# Functional Magnetic Resonance Imaging

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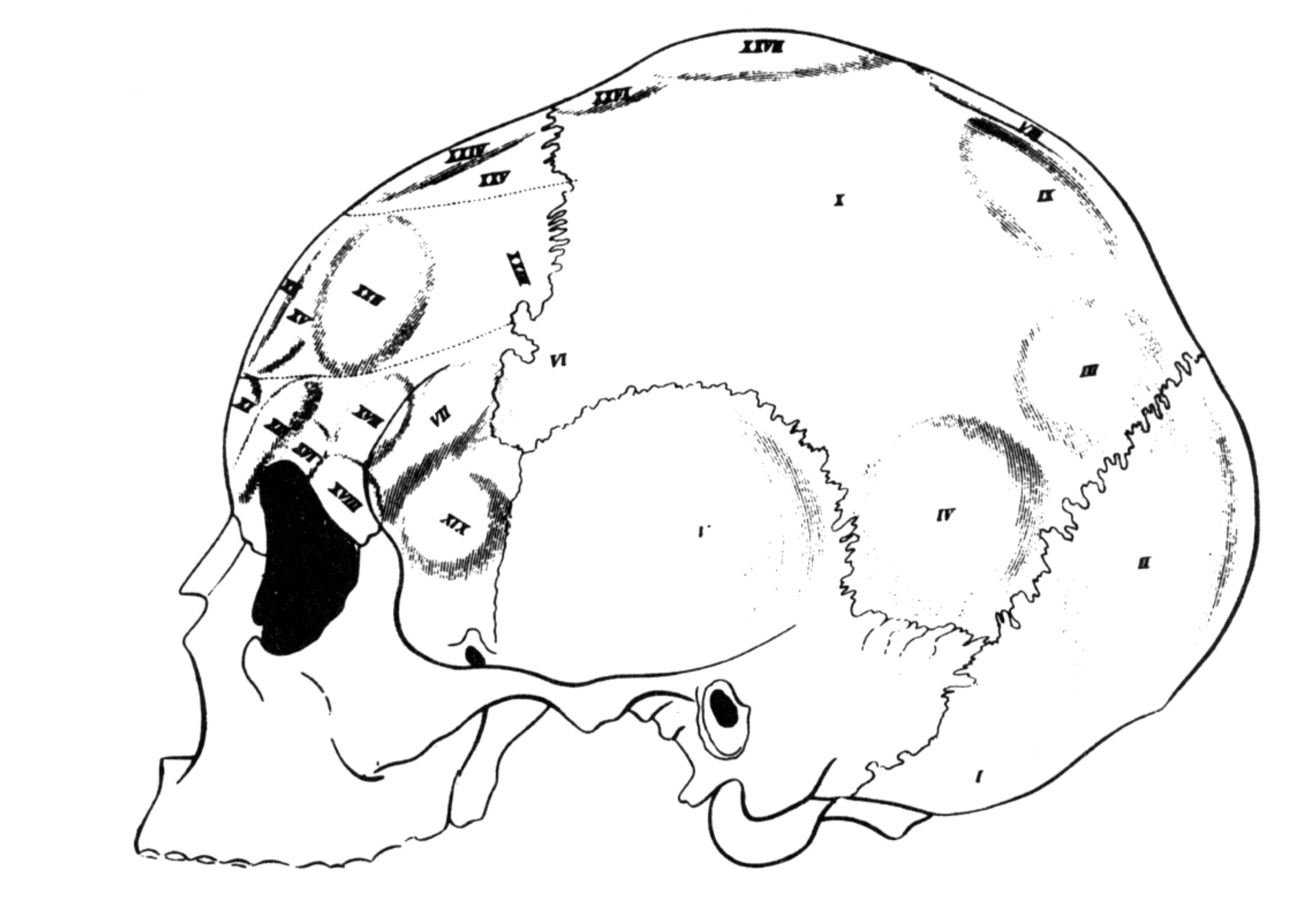
# Outline

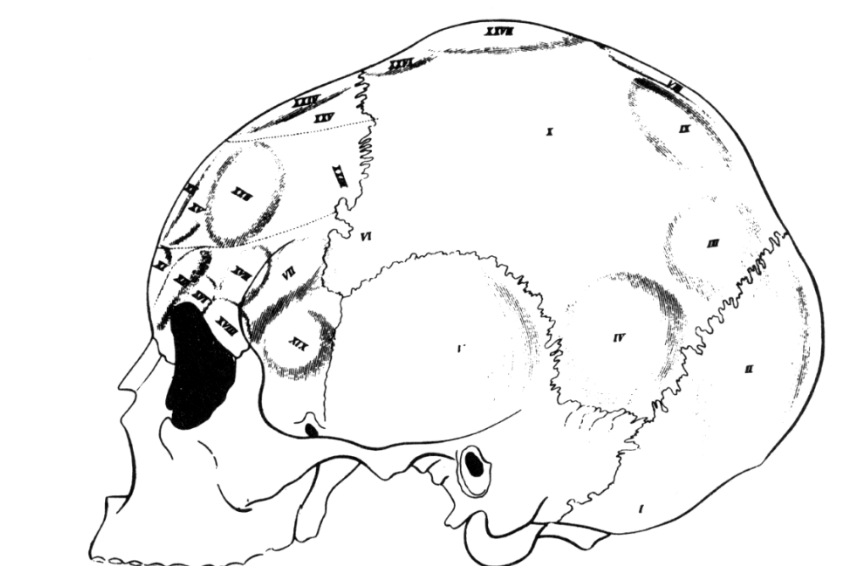
- What is fMRI?
- Key Concepts
- MRI Scanners
- MRI in Detail

# 1. What is fMRI ?

# isn't
# 1. What ~~is~~ fMRI ?

# fMRI is not bumpology





from Gall (c. 1810)

