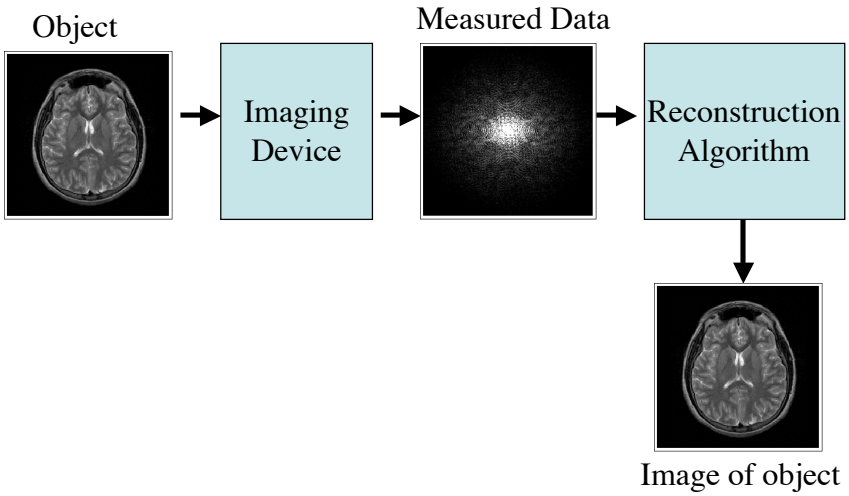
Bioengineering 280A
Principles of
Biomedical Imaging

Fall Quarter 2005
Lecture 1

Goals of the Course

1. Develop a firm understanding of the fundamentals of medical imaging, including an appreciation for the common principles underlying the various modalities.
2. Gain a basic understanding of the physical principles underlying the major modalities, including X-ray, computed tomography, MRI, and ultrasound.

Basic Imaging



Brief History of Medical Imaging

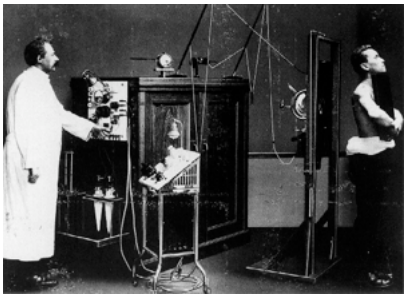
1895 - Roentgen discovers X-rays
1942 - Dussik demonstrates transmission ultrasound in the brain.
1946 - Bloch and Purcell discover nuclear magnetic resonance (NMR)
1972 - Hounsfield develops the first computed tomography scanner.
1973 - Lauterbur invents magnetic resonance imaging (MRI)
1974 - Ledley develops the first whole body CT scanner.

X-Rays

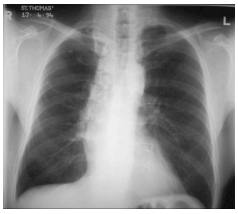
8 November 1895, Wilhelm Conrad Roentgen discovers X-rays. Receives first Nobel Prize in Physics in 1901.

22 November 1895 X-ray of Mrs. Roentegen's hand.

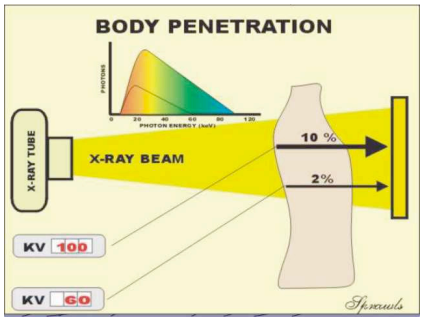
X-Ray

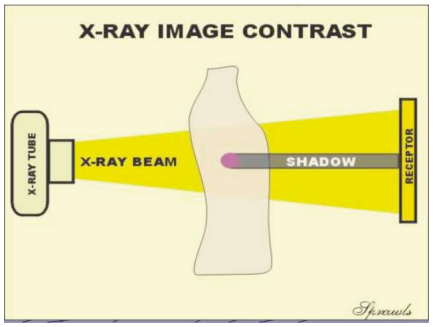


An early X-ray imaging system



X-Ray





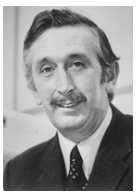
Computed Tomography

1917 Johann Radon establishes the mathematical framework for tomography, now called the Radon transform.

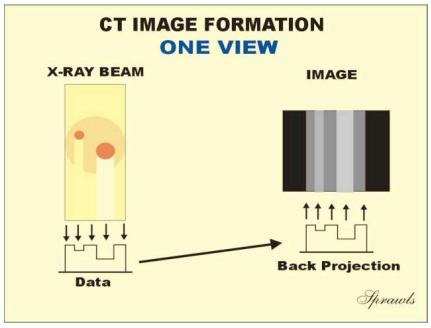
1963. Allan Cormack publishes mathematical analysis of tomographic image reconstruction. Is unaware of Radon's work.

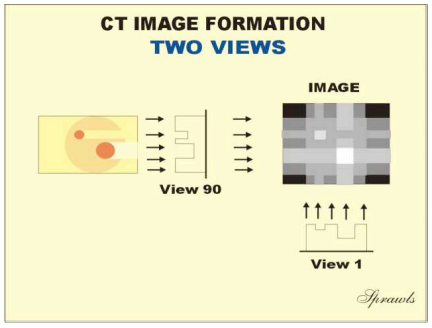
1972 Godfrey Hounsfield develops first CT system. Unaware of either Radon or Cormack's work, develops his own reconstruction method.

