011

Elastography – how it works



Abbe School of Photonics, 18 June 2013 Sampson, Optical elastography The University of Western Australia

(Non-optical) elastography through the years



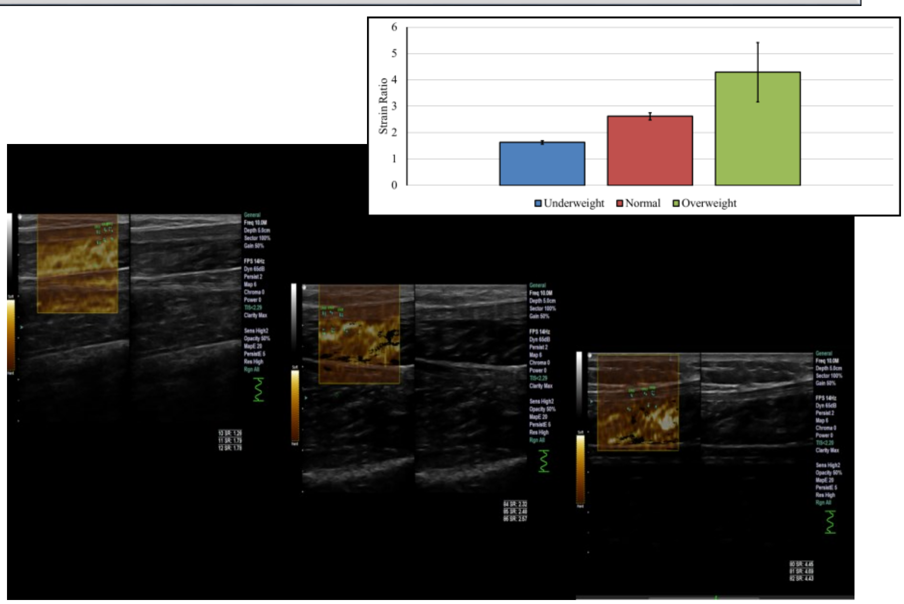
SMURF: spatially modulated ultrasound radiation force;
CR: Crawling; ARFI: Acoustic radiation force impulse

Parker *et al.*, *Phys. Med. Biol.* 56(1), 513, 2011

Abbe School of Photonics, 18 June 2013 Sampson, Optical elastography The University of Western Australia

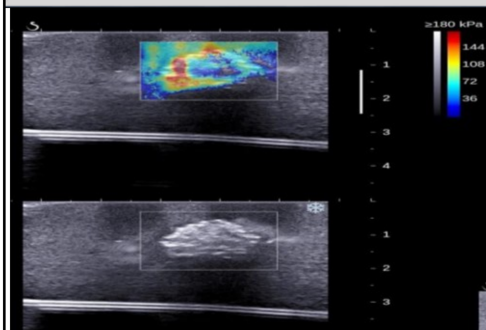
Our Research

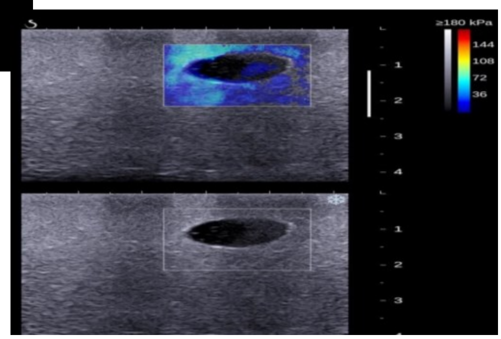
- Achilles Tendon



Our Research

- Breast Phantom





Our Research

- Bicep Tendon/ Muscle

Bicep Muscle/ Tendon

Strain Elastography

Trained Individuals

Untrained Individuals

Objectives

- Relaxed vs Tensed
- Dominant vs Non-Dominant

Current research in our group

- Strain Elastography
- Phantoms
  - Breast
  - Thyroid
  - Depth phantom (ordered)
- Achilles Tendon
- Breast Phantom
- Thyroid Phantom
- Biceps brachii
- Advantage
  - Healthy volunteers
- Problem
  - Patients
  - New ideas to be implemented on healthy individuals

Publications

Society for Science and Education United Kingdom
JBEMi JOURNAL OF BIOMEDICAL ENGINEERING AND MEDICAL IMAGING
ISSN: 2055-1266

A Comparative Study of Shear-Wave Elastography and Strain Elastography on a Breast Phantom for Diagnosis of Tumor and Cyst

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ABSTRACT

A lump in breast may suggest a possible development of breast cancer. As the tumor develops, it changes the physical property of the tissue by changing its stiffness. To detect the tumor generally mammography is performed. The findings of mammography are often inaccurate as it does not take into account the stiffness of tissue. Elastography is an imaging technique to measure the stiffness of tissues. In the current study, we have used a breast phantom to analyze differences between a tumor and a cyst via comparing shear-wave elastography and strain elastography techniques. Both the techniques performed equally for the diagnosis of tumour. However, it is suggested that strain elastography must be used in the diagnosis of a cyst as it provides enhanced details of the surrounding tissues.

Key-words: Elastogrpahy, Shear-wave, Strain, Ultrasound, breast, tumor, phantom.

