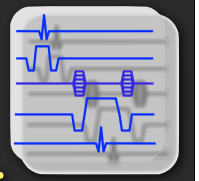


Principles of MRI

EE225E / BIO265

Instructor: Miki Lustig
UC Berkeley, EECS

Today....

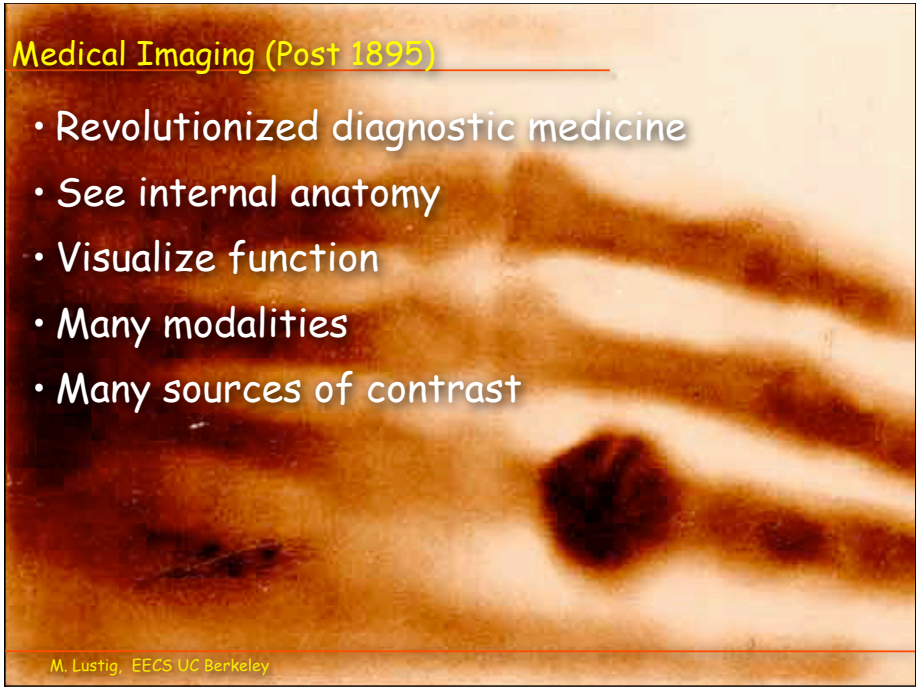
- Administration
  - http://www-inst.eecs.berkeley.edu/~ee225e/sp14/
- Intro to Medical Imaging and MRI

Medical Imaging (Before 1895)

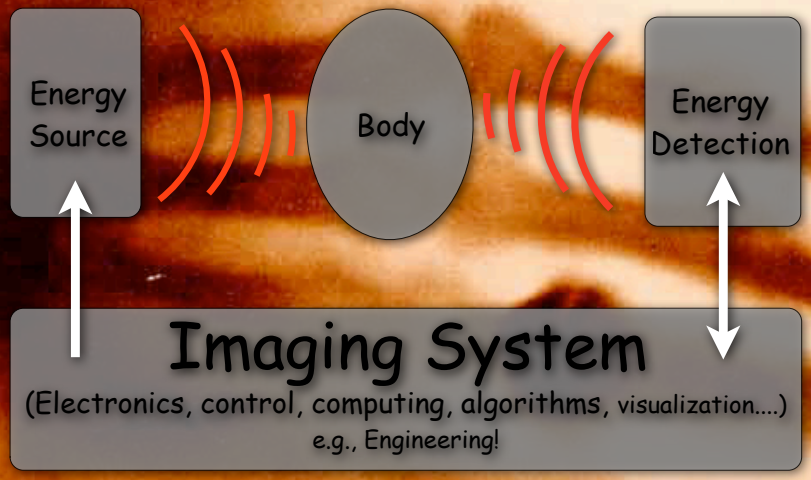
- Only way to see is to cut!

Medical Imaging (Post 1895)

- Revolutionized diagnostic medicine
- See internal anatomy
- Visualize function
- Many modalities
- Many sources of contrast



Basic Concept



Medical Imaging System Requirements

- Diagnostic contrast
- Sensitivity
- Specificity
- Function
- High Spatial-resolution
- High Temporal-resolution
- Safe
- Fast

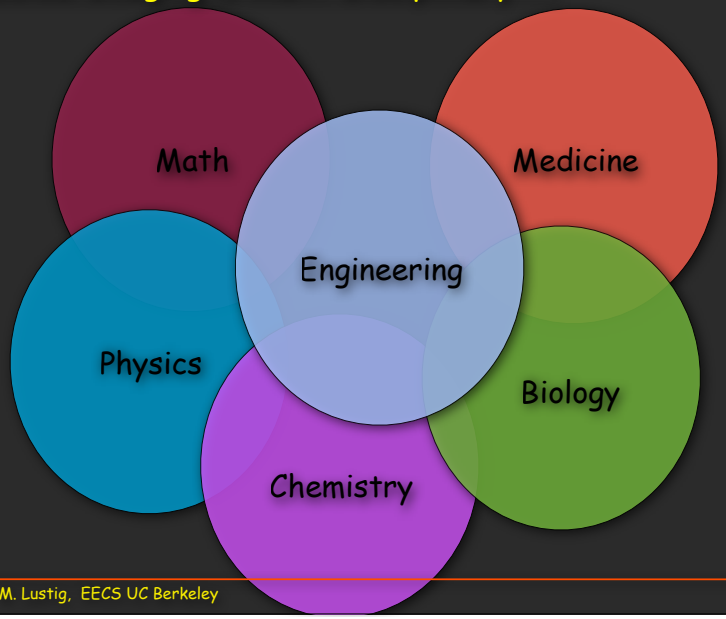
- Inexpensive
- Easy to use

- Can't satisfy all
- Many modalities
- Often several used to make diagnosis

Common Imaging Modalities

- Projection X-Ray (Electromagnetic)
- Computed Tomography (Electromagnetic)
- UltraSound (Sound waves)
- Positron Emission Tomography (Nuclear)
- Single-Photon Emission Tomography (Nuclear)
- Magnetic Resonance Imaging (magnetic)

Medical Imaging is Multi-Disciplinary



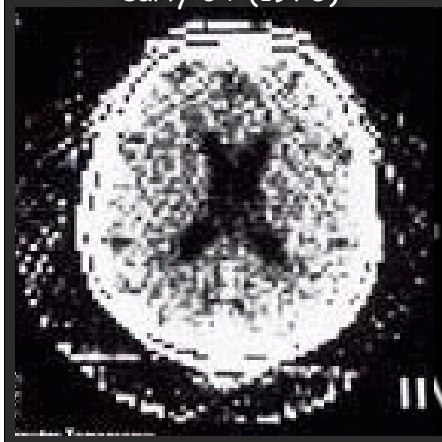
Engineering Advances

1st x-ray (1895)

x-ray today

Engineering Advances

early CT (1975)