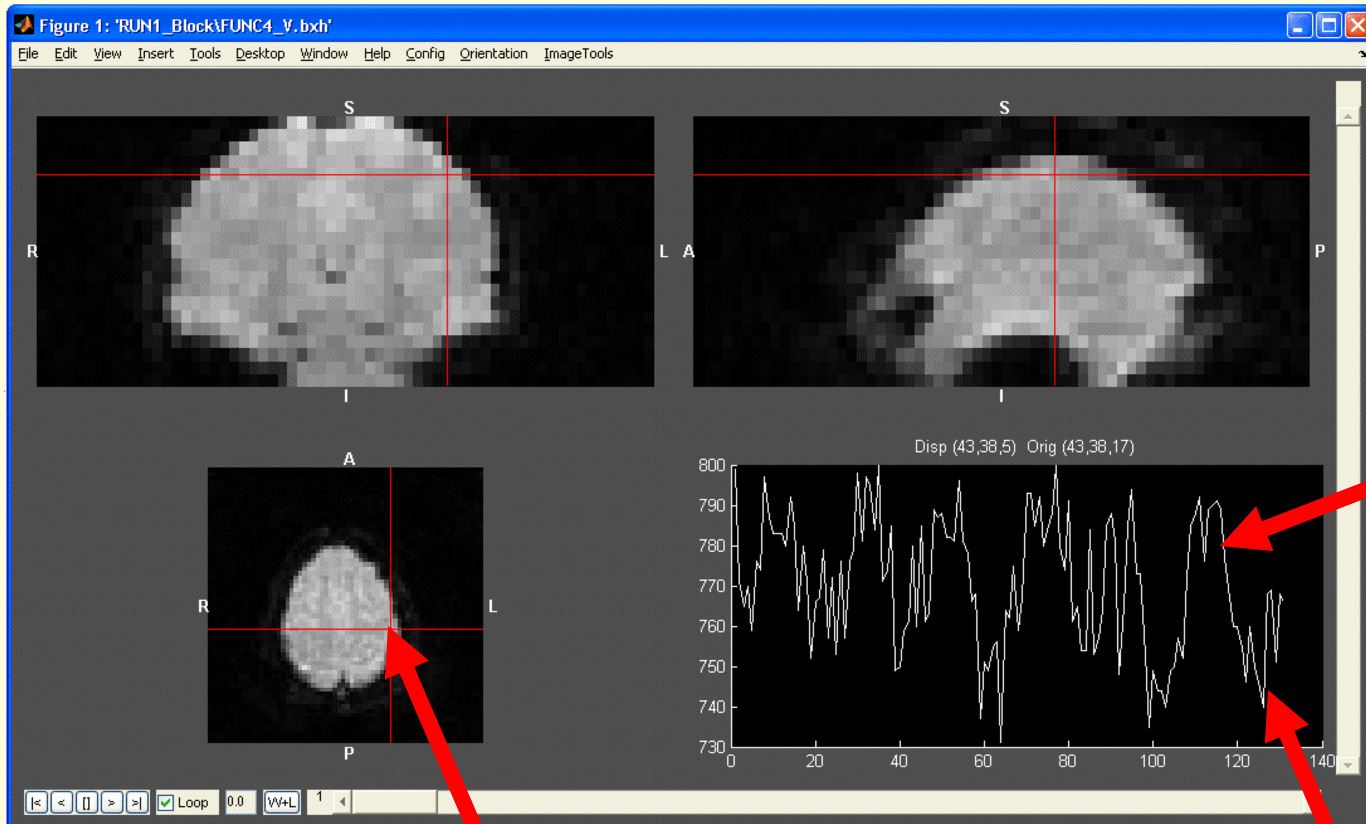
Franz Joseph Gall (1758-1828)

Johann Spurzheim (1776-1832)

- <u>Phrenology</u> claimed that bumps on the skull reflected exaggerated functions/traits
- It lacked any *mechanism* underlying its claims.
- It used anecdotal, rather than scientific, evidence.
- Nevertheless, its central idea persisted:

  *Localization of Function*

# fMRI is not mind-reading

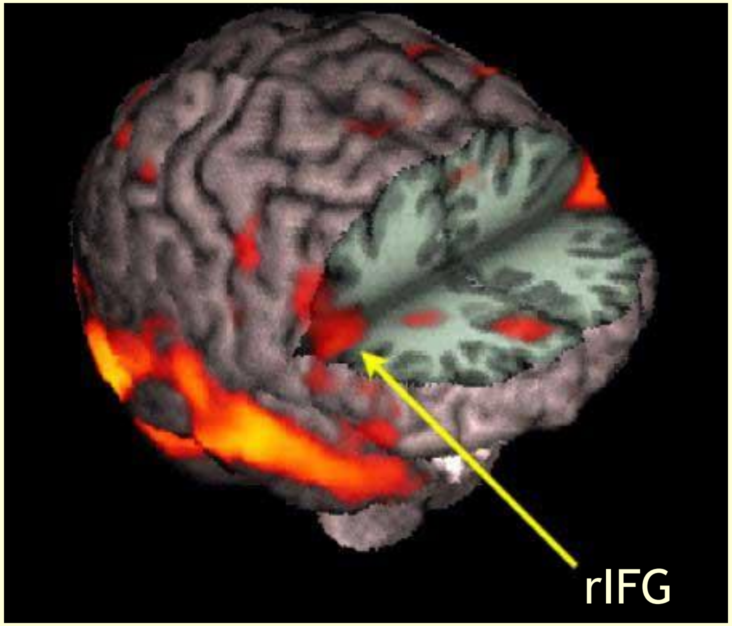



This is not a thought.

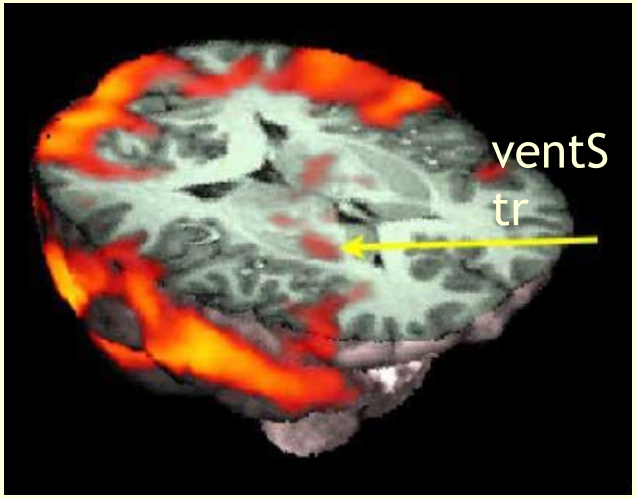
This is not a thought.

This is not an anti-thought.

# fMRI is not a *window on the brain*




"Mirror neuron activity in the right posterior inferior frontal gyrus – indicating identification and empathy - while watching the Disney/NFL ad."



