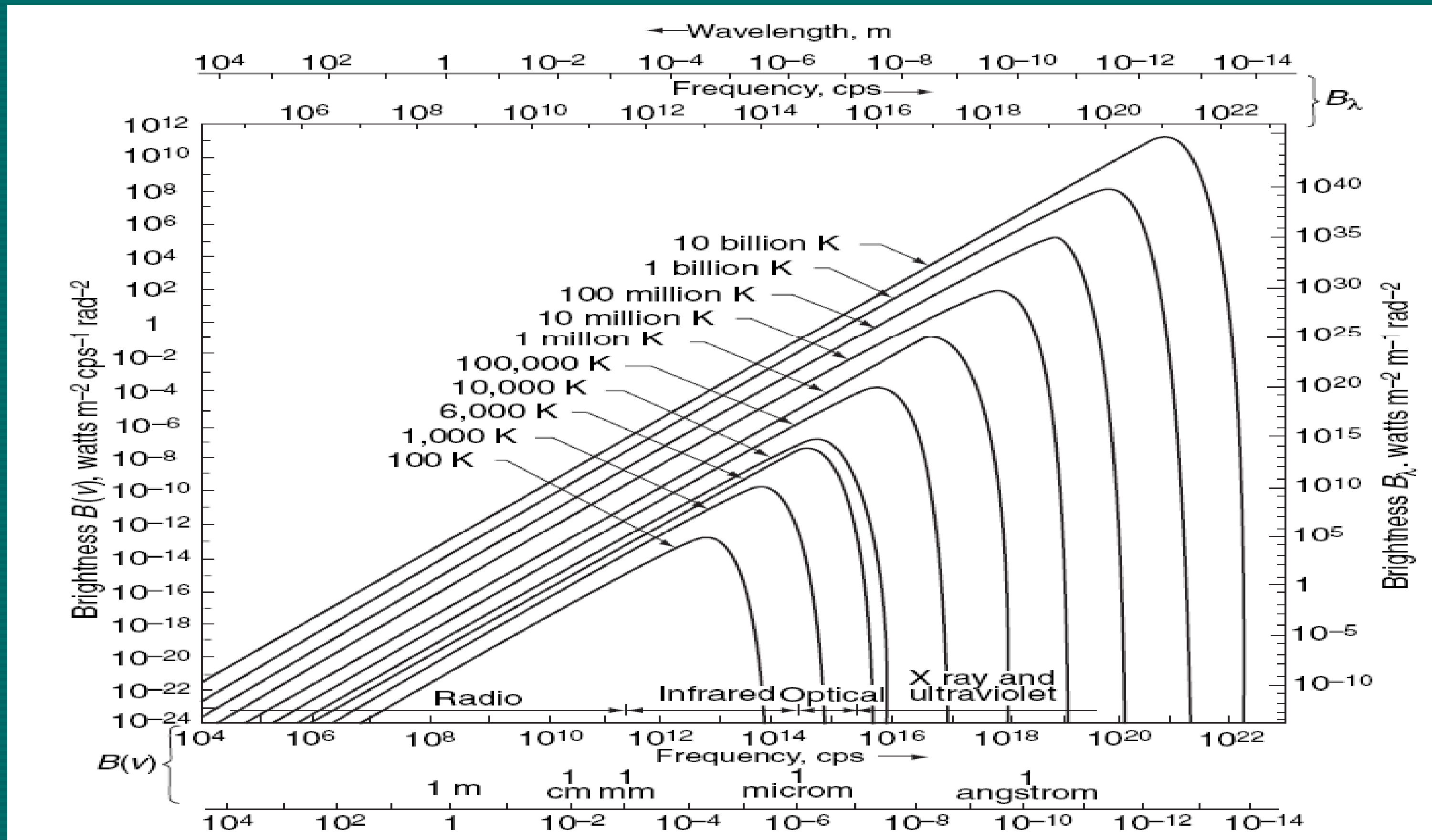
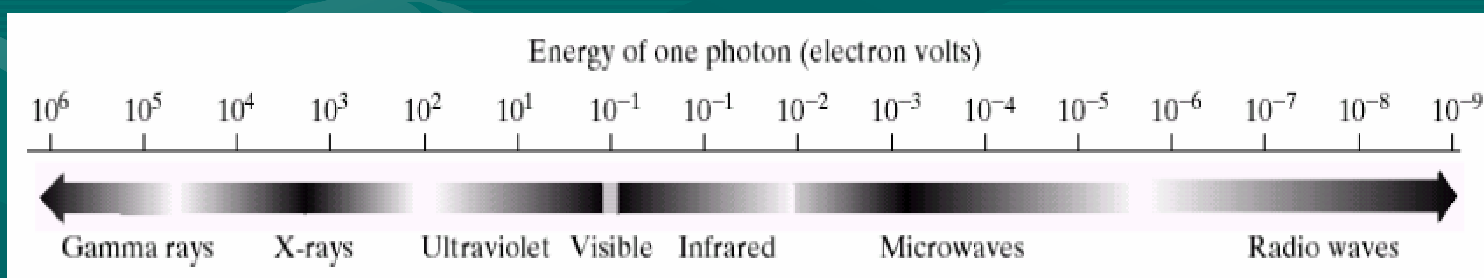
Introduction to Signal and Image Processing



Wavelength, m
10^4 10^2 1 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10} 10^{-12} 10^{-14}
Frequency, cps
10^6 10^8 10^{10} 10^{12} 10^{14} 10^{16} 10^{18} 10^{20} 10^{22}
B_λ
Brightness $B(\nu)$, watts m^{-2} cps^{-1} rad^{-2}
Brightness B_λ, watts m^{-2} m^{-1} rad^{-2}
10 billion K
1 billion K
100 million K
10 million K
1 millon K
100,000 K
10,000 K
6,000 K
1,000 K
100 K
Radio
Infrared
Optical
X ray and ultraviolet
$B(\nu)$
Frequency, cps
1 m
1 cm
1 mm
1 microm
1 angstrom



Energy of one photon (electron volts)
10^6 10^5 10^4 10^3 10^2 10^1 10^{-1} 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9}
Gamma rays
X-rays
Ultraviolet
Visible
Infrared
Microwaves
Radio waves