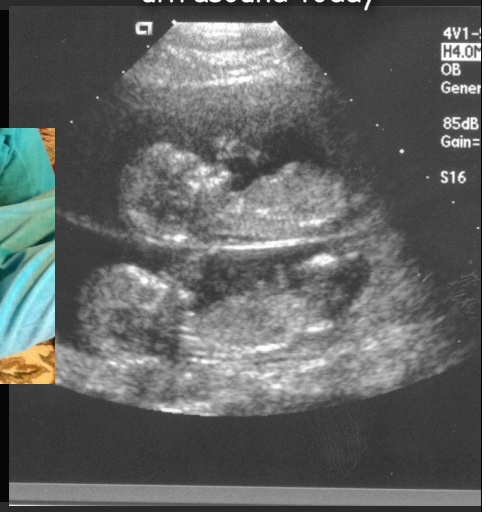


CT today

Engineering Advances

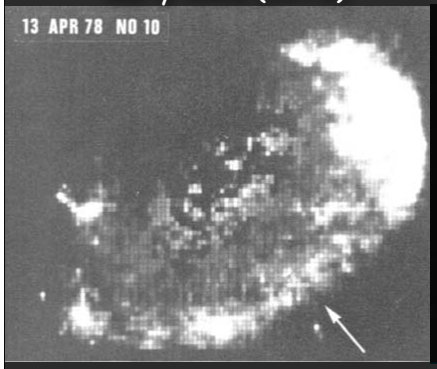
early ultrasound (1959)

ultrasound today

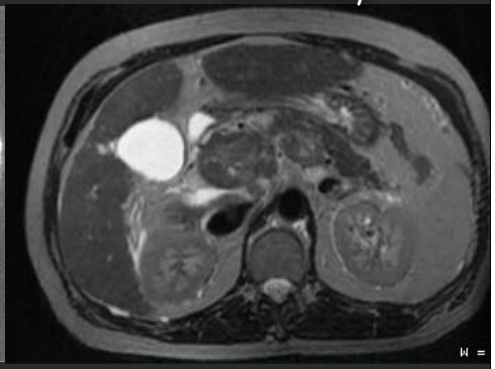


Engineering Advances

early MRI (1978)

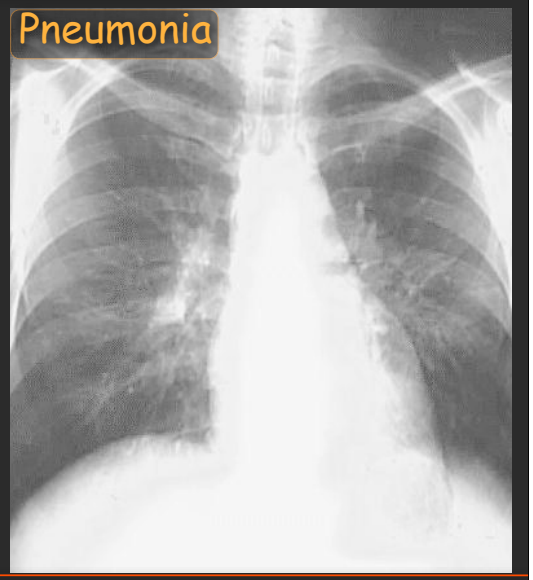


MRI today



Projection X-Ray

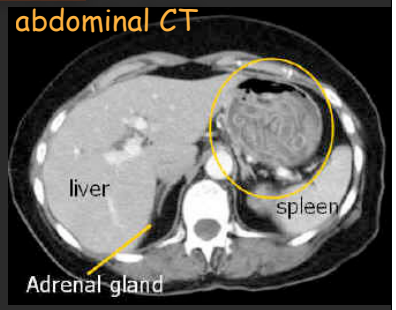
- Projection Format
- Small Dose
- Fast
- Inexpensive



Projection

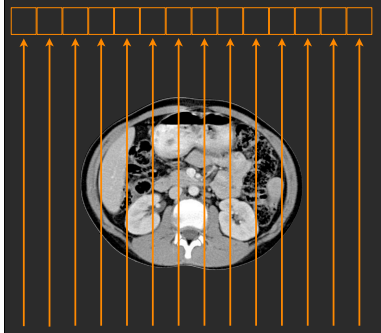
Computed Tomography (CT)

- Tomographic
- Fast
- High-Res
- Moderate dose
- ~1M$



Many Projections

Computed Tomography

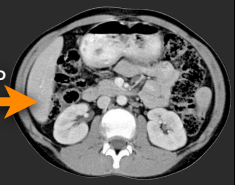


x-ray source

Sinogram

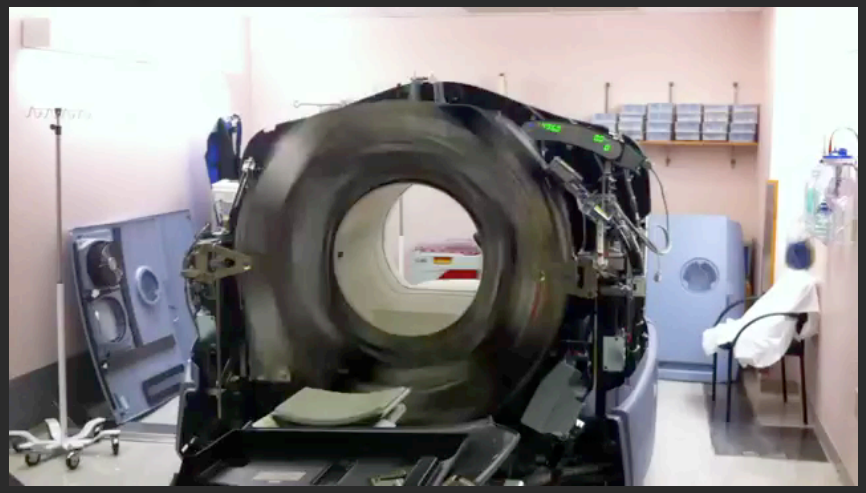
FBP

cross-section



Computed Tomography

- Gantry rotation



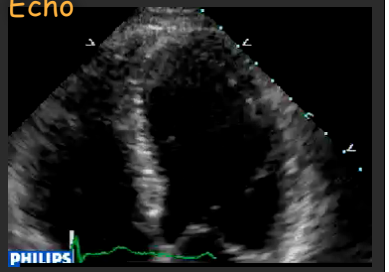
http://www.youtube.com/watch?v=4gklQHM19aY&feature=related

Ultrasound

- Real-time
- Inexpensive
- No-radiation
- Many applications

- Low contrast and penetration

Echo



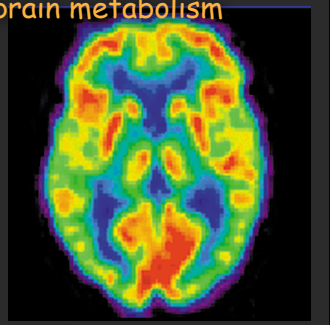
Anatomy vs Function

Nuclear Medicine

- Specific metabolic information (function)
- Low-res
- High dose
- 1-2M$

- SPECT: Gamma radiation
- PET: Positron-> Gamma

brain metabolism



PET

Magnetic Resonance Imaging (MRI)

- NMR: Nuclear Magnetic Resonance
- MRI : Magnetic Resonance Imaging
  - please don't say MRI imaging!

- MRI is VERY VERY VERY different from CT!
- Cost: 1M-3M, mainly because of the Magnet

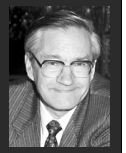
History

- 1946 - Felix Bloch (Stanford) Edward Purcell (Harvard) independently discovered NMR. Nobel Prize (Physics) in 1952.

- 1971 - Raymond Damadian showed changes in MR parameters (T1 and T2) in cancer. People started thinking about medical NMR applications.
- 1972 - Invention of CT by Hounsfield and Cormack. Nobel Prize (Medicine) in 1979.