1979 Hounsfield and Cormack receive the Nobel Prize in Physiology or Medicine.



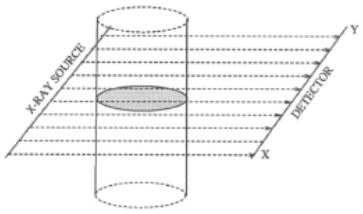
Computed Tomography

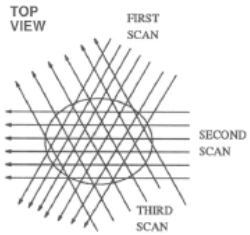


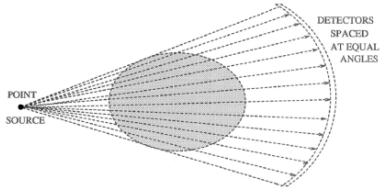


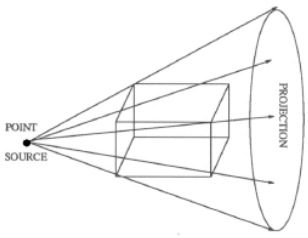
From http://www.sprawls.org/resources/CTIMG/classroom.htm

Computed Tomography



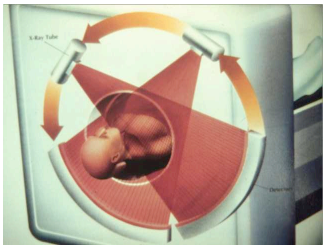


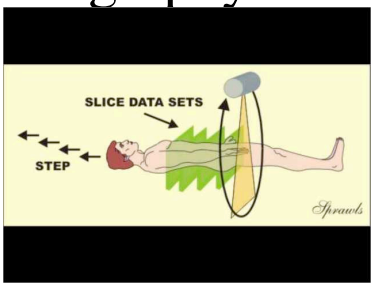


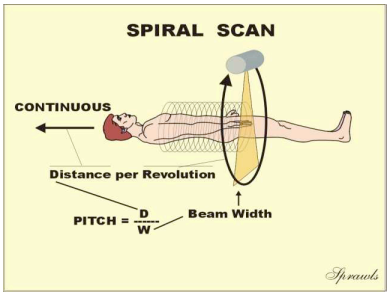


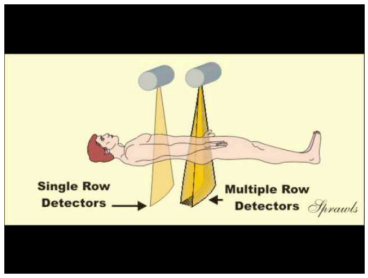
From http://www.sv.vt.edu/xray_ct/parallel/Parallel_CT.html

Computed Tomography









From http://www.sprawls.org/resources/CTIMG/classroom.htm

Computed Tomography

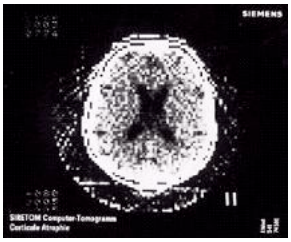
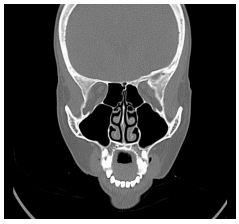
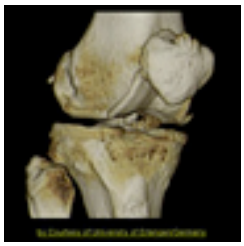


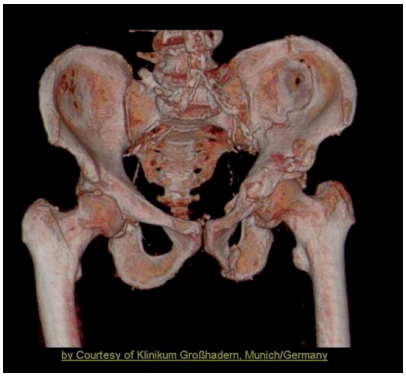
Image from Siemens Siretom CT scanner, circa 1975. 128x128 matrix.

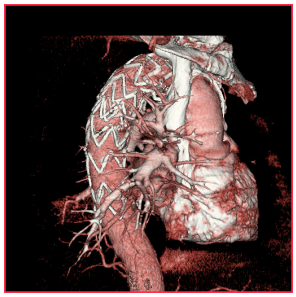
Modern CT image acquired with a Siemens scanner. 512x512 matrix.

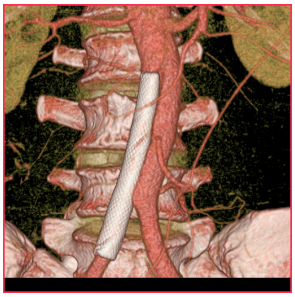
Computed Tomography

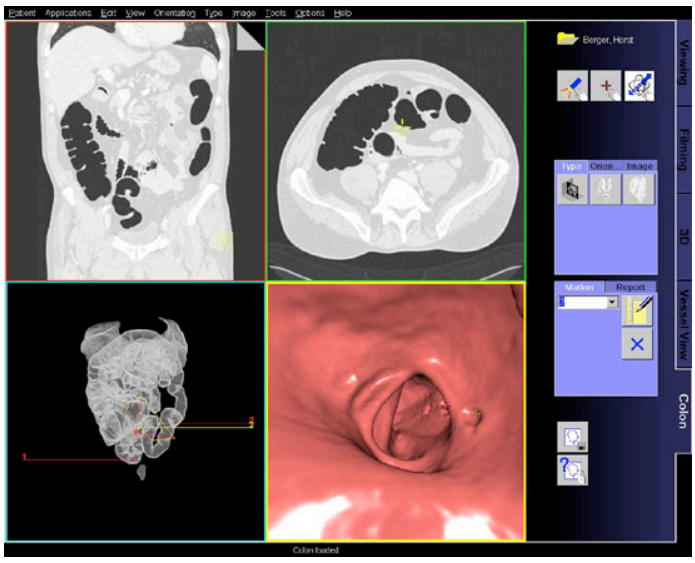








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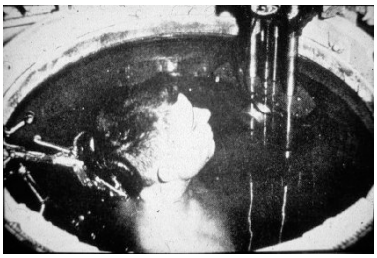
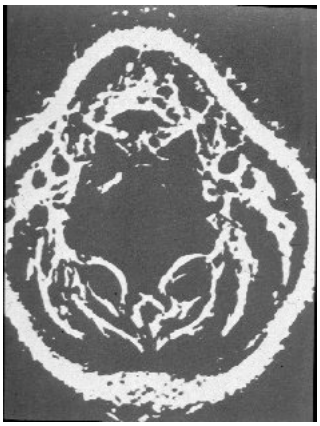
History of Ultrasound

1942 Dr.Karl Theodore Dussik
Transmission ultrasound investigation of the brain
First published work on medical ultrasonics.

