BSB663
Image Processing

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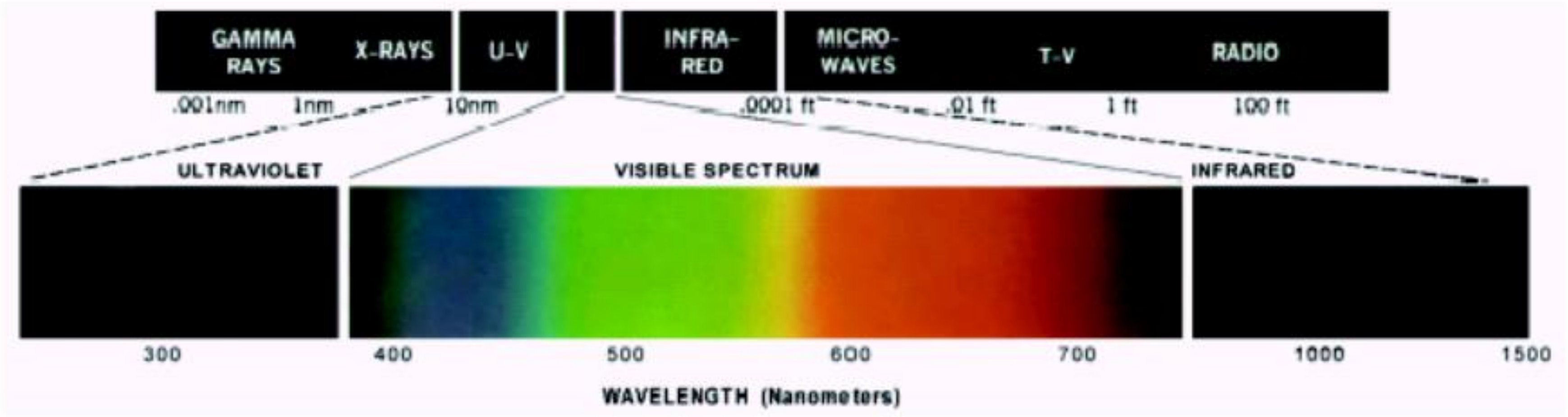
Slides are adapted from
Gonzales & Woods,
Emmanuel Agu
Allison Okamura,
Douglas C. Noll

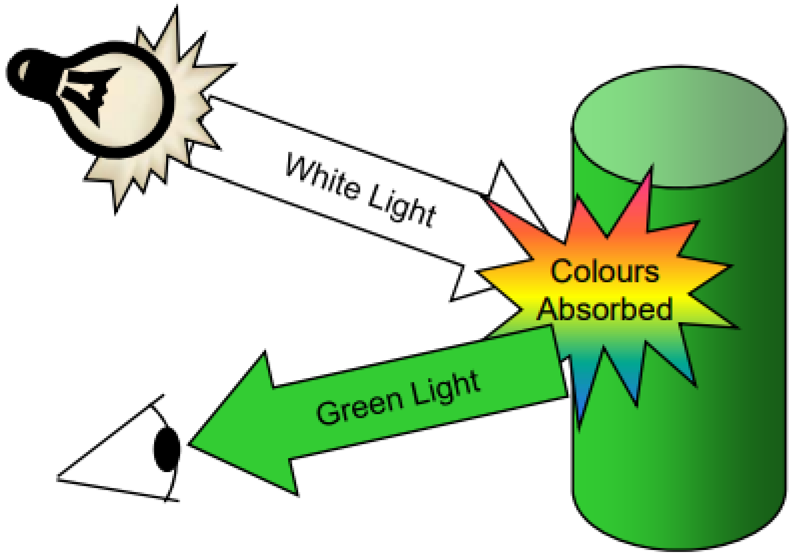
Ligth and Electromagnetic Spectrum

- Light: just a particular part of electromagnetic spectrum that can be sensed by the human eye
- The electromagnetic spectrum is split up according to the wavelengths of different forms of energy



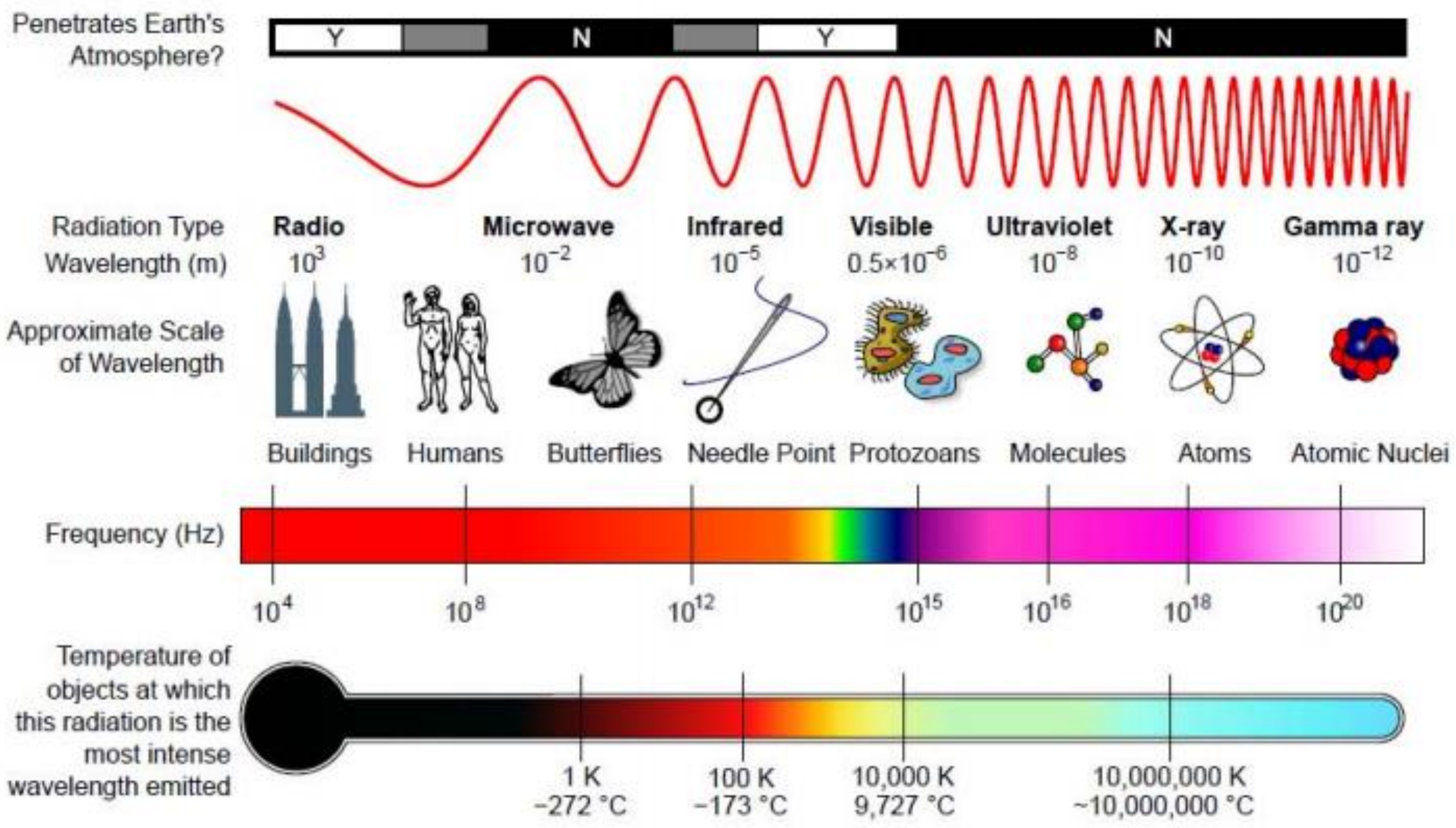
Reflected Light

- The colours humans perceive are determined by nature of light reflected from an object
- For example, if white light (contains all wavelengths) is shone onto green object it absorbs most wavelengths absorbed except green wavelength (color)



Electromagnetic Spectrum and IP

- Images can be made from any form of EM radiation



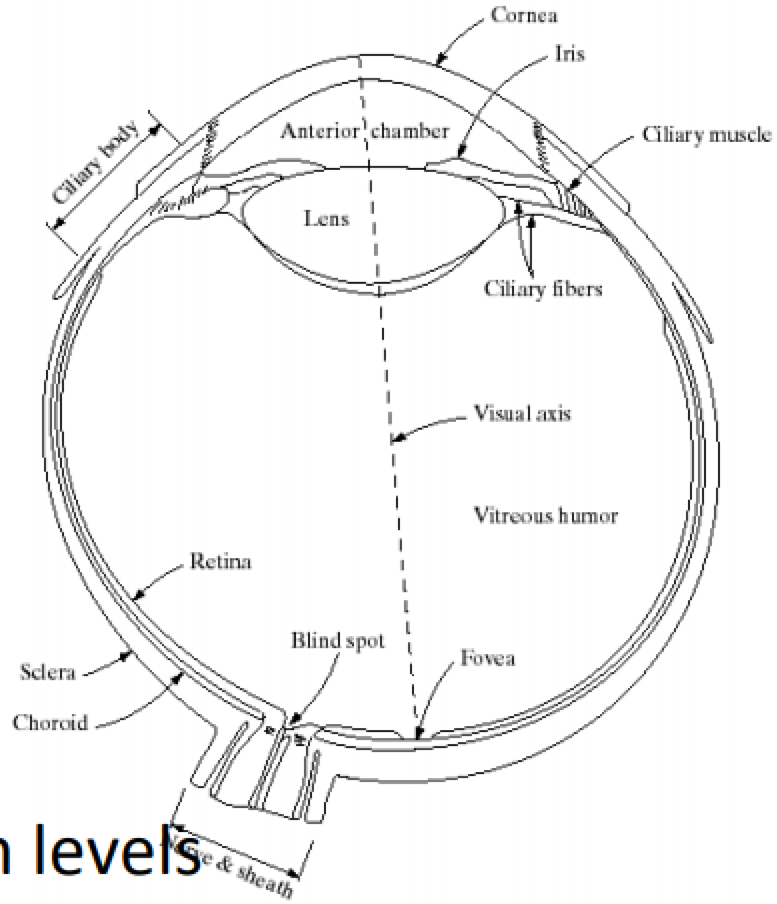
From Wikipedia

Images from Different EM Radiation

- Radar imaging (radio waves)
- Magnetic Resonance Imaging (MRI) (Radio waves)
- Microwave imaging
- Infrared imaging
- Photographs
- Ultraviolet imaging telescopes
- X-rays and Computed tomography
- Positron emission tomography (gamma rays)
- Ultrasound (not EM waves)

Human Visual System: Structure Of The Human Eye

- The lens focuses light from objects onto the retina



- Retina covered with light receptors called ***cones*** (6-7 million) and ***rods*** (75-150 million)
- Cones concentrated around fovea. Very sensitive to colour
- Rods more spread out and sensitive to low illumination levels

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

Image Formation In The Eye

- Muscles in eye can change the shape of the lens allowing us focus on near or far objects
- An image is focused onto retina exciting the rods and cones and send signals to the brain

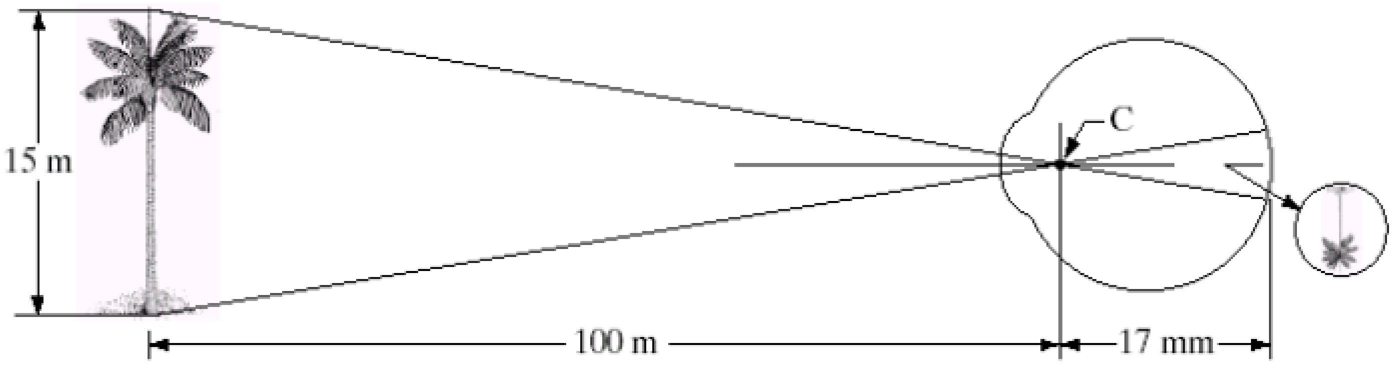
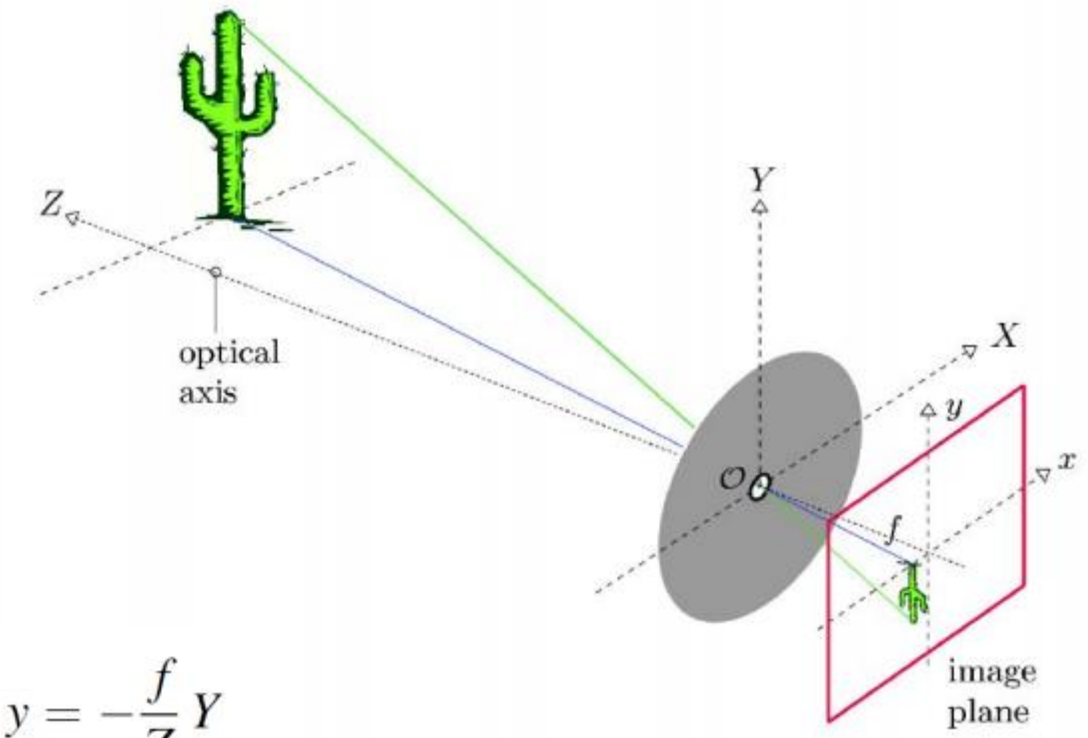