- 1973 - Lauterbur described MRI in a similar way to CT

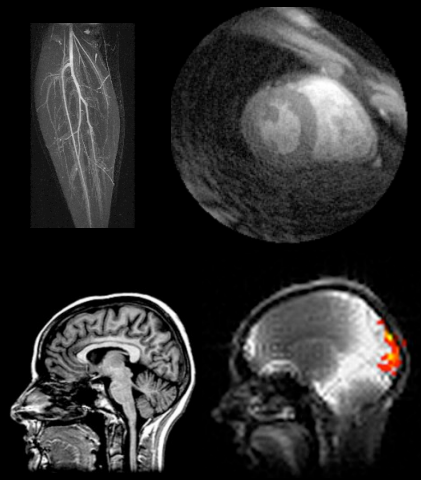
History



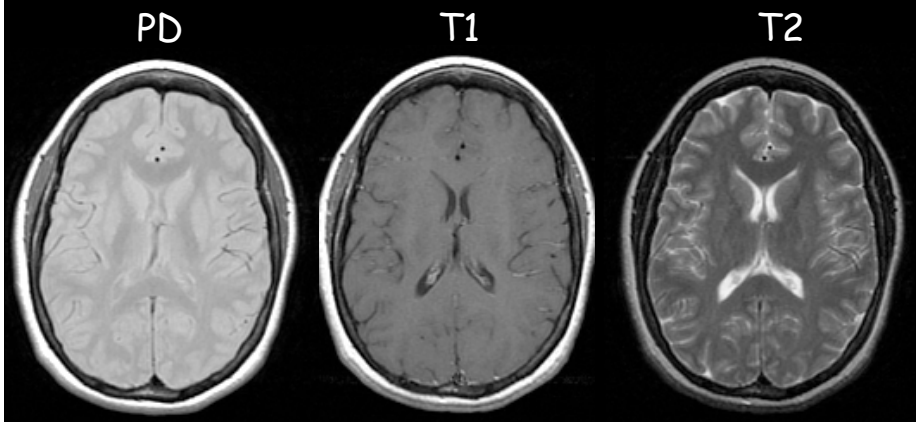
- 1975 - Ernst proposed key concepts. Nobel prize (Chemistry) 1991.
- 1970's - Mansfield contributes key ideas (slice selection)
- 1982 - Widespread clinical MRI begins.
- 2003 - Lauterbur/Mansfield receive Nobel prize (Medicine) for their contributions.

MR Imaging

- Magnetic resonance imaging has revolutionized medicine
- Directly visualizes soft tissues in 3D
- Wide range of contrast mechanisms
  - Tissue character (solid, soft, liquid, fat, ...)
  - Diffusion
  - Temperature
  - Flow, velocity
  - Oxygen Saturation



Neuro Examples

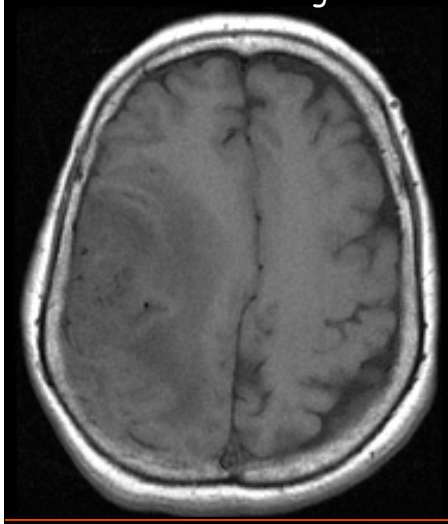


Many different contrasts available

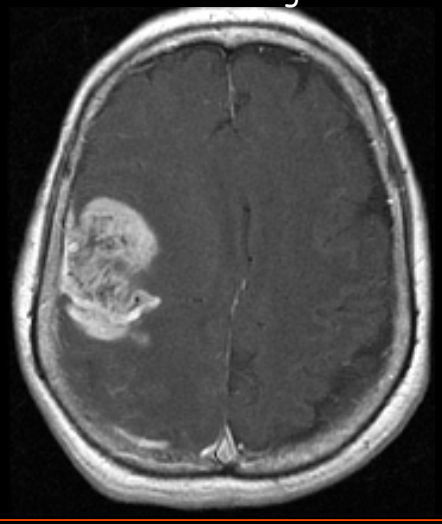
K. Pauly, G. Gold
Stanford Rad 220

Clinical Example

No Contrast Agent



Contrast Agent



*K. Pauly, G. Gold, RAD220

Body Examples

Abdominal Blood Vessels

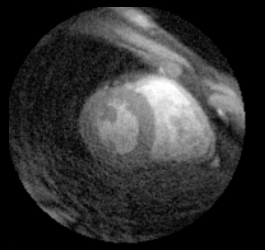
Knee

*K. Pauly, G. Gold, RAD220

Cardiac MRI

gated

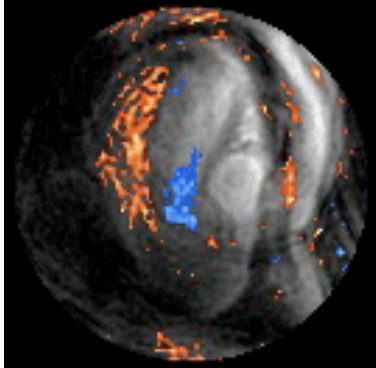
real-time



*Courtesy Juan Santos

Flow Imaging Examples

Real-time color flow

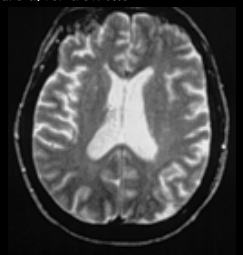


4D flow

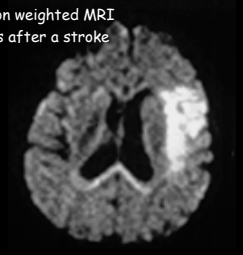
*Juan Santos, Stanford
*Marc Alley, Stanford

Diffusion Examples

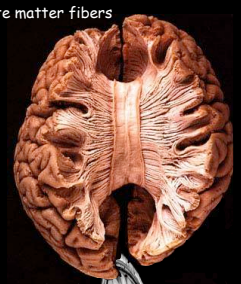
T2 weighted standard MRI
3 hours after a stroke



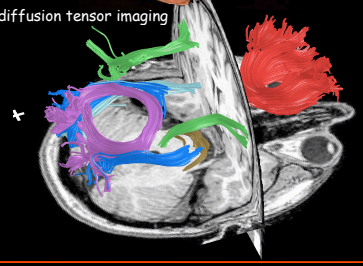
diffusion weighted MRI
3 hours after a stroke



White matter fibers



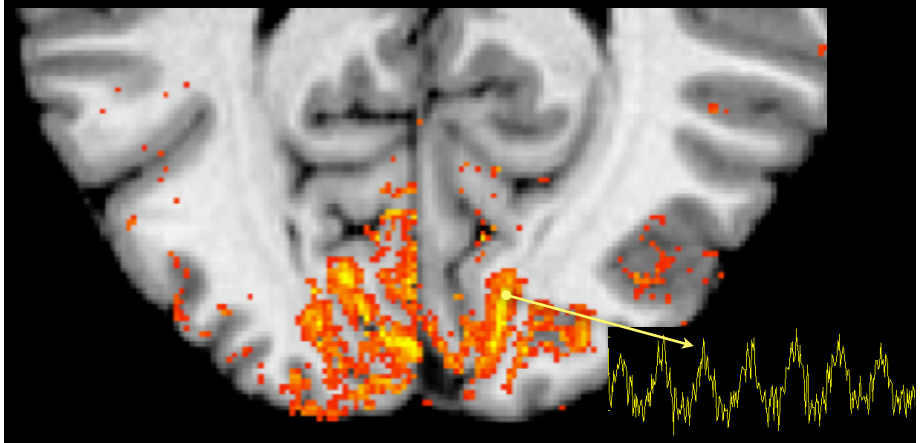
diffusion tensor imaging



*Dr. Steven Warach, Beth Israel Hospital, Boston, MA
*The Virtual Hospital (www.vh.org); TH Williams, N Gluhbegovic, JY Jew
*Brian Wandell, Stanford