Various Types of signals

1 Dimensional

2 Dimensional and

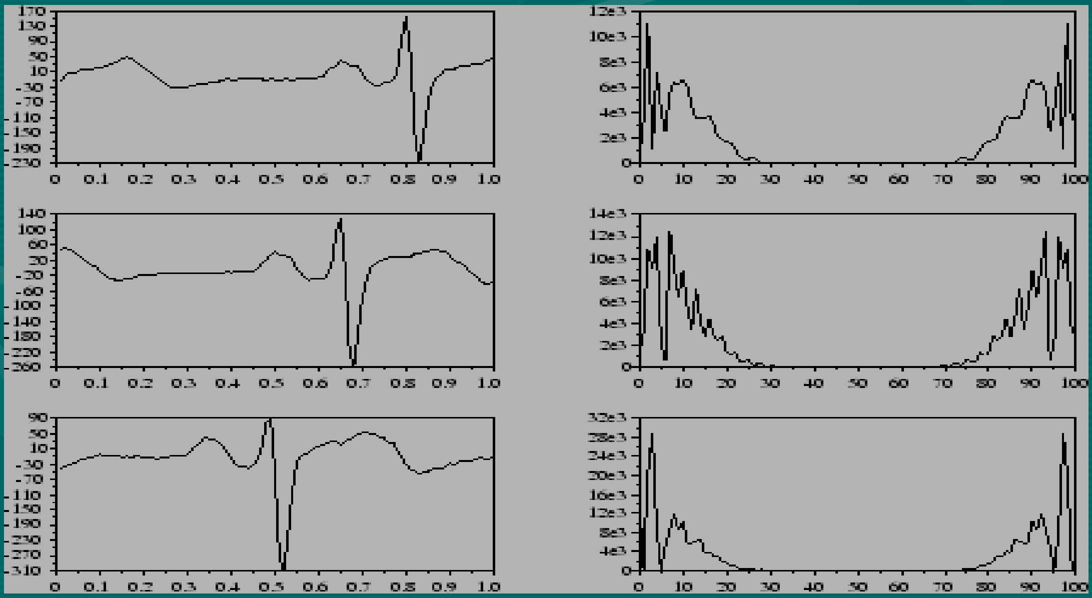
3 Dimensional Signals

1D Signal Examples

1 Voice signals

2 ECG and EEG Signals

Power spectrum of EEG Signals



2 D Signals

Phil Noble / AP

Mike Hewitt / Allsport

Patrick Gardin / AP

Andy Barron / Reno Gazette-Journal

Sydney Morning Herald

More 2D Signals

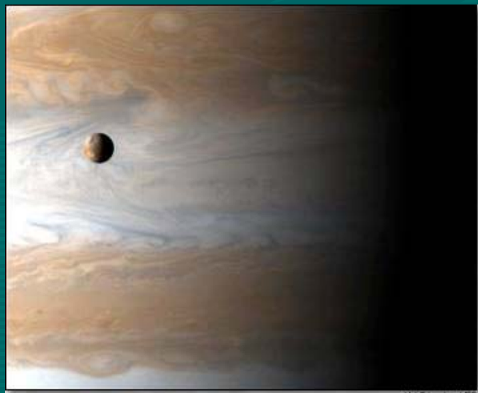

Eric Miller / Reuters


Mark Garkfinkel / The Boston Herald

Jeff J. Mitchell / Reuters

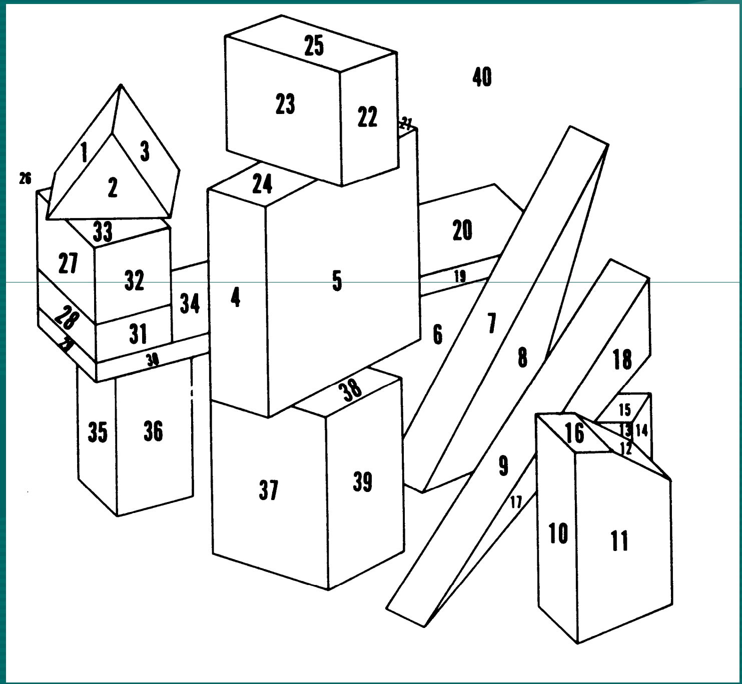

Monroe County Sheriffs Department / Newsmakers


Uno Andersson / AP

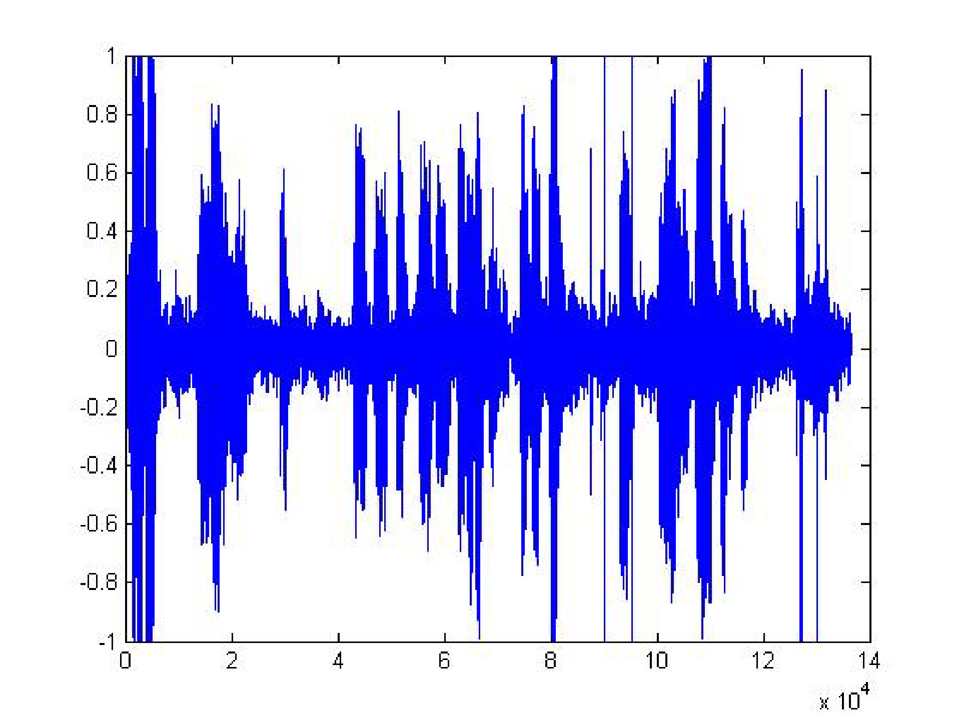

NASA via AFP

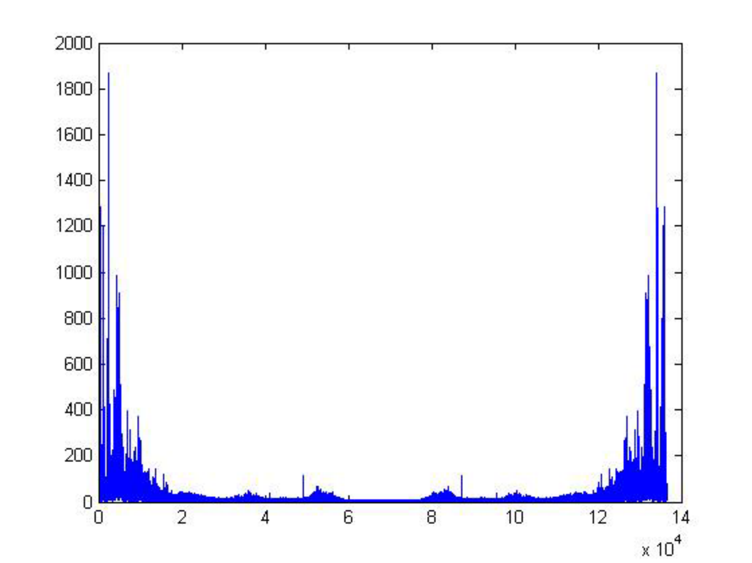
From Turing to Marr
Images from visible range only?
Can you see sound?