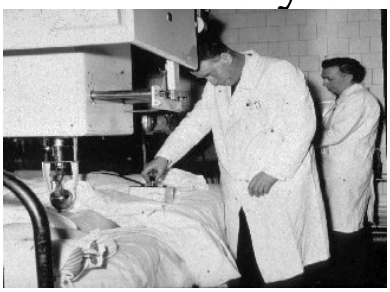
History of Ultrasound

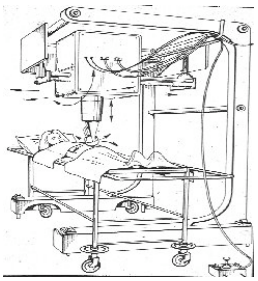


Holmes and Howry, 1955
Subject submerged in water tank to achieve good acoustic coupling.
Image of normal neck.

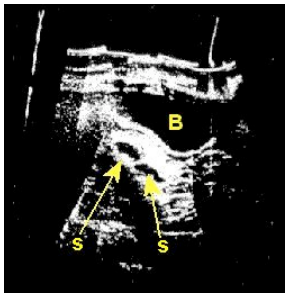


History of Ultrasound





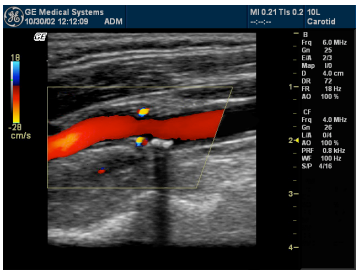
Automatic scanner, Glasgow, ca 1959. Image shows twin gestation sacs (s) and bladder (B).

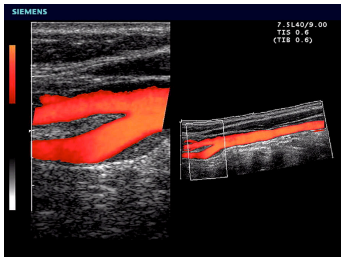


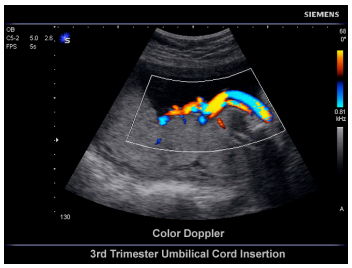
Ultrasound System

Acuson Sequoia

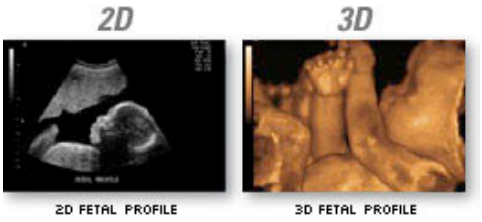
Doppler Ultrasound

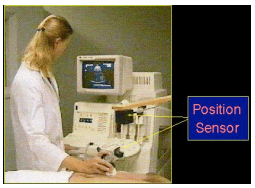






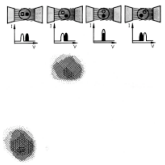
3D Ultrasound





History of MRI

1946: Felix Bloch (Stanford) and Edward Purcell (Harvard) demonstrate nuclear magnetic resonance (NMR)



1973: Paul Lauterbur (SUNY) published first MRI image in Nature.

History of MRI

Late 1970's: First human MRI images

Early 1980's: First commercial MRI systems

1993: functional MRI in humans demonstrated

Clinical MRI System

3 Tesla Magnet at UCSD

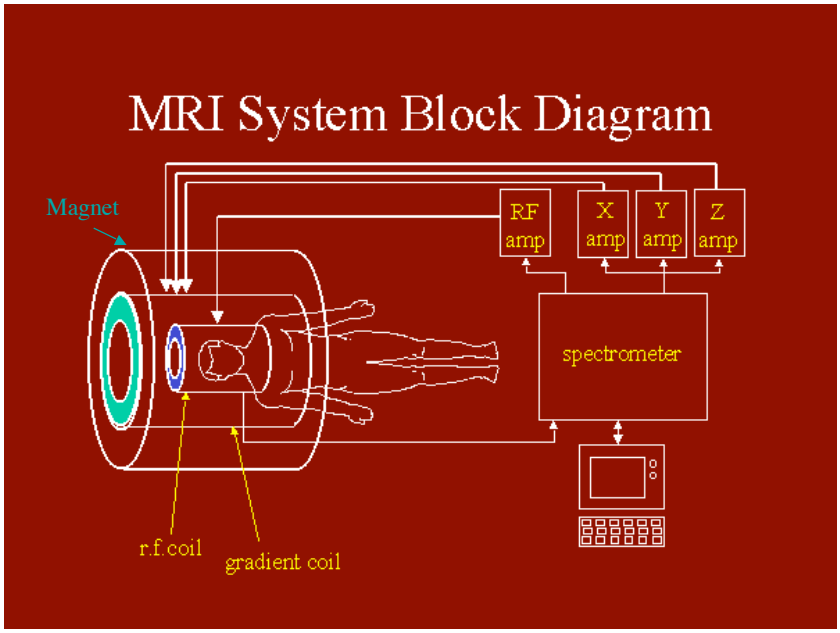
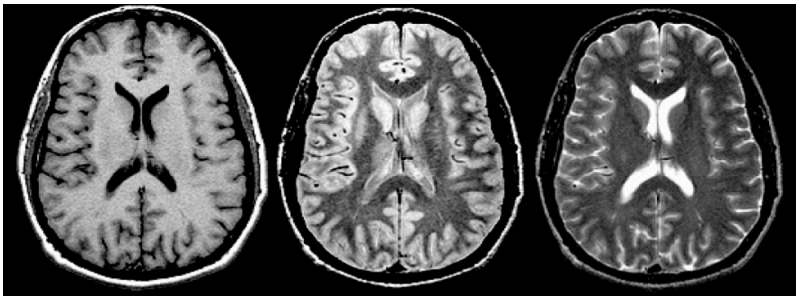