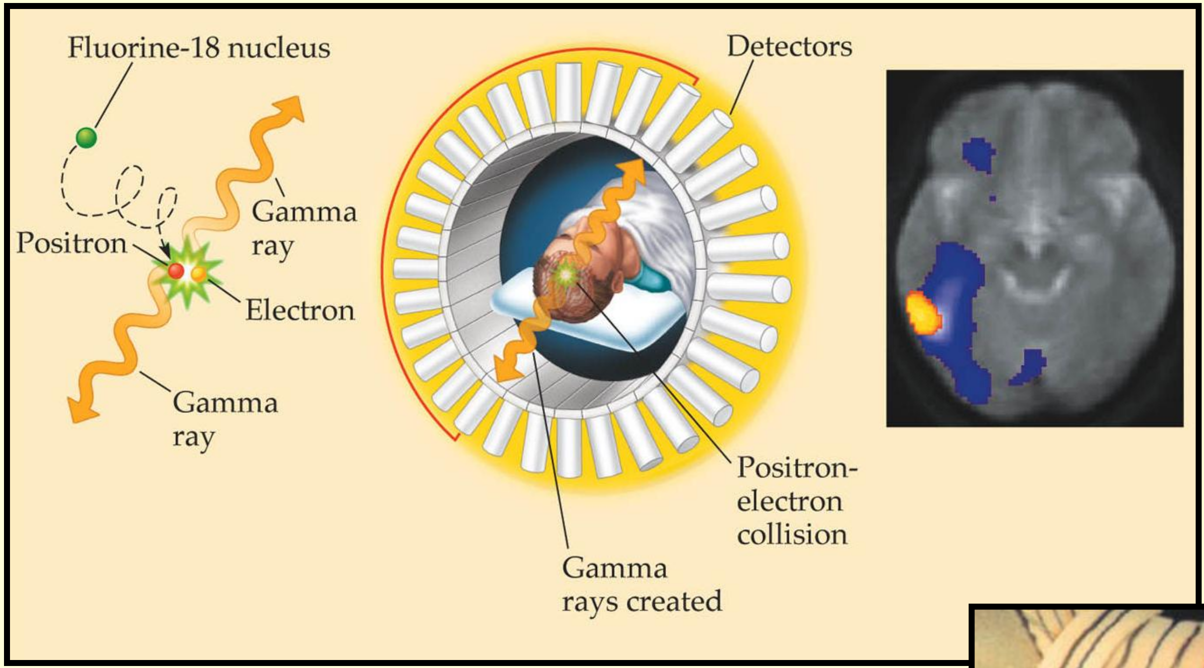

"Ventral striatum activity – indicating reward processing - while watching the Disney/NFL ad."

[Citations omitted to protect the offenders.]

# Activation Alone is insufficient:
## An Example of the Limitation of Reverse Inference in fMRI

- Insula
  - Interoception
  - Emotional processing
    - Disgust
    - Empathy
  - Social norm violations
  - Consciousness
  - Smoking (damage produces cessation)
  - Phonological processing
  - Language production

# fMRI is not invasive




Positron Emission Tomography (PET)

Intracranial Stimulation / Recording

# FMRI is… a technique for measuring metabolic correlates of neuronal activity

- Uses a standard MRI scanner
- Acquires a series of images (numbers)
- Measures changes in blood oxygenation
- Use non-invasive, non-ionizing radiation
- Can be repeated many times
- Can be used for a wide range of subjects
- Combines good spatial and reasonable temporal resolution

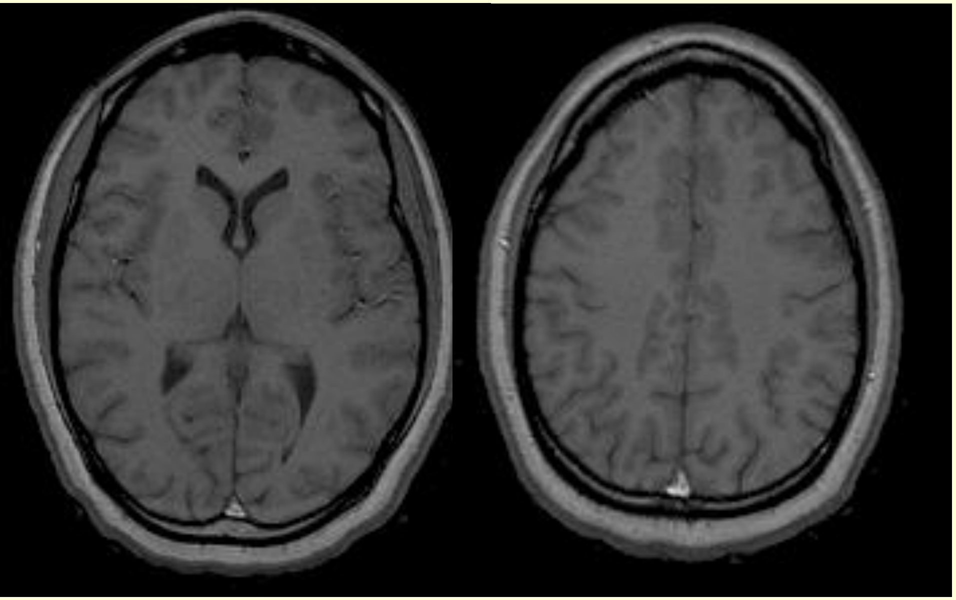
# 2. Key Concepts

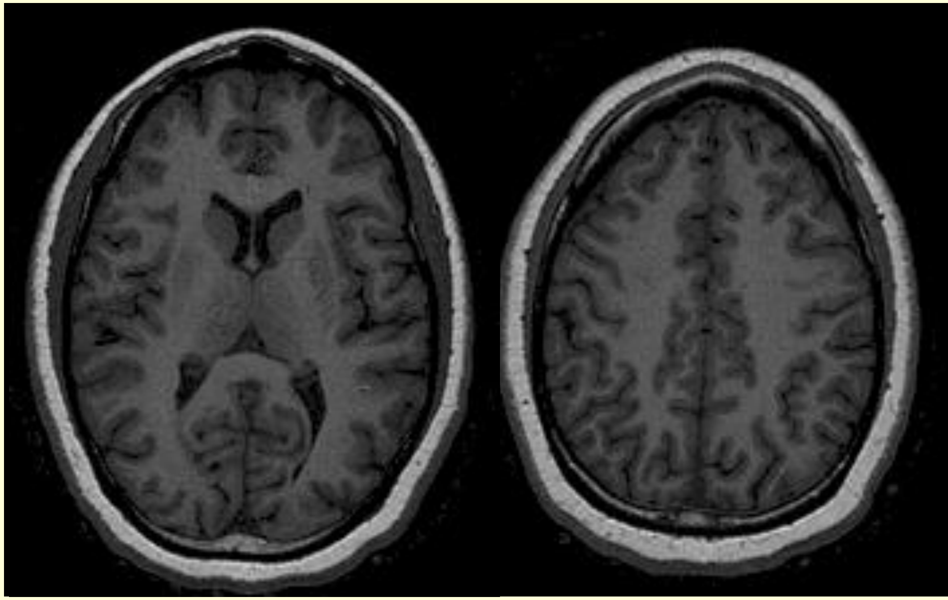
# Key Concepts

- Contrast
- Spatial Resolution
- Temporal Resolution
- <u>Functional</u> Resolution