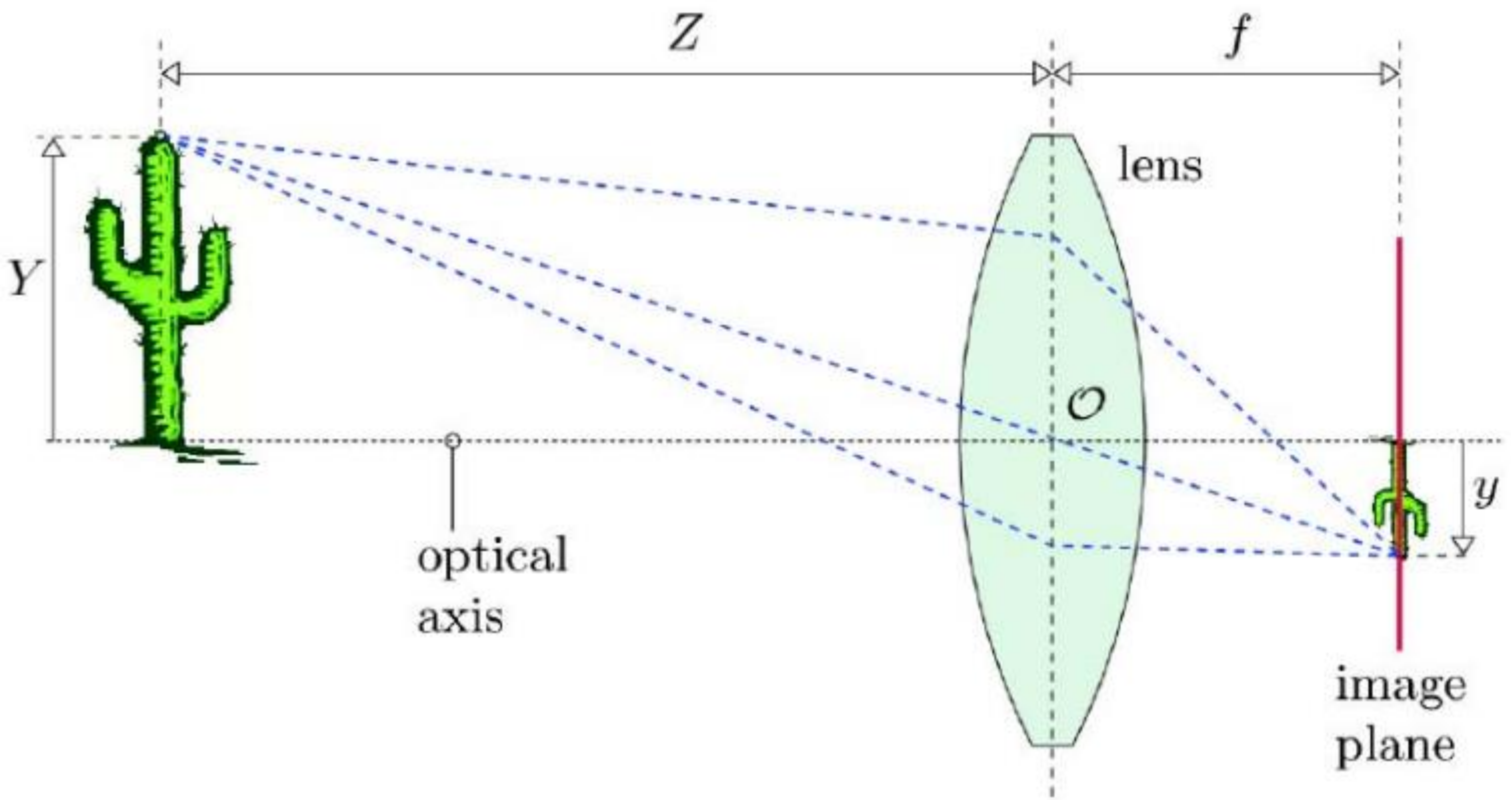
Image Formation

- The Pinhole Camera (abstraction)
  - First described by ancient Chinese and Greeks (300-400AD)



$$x = -\frac{f}{Z}X, \qquad y = -\frac{f}{Z}Y$$

Thin lens

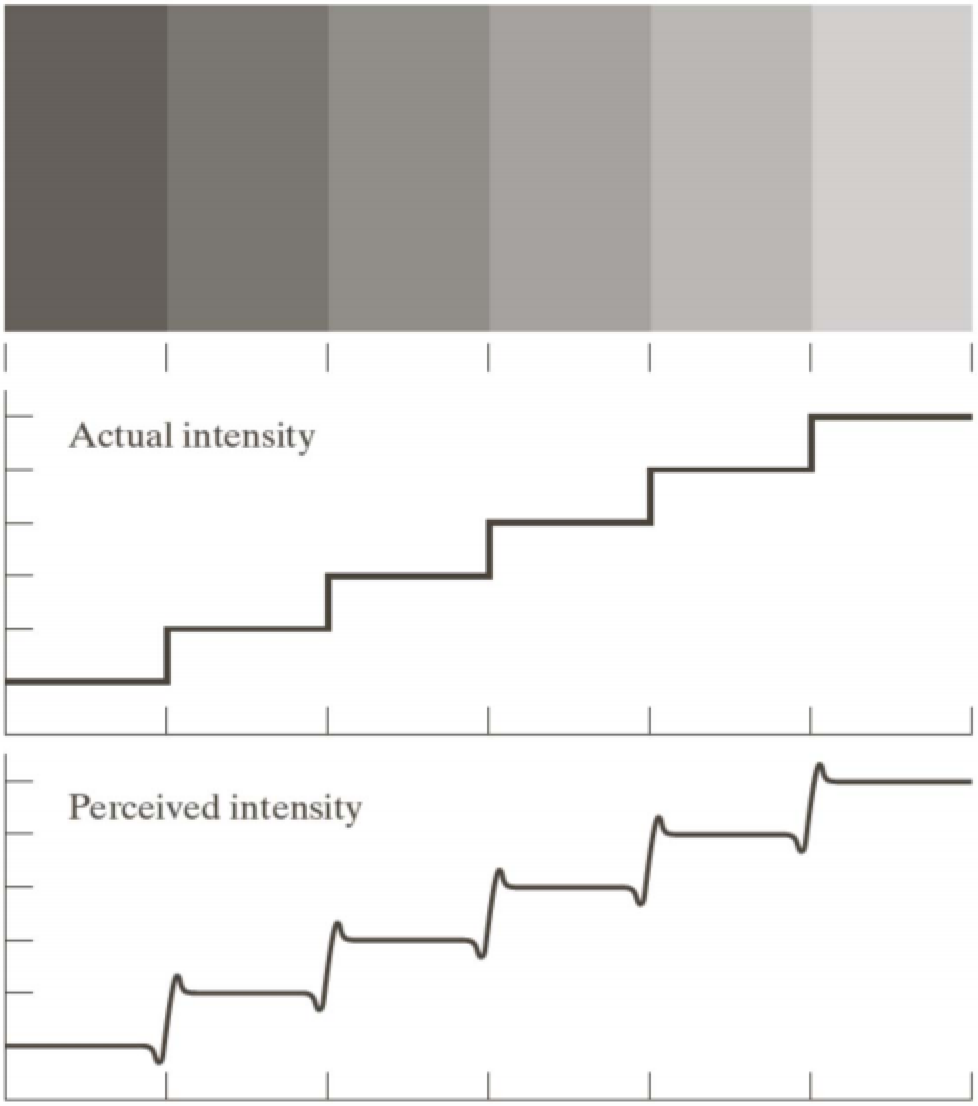


Brightness Adaptation & Discrimination

- 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, ***perceived intensity*** of a region is related to the light intensities of the regions surrounding it

Brightness Adaptation & Discrimination: Mach Band Effect

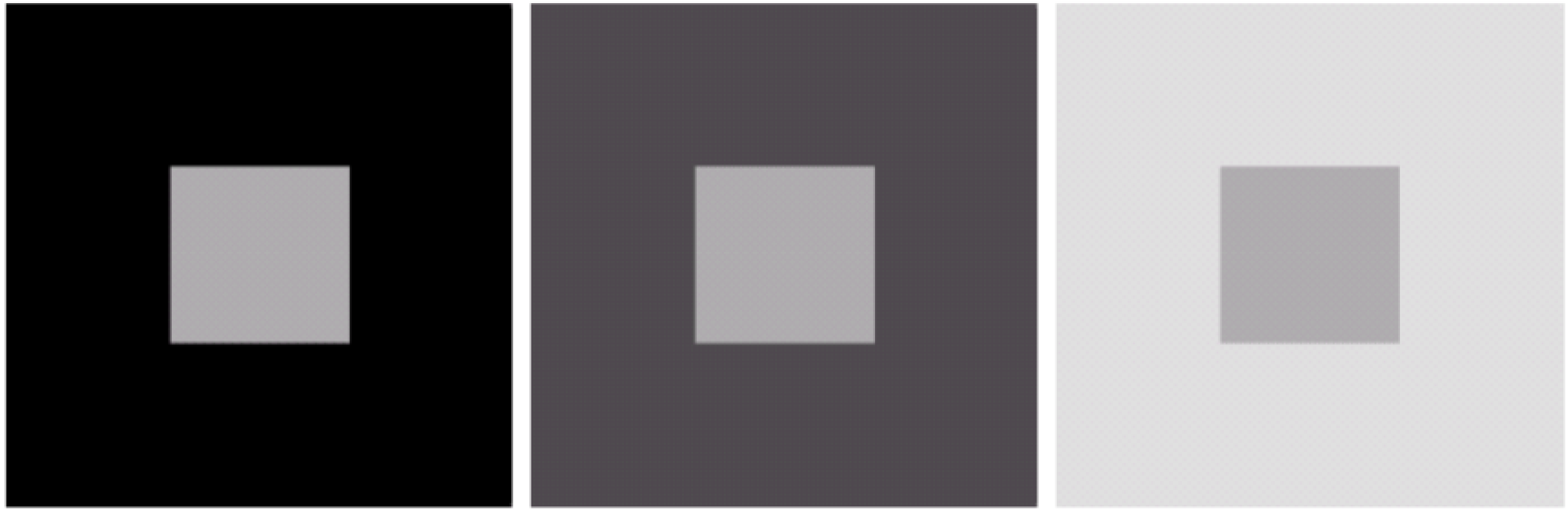
Images taken from Gonzalez & Woods, Digital Image Processing (2002)



Perceived intensity overshoots or undershoots at areas of intensity change

Brightness Adaptation & Discrimination

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



An example of *simultaneous contrast*

All inner squares have same intensity but appear darker as outer square (surrounding area) gets lighter

Image Acquisition

- Images typically generated by ***illuminating a scene*** and absorbing energy reflected by scene objects

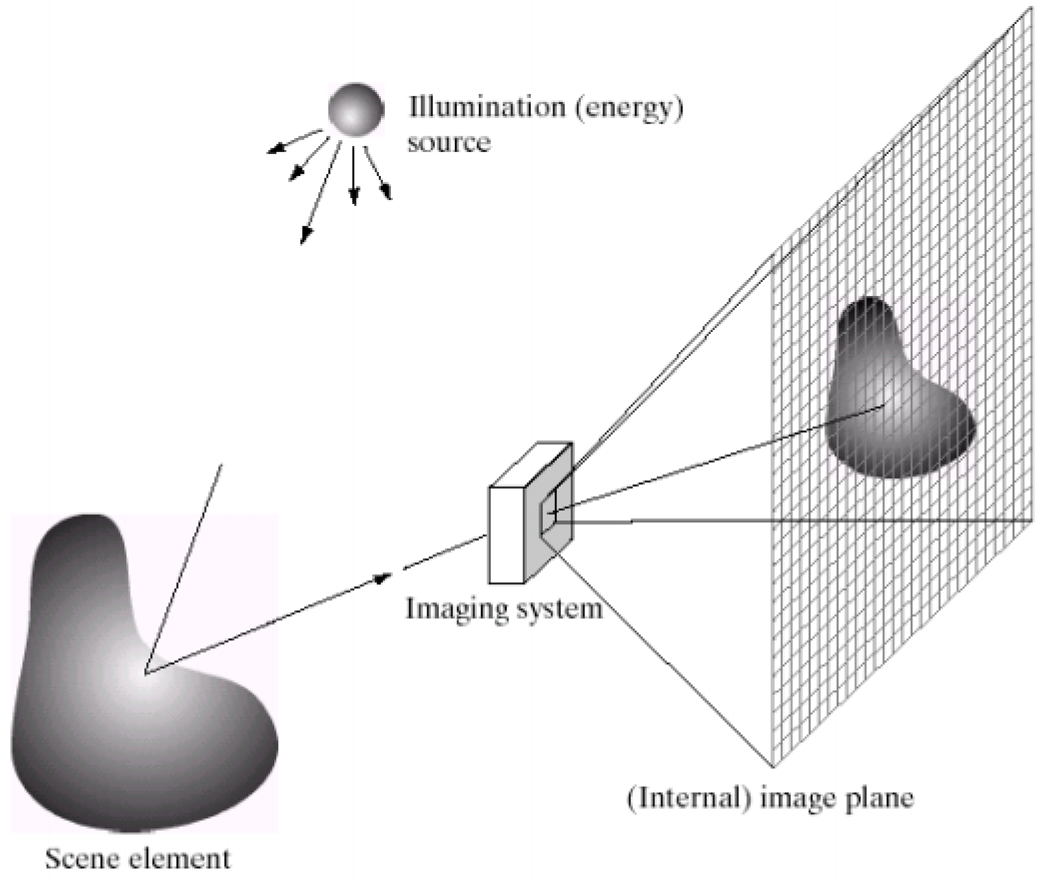
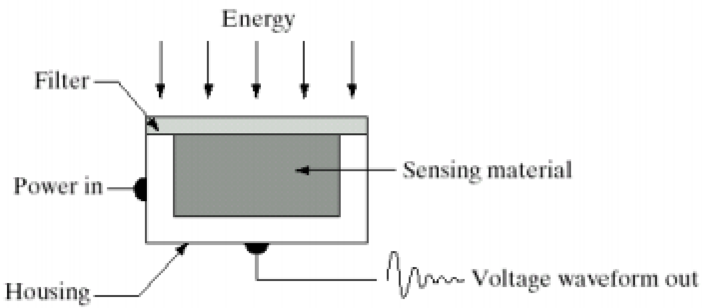


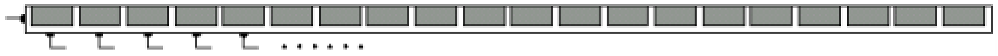
Image Sensing

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

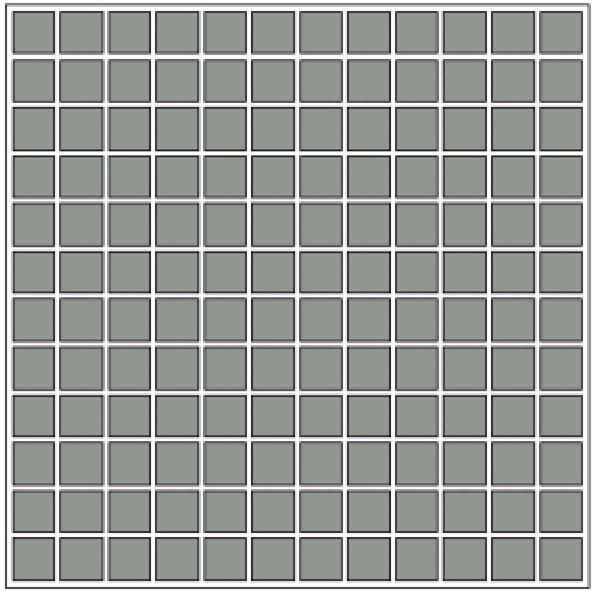
- Incoming energy (e.g. light) lands on a sensor material responsive to that type of energy, generating a voltage
- Collections of sensors are arranged to capture images