Functional MRI Example

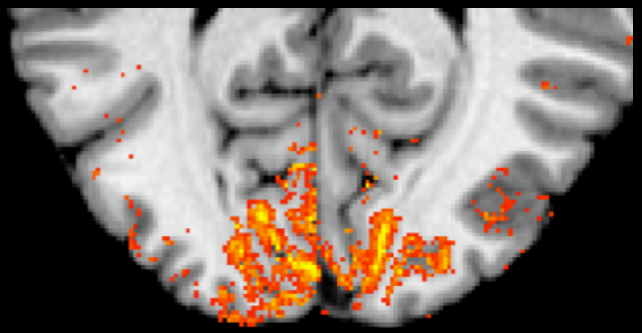
Sensitivity to blood oxygenation - response to brain activity



*Karla Miller, Oxford
*Mark Jenkinson, FMRIB

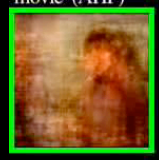
Taking fMRI further

- fMRI decoding : "Mind Reading"
  Gallant Lab, UC Berkeley



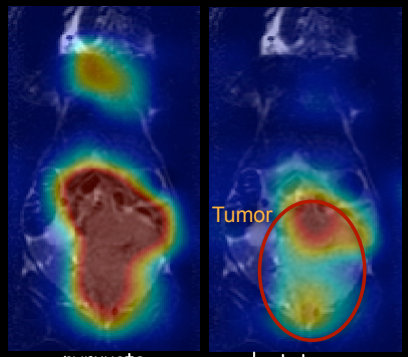
Presented movie

Reconstructed movie (AHP)



Spectroscopy Imaging

- Functional Imaging (metabolism)
- Also other nuclei (13C, phosphor)



pyruvate lactate

* P. Larson, D Vigneron, UCSF

Go Bears!

Bear with us! The moment when an enormous grizzly undergoes an MRI scan after suffering seizures

By DAILY MAIL REPORTER

PUBLISHED: 13:04 EST, 20 January 2014 | **UPDATED:** 14:29 EST, 20 January 2014

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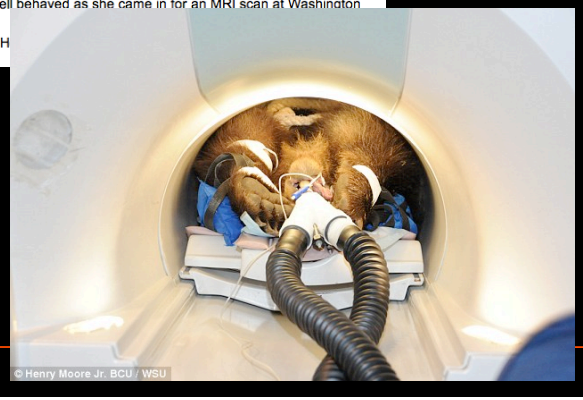
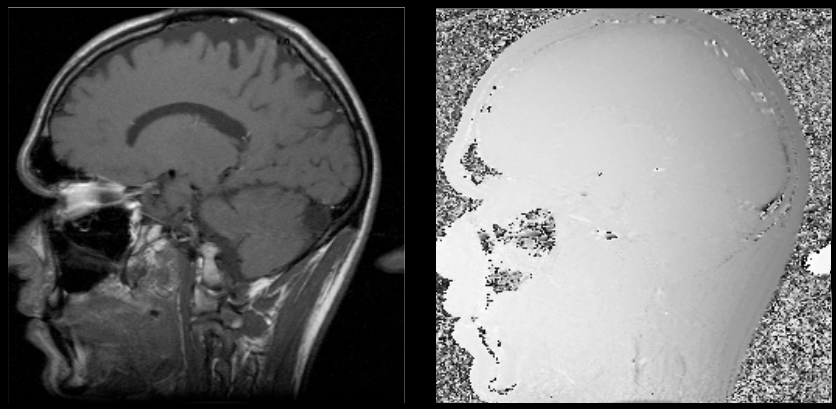
A young Montata grizzly was beary well behaved as she came in for an MRI scan at Washington Statue University

Scientists at the Veterinary Teaching H
causing her to have seizures.