A Brief History



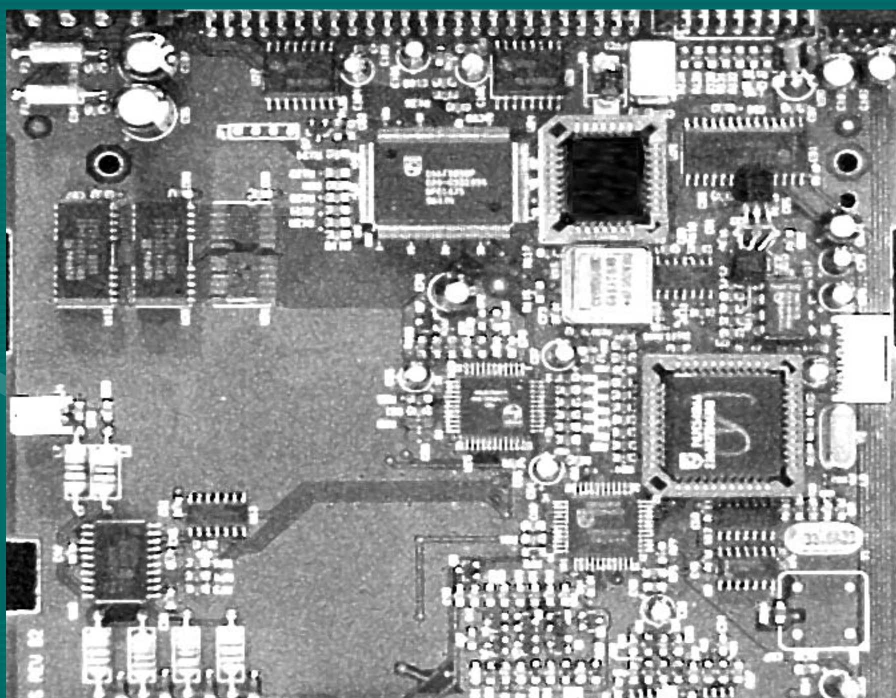
Here is the visual of Sound waves





Imaging in the Visible Band

- Automated visual inspection of manufactured goods



Imaging in the Visible Band

- Processing of fingerprints for automated search of a database
- Automated license plate reading

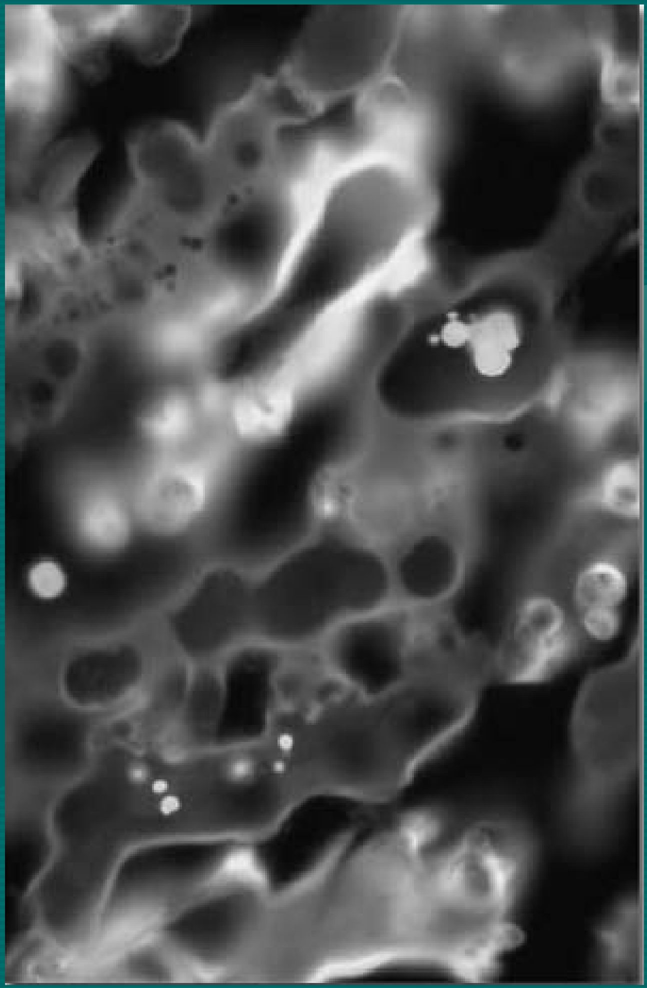
Imaging in the Visible/Infrared Band

- Remote sensing: to obtain images of the earth from space for purposes of monitoring environmental conditions
- Usually a scene is imaged in several bands



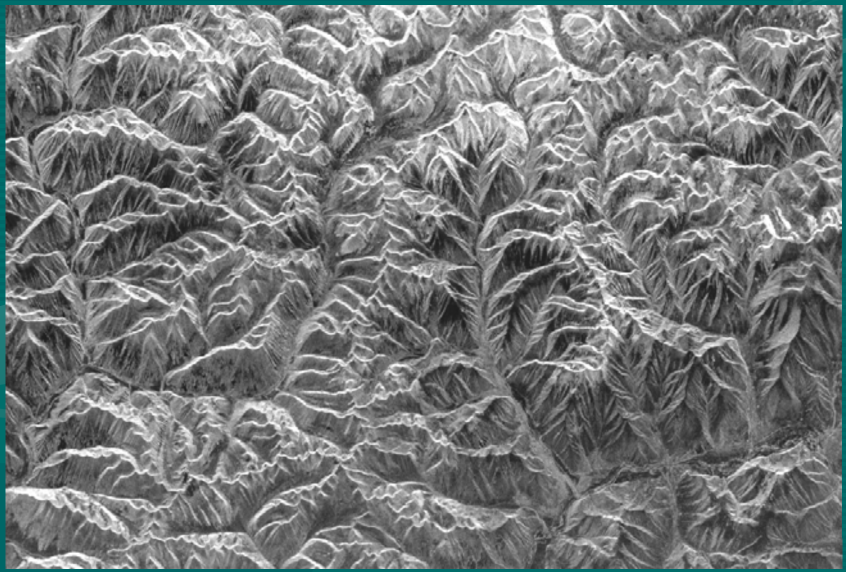
Imaging in the Ultraviolet (UV) Band

- Ultraviolet light is used in fluorescence microscopy.
- Fluorescence: a phenomena in which some material (called fluorescent) emit visible light when ultraviolet light is directed at them.



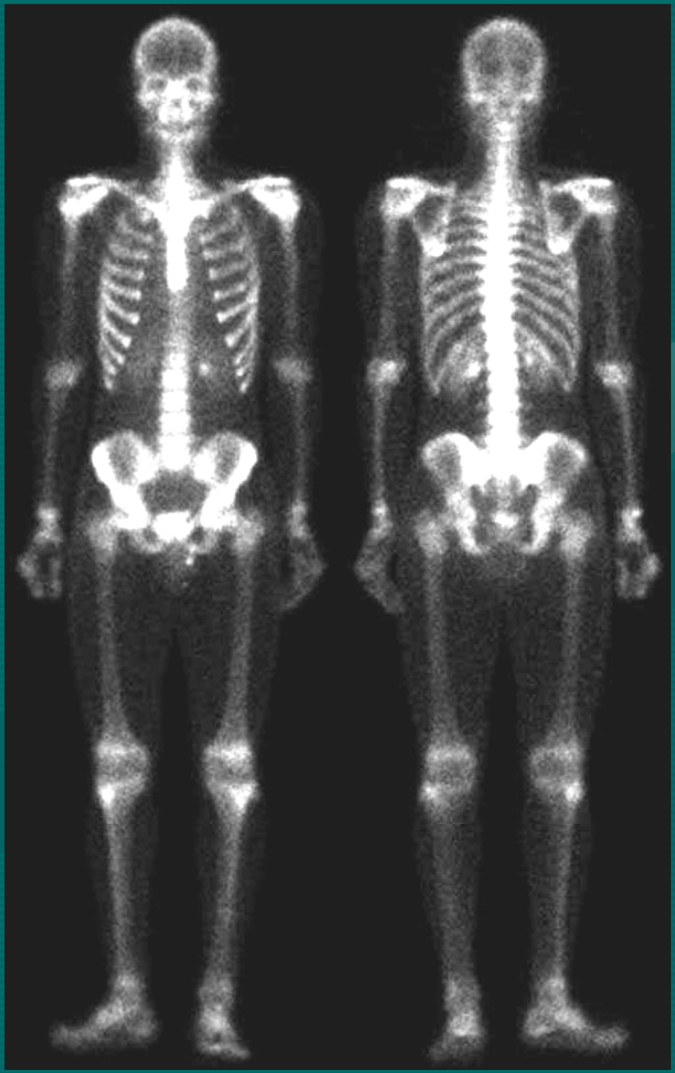
Imaging in the Microwave Band

- The dominant application of imaging in the microwave band is radar, where radar works like a flash camera.
- Unique feature: able to collect data over virtually any region at any time regardless of weather or lighting condition.