Imaging Sensor



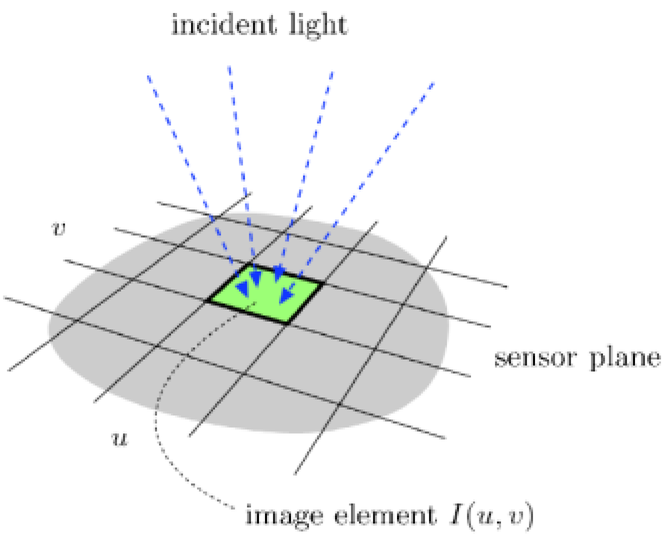
Line of Image Sensors



Array of Image Sensors

Spatial sampling

- Cannot record image values for all (x,y)
- Sample/record image values at discrete (x,y)
- Sensors arranged in grid to sample image



$F(x,y)$

148	123	52	107	123	162	172	123	64	89	⋯
147	130	92	95	98	130	171	155	169	163	⋯
141	118	121	148	117	107	144	137	136	134	⋯
82	106	93	172	149	131	138	114	113	129	⋯
57	101	72	54	109	111	104	135	106	125	⋯
138	135	114	82	121	110	34	76	101	111	⋯
138	102	128	159	168	147	116	129	124	117	⋯
113	89	89	109	106	126	114	150	164	145	⋯
120	121	123	87	85	70	119	64	79	127	⋯
145	141	143	134	111	124	117	113	64	112	⋯
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	

$I(u,v)$

Image (spatial) sampling

- A digital sensor can only measure a limited number of **samples** at a **discrete** set of energy levels

- **Sampling** can be thought of as:

  Continuous signal x comb function

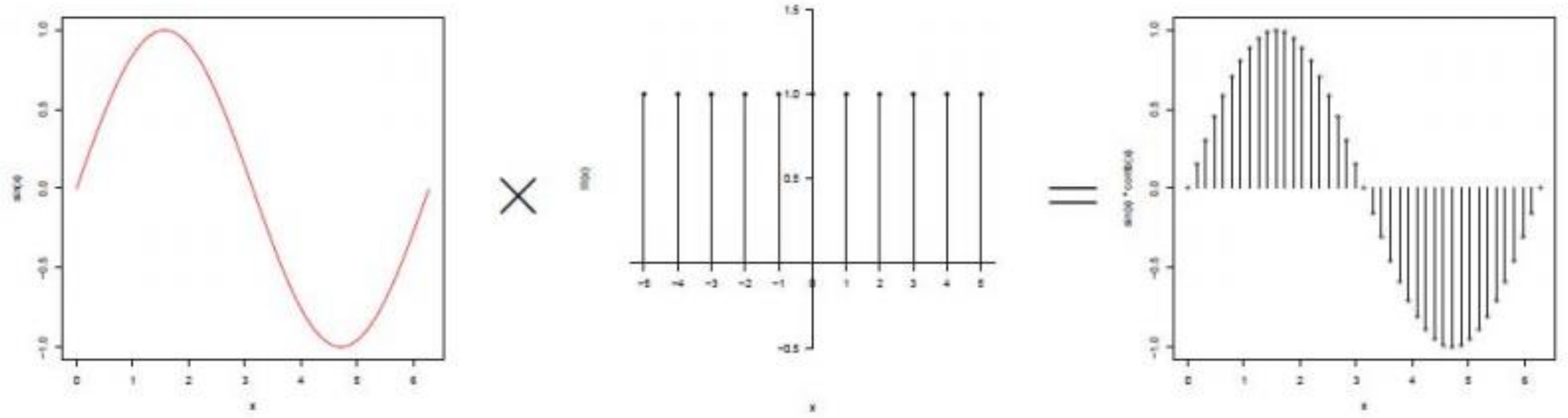


Image quantization

- ***Quantization*:** process of converting continuous **analog** signal into its digital representation
- Discretize image *I(u,v)* values
- Limit values image can take

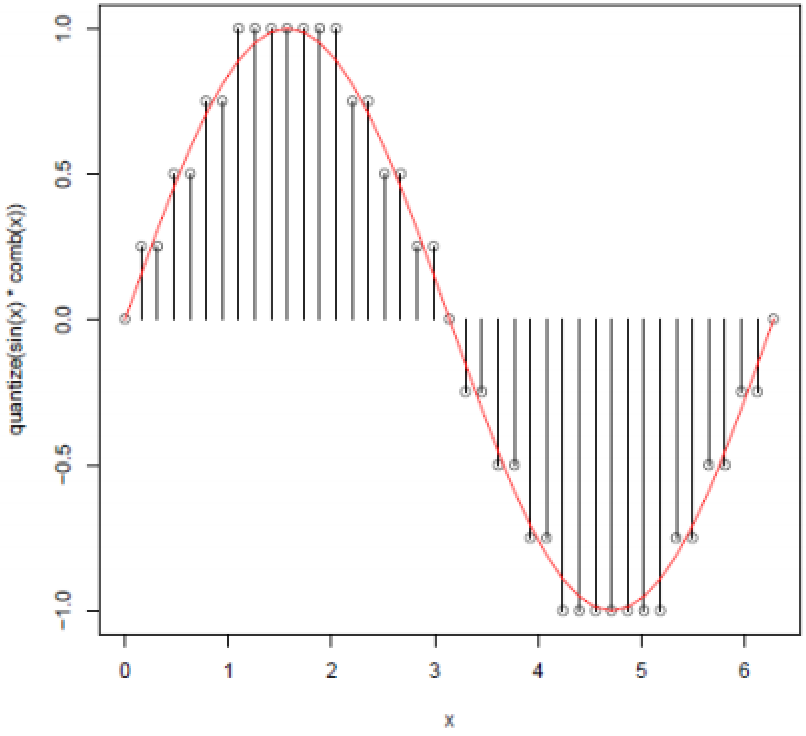


Image Sampling and Quantization

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

- Sampling and quantization generates **approximation** of a real world scene

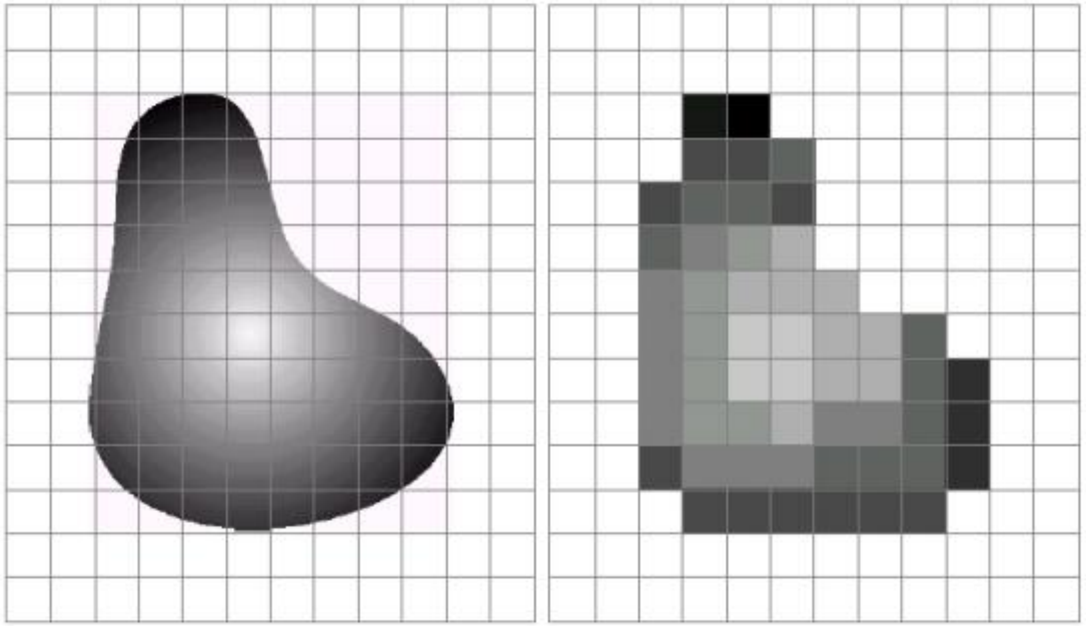


Image as a function

A simple image

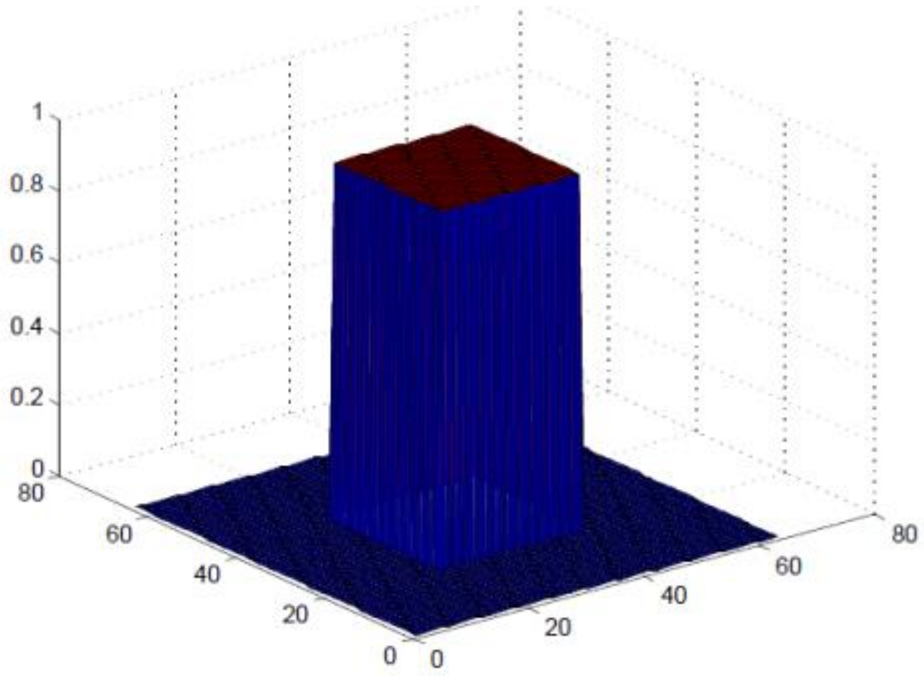
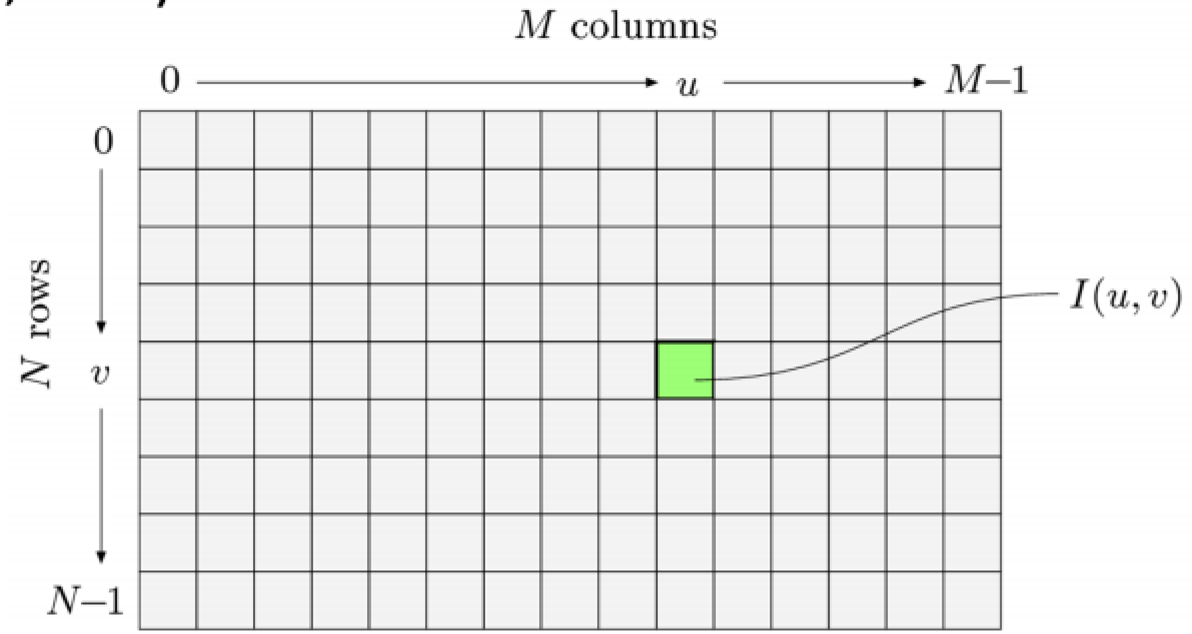


Image function as a height field

Representing Images

- Image data structure is 2D array of pixel values
- Pixel values are gray levels in range 0-255 or RGB colors
- Array values can be any data type (bit, byte, int, float, double, etc.)