Image from http://www.fmrib.ox.ac.uk/~stuart/lectures/lecture1/

Image Contrast



T_1-weighted Density-weighted T_2-weighted

Image from Rick Buxton

MR Angiography

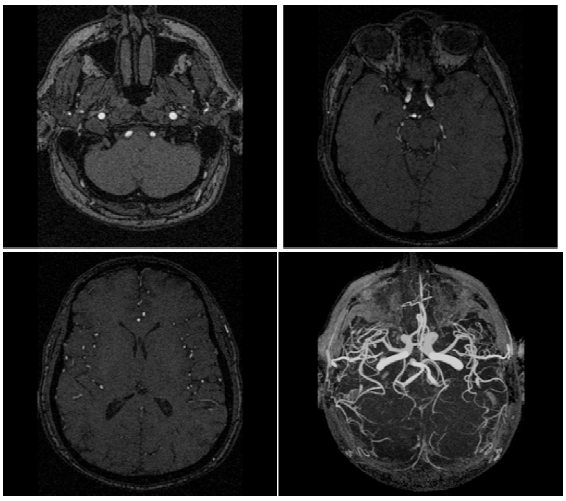


Image from R. Buxton

Perfusion Imaging with Contrast

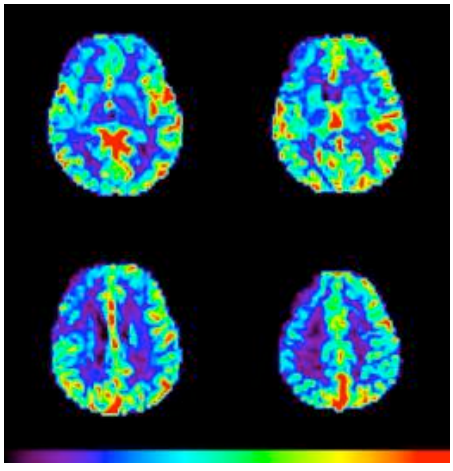


Image from http://irc.chmcc.org/PowerPoint_HTML/pMRI/moyamoya_files/frame.htm

Perfusion Imaging with ASL

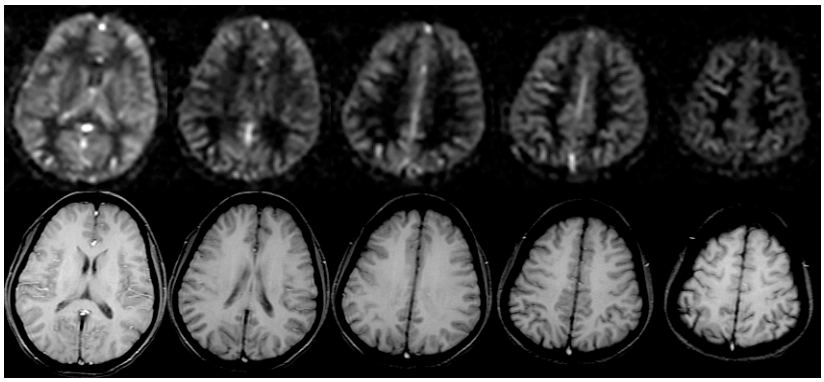


Image from E.C. Wong

Cardiac Imaging

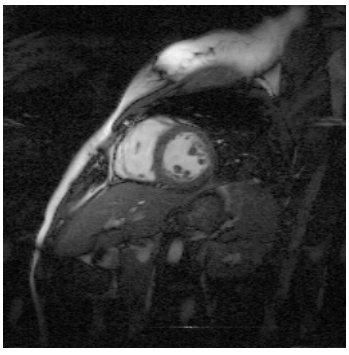


Image fromhttp://www.bidmc.harvard.edu/cmr/smash/smash.html

Cardiac Tagging

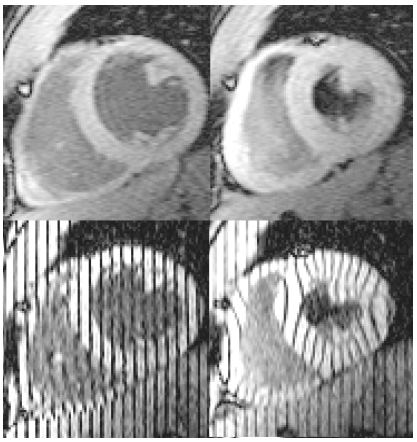


Image from http://www.mri.jhu.edu/~emcveigh/LabIntro/tagging.html

Hyperpolarized Helium

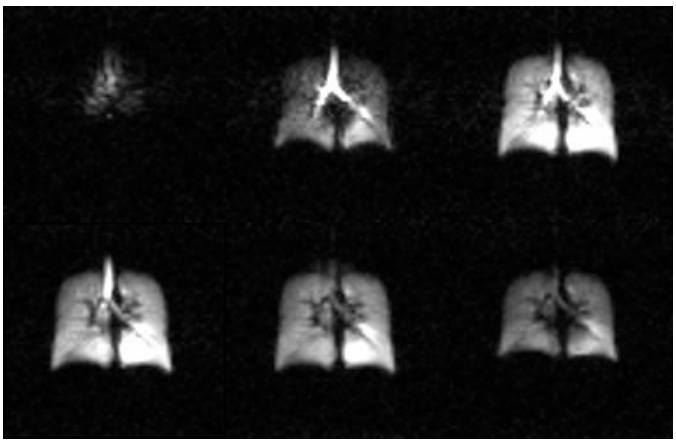


Image from http://www.physics.utah.edu/~saam/#RES

Functional MRI

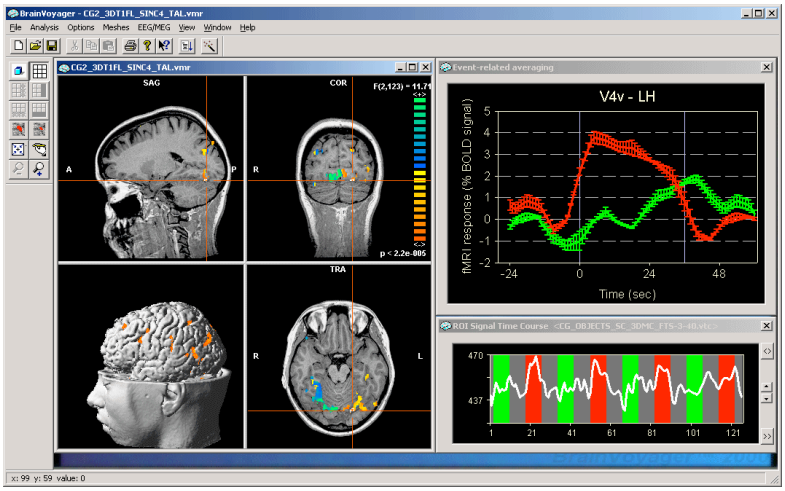


Image from http://www.brainvoyager.de/

Diffusion Tensor Imaging