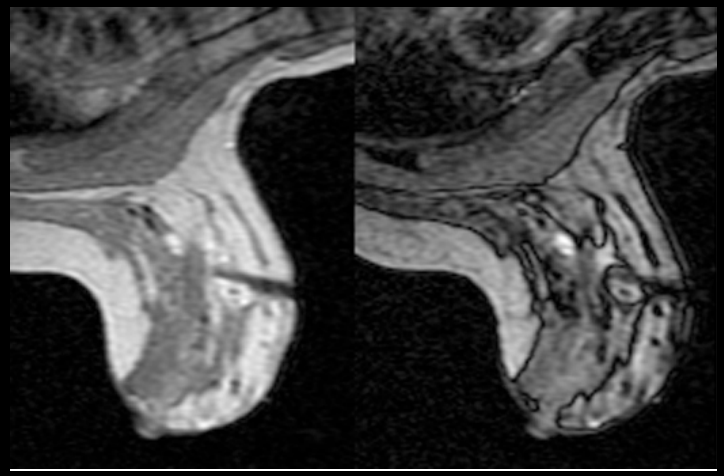
M. Lustig, EECS UC Berkeley

Phase



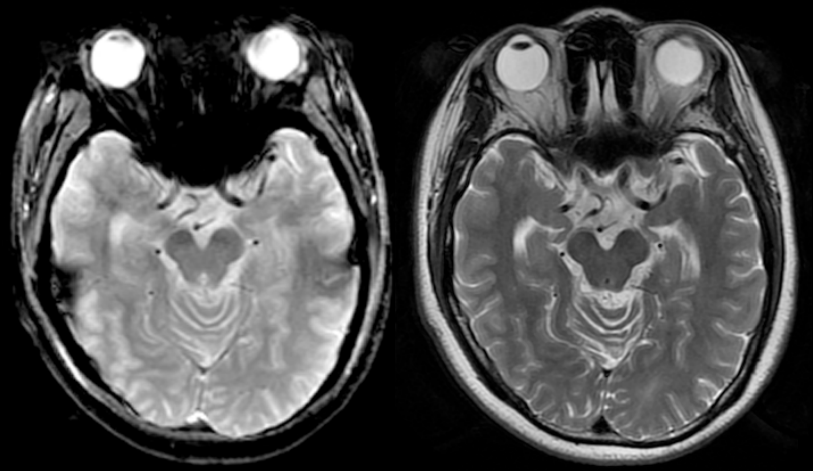
*K. Pauly, G. Gold, RAD220

Breast



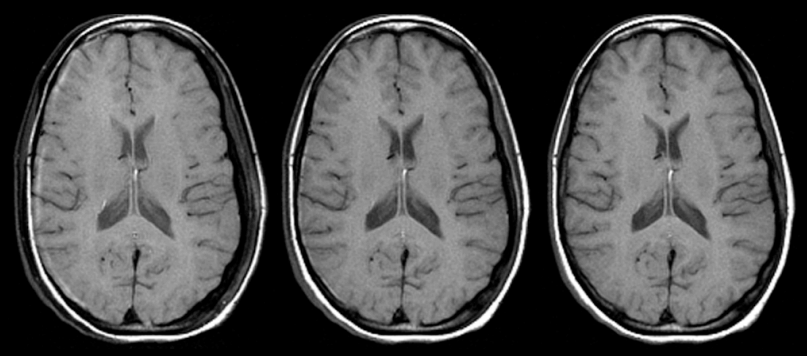
*K. Pauly, G. Gold, RAD220

Spin-Echo vs Gradient Echo



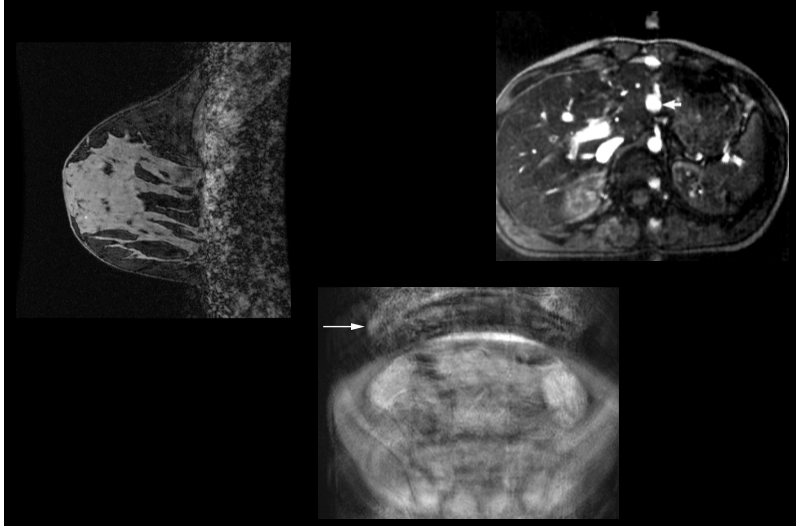
*K. Pauly, G. Gold, RAD220

Chemical-shift



*images, courtesy of Brian Hargreaves

Motion Artifacts



`

- If you have an iPhone, please install:
  - Tone Generator app (Michael Heinz)
-

How Does MRI Work?

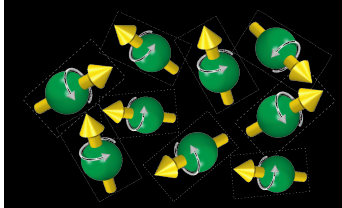
- Magnetic Polarization
  -- Very strong uniform magnet
- Excitation
  -- Very powerful RF transmitter
- Acquisition
  -- Location is encoded by gradient magnetic fields
  -- Very powerful audio amps

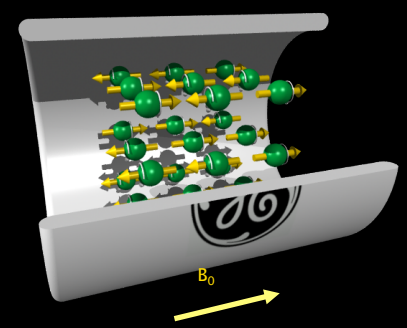
Polarization

- Protons have a magnetic moment
- Protons have spins
- Like rotating magnets

Polarization

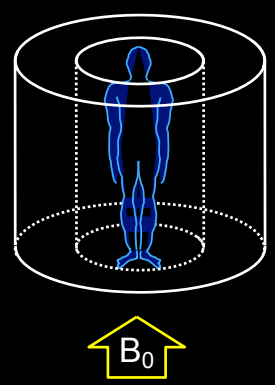
- Body has a lot of protons
- In a strong magnetic field B0, spins align with B0 giving a net magnetization





*Graphic rendering Bill Overall

Polarizing Magnet

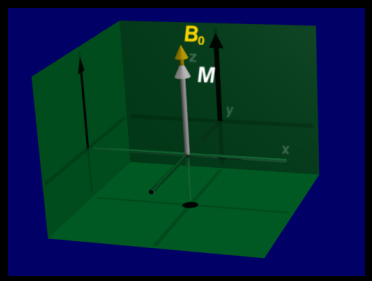


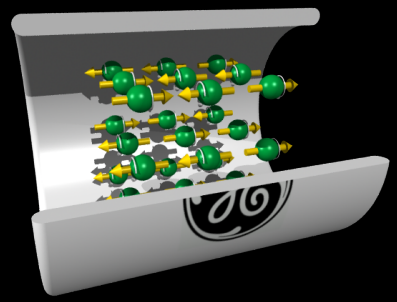
- 0.1 to 12 Tesla
- 0.5 to 3 T common
- 1 T is 10,000 Gauss
- Earth's field is 0.5G
- Typically a superconducting magnet

Typical 1.5T MRI System

Polarizaion

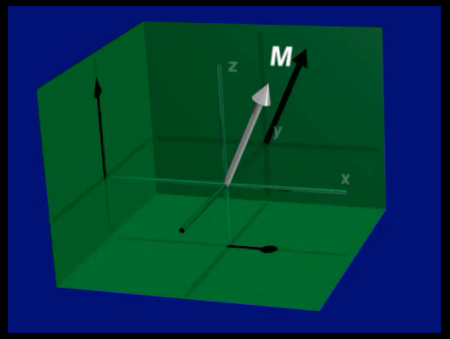
- Polarization results in net magnetization





Free Precession

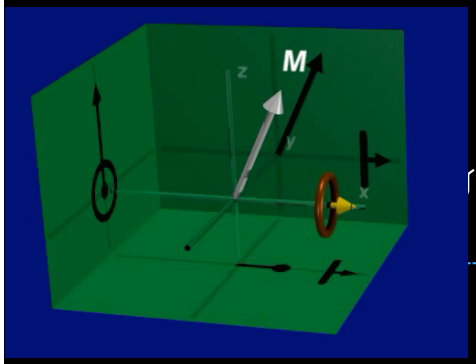
- Much like a spinning top
- Frequency proportional to the field
- f = 64MhZ @ 1.5T



MIT physics demos

Free Precession

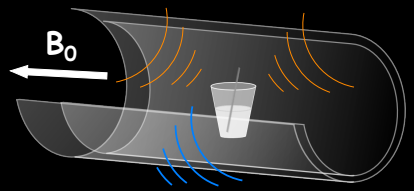
- Precession induces magnetic flux
- Flux induces voltage in a coil



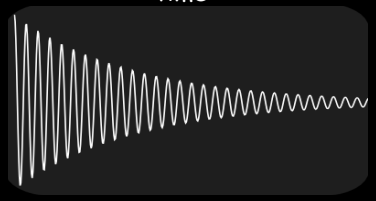
Signal

Intro to MRI - The NMR signal

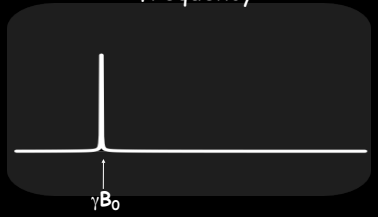
- Signal from ^{1}H (mostly water)
- Magnetic field ⇒ Magnetization
- Radio frequency ⇒ Excitation
- Frequency ∝ Magnetic field



time



frequency



Intro to MRI - The NMR signal

- Signal from ^1H (mostly water)
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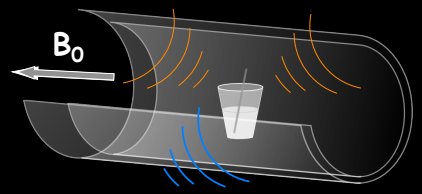
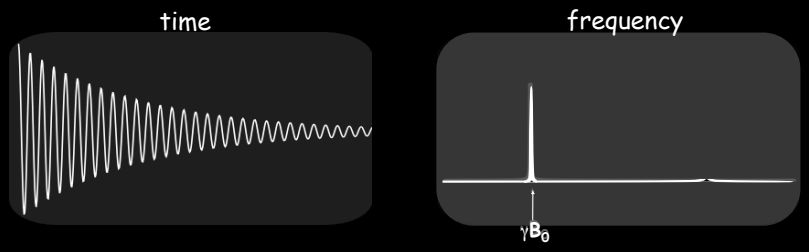
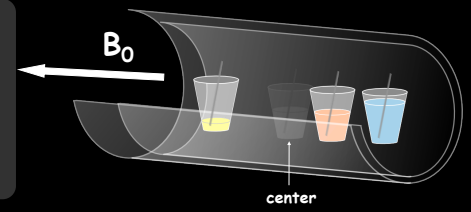
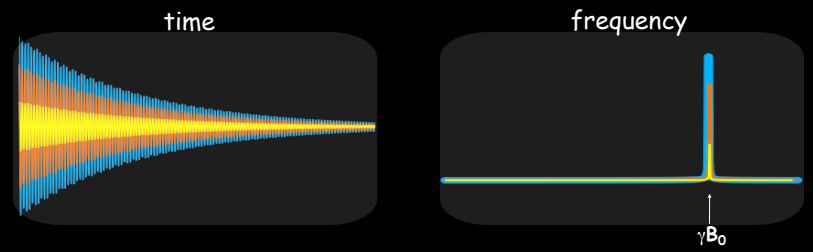