1 Introduction

Changes in elasticity of tissue is attributed to pathological condition [1]. Various cancers appear as hard nodules as a result of increased density, while other diseases involves deposition of fat or collagen that might alter the tissue elasticity. Cysts filled with fluid may also be invisible to traditional ultrasound examination. In several cases, a diminished pathological lesion or a lesion that is not superficial may not be detected via conventional ultrasound technique [2]. Conventional ultrasound is a qualitative method [3], however there was a need to a more quantitative approach to differentiate healthy tissues from the diseased. To overcome this issue ultrasound elastography was introduced.

Elastography is a medical imaging technique that is non-invasive, which detects tumors according to their stiffness when compared to normal tissue.

Elastography is a non-invasive medical imaging technique. The purpose of this technique is detecting tumors based on their stiffness (elasticity) compared to normal tissue. Ultrasonic imaging used for the most common type of elastography to compare the shapes of the tissue under examination before and after it is compressed slightly. Normal tissue tend to be less stiff cancerous tumors. Elastogram is an image show as different shades of light and dark, also has different degree of stiffness. The elastogram show up

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Influence of BMI on Elastographic strain ratios of Achilles tendon

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Abstract

The Achilles tendon have two major problems due to injury; one being a chronic injury called Achilles tendinopathy and the second being acute injury which are more commonly known as Achilles tendon rupture. Changes in stiffness of Achilles tendon is alarming and can cause deleterious effects on quality of life in an individual. Achilles tendon is reported to be affected significantly due to the weight of an individual. The effect of Body Mass Index (BMI) on stiffness of Achilles tendon was evaluated in the current study. Elastography was performed on individuals ranging from 19 to 23 years for detecting the stiffness of the Achilles tendon. Individuals were grouped according to their BMI in 3 categories (underweight, normal and overweight) and their strain ratios were measured. The strain ratio results for all volunteers were ranging from 1.03 to 6 (1.03 for underweight and 6 for overweight). Difference in weight of individuals effect the Achilles tendon stiffness. The overweight individuals had the highest stiffness while the underweight individuals had the lowest. It is concluded that higher stiffness may likely lead to Achilles tendon injury.

ORIGINAL RESEARCH

Body Mass Index and Segmental Mass Correlation With Elastographic Strain Ratios of the Quadriceps Tendon

Mahdi Al-Qahtani, PhD, Saleh Al-Tayyar, PhD, Eraj Humayun Mirza, PhD, Abdulrhman Al-Musallam, BS, Ahmad Al-Suwayyid, BS, Ravish Javed, MS

Objectives—The aim of this study was to establish a relationship between quadriceps tendon stiffness and its properties and variations in the body mass index (BMI) and segmental mass.

Methods—This study was conducted in 3 groups according to their BMI (A, low [<18.5 kg/m^2]; B, normal [18.5–25.0 kg/m^2]; and C, high [>25.0 kg/m^2]). All of the participants included had a sedentary lifestyle and did not do any weightlifting or any kind of sports activity in the previous 6 months. Ultrasound measurements were performed on the participants' lower right extremities, since it was the dominant side for all of the participants.

Results—A total of 40 healthy untrained men participated in the study. The mean age of the participants $\pm$ SD was 22.1 $\pm$ 1.3 years; the age ranges for groups A ($n = 6$), B ($n = 18$), and C ($n = 16$) were 19–23, 19–25, and 20–25 years, respectively; 28 of the participants were nonsmokers, and 12 of were smokers. A strong statistical difference (all $P < .05$) was witnessed for most of the parameters (BMI, body fat mass, dominant leg body fat content, fat-free mass index, tendon thickness, and strain ratio) among the groups.

Conclusions—The length of the tendon did not show a significant increase with an increase in the BMI, body fat mass, dominant leg body fat content, and fat-free mass index. However, a greater intensification was observed for the thickness of the tendon with a significant increase in tendon stiffness (with the use of external reference material).

Key Words—body mass index; elastography; quadriceps tendon; strain ratio; ultrasound

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Abbreviations
BMI, body mass index; MRI, magnetic resonance imaging; SE, strain elastography; US, ultrasound

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In the human body, the knee is considered one of the complex structures. The stability of the knee joint is of vital importance for both athletes and nonathletes. A higher incidence of injuries occurs from either overuse or underuse of muscles responsible for movement of the knee joint in athletes and individuals who have sedentary lifestyles, respectively. The incidence rate of knee instability is very high among nonathletes (both young and old individuals), and numerous studies have been conducted over the last decade.[1] For instance, in one in-depth study conducted on professional footballers over 7 consecutive seasons, it was observed that knee instability contributed to the second-highest injury rate after thigh injury.[2] Quadriceps tendon injuries have a high chance

 | J Ultrasound Med 2018; 9999:1–9 | 0278-4297 | www.aium.org

US and MR elastography – Summary

- Used for diagnostic imaging
  – disease correlates with stiffness
- Commercially available
- Suitable for clinical use
- Lower resolution than optics
  - Probes disease at advanced stage
  - Likely to miss small extensions of disease, *e.g.*, tumour margins