Principles of MRI
EE225E / BIO265

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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

Imaging System

(Electronics, control, computing, algorithms, visualization...) e.g., Engineering!

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

Math

Physics

Chemistry

Engineering

Biology

Medicine
**Projection X-Ray**
- Projection Format
- Small Dose
- Fast
- Inexpensive

**Computed Tomography (CT)**
- Tomographic
- Fast
- High-Res
- Moderate dose
- ~1M$

**Computed Tomography**
- Gantry rotation

**Sinogram**
- cross-section
- x-ray source

[Link to video](https://www.youtube.com/watch?v=4gklQHM19aY&feature=related)
**Ultrasound**

- Real-time
- Inexpensive
- No-radiation
- Many applications
- Low contrast and penetration

**Nuclear Medicine**

- Specific metabolic information (function)
- Low-res
- High dose
- 1-2M$
- SPECT: Gamma radiation
- PET: Positron-> Gamma

**Anatomy vs Function**

**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

- 1971 - Raymond Damadian showed changes in MR parameters (T1 and T2) in cancer. People started thinking about medical NMR applications.
- 1973 - Lauterbur described MRI in a similar way to CT.
- 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
Clinical Example

No Contrast Agent

Contrast Agent

Precontrast

Postcontrast

No Contrast Agent

Contrast Agent

Precontrast

Postcontrast

Body Examples

Abdominal Blood Vessels

Knee

Cardiac MRI

gated

real-time

Flow Imaging Examples

Real-time color flow

4D flow

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K. Pauly, G. Gold, RAD220

*Courtesy Juan Santos

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**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

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**Functional MRI Example**

Sensitivity to blood oxygenation - response to brain activity

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**Taking fMRI further**

- fMRI decoding: “Mind Reading”
  - Gallant Lab, UC Berkeley

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**Spectroscopy Imaging**

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

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

*Karla Miller, Oxford*
*Dr. Steven Warach, Beth Israel Hospital, Boston, MA*
*Brian Wandell, Stanford*

*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


A young Montanna grizzly was beary well behaved as she came in for an MRI scan at Washington State University.

Scientists at the Veterinary Teaching Hospital caused her to have seizures.

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**Phase**

The data is complex: there is magnitude and phase. We typically look at the magnitude.

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**Breast**

Water and fat are "in phase" and "out of phase".

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**Spin-Echo vs Gradient Echo**

K. Pauly, G. Gold, RAD220

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Chemical-shift

Motion Artifacts

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

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

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

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

- Body has a lot of protons
- In a strong magnetic field $B_0$, spins align with $B_0$ giving a net magnetization
**Polarization**

- Polarization results in net magnetization

**Free Precession**

- Much like a spinning top
- Frequency proportional to the field
- \( f = 64 \text{MHz} @ 1.5T \)

**Free Precession**

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

**Intro to MRI - The NMR signal**

- Signal from \(^1\text{H}\) (mostly water)
- Magnetic field \(\Rightarrow\) Magnetization
- Radio frequency \(\Rightarrow\) Excitation
- Frequency \(\propto\) Magnetic field
Intro to MRI - The NMR signal

- Signal from $^1$H (mostly water)
- Magnetic field $\Rightarrow$ Magnetization
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- Frequency $\propto$ Magnetic field

Intro to MRI - Imaging

- $B_0$ Missing spatial information
- Add gradient field, $G$
  - Mapping: spatial position $\Rightarrow$ frequency

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Simple Slice Selective Imaging

RF
Gz
Gy
Gx
A/D

Excitation

Slice selection

RF
Gz

ω = γ Gz Z

z
Frequency

RF Spectrum

Slice Profile
**Simple Slice Selective Imaging**

- **RF**
- **Gz**
- **Gy**
- **Gx**
- **A/D**

**Acquisition**

**2D Imaging: k-space**

- Gradient fields cause linear phase
  \[ m(r)e^{-2\pi ik(t) \cdot r} \]
- Receive integrated signal
  \[ \int_{r \in V} m(r')e^{-2\pi ik(t) \cdot r'} \, dr' \]
- Give spatial frequency information
  \[ s(t) = F\{m(r)\}(k(t)) \]

**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**

- 2DFT pulse-sequence
MR Imaging

- k-space (Raw Data)
- Image
- Fourier transform

Pulse Sequence

- Spiral pulse-sequence
- k-space

k-space Sampling - resolution

- Fourier transform
- Image

k-space Sampling - FOV

- FOV
- Δk=1/FOV
MRI is all about contrast......

The Toilette Analogy (©2009 Al Macovski)

• Excitation = Flush
• T2 = Active flushing ~5 second
• T1 = Refilling time ~1 min

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

Relaxation
### 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.

You -- Get cervical, thoracic and lumbar T2 weighted Fast Spin-Echo MRIs.