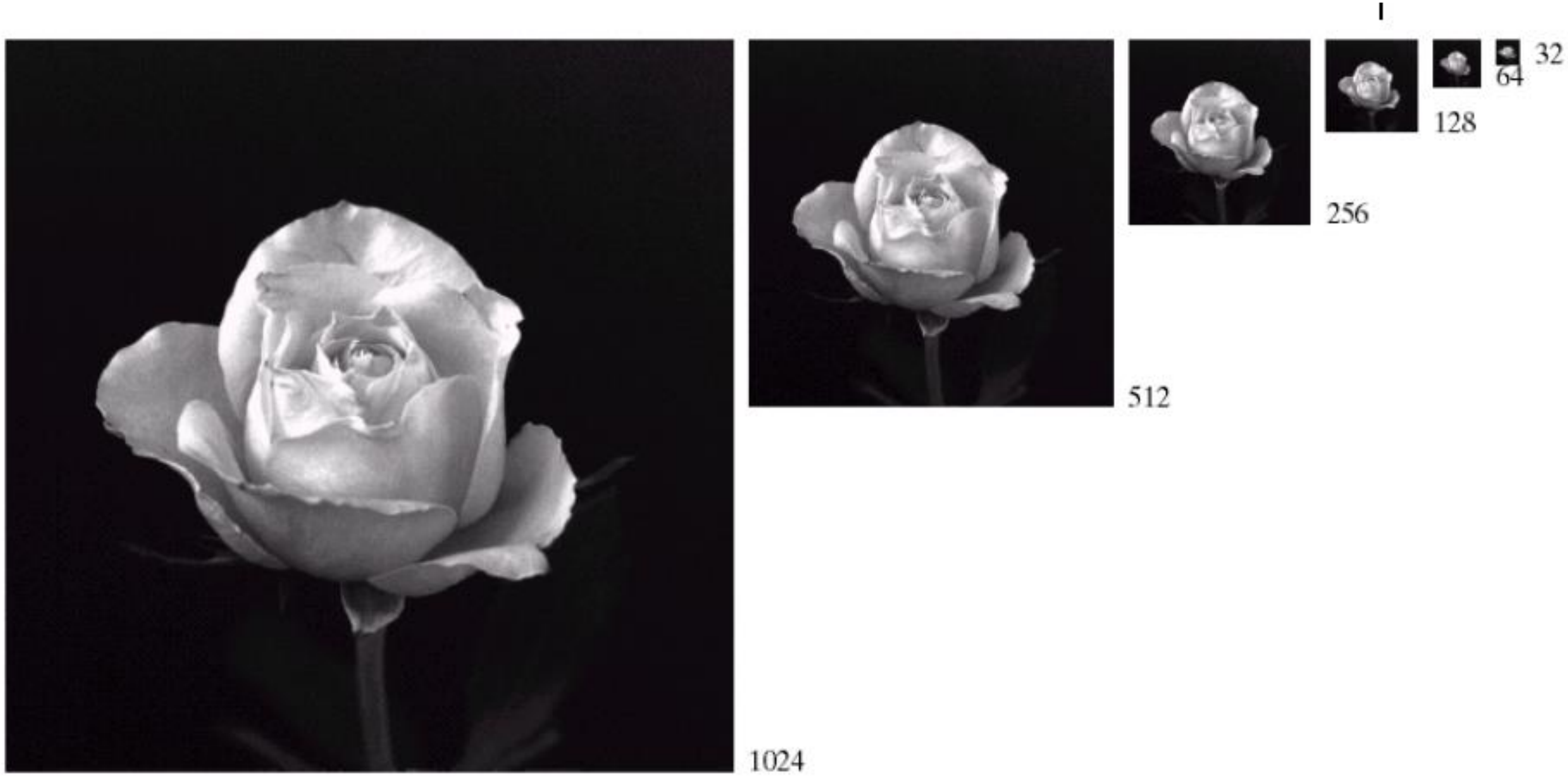


Spatial resolution

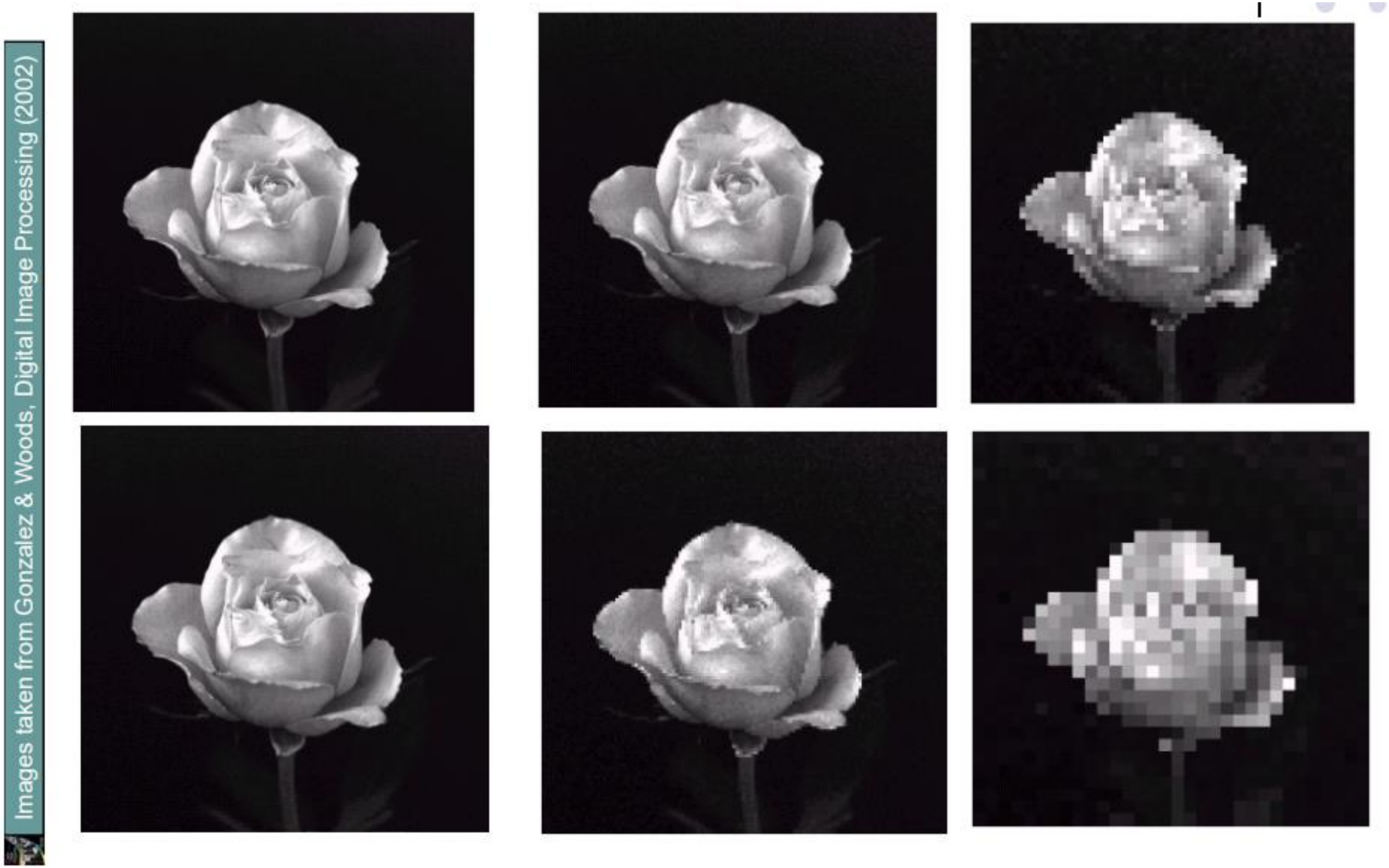
- *The **spatial resolution*** of an image is determined by how fine/coarse sampling was carried out
- **Spatial resolution:** smallest discernable image detail
  - Vision specialists talk about image resolution
  - Graphic designers talk about *dots per inch* (DPI)

Spatial resolution

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



Spatial resolution : Stretched images

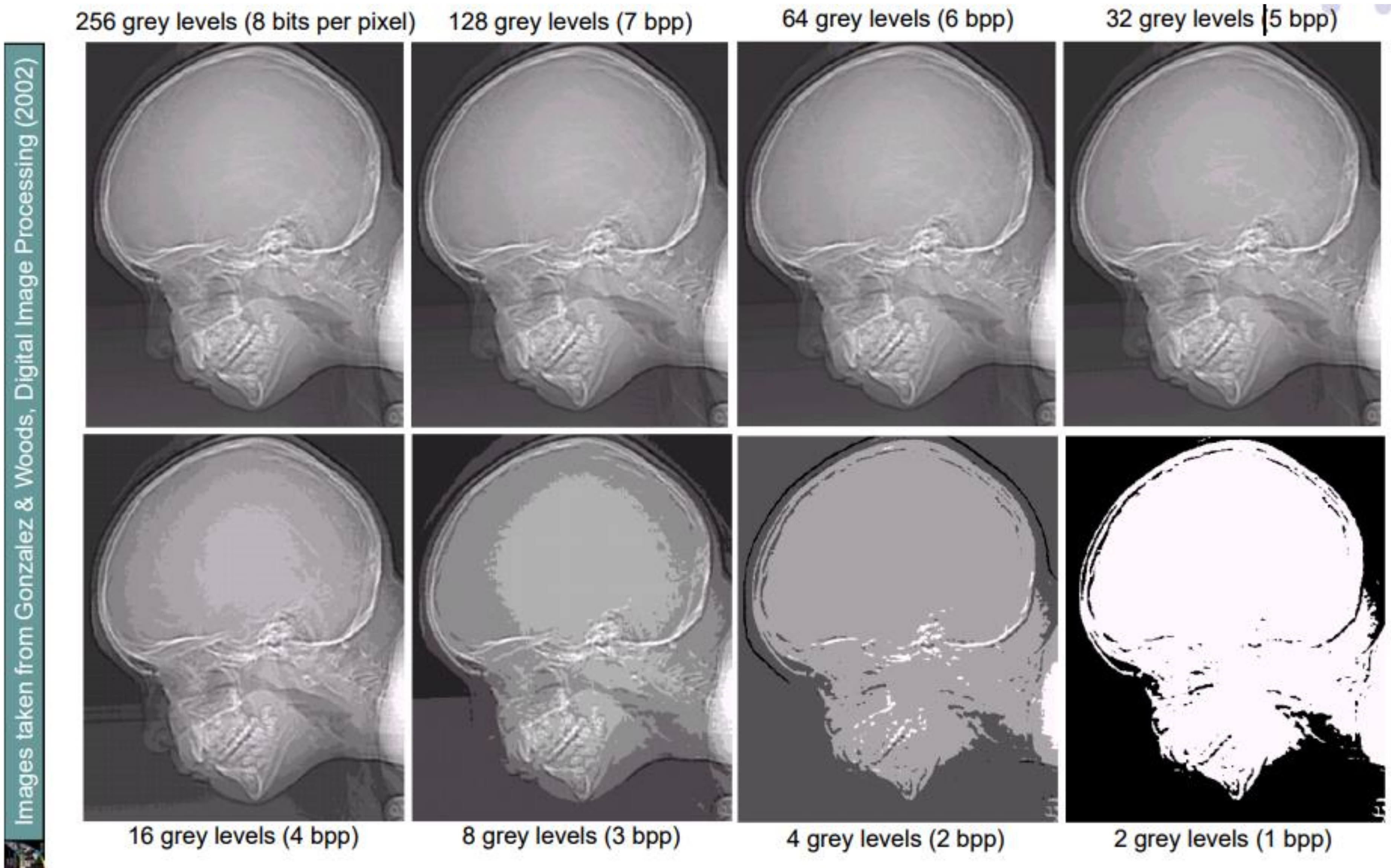


Intensity level resolution

- ***Intensity level resolution*:** 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 usually given in terms of 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



Resolution: How Much Is Enough?

- The big question with resolution is always *how much is enough*?
  - Depends on what is in the image *(details)* and what you would like to do with it *(applications)*
  - Key questions:
    - Does image look aesthetically pleasing?
    - Can you see what you need to see in image?

Resolution: How Much Is Enough?

- **Example:** Picture on right okay for counting number of cars, but not for reading the number plate

Intensity Level Resolution

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

Low Detail

Medium Detail

High Detail

Image File Formats

- Hundreds of image file formats. Examples
  - Tagged Image File Format (TIFF)
  - Graphics Interchange Format (GIF)
  - Portable Network Graphics (PNG)
  - JPEG, BMP, Portable Bitmap Format (PBM), etc
- Image pixel values can be
  - **Grayscale:** 0 – 255 range
  - **Binary:** 0 or 1
  - **Color:** RGB colors in 0-255 range (or other color model)
  - **Application specific** (e.g. floating point values in astronomy)

How many Bits Per Image Element?

Grayscale (Intensity Images):

Chan.	*Bits/Pix.*	*Range*	*Use*
1	1	$0\ldots1$	Binary image: document, illustration, fax
1	8	$0\ldots255$	Universal: photo, scan, print
1	12	$0\ldots4095$	High quality: photo, scan, print
1	14	$0\ldots16383$	Professional: photo, scan, print
1	16	$0\ldots65535$	Highest quality: medicine, astronomy

Color Images:

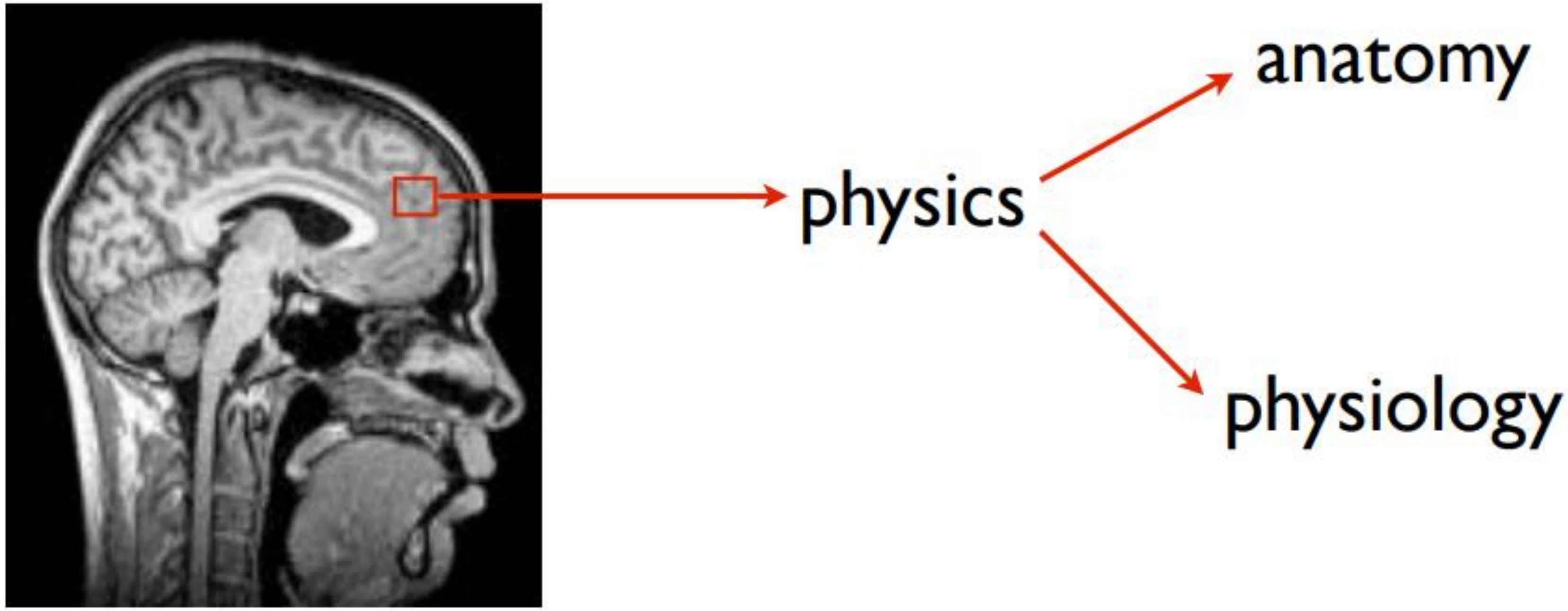
Chan.	*Bits/Pix.*	*Range*	*Use*
3	24	$[0\ldots255]^3$	RGB, universal: photo, scan, print
3	36	$[0\ldots4095]^3$	RGB, high quality: photo, scan, print
3	42	$[0\ldots16383]^3$	RGB, professional: photo, scan, print
4	32	$[0\ldots255]^4$	CMYK, digital prepress

Special Images:

Chan.	*Bits/Pix.*	*Range*	*Use*
1	16	$-32768\ldots32767$	Whole numbers pos./neg., increased range
1	32	$\pm3.4 \cdot 10^{38}$	Floating point: medicine, astronomy
1	64	$\pm1.8 \cdot 10^{308}$	Floating point: internal processing

why use medical images?

intensity values are related to physical tissue characteristics which in turn relate to
(1) anatomical information and/or
(2) a physiological phenomenon



what should you consider when selecting an imaging modality?