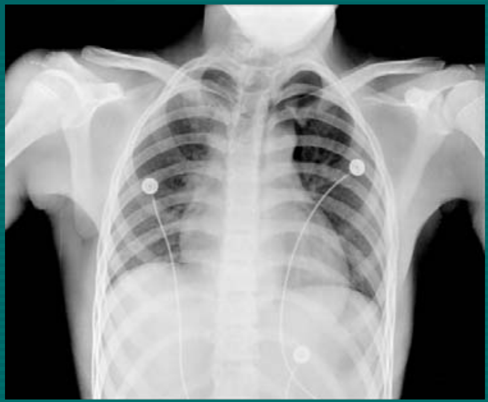
Gamma-ray Imaging

- Imaging based on gamma rays.
- Nuclear medicine: inject the patient with a radioactive isotope that emits gamma rays. Images are produced from the emissions collected by gamma ray detectors.

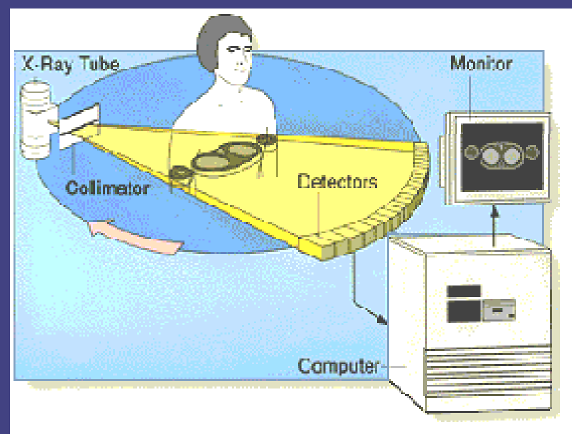


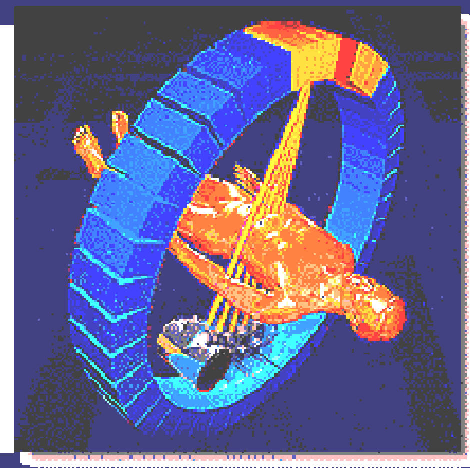
X-ray Imaging

- X-rays are used extensively in medical imaging and in industry.
- X-ray tube: a cathode which is heated and releases electrons. Electrons fly at high speed to the positively charged anode.
- When the electrons strike a nucleus, energy is released in the form of X-ray radiation.
- The intensity of the X-ray is modified by absorption as it passes through the patient.



CT





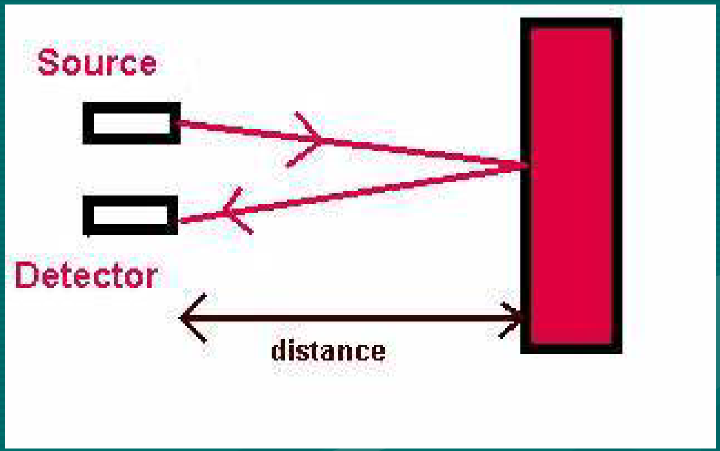
Computed tomography (CT) is a medical imaging method employing tomography, where digital geometry processing is used to generate a three-dimensional image of the internals of an object from a large series of 2-dimensional X-ray images taken around a single axis of rotation.

Acoustic (Ultrasound) Imaging

- Ultrasound imaging used mainly in obstetrics.
- Basic procedure in ultrasound imaging:
  1. Ultrasound system transmits high-frequency (1 to 5 MHz) sound pulses into the body.
  2. The sound waves travel into the body and hit a boundary between tissues (e.g., soft tissue and bone). Some of the sound waves are reflected back to the probe, while some travel on further until they reach another boundary.

Acoustic (Ultrasound) Imaging

3. The reflected waves are picked by the probe and relayed to a computer.
4. The computer calculates the distance from the probe to the tissue using the speed of sound in tissue.
5. The system displays the distance and intensities of the echoes on the screen, forming a two-dimensional image.