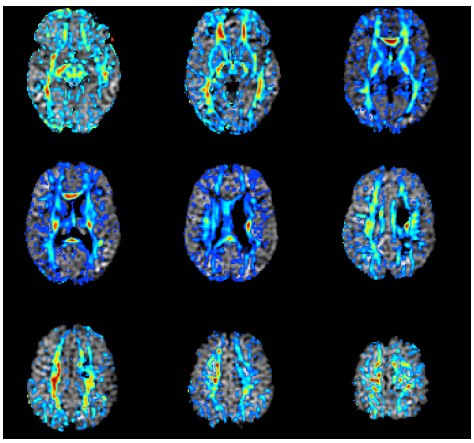


Image from L. Frank

MR Microscopy

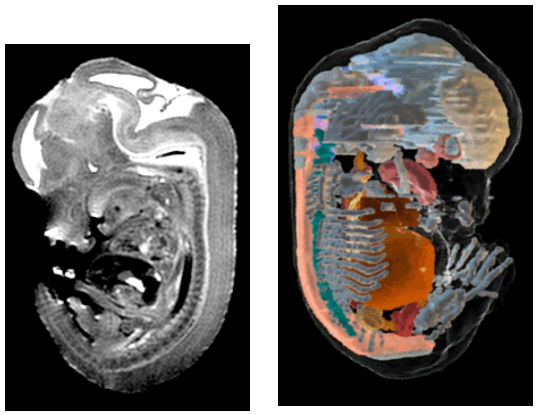


Image from http://mouseatlas.caltech.edu/

MR Spectroscopy

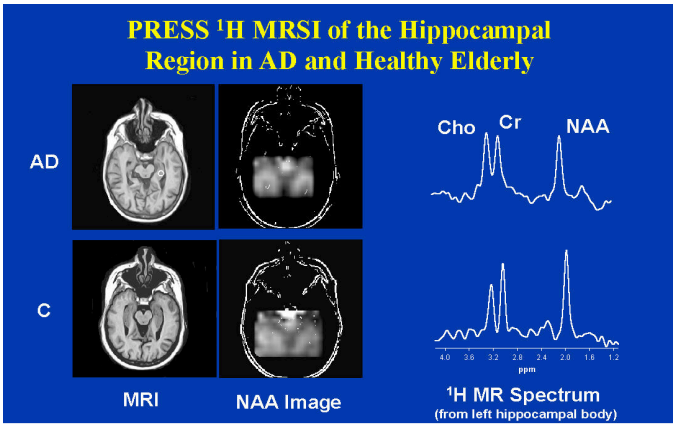
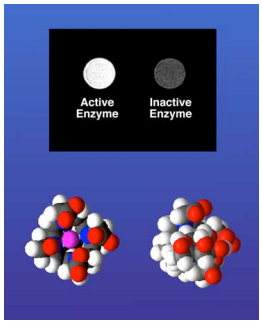


Image from http://www.sf.med.va.gov/mrs/ad/result.htm

Molecular Imaging



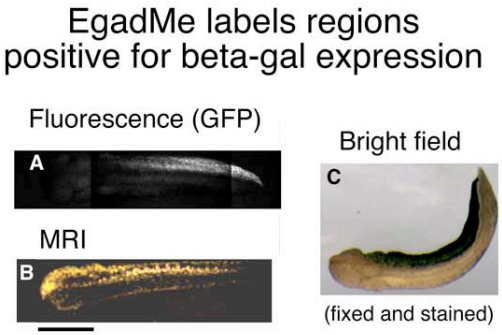
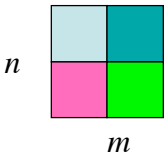


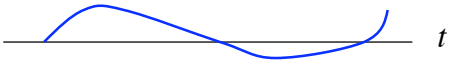
Image from http://quad.bic.caltech.edu/~meadegroup/smart%20contrast%20agents.htm

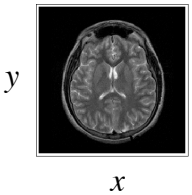
Signals and Images

Discrete-time/space signal/image: continuous valued function with a discrete time/space index, denoted as *s[n]* for 1D, *s[m,n]* for 2D , etc.



Continuous-time/space signal/image: continuous valued function with a continuous time/space index, denoted as *s(t)* or *s(x)* for 1D, *s(x,y)* for 2D, etc.





2D Image

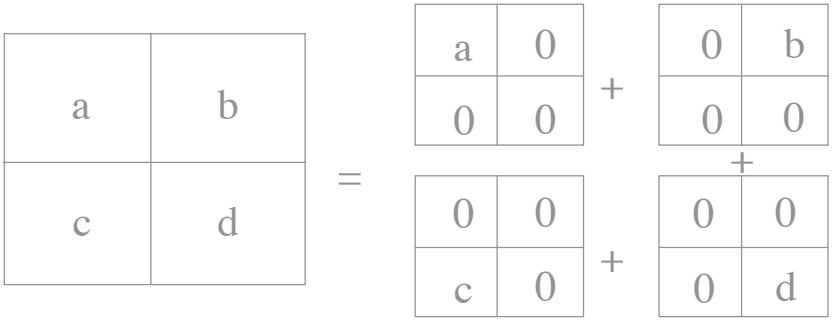
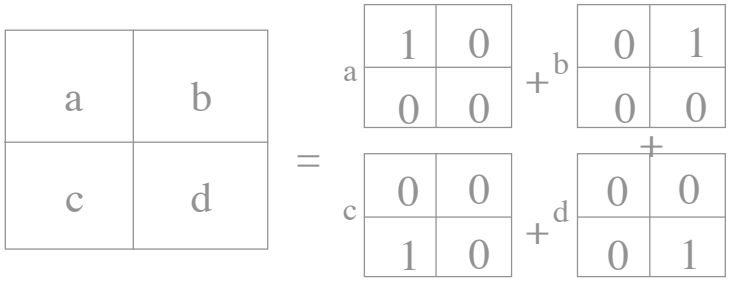