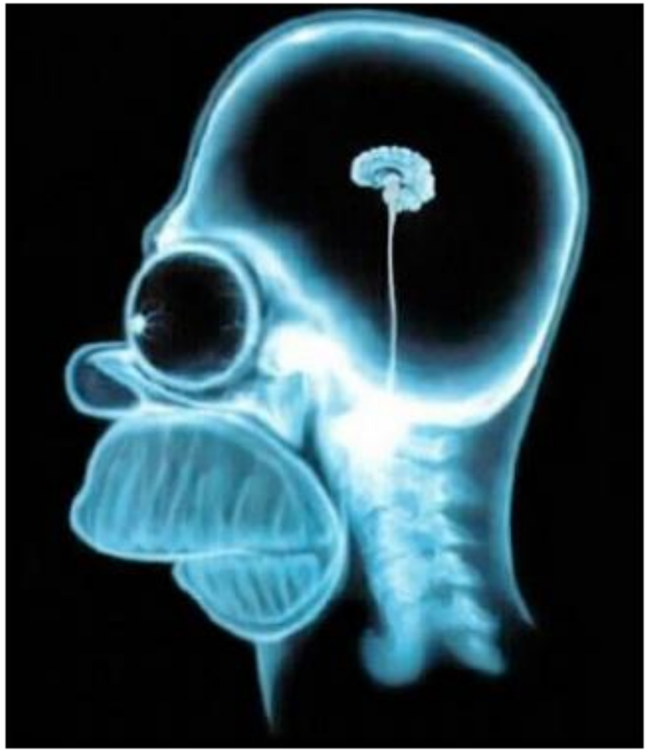
technical specifications:

- spatial resolution
- temporal resolution
- field of view
- types of biological and physiologic information

traditional imaging

vs.

functional imaging



physiologic information is interpreted

physiologic information is computed

projection imaging:

- 2D cross images are generated by capturing a "view" from a single direction

vs.

tomographic images:

- 3D images are generated by stacking a set of 2D cross sectional image slices
- derived from the Greek *tomos* (slice) and *graphein* (to write)

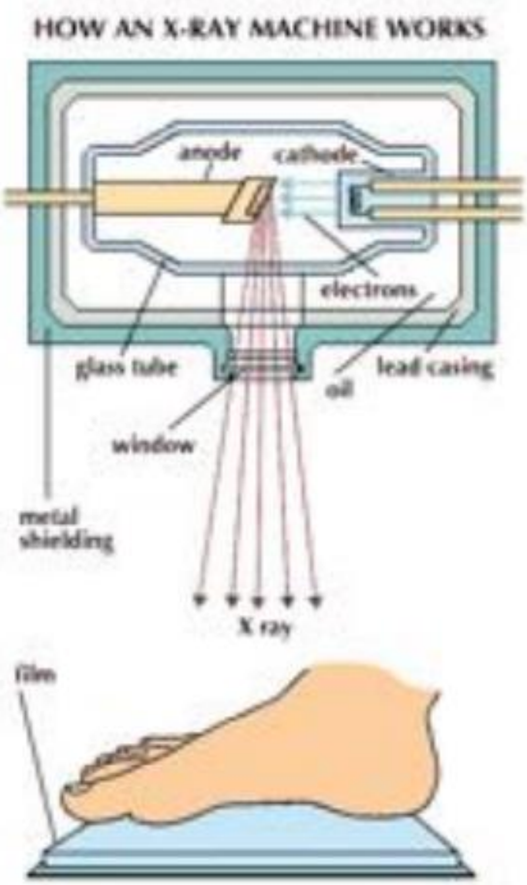
Major Modalities

- Projection X-ray (Radiography)
- X-ray Computed Tomography (CT)
- Nuclear Medicine (SPECT, PET)
- Ultrasound
- Magnetic Resonance Imaging

in the beginning, there was x-ray

physics: density of x-ray absorption
(x-rays are a form of ionizing radiation)

first "medical" x-ray, 1895

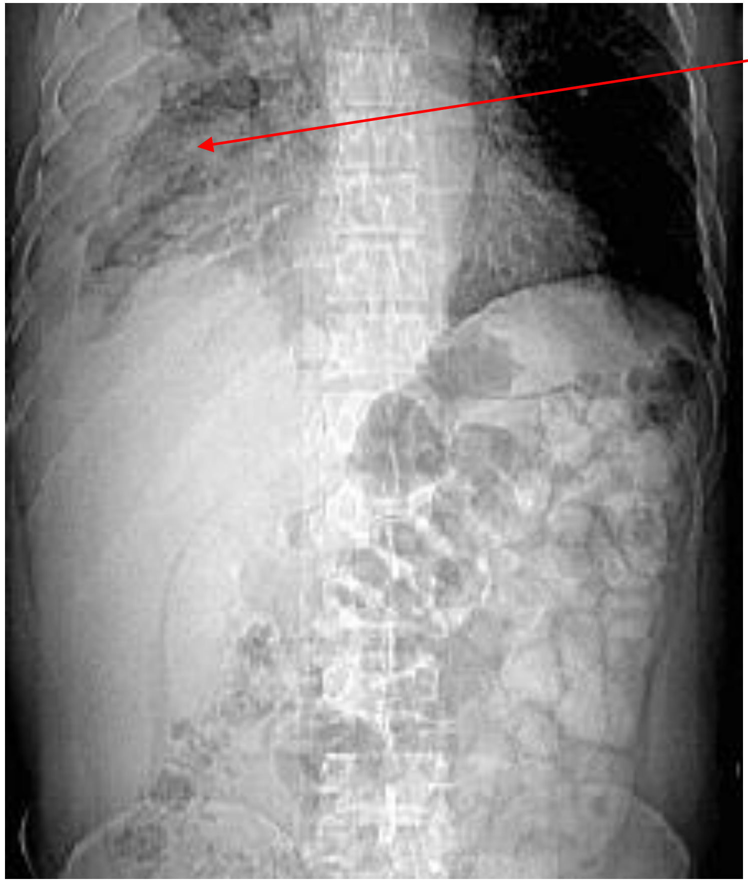


http://www.britannica.com/

gray value on film is proportional to radiation energy

X-ray Imaging
Projection vs Tomographic

Chest
Mass



Projection Image

Cross-sectional Image

mammogram machine

uses low-energy X-rays for detection of early cancer (microcalcifications)

traditional configurations of x-ray and fluoroscopy machines

early fluoroscope
(Britannica Film)

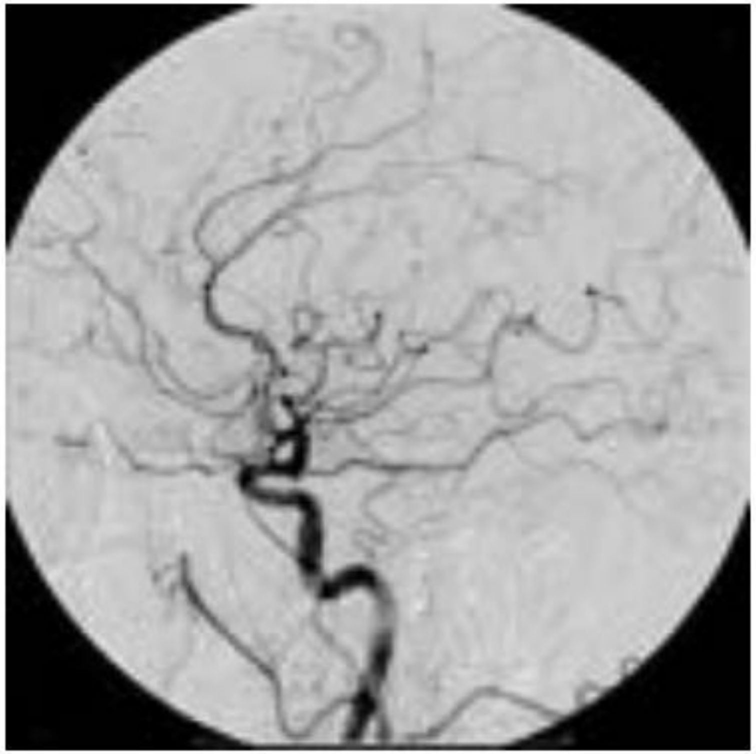
Philips digital multi-
functional X-ray system

c-arm fluoroscopy

Philips XperCT (CT-like imaging, more on CT later)

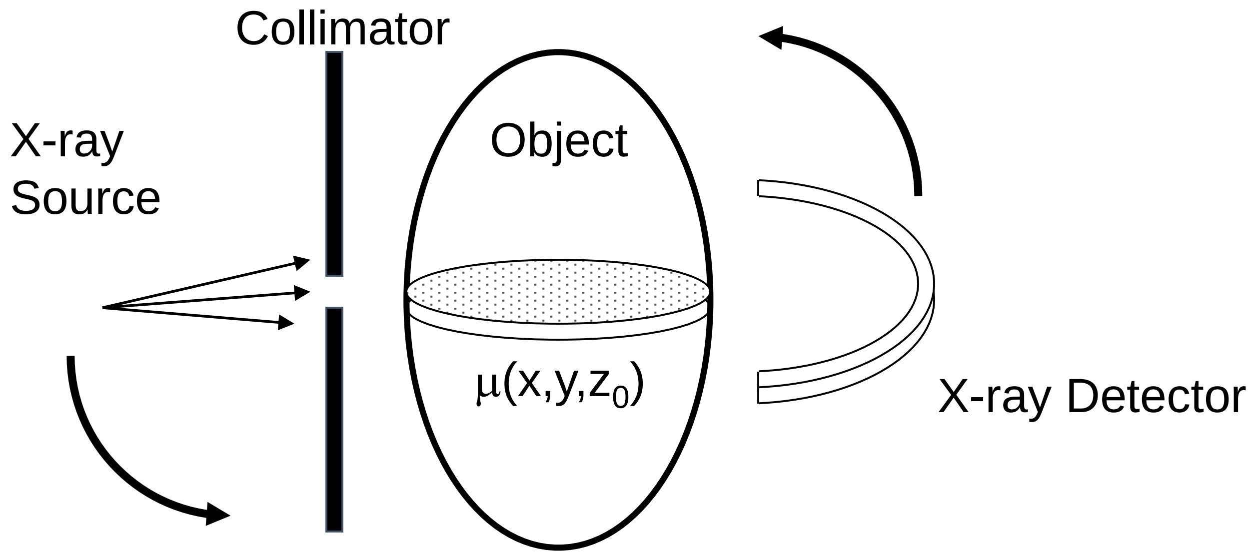
digital subtraction angiography (DSA)

create a pre-contrast image, then subtract it from later images after a contrast medium has been introduced



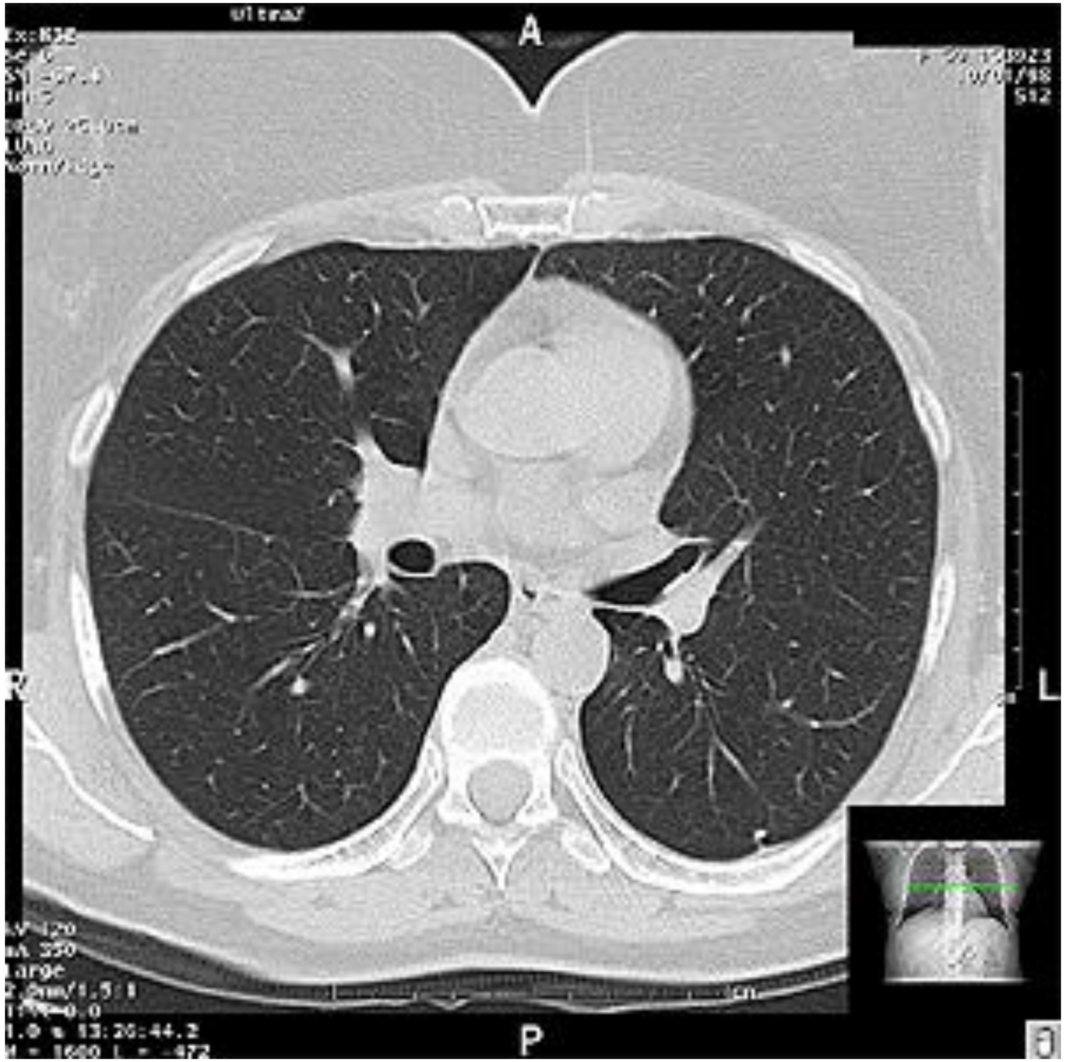
iodine and barium are common types of contrast mediums for x-ray, since they attenuate x-rays (vessels become dark)

X-ray Computed Tomography



- Uses x-rays, but exposure is limited to a slice (or “a couple of” slices) by a collimator
- Source and detector rotate around object – projections from many angles
- The desired image, $I(x,y) = \mu(x,y,z_0)$, is computed from the projections

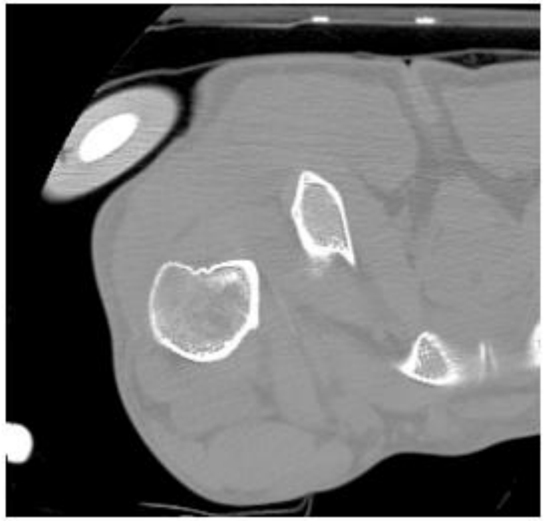
X-ray Computed Tomography



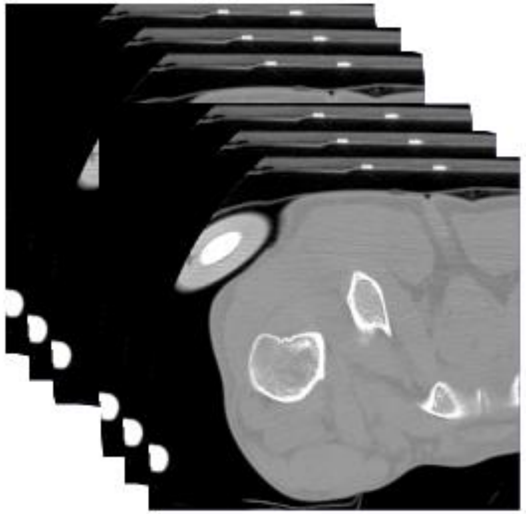
computed tomography (CT scan)