# Contrast: Conceptual Overview

# Contrast: Anatomical



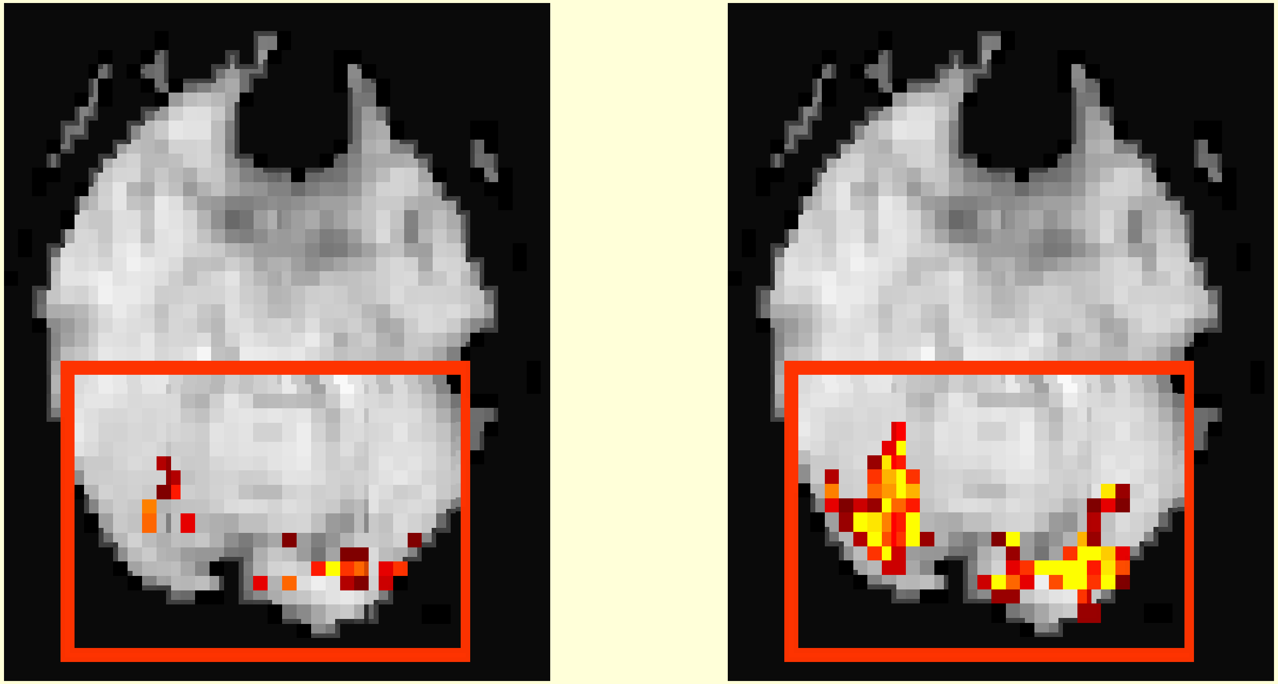


Contrast:

1) An intensity difference between quantities: “How much?”
2) The quantity being measured: “What?”

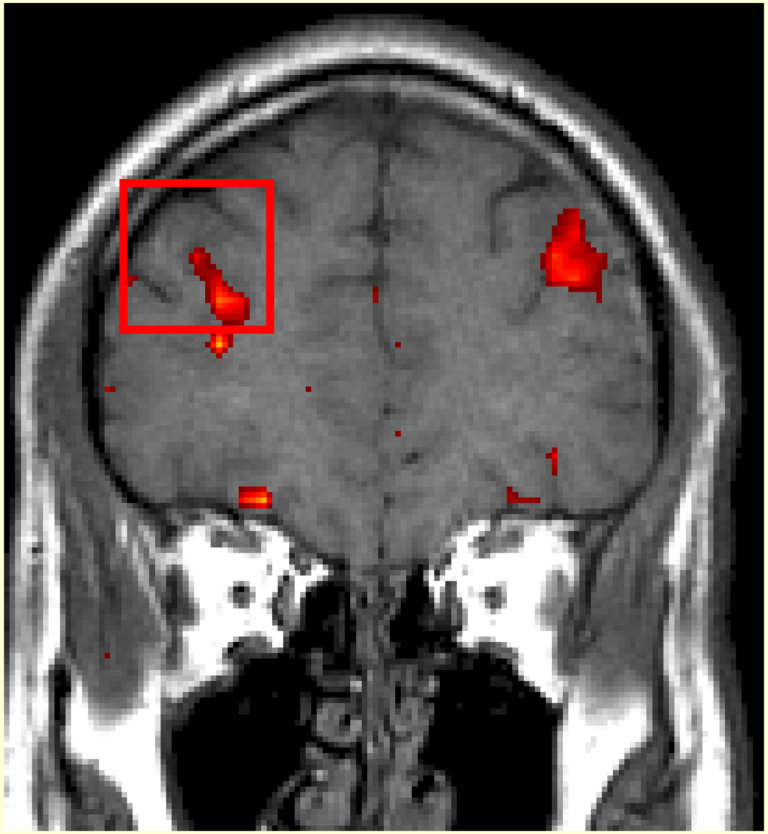
Contrast-to-noise: The magnitude of the intensity difference between quantities divided by the variability in their measurements.