Intro to MRI - Imaging

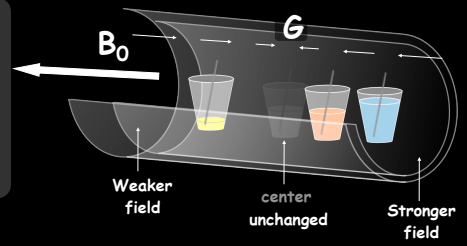
- B_0 Missing spatial information

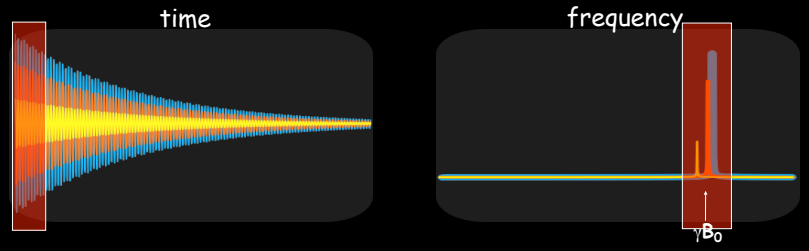




Intro to MRI - Imaging

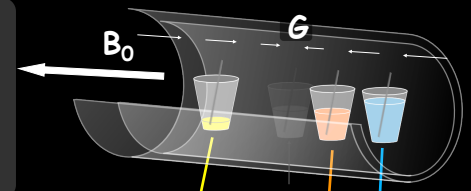
- B_0 Missing spatial information
- Add gradient field, G

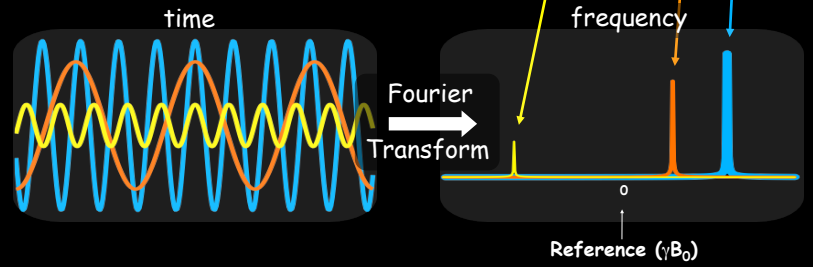




Intro to MRI - Imaging

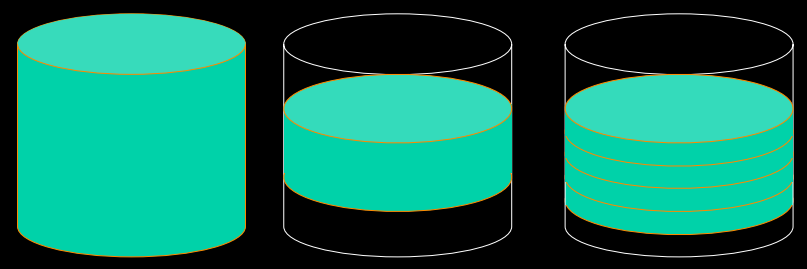
- B_0 Missing spatial information
- Add gradient field, G
- Mapping:
  spatial position ⇒ frequency



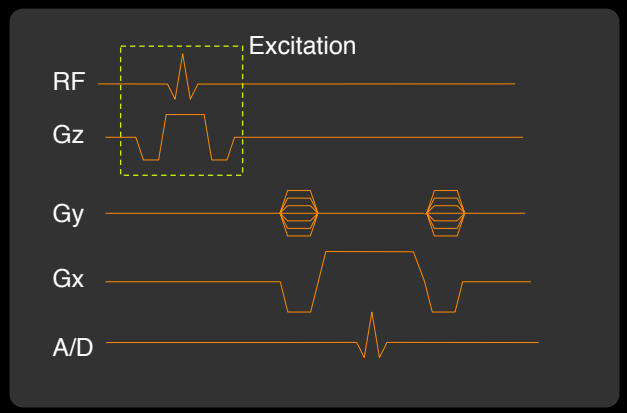


iPhone Imaging

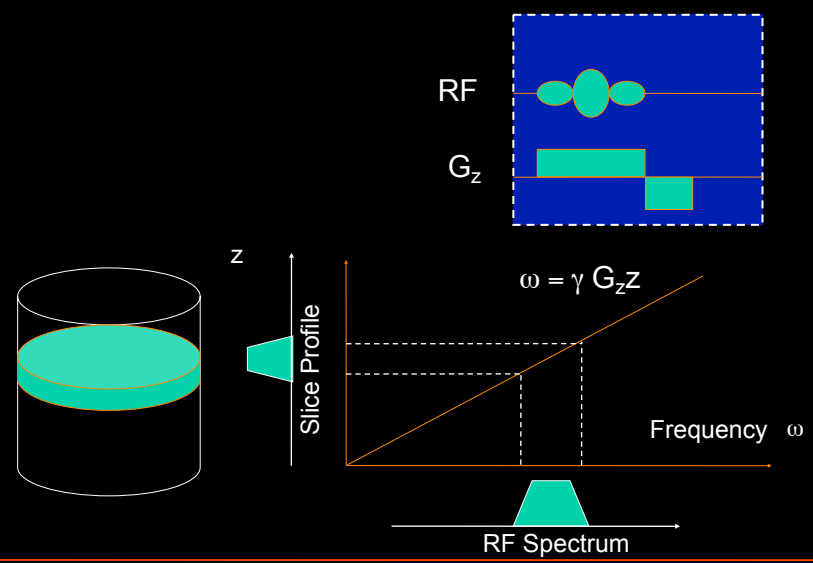
Imaging geometry



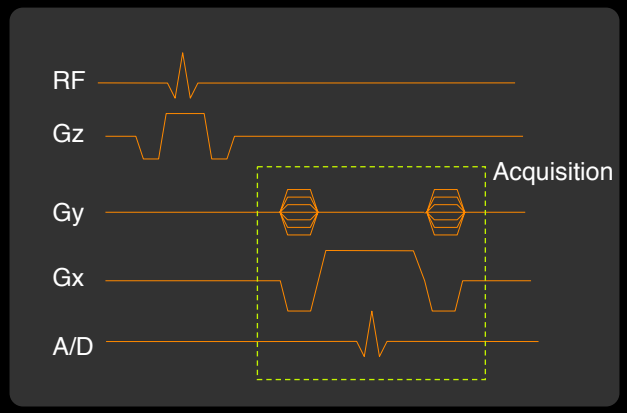
Simple Slice Selective Imaging



Slice selection



Simple Slice Selective Imaging



2D Imaging: k-space

- Gradient fields cause linear phase

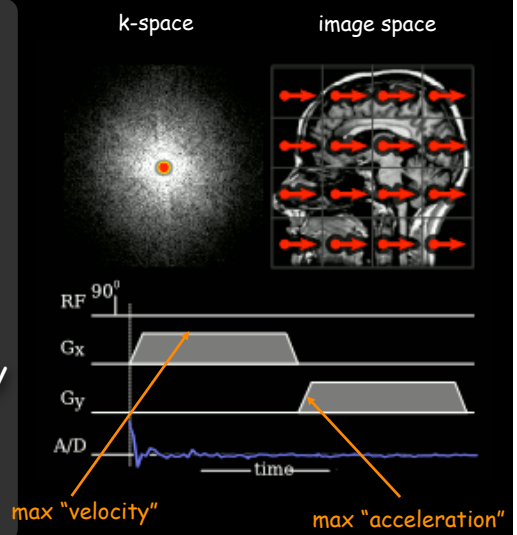
$$m(r)e^{-2\pi i k(t)\cdot r}$$

- Receive integrated signal

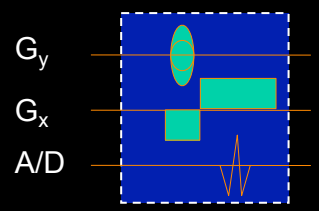
$$\int_{r\in V} m(r')e^{-2\pi i k(t)\cdot r'}\,dr'$$