3D images are generated from a large series of 2D X-ray images taken around a single axis of rotation (produces a volume of data for analysis)

physics: same as x-ray



single slice



series of parallel slices 2mm apart

computed tomography (CT scan)

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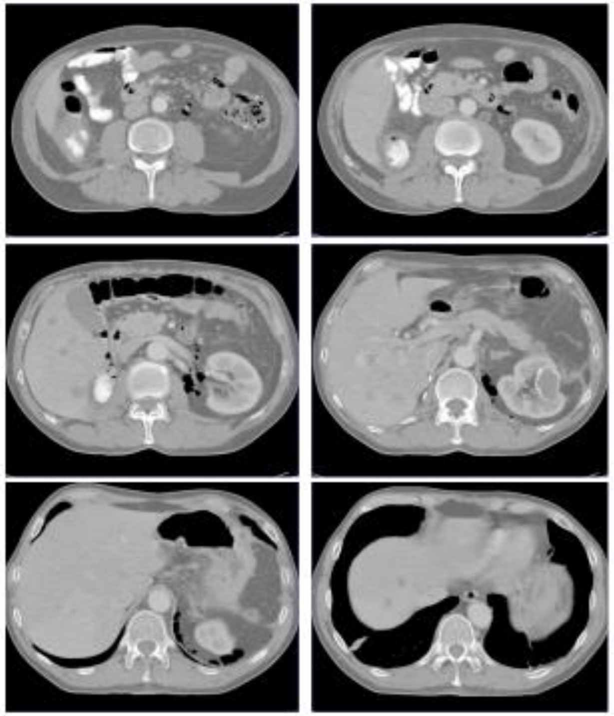
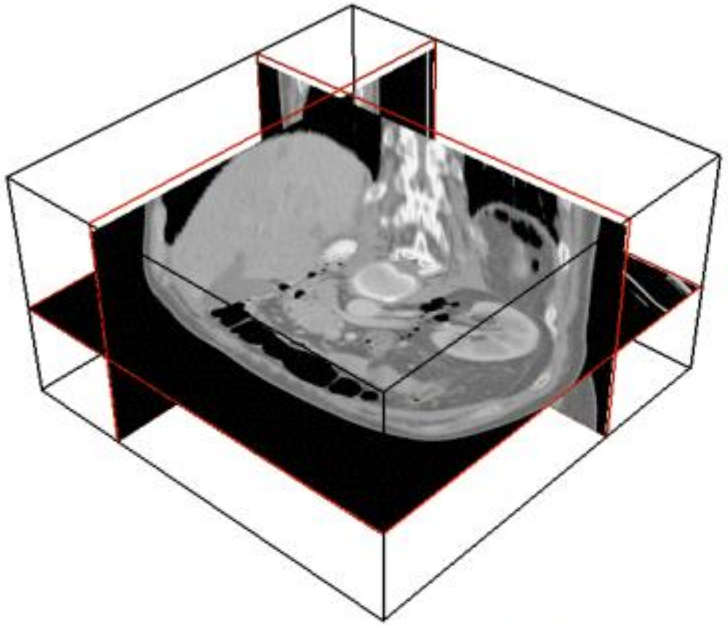
physics: same as x-ray





emitter/receiver configuration

http://www.youtube.com/watch?v=M-4o0DxBgZk

CT machines

two examples from Philips (Brilliance 6 and 40)
differ in number of images per second, number of detectors, etc.

ultrasound imaging (diagnostic)

physics: variations of acoustic impedance

1. probe sends high-frequency sound waves (1-5 MHz) into the body
2. sound waves travel into tissue and get reflected by boundaries
3. reflected waves are recorded by the probe
4. time of flight gives spatial information about the boundaries

the desired frequency of signal is chosen based on a trade-off of resolution and attenuation

ultrasound

A-mode (amplitude mode): a single transducer scans a line through the body with the echoes plotted on screen as a function of depth.

Therapeutic ultrasound aimed at a specific tumor or calculus is also A-mode, to allow for accurate focus of the destructive wave energy.

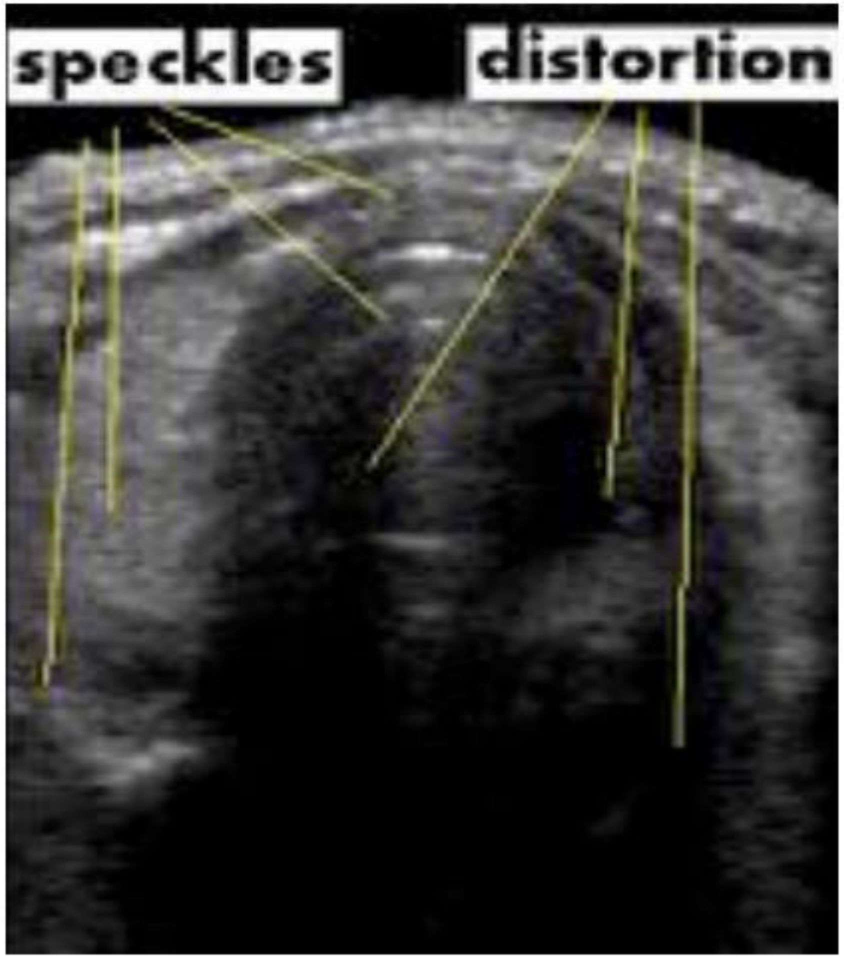
B-mode (brightness mode) or 2D mode: a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen

common application: fetal ultrasound

images courtesy Nora M. Su

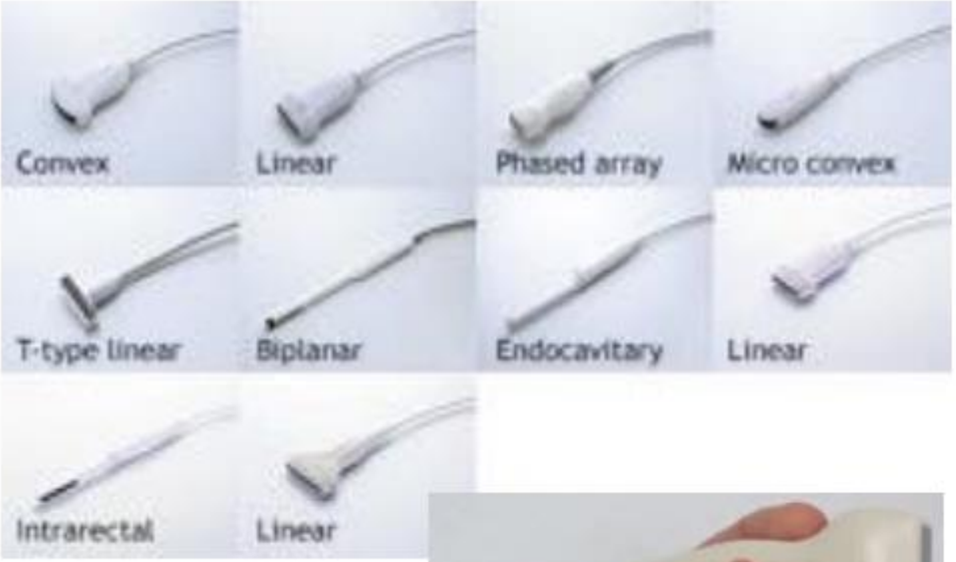
ultrasound characteristics

- No radiation
- Poor resolution (~1mm) non-uniform, distortion, noisy
- Low penetration properties
- One 2D slice or several slices (2.5D)
- Relatively cheap and easy to use
- Preoperative and intraoperative use



ultrasound machine

Ultrasonix

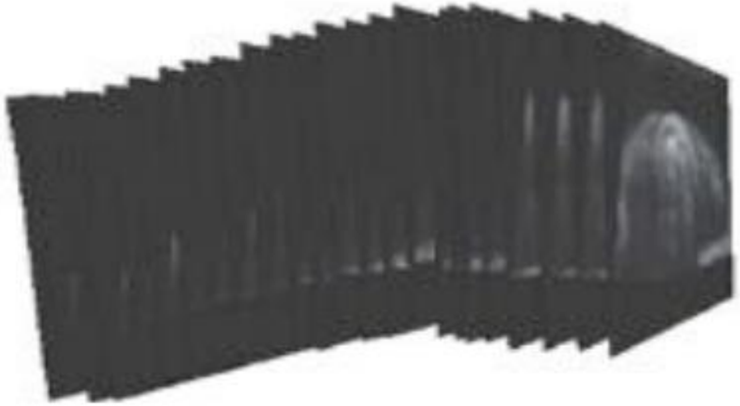


ultrasound transducers/probes

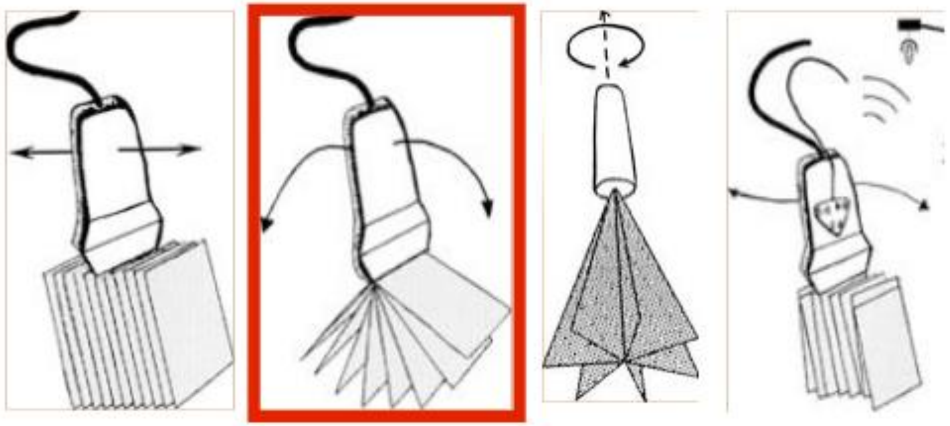
http://used-medicalequipmentblog.blogspot.com/