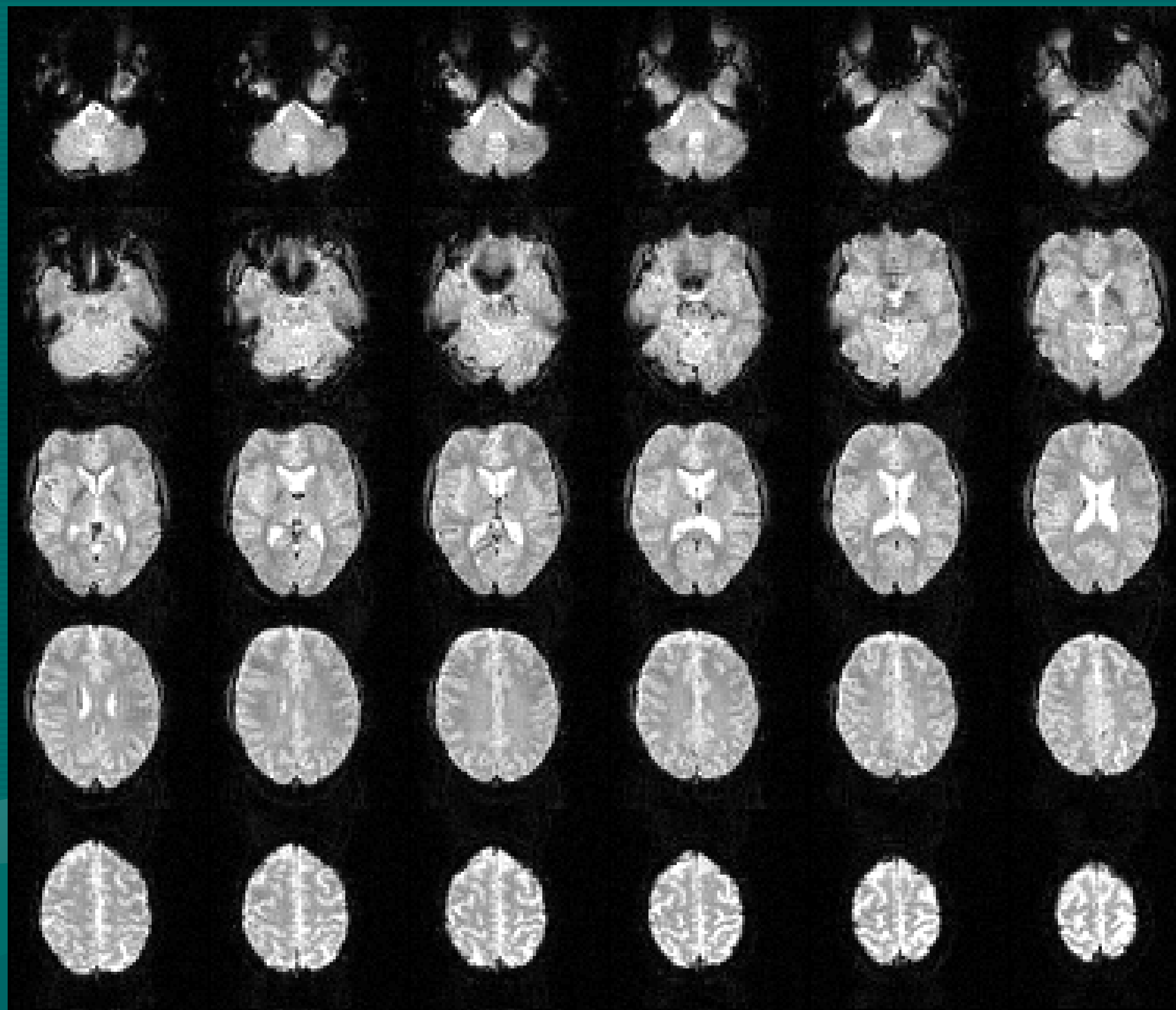
PET

- Positron Emission Tomography (PET): the patient is given a radioactive isotope that emits positron.
- Positron generates gamma rays which are detected and an image is created.

MRI

- Magnetic Resonance Imaging (MRI): The radio waves pass through a patient' body in short pulses, which is kept in a high magnetic field.
- Each pulse causes a responding pulse emitted by the patient's tissue.
- The signal origin and strength are determined by a computer, which produces a two dimensional image of a section of the patient.

Functional MRI (fMRI)



Applications

- **In Medicine**
  - Enhance the contrast or code the intensity levels into colour for easier representation of X-Rays and other Bio-Medical Images
- **In Geography**
  - Study pollution patterns from aerial and satellite imagery.
- **In Archaeology**
  - Used to process degraded images of unrecoverable objects or experimental results too expensive to duplicate
  - Restoration of blurred pictures that were the only available records of rare artefacts lost or damaged after being photographed.

Applications …

- **In Physics**
  - Enhance images of experiments in areas such as high-energy plasmas and electron microscopy.
- **Other Application Areas**
  - Law Enforcement
  - Defence
  - Industrial Applications (E.g. Vision based automation)
  - Surveillance
  - Biology

Applications …

Applications of Image processing depends on the *type of operation*
required for a particular image. These operations can be

- Image Enhancement
- Image Restoration
- Image Compression
- Image Transforms/Filtering

Problems in machine perception that utilizes image processing techniques

Automatic Character Recognition
Industrial Machine Vision for product assembly and inspection
Military recognizance
Automatic processing of fingerprints
Screening of X-Rays and blood samples
Machine processing of aerial and satellite images for weather prediction and crop assessment

Why Digital Image Processing ?

Processing for human interpretation:

- Enhancement
- Contrast
- Assignment of colours for different levels of brightness in a greyscale image
- Removal of blurring that results from camera motion, incorrect focussing
- Combining of two images (Registration, Morphing)
- Construction of panoramic images.

Processing for Machine Perception (Information required is different)

Different from visual features used by human beings to interpret the contents of an image

Requires : Statistical Moments, Fourier Transform Coefficients, Multidimensional distance measures

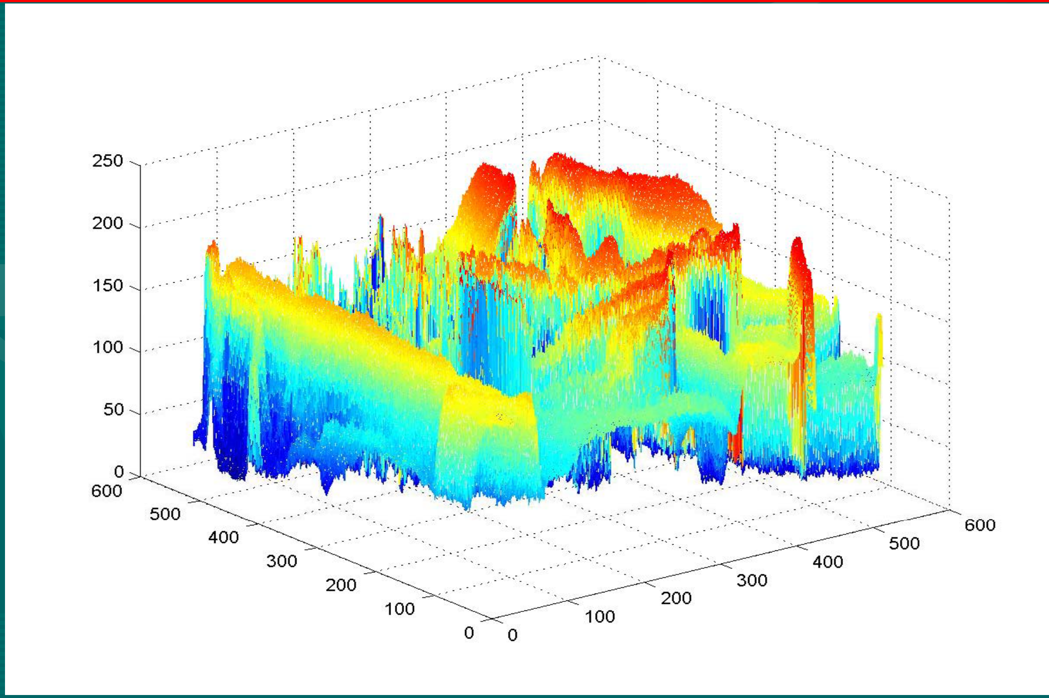
Digital Image Representation

Image refers to a two-dimensional light intensity function *f(x,y)*, where *x* and *y* denote spatial coordinates and the value of f at any point is proportional to the brightness (or gray level) of the image at that point.

Digital Image Representation

- A digital image is an image *f(x,y)* that has been discretized both in spatial coordinates and brightness (and may be colours also).
- A digital image : A matrix whose row and column indices identify a point in the image and the corresponding matrix element gives the grey level at that point. The elements of such a digital image are called image elements, picture elements, pixels or pels.