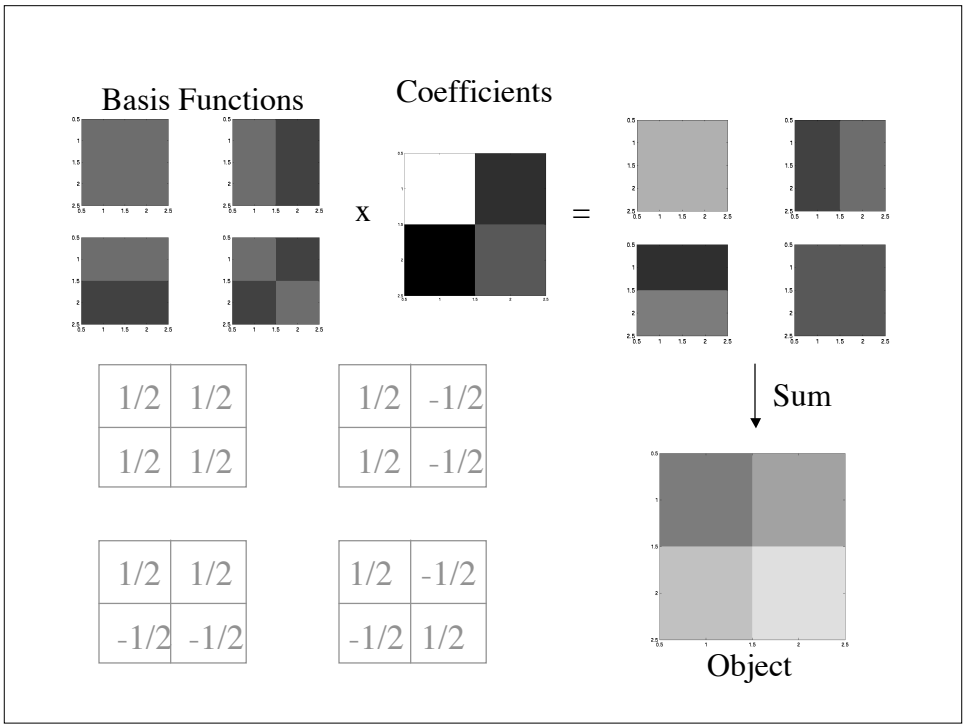
Image Decomposition

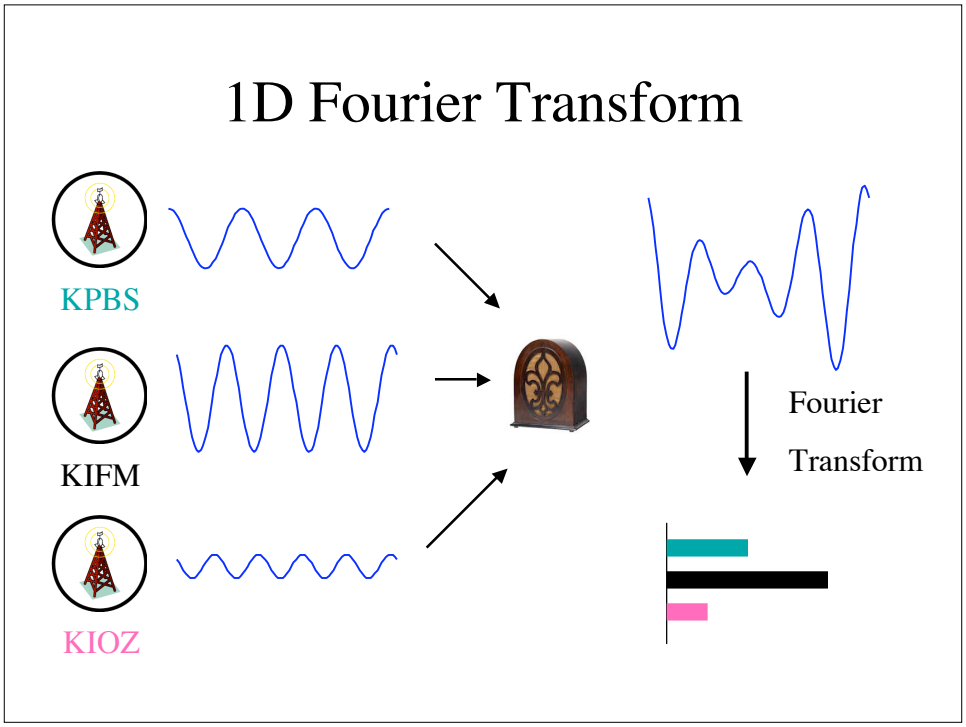


$$g[m,n] = a\delta[m,n] + b\delta[m,n-1] + c\delta[m-1,n] + d\delta[m-1,n-1]$$

$$= \sum_{k=0}^{1}\sum_{l=0}^{1} g[k,l]\delta[m-k,n-l]$$

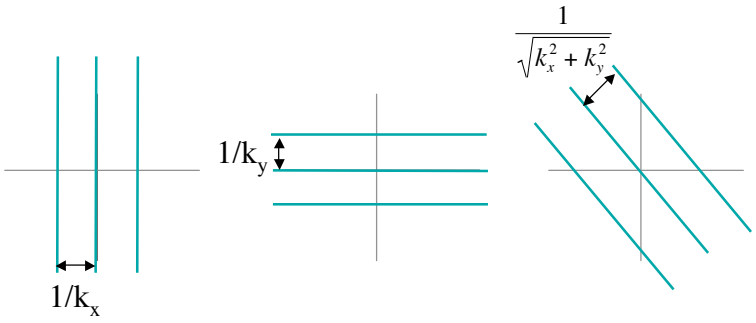
$$= \sum_{k=0}^{1}\sum_{l=0}^{1} c_{k,l} b_{k,l}[m,n]$$


Basis Functions
Coefficients
x
=
1/2 1/2
1/2 1/2
1/2 -1/2
1/2 -1/2
1/2 1/2
-1/2 -1/2
1/2 -1/2
-1/2 1/2
Sum
Object