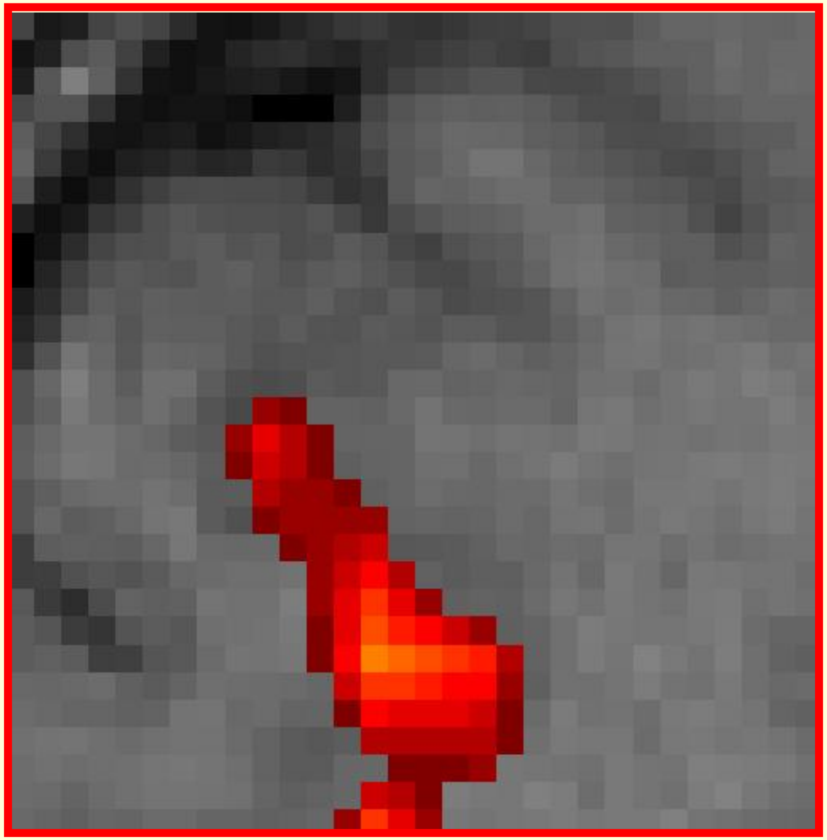
# Contrast: Functional



Contrast-to-noise is critical for fMRI: How effectively can we decide whether a given brain region has property X or property Y?

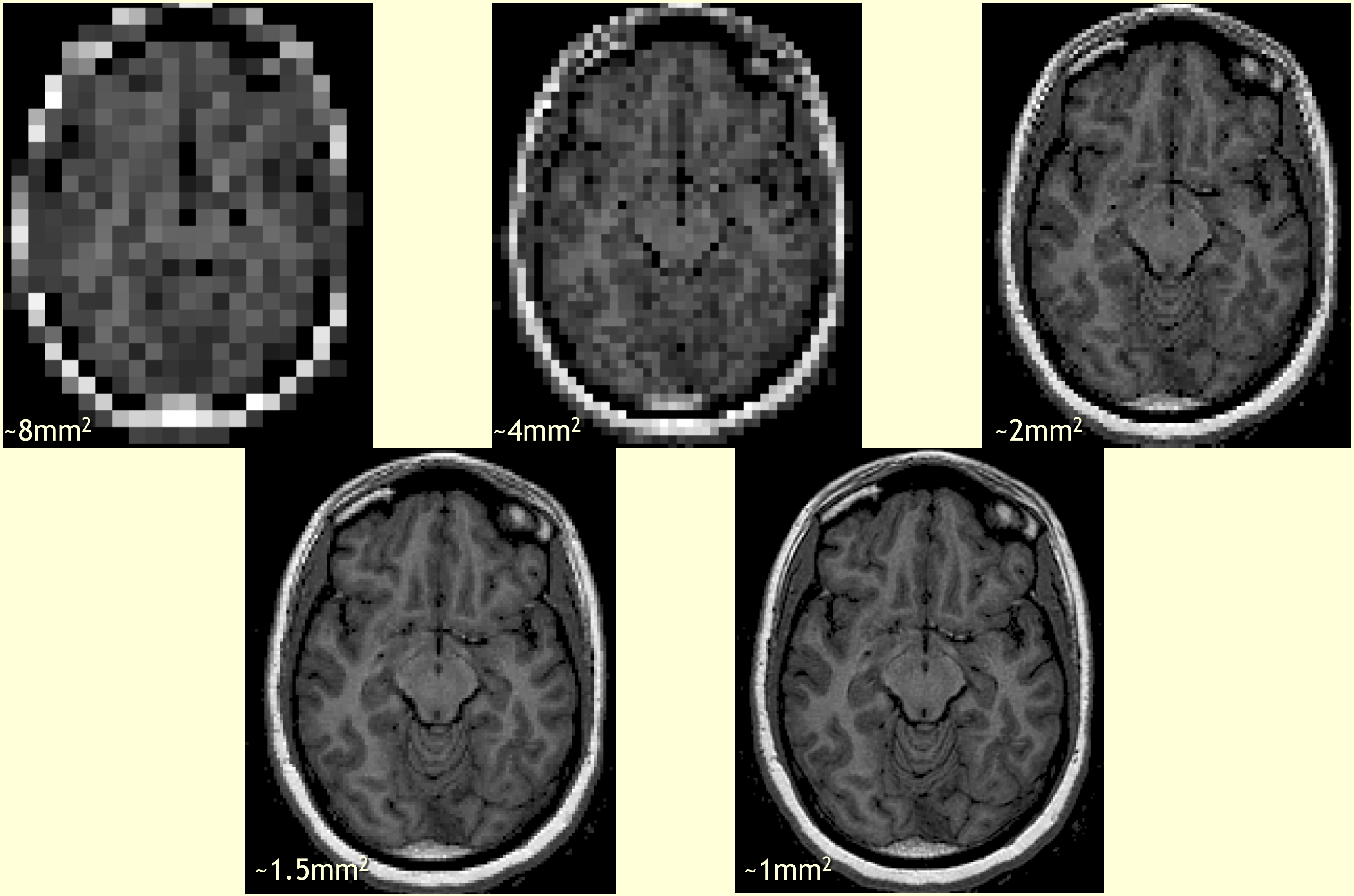
# Spatial Resolution: Voxels





Voxel (volume element): A small rectangular prism that is the basic sampling unit of fMRI.
Typical anatomical voxel: $(1.5\text{mm})^3$. Typical functional voxel: $(4\text{mm})^3$.