Image seen with Its 3rd dimension



Steps in Image Processing

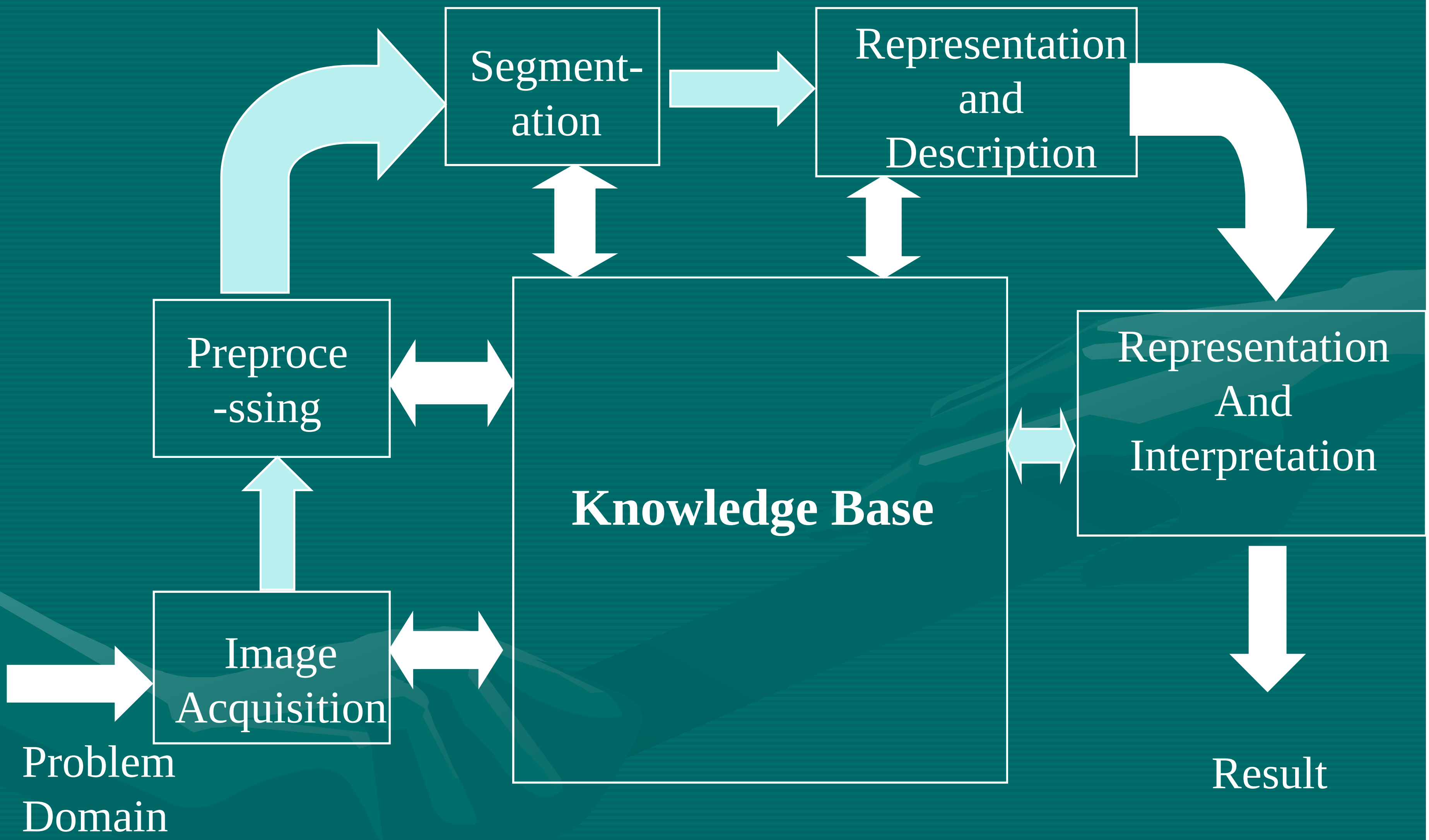


Image Representations

- Image requires to be represented at various levels
- Bottom-up approach : From Pixel to Scenes (or Events or even at higher levels, say life in Korea)
- Top-down approach : Scene (or Object) Level to Pixel level

$\leftrightarrow$ Pixels $\leftrightarrow$ Segments $\leftrightarrow$ Objects $\leftrightarrow$ Scenes $\leftrightarrow$

Steps in Image Processing

- **Image Acquisition**
  - Acquire digital images
  - Requires an image sensor and the capability to digitize the signal produced by the sensor.
- **Preprocessing**
  - Improve the image in ways that increase the chances of success of other processes. Examples:
    - Enhancing contrast
    - Removing noise
- **Segmentation**
  - Partition an input image into its constituent parts or objects.
  - **(Autonomous segmentation - Most difficult!!)**

Steps in Image Processing

- **Representation and Description**
  - Segmented image parts needs to be represented as either
    - Boundaries - This is appropriate when the focus is on external shape characteristics such as corners and inflections
    - Regions - This is appropriate when the focus is on internal properties such as texture
  - Once the appropriate representation scheme is chosen, then a method must be used to describe the data.
  - **Description (feature selection)** deals with extracting features that results in some quantitative information of interest or features that are basic for differentiating one class of objects from another.

Steps in Image Processing

- **Recognition and Interpretation**
  - Recognition - Process that assigns a label to an object based ion the information provided by its descriptors.
  - Interpretation - Assigning meaning to an ensemble of recognized objects.

Knowledge Base : Knowledge about a problem is coded into image processing systems in the form of knowledge database

Elements of Digital Image Processing Systems

- **Image Acquisition**
  - - ***Physical device t***hat is sensitive to a band in the electro-magnetic energy spectrum and that produces an electrical signal output proportional to the level of energy sensed.
  - - A ***Digitizer*** to convert the electrical output of the physical device into digital form.

- **Storage** - The amount of storage required for an image depends on the resolution of the sensing device as well as the number of bits required to code each pixel. Storage falls into 3 categories
  - 1. Short term storage for use during pre-processing
  - 2. on-line storage for relatively fast-recall.
  - 3. archival storage, characterized by infrequent access

Elements ....

- **Methods of storage**
  - \- Computer Memory
  - \- Frame Buffers
  - \- Magnetic disks, Magneto-Optical Disks (online storage)
  - \- Magnetic Tapes and Optical Disks - Archival Storage
- **Processing** - involves procedures that are usually expressed in algorithmic form.
  - \- Usually done in software
  - \- Use of hardware for real time applications

Elements …

- **Communication**
  - Involves local communication (handled by the LAN communication protocols) and remote communication.
  - - Remote Communication - presents lots of challenges as images consume lot of bandwidth
- **Display** - This is one of the most important elements of the entire system as it enables the end user to see the results at each step of image processing.

Image Processing is characterized by specific solutions

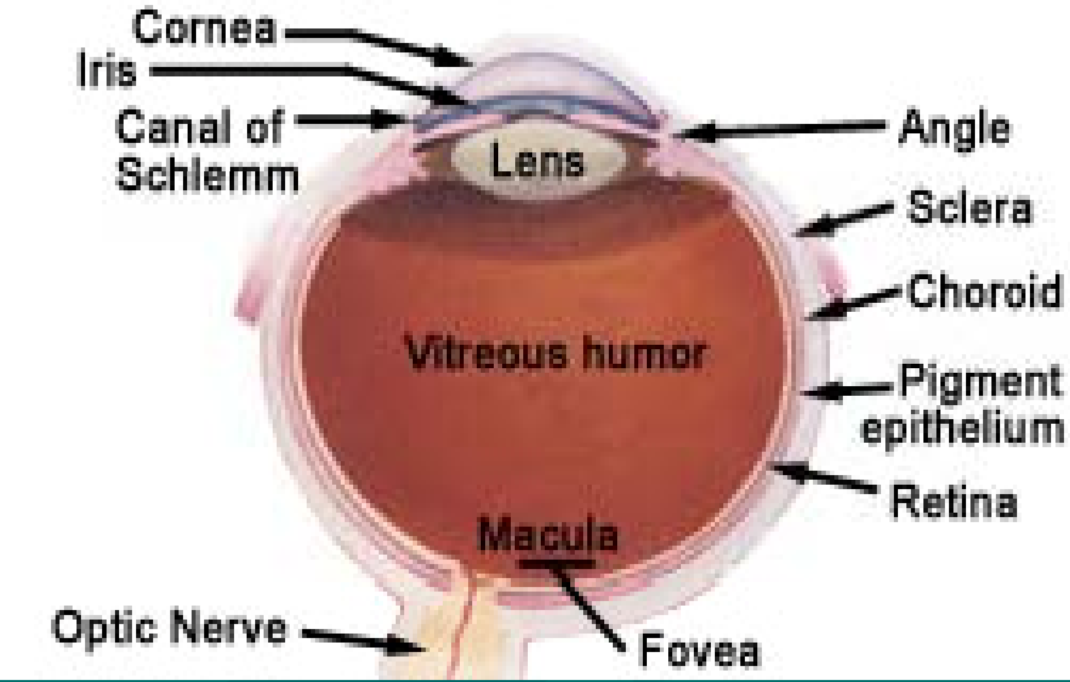
Techniques that work well in one area can be totally inadequate in another.