1D Fourier Transform
KPBS
KIFM
KIOZ
Fourier
Transform

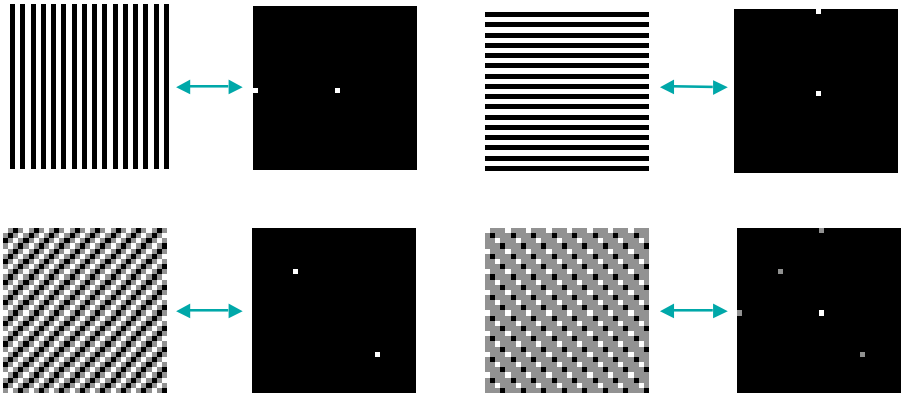
2D Plane Waves

$$e^{j2\pi(k_x x + k_y y)} = \cos\left(2\pi(k_x x + k_y y)\right) + j\sin\left(2\pi(k_x x + k_y y)\right)$$