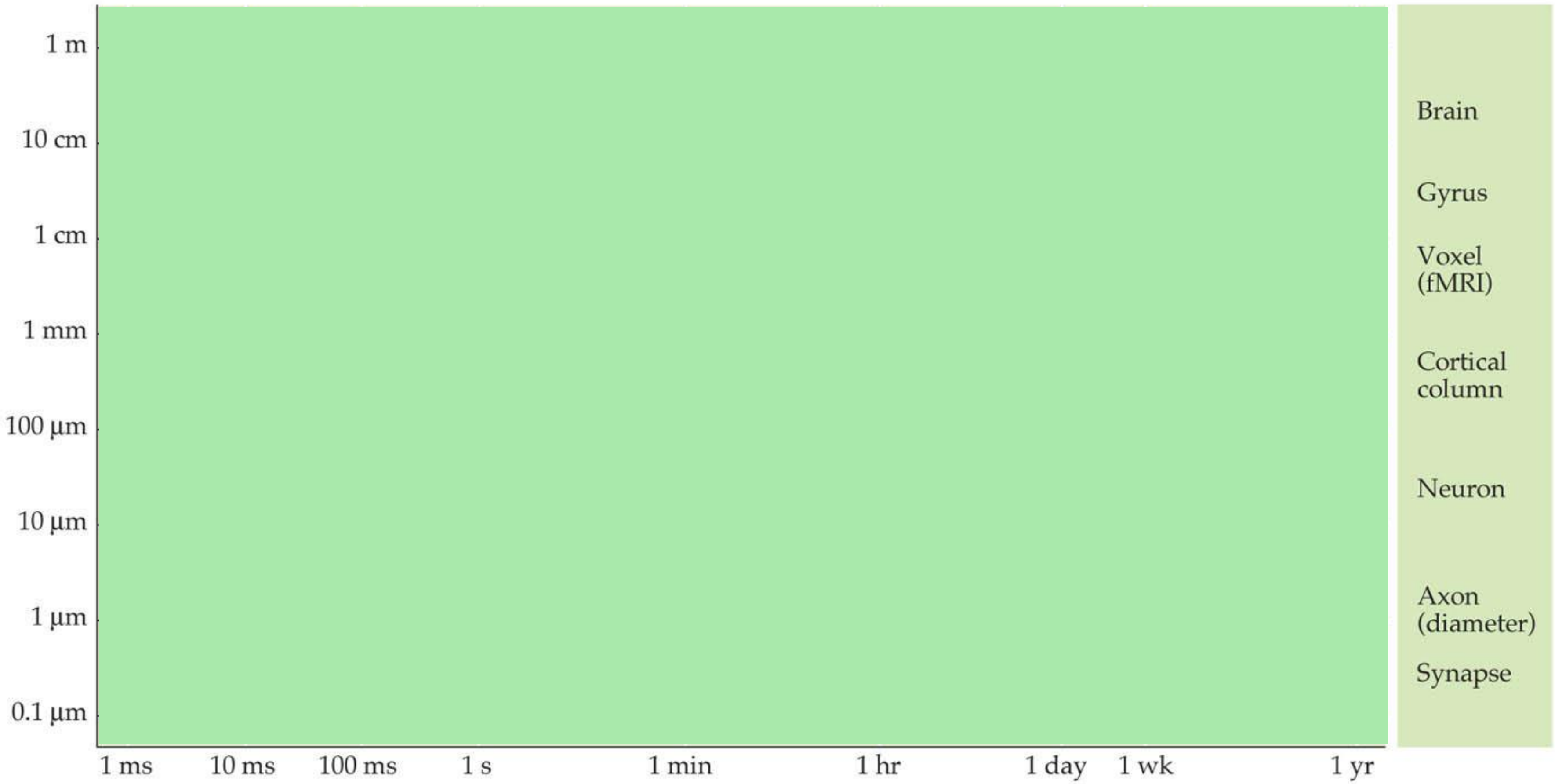
# Spatial Resolution: Examples



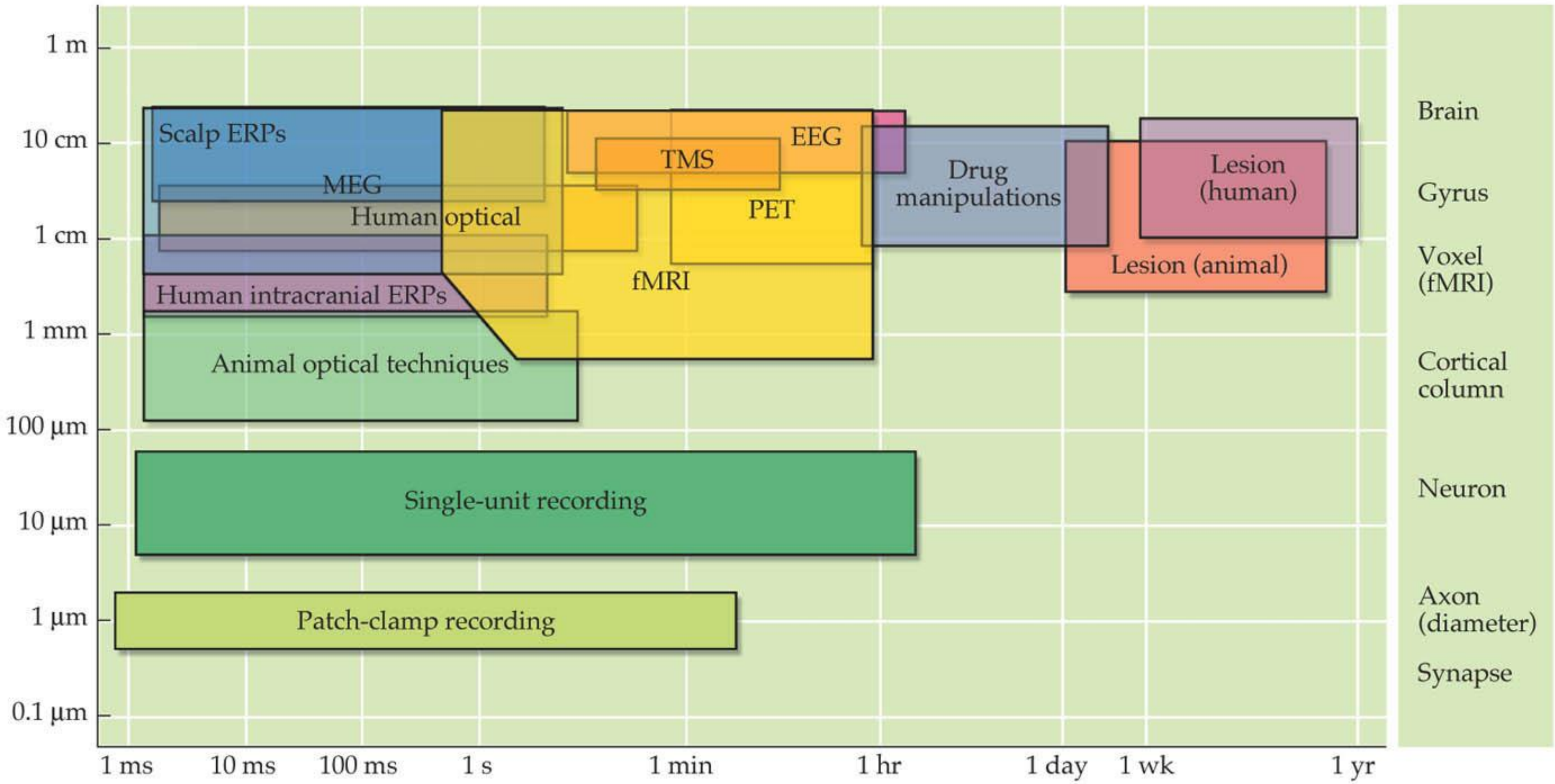
# Temporal Resolution

- Determining factors
  - Sampling rate, usually repetition time (TR)
  - Dependent variable, usually BOLD response
    - BOLD response is sluggish
      - 2-3 seconds to rise above baseline
      - 4-6 seconds to peak
  - Experimental design

- Most FMRI studies have temporal resolution on the order of a few seconds
  - With specialized designs and data acquisition, this can be improved to ~100ms