3D ultrasound

reconstruct 3D data from 2D slices

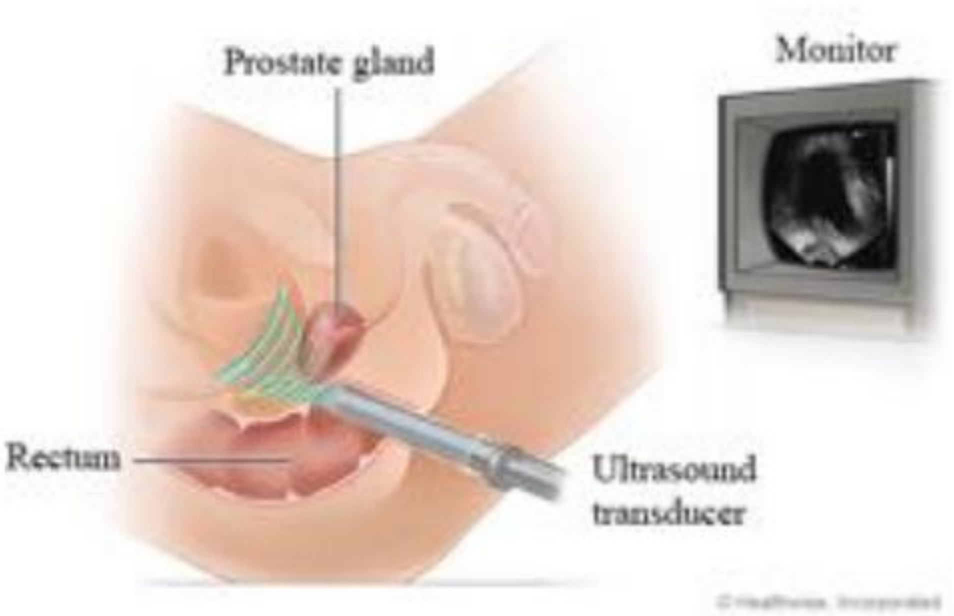


acquisition methods: linear, rotation, fan-like, hand



L. Joskowicz © 2011

transrectal ultrasound



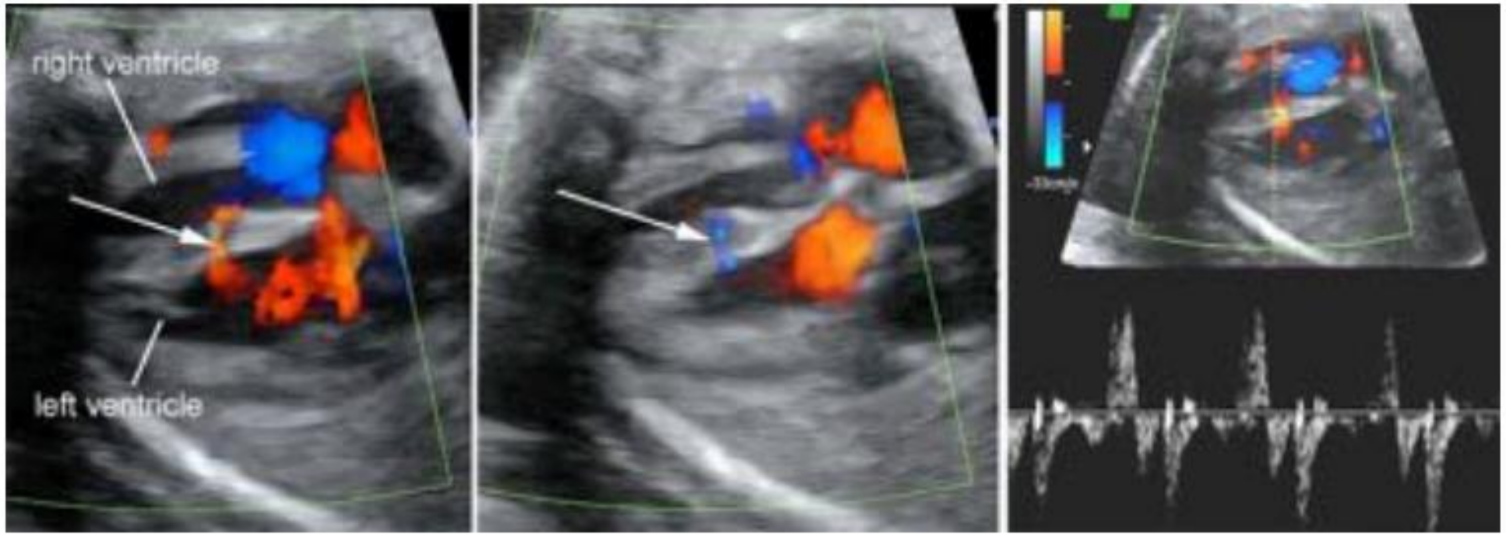
prostate brachytherapy

http://www2.cfpc.ca

https://myhealth.alberta.ca/

Doppler ultrasound

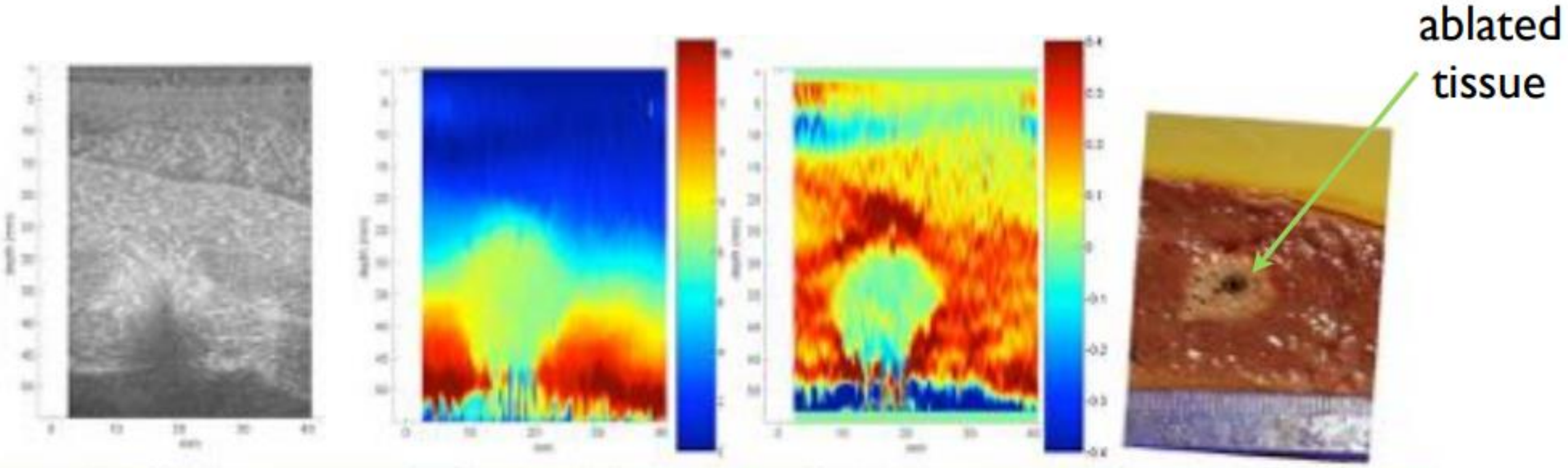
employs the Doppler effect to determine whether structures (typically blood) are moving towards or away from the probe, and their relative velocity



color and pulsed Doppler of blood shunting across a muscular ventricular septal defect (in the heart)

http://www.glowm.com/

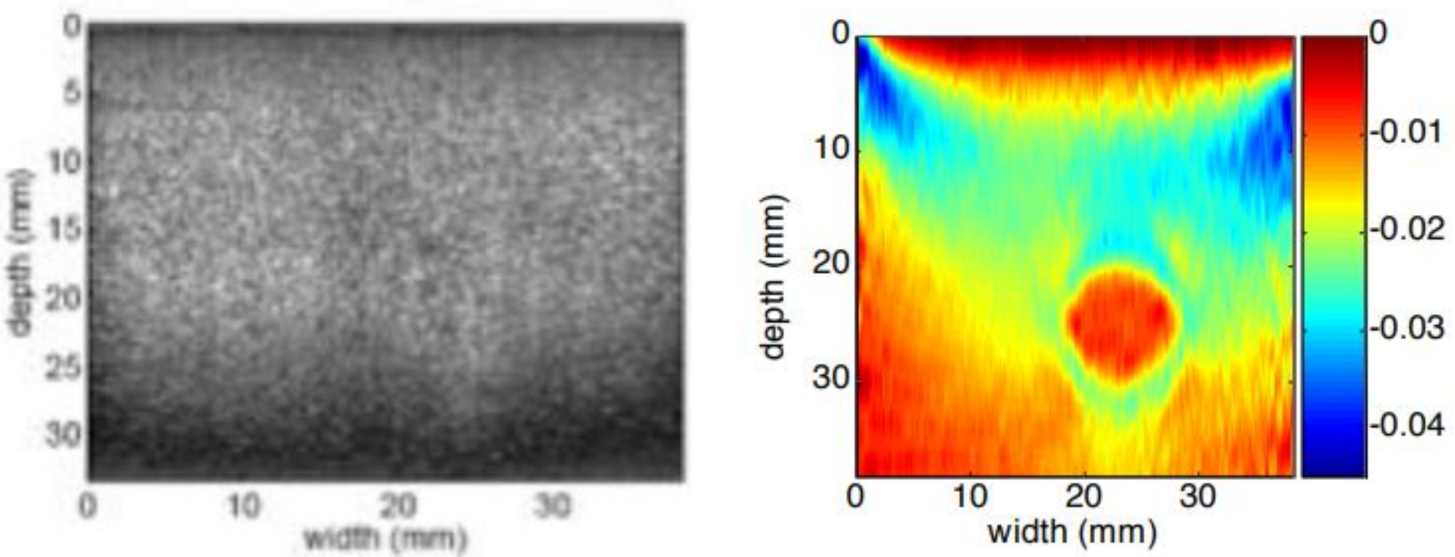
ultrasound elastography



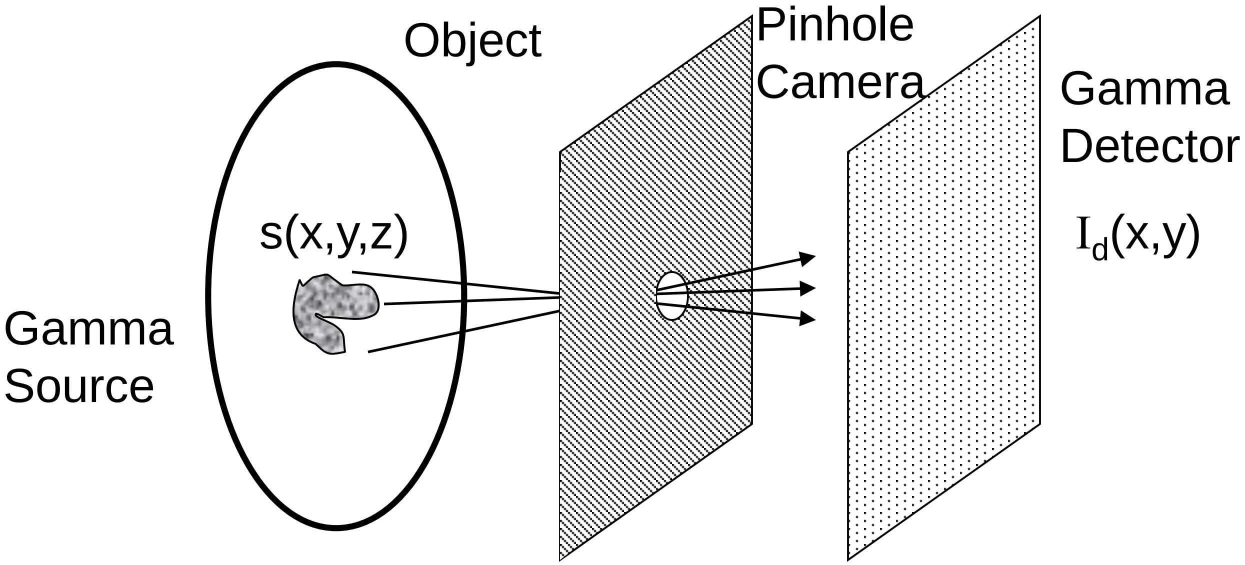
B-mode image | Displacement image | Strain image | Gross pathology image

Freehand palpation elastograms

Boctor, Rivaz, Fleming, Foroughi, Fichtinger, Hager (2008)



Nuclear Medicine (Scintigraphy)



- Detector records *emission* of gamma photons from radioisotopes introduced into the body

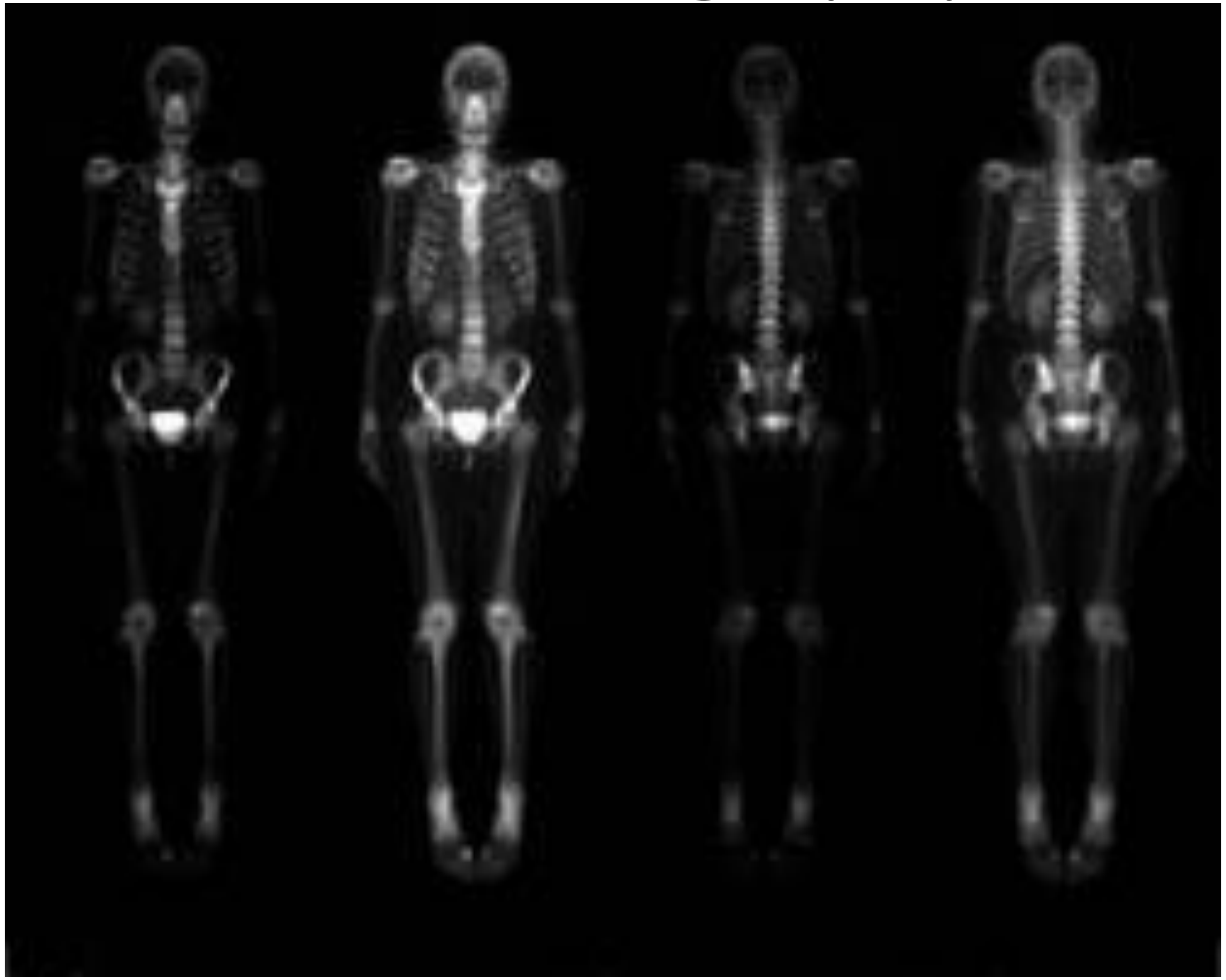
$$I_d(x,y) = \int s(x,y,z)d\vec{l}\,)$$

- The integral is a line-integral or a “projection” through obj
- Source s(x,y,z) usually represents a selective uptake of a radio-labeled pharmaceutical

Nuclear Medicine (Scintigraphy)

- Issue: Pinhole Size
  - Large pinhole – more photons, better SNR
  - Large pinhole – more blur, reduced resolution
- Issue: Half-life
  - Long half lives are easier to handle, but continue to irradiate patient after imaging is done
- Issue: Functional Specificity
  - Pharmaceuticals must be specific to function of interest
  - E.g. Thallium, Technicium
- Issue: No depth info
  - Nuclear Medicine Computed Tomography (SPECT, PET)

Nuclear Medicine (Scintigraphy)



Bone Scan

SPECT Scanner (3 heads)

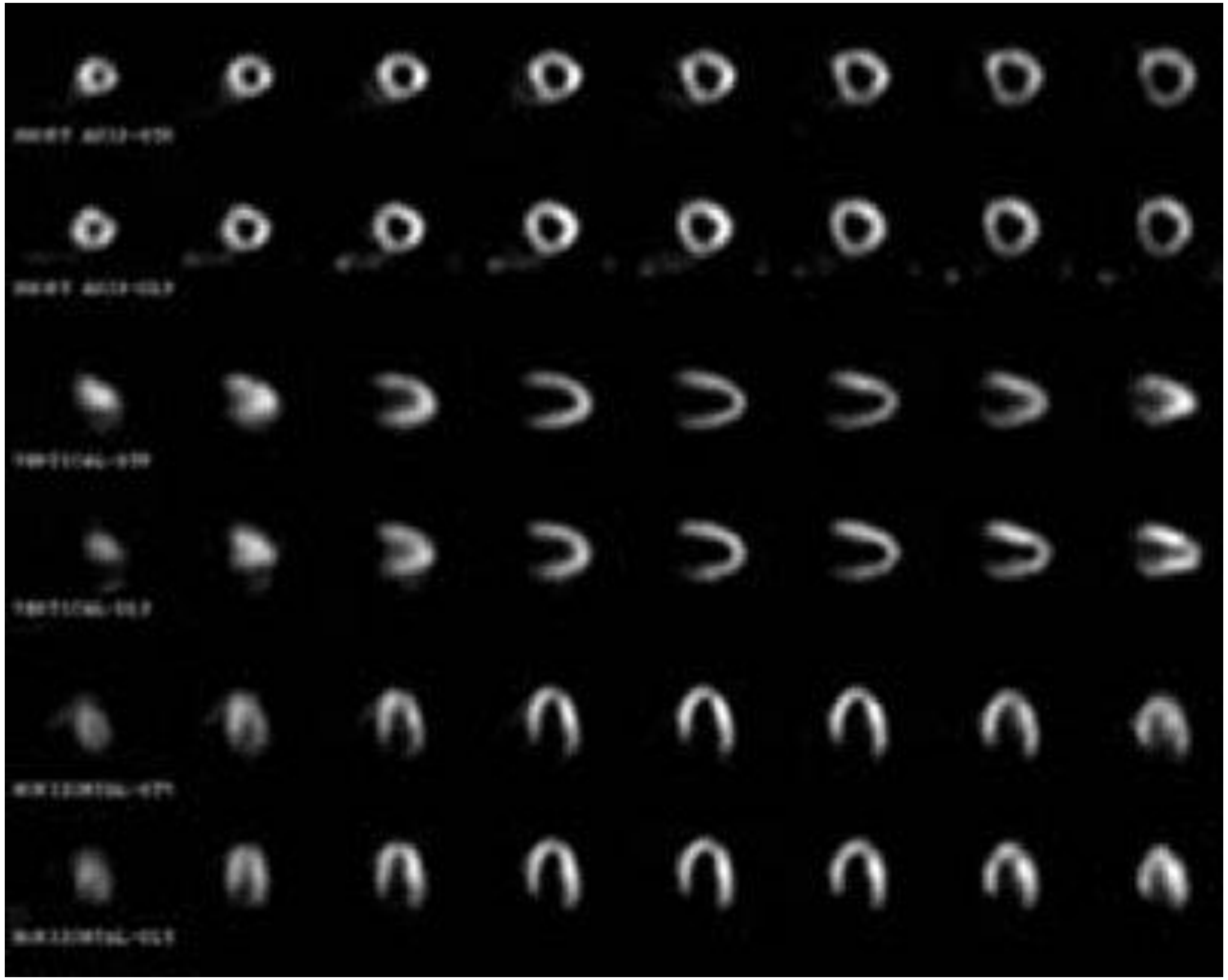
QuickTime™ and a
decompressor
are needed to see this picture.