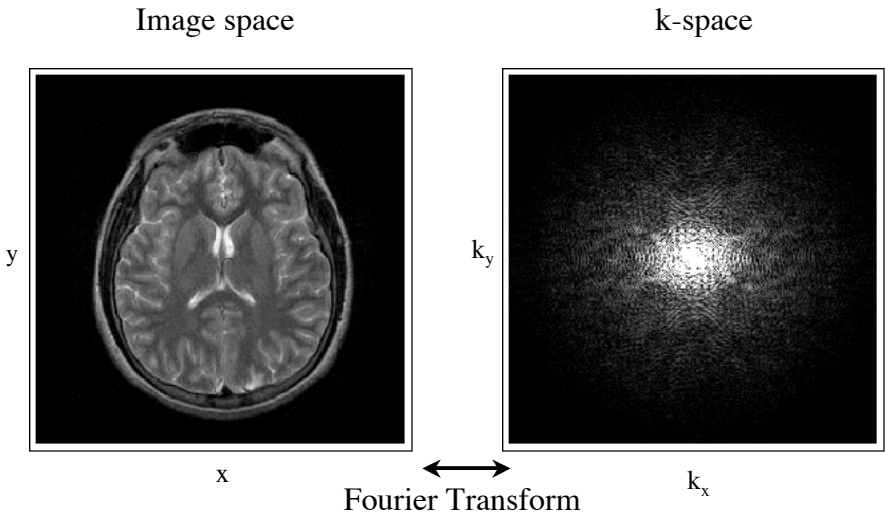


$\cos(2\pi k_x x)$ $\cos(2\pi k_y y)$ $\cos(2\pi k_x x + 2\pi k_y y)$

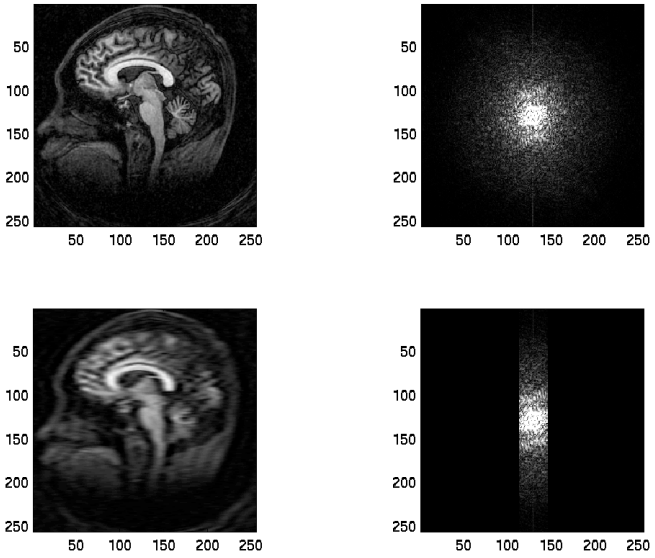
2D Fourier Transform



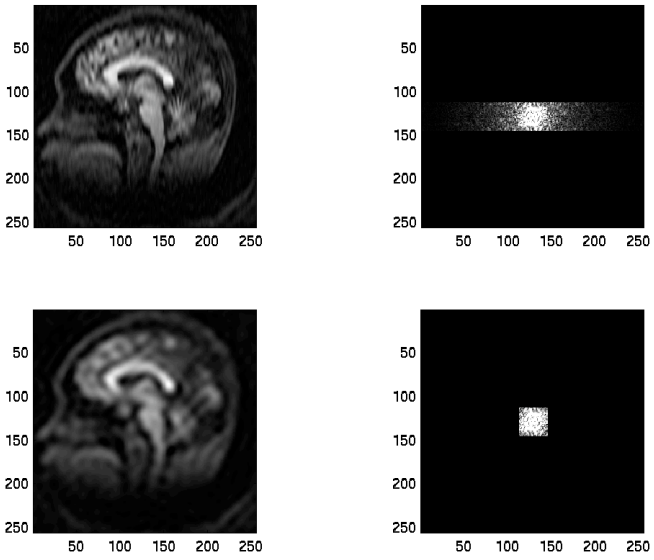
k-space



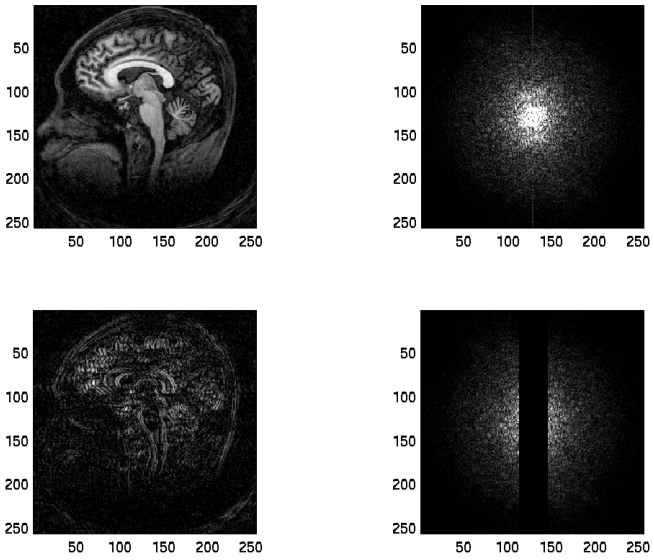
Examples



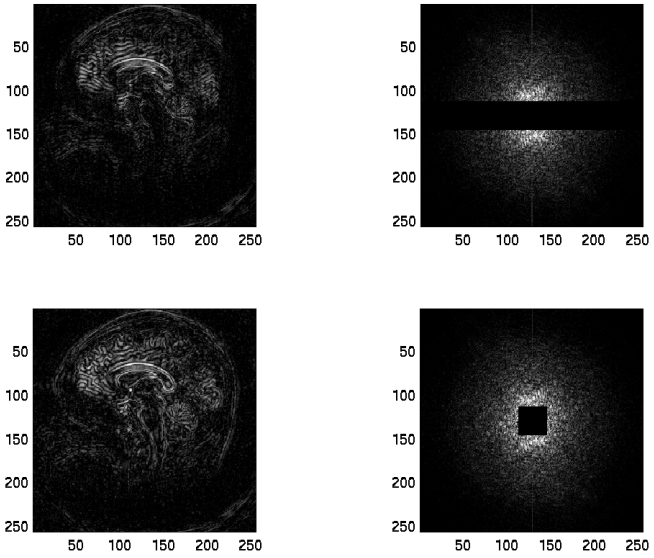
Examples



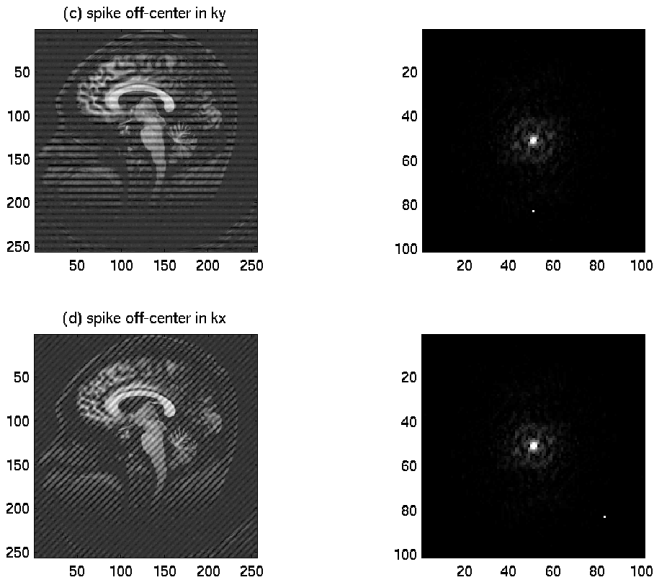
Examples



Examples



Examples



2D Fourier Transform

Fourier Transform

$$G(k_x,k_y) = F\left[g(x,y)\right] = \left\langle e^{j2\pi\left(k_x x + k_y y\right)}, g \right\rangle = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} g(x,y)e^{-j2\pi\left(k_x x + k_y y\right)}dxdy$$

Inverse Fourier Transform

$$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(k_x,k_y)e^{j2\pi\left(k_x x + k_y y\right)}dk_x dk_y$$

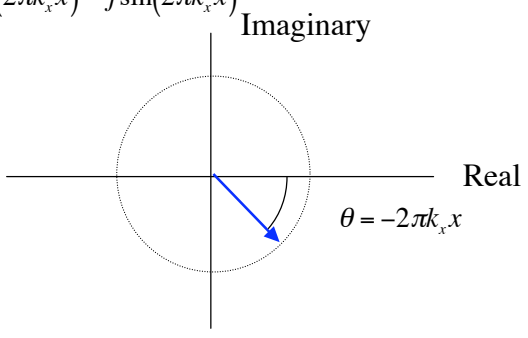
Phasor Diagram

Recall that a complex number has the form

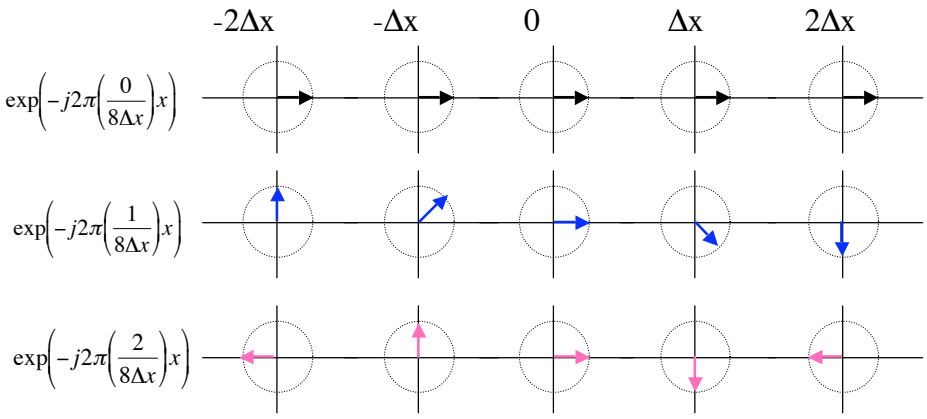
$$z = a + jb = \left|z\right|\exp(j\theta) = \left|z\right|\left(\cos\theta + j\sin\theta\right)$$

where $\left|z\right| = \sqrt{a^2 + b^2}$ and $\theta = \tan^{-1}\left(b/a\right)$

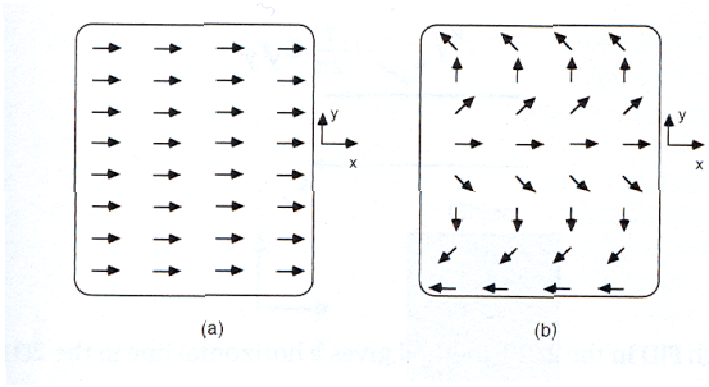
$$e^{-j2\pi k_x x} = \cos\left(2\pi k_x x\right) - j\sin\left(2\pi k_x x\right)$$



Interpretation



Interpretation



$k_x=0; k_y=0$ $k_x=0; k_y\neq0$

Fig 3.12 from Nishimura