*FUNCTIONAL MAGNETIC RESONANCE IMAGING,* **Figure 1.7** 



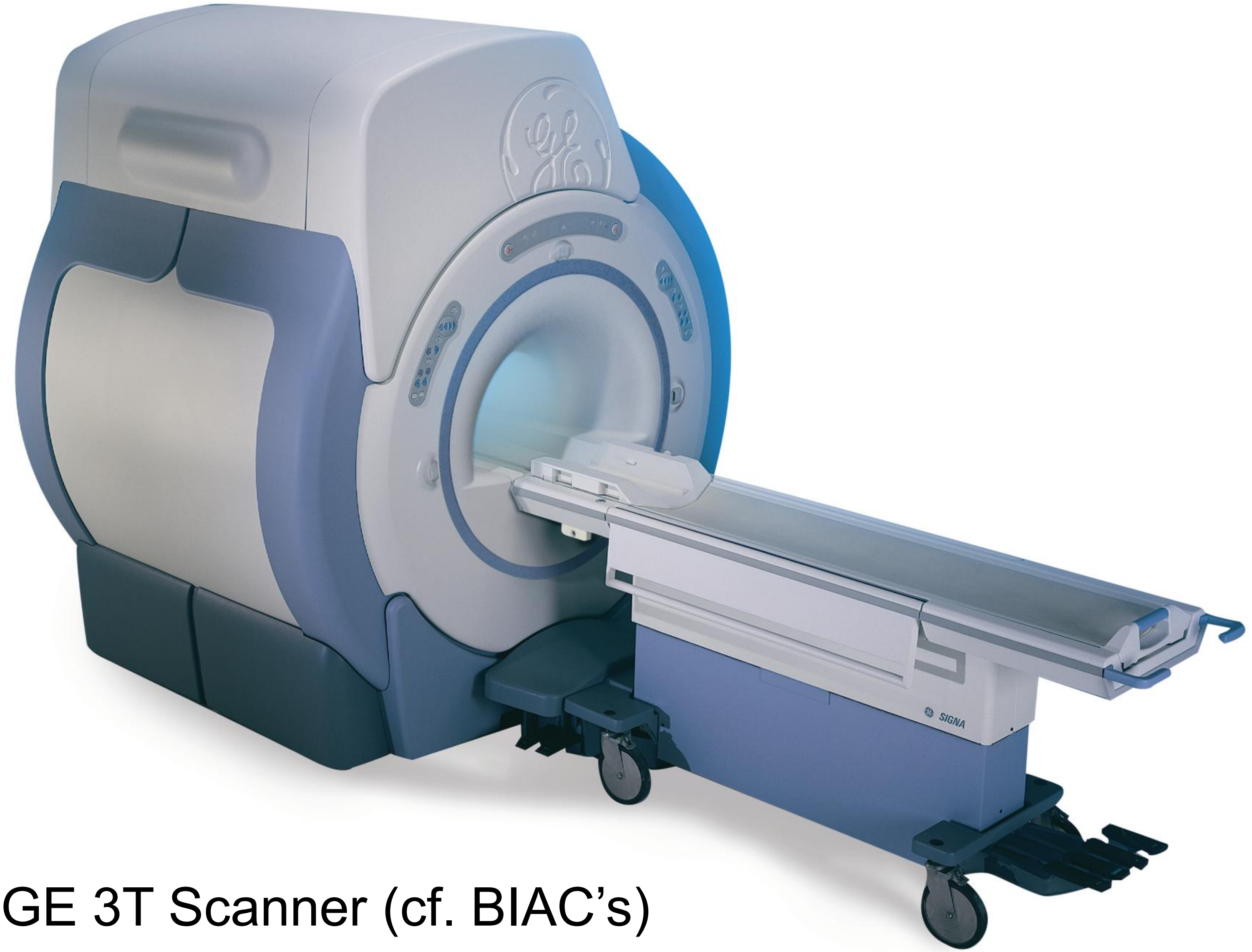

*FUNCTIONAL MAGNETIC RESONANCE IMAGING*, Figure 1.7 

# Functional Resolution

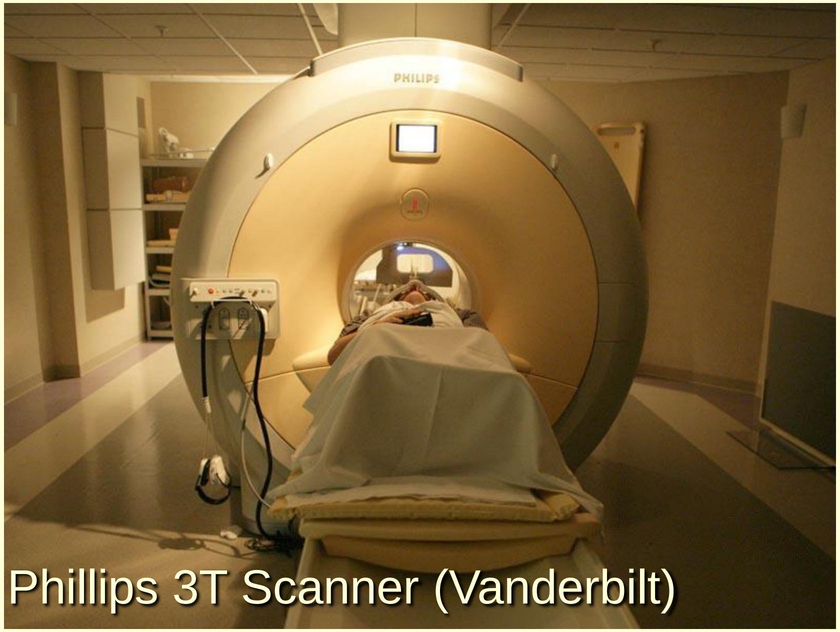
The ability of a measurement technique to identify the relation between underlying neuronal activity and a cognitive or behavioral phenomenon.

Functional resolution is limited both by the intrinsic <u>properties of our brain measure</u> and by our ability to <u>manipulate the experimental design</u> to allow variation in the phenomenon of interest.

# 3. MRI Scanners




GE 3T Scanner (cf. BIAC's)



Phillips 3T Scanner (Vanderbilt)

Siemens 3T Scanner


Phillips 0.6T Open Scanner