Nuclear Medicine (SPECT)

Short Axis

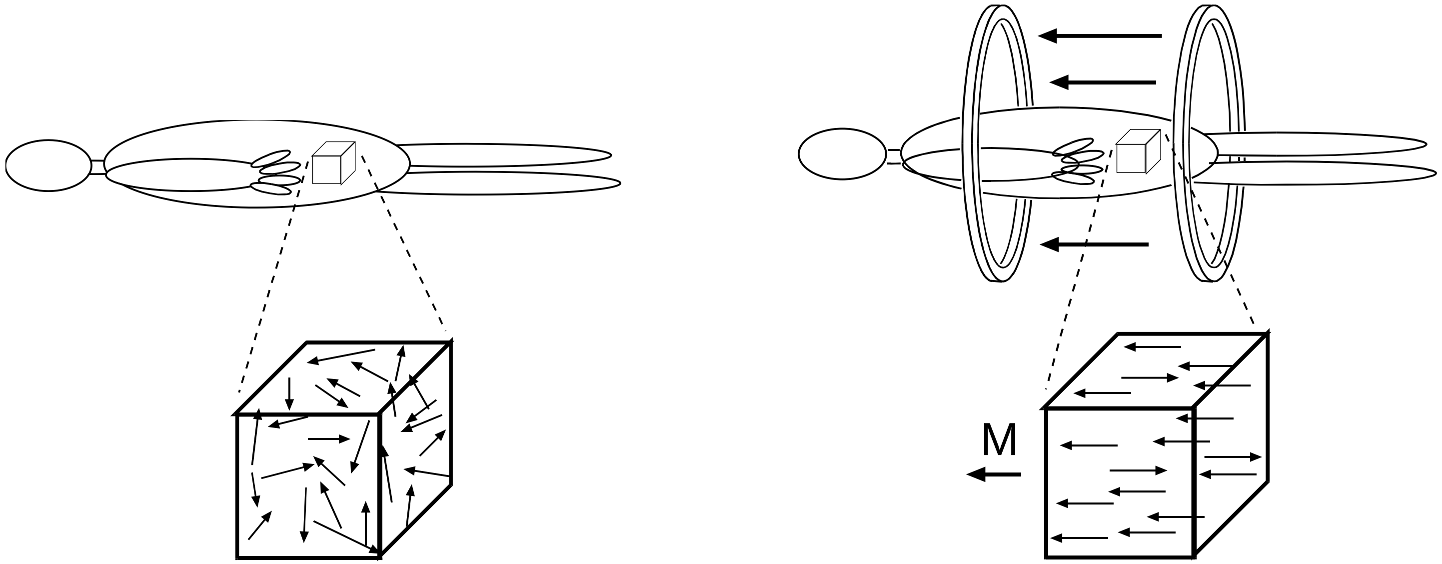
Long Axis

Long Axis



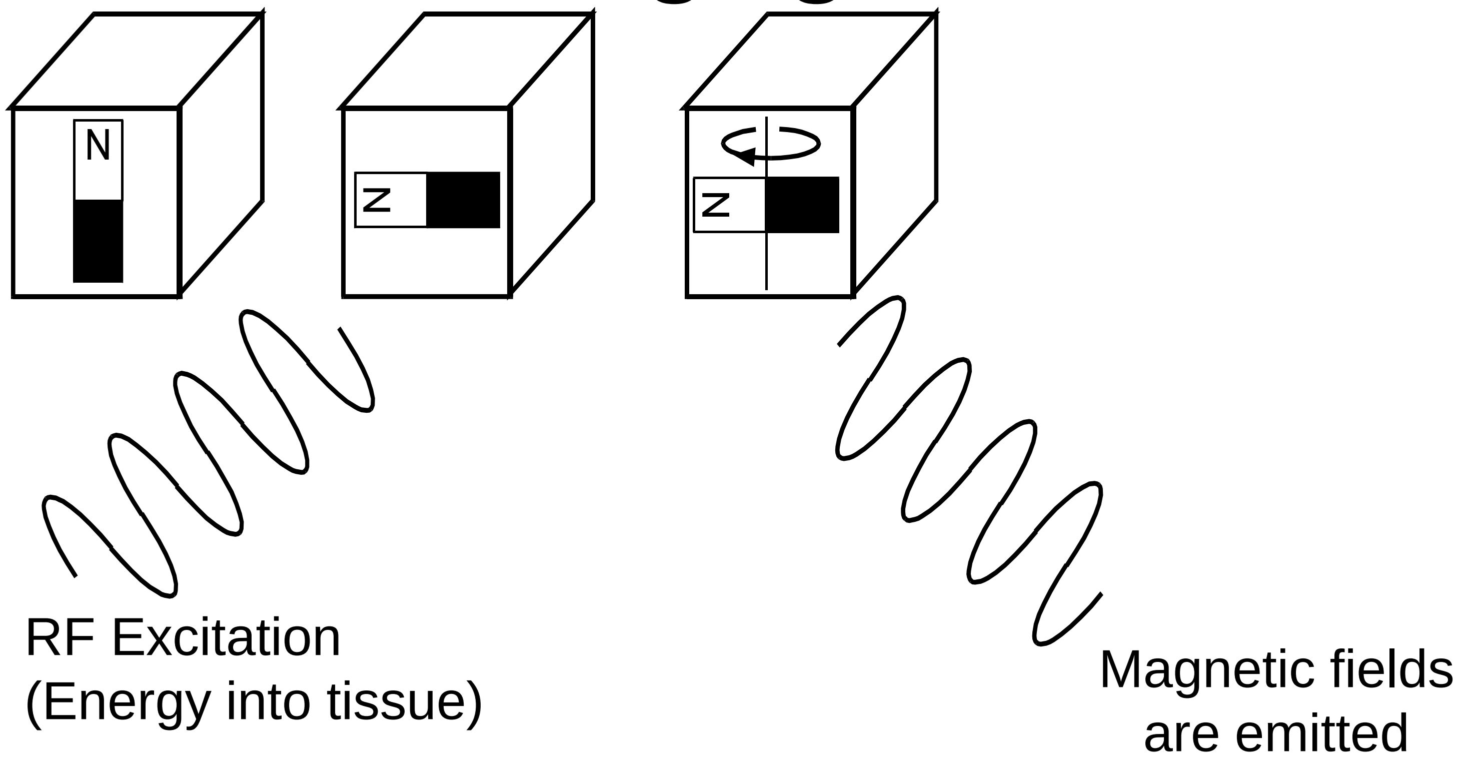
Cardiac (Left Ventricle) Perfusion Scan

Magnetic Resonance Imaging



- Atomic nuclei and hydrogen nuclei, ^{1}H, in particular, have a magnetic moment
  - Moments tend to become aligned to applied field
  - Creates magnetization, m(x,y,z) (a tissue property)
- MRI makes images of m(x,y,z)

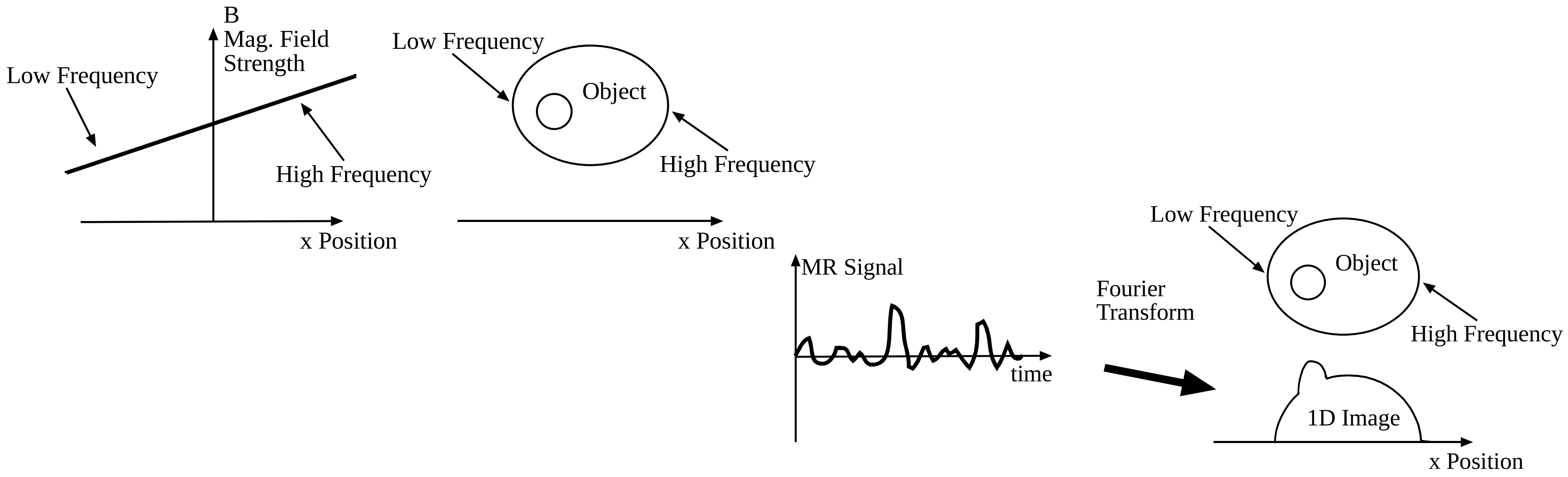
Magnetic Resonance Imaging



- The magnetization is excited into an observable state
- Magnetization emits energy at a resonant frequency:

$$\omega = \lambda B$$ (63 MHz at 1.5 T)

Magnetic Resonance Imaging

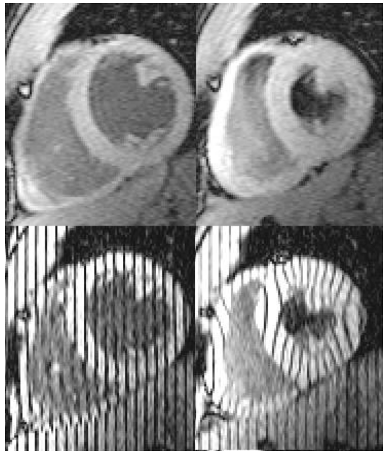


- Frequency is proportional to magnetic field
  - We can create a frequency vs. space variation:

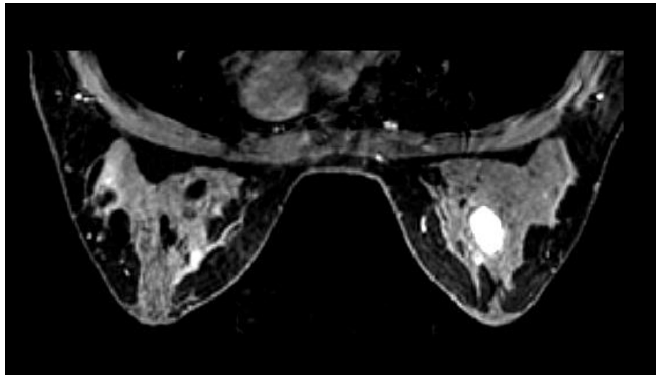
$$\omega(x,y,z) = \lambda\, B(x,y,z)$$

  - Use Fourier analysis to determine spatial location
- Interestingly, λ is much larger than resolution – not imaging EM direction, but using its frequency

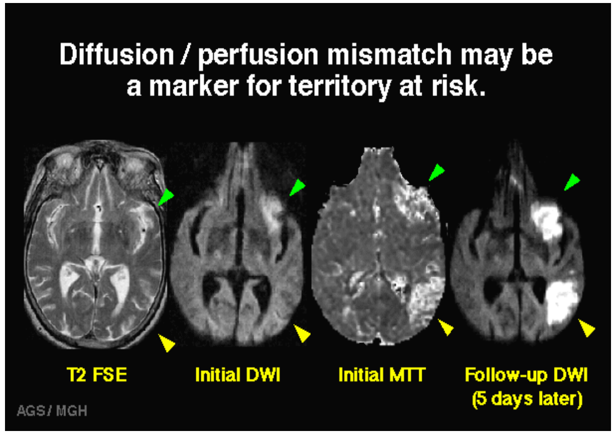
MRI



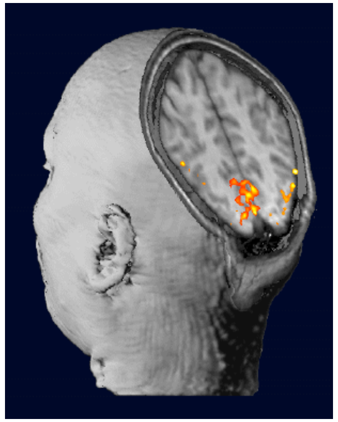
cardiac



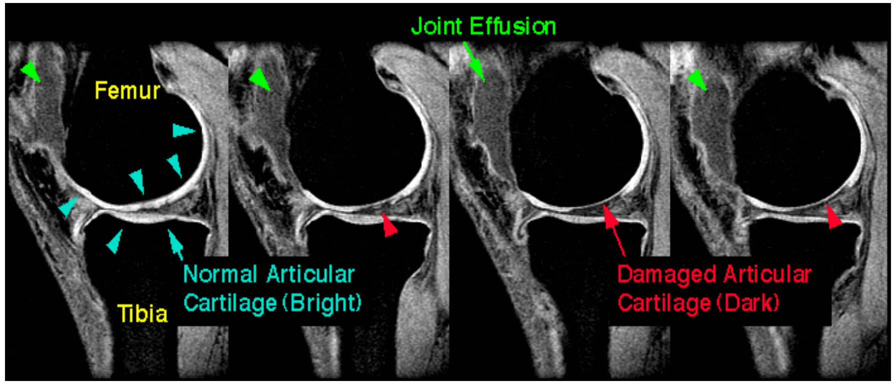
cancer



stroke



neuro function



joint

lung