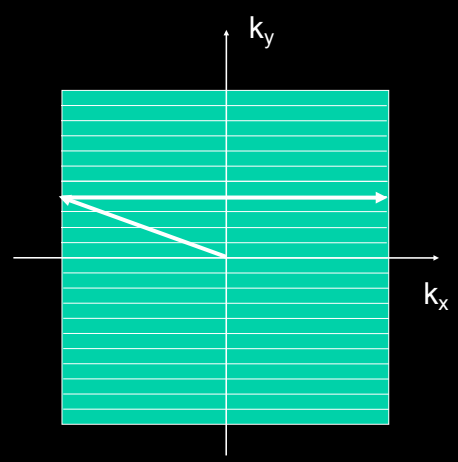
- give spatial frequency information

$$s(t) = \mathcal{F}\{m(r)\}(k(t))$$



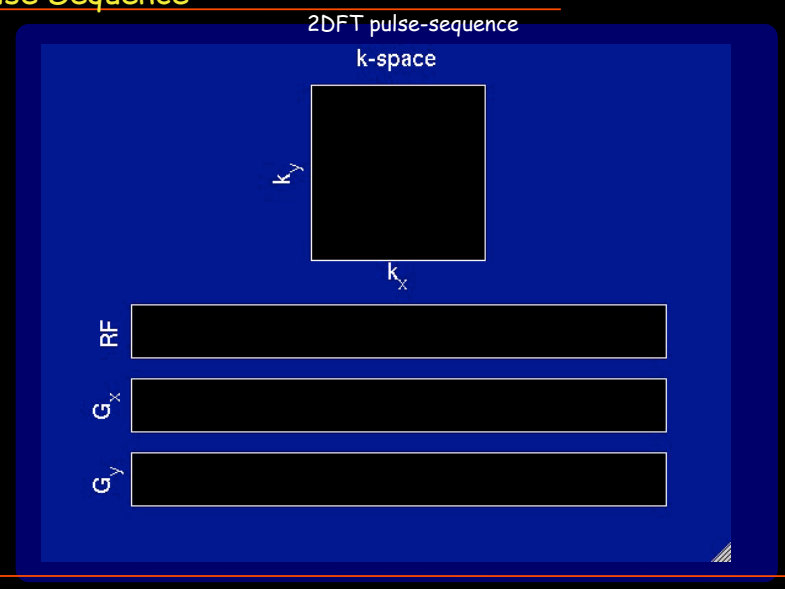
2DFT, or spin warp



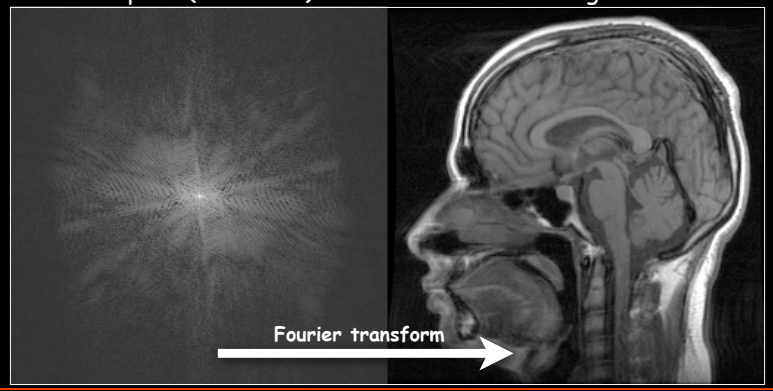


- One line of k-space for each acquisition
- Repeat N times for an NxN image
- Recon is 2DFT
- TR 400 ms, 256x256 image < 2 minutes