FONAR 0.6T MR
Operating Room

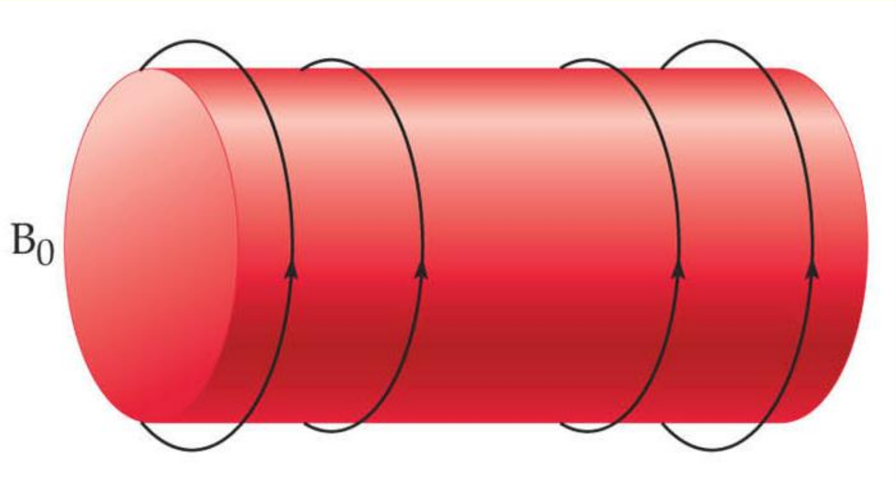
# Main Components of a Scanner

1. Magnetic: Static Magnetic Field Coils
2. Resonance: Radiofrequency Coil
3. Imaging: Gradient Field Coils

- Shimming Coils
- Data transfer and storage computers
- Physiological monitoring, stimulus display, and behavioral recording hardware

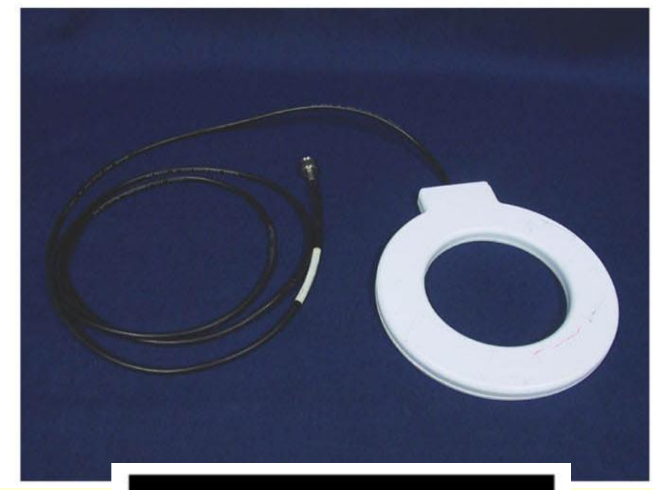
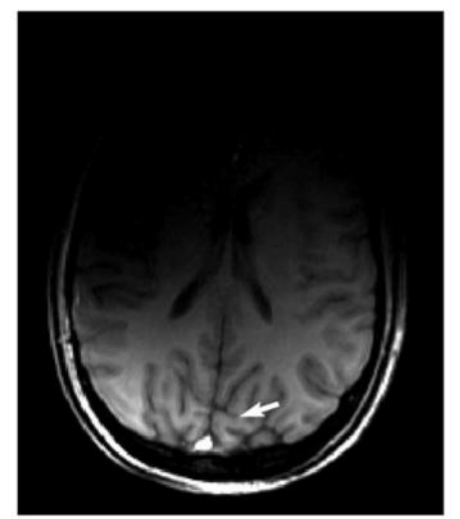
# 1. Magnetic: Static Field Coils

The scanner contains large parallel coilings of wires.
These generate the main magnetic field ($B_0$), which gives the scanner its field strength (e.g., 3T).

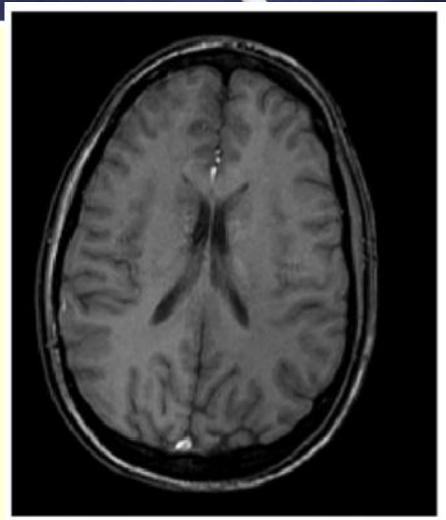


# 2. Resonance: Radiofrequency Coils