Digital Image Fundamentals

1. Elements of Visual Perception

Structure of the Human Eye

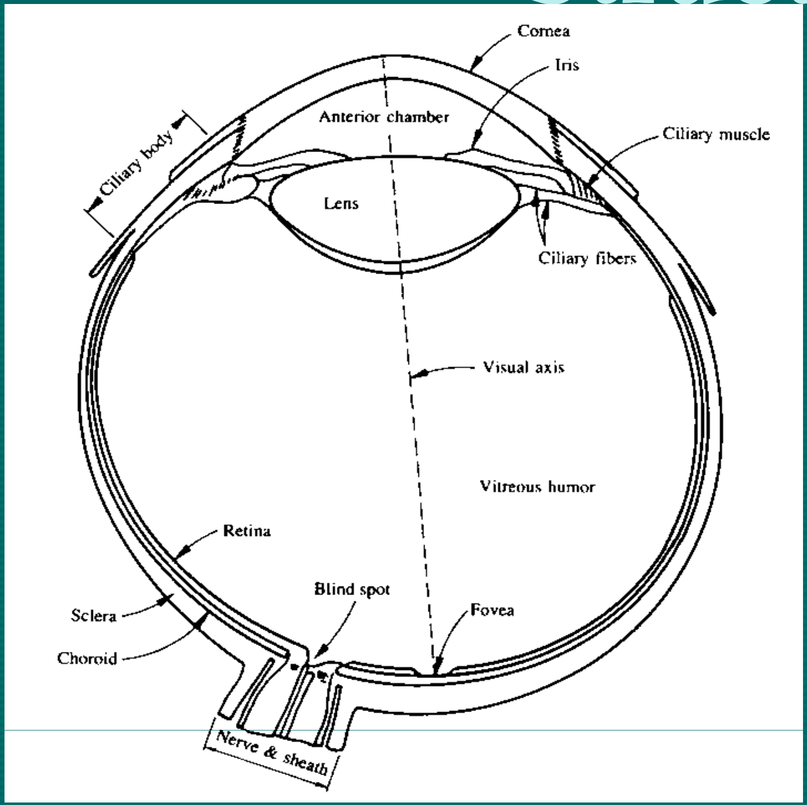
- Eye: Sphere, diameter of 20 mm
- Consists of 3 membranes:
  1. Cornea and sclera
  2. Choroid
  3. Retina
- Cornea: transparent
- Sclera: opaque, connected to cornea
- Choroid: network of blood vessels

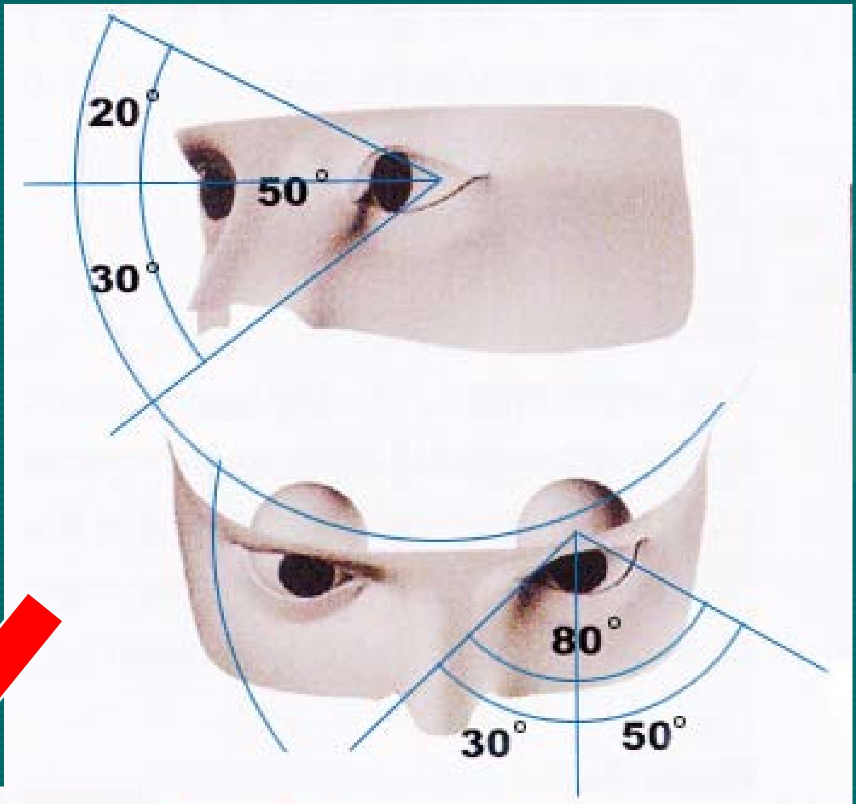


In front choroid is connected to iris diaphragm

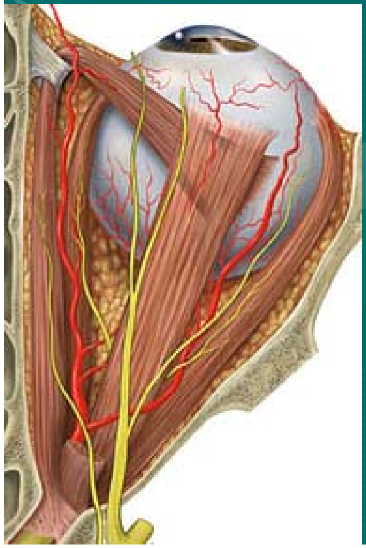
- Iris: contracts or expands to control amount of light
- Pupil: central opening of iris, 2 to 8 mm in diameter

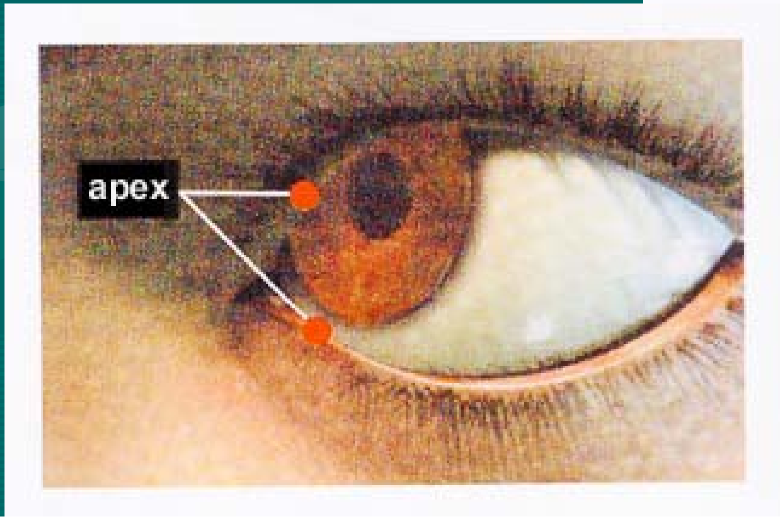
Structure of Human Eye ..