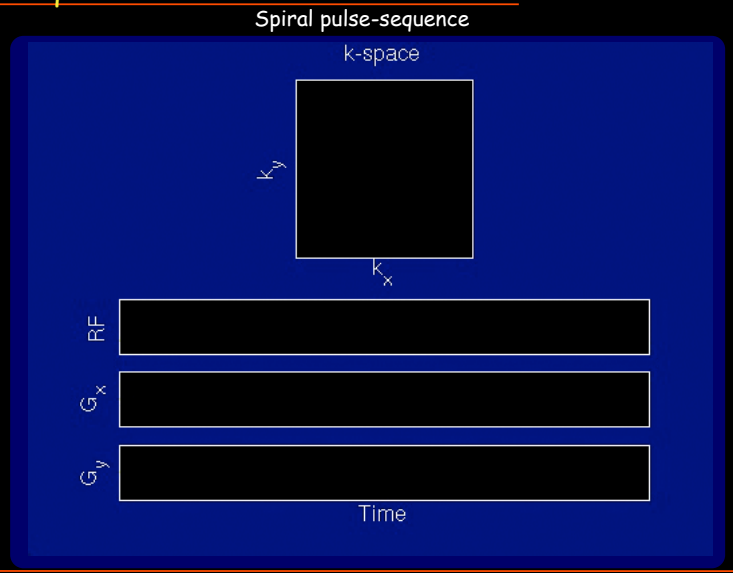
Pulse Sequence



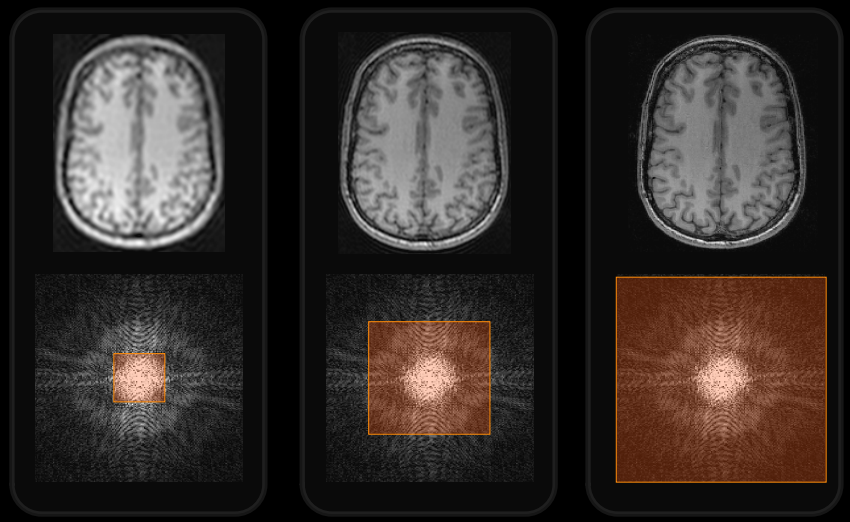
MR Imaging



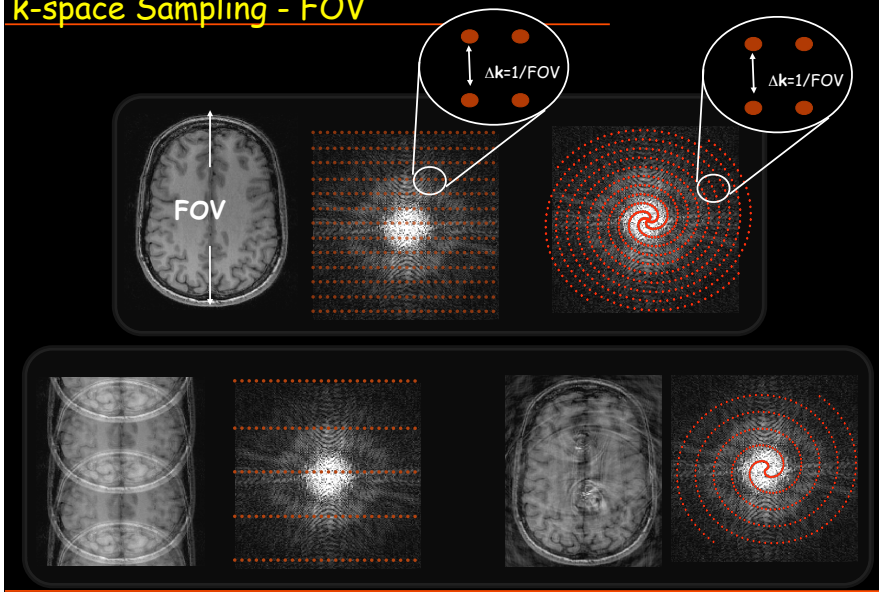
Pulse Sequence



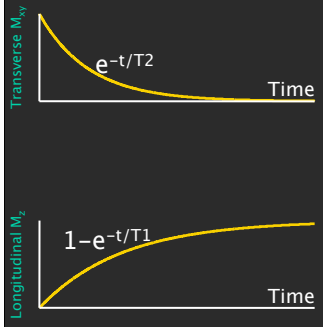
k-space Sampling - resolution

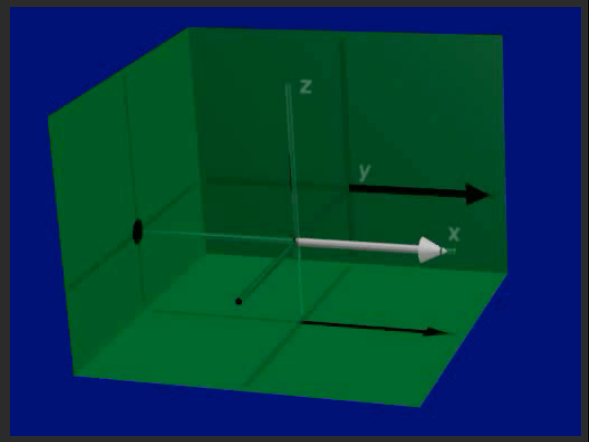


k-space Sampling - FOV



Relaxation





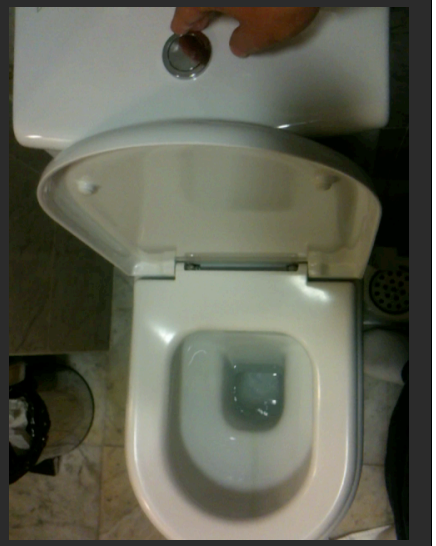
The Toilette Analogy (©2009 Al Macovski)

- Excitation = Flush
- T2 = Active flushing ~5 second

- T1 = Refilling time ~1min

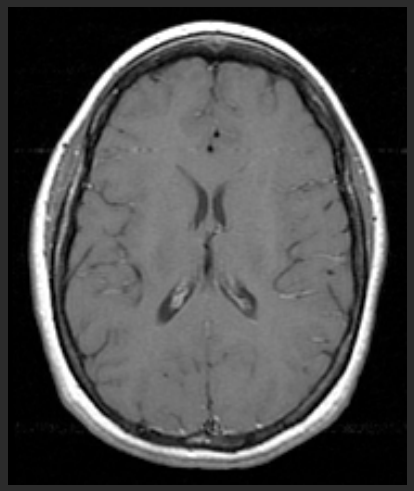
The Toilette Analogy, Steady-state

- Flush - Refill
- Flush continuously
  - Never fully refills
  - After a while, same from flush to flush
  - "Steady state"
- Timing creates contrast

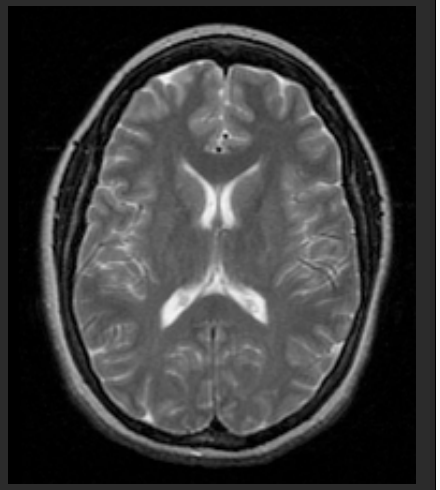


Contrast

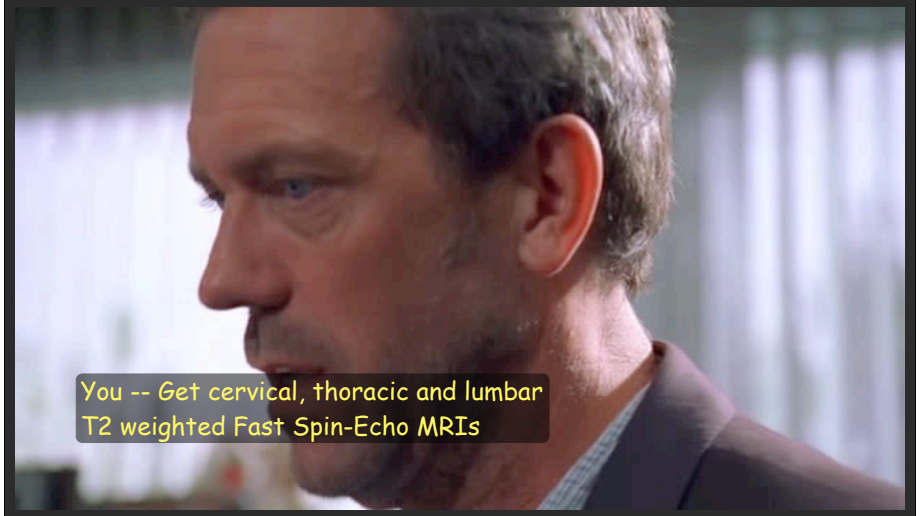
T1



T2



House Prefers T2 .....



MRI at UCSF and Berkeley

- Berkeley has a 3.0 T Siemens whole body scanner dedicated to Neuroscience at the Helen Wills Neuroscience Institute
- UCSF has several GE & Siemens scanners (1.5T, 3T and a 7T)
- Berkeley has Prof. Alex Pines, John Clarke, Tom Budinger, Steve Conolly and myself on the basic NMR/MRI technology
- UCSF has dozens of MRI researchers **Peder Larson, Daniel Vigneron, Xiaoliang Zhang, Duan Xu, John Kurhanewicz, Sarah Nelson, Sharmila Majumdar, David Saloner, Nola Hylton, Michael Wendland, Sabrina Ronen, and Alastair Martin**