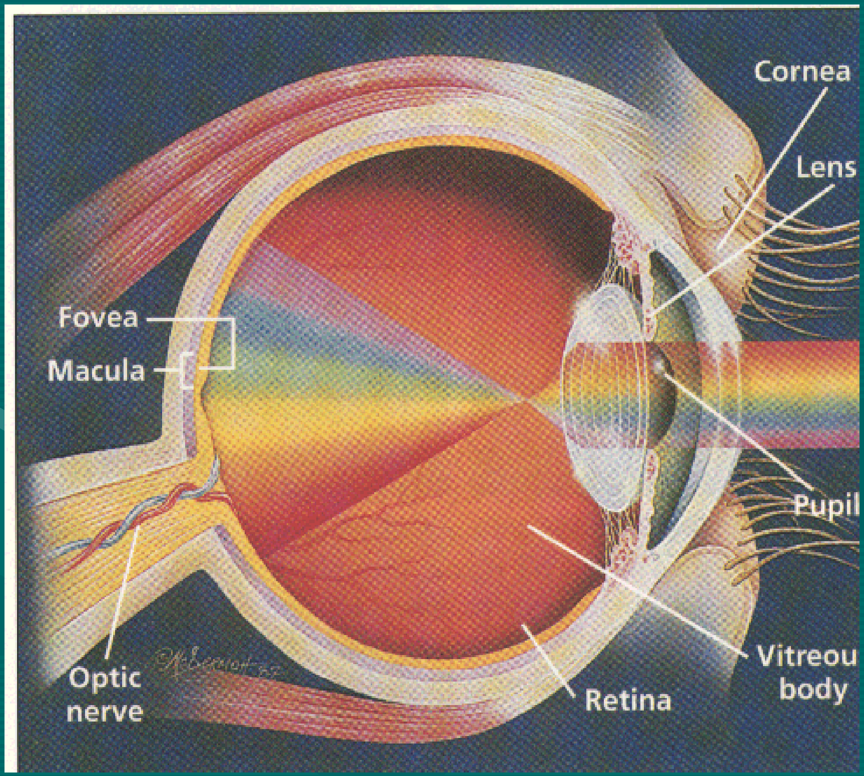
Movable range of an eye

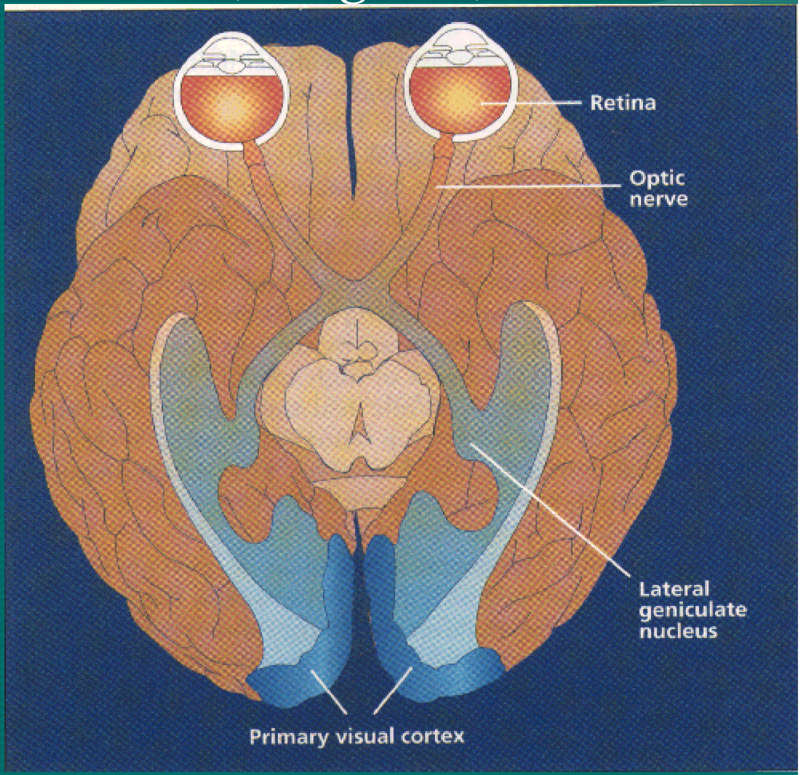




The Eye - What can we get from it ?

- **Human Eye**
- **Definition of terms** - Smooth Pursuit, Vergence,





The Eye

- **Visual Front End Processor**
  - **Simplifies the complexity of input image to a great extent before passing it to upper layer (i.e. to Brain)**

Structure of the Human Eye

- **Lens:**

– focuses light on retina

– Contains 60% to 70% water

– Absorbs 8% of visible light

– High absorption in infrared and ultraviolet (can cause damage to eye)

- Retina: the inner most layer, covers the posteriori portion of eye
- When eye is properly focused, light of an object is imaged on the retina
- Light receptors are distributed over the surface of retina

Structure of Human Eye

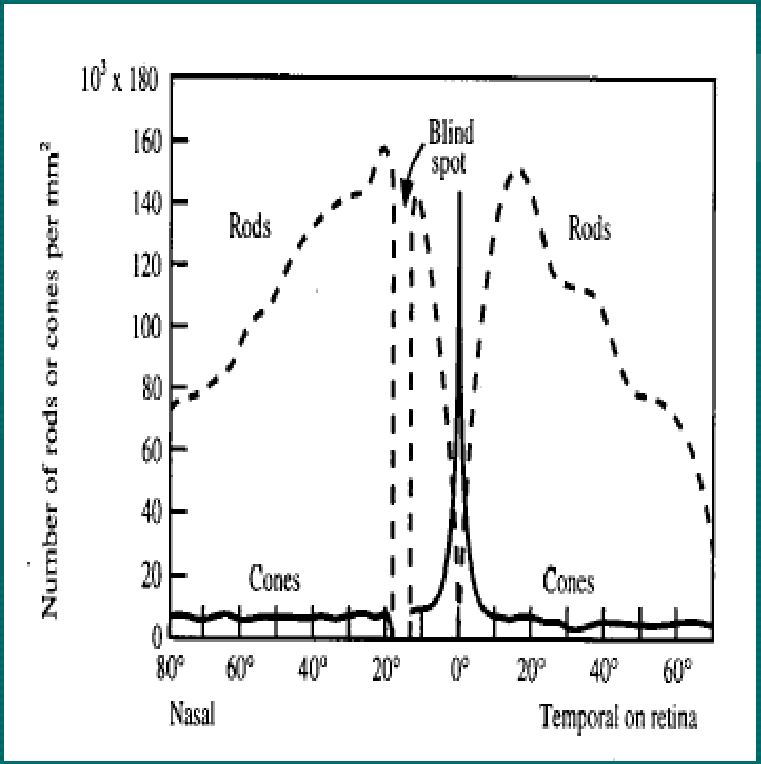
- **Retina contains light receptors: Cones & rods**

– **Cones**:

- 6 to 7 million,
- located mainly in central part of retina fovea)
- Sensitive to color,
- Can resolve fine details because each one is connected to its nerve
- Cone vision: photopic or bright-light

– Rods:

- 75 to 150 million,
- No color vision, responsible for lowlight vision,
- Distributed a wide region on the retina
- Rod vision: scotopic or dim-light



Structure of Human Eye

- Blind spot: a region of retina without receptors, optic nerves go through this part
- Fovea: a circular area of about 1.5 mm in diameter
- A comparison between eye (fovea) and a CCD camera:

– Density of cones in fovea: 150,000 /mm2

– Number of cones: 337,000

– A medium resolution CCD chip has the same number of elements in a 7mm x 7mm area.

Image Formation in the Eye

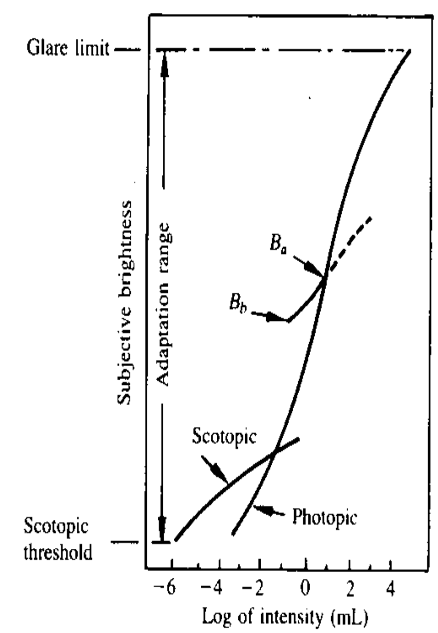
- ***Lens is flexible***
- Refraction of lens is controlled by its thickness
- Thickness is controlled by the tension of muscles connected to the lens
- ***Focus on distance objects***: lens is relatively flattened, ***refractive power is minimum***
- ***Focus on near objects***: lens is thicker, ***refractive power is maximum***

Brightness Adaptation and Discrimination

• The dynamic range of light intensity to which eye can adapt is enormous – (on the order of 10^{10})- from the ***scotopic threshold*** to the glare limit

• HVS can not operate over the entire range (see figure) simultaneously.

It accomplishes large variations due to ***brightness adaptation***



• Ability of the eye to ***discriminate between changes in brightness*** at any specific adaptation level.

• Brightness (light perceived by visual system) is logarithmic function of light intensity.

Weber Experiments – ***brightness discrimination of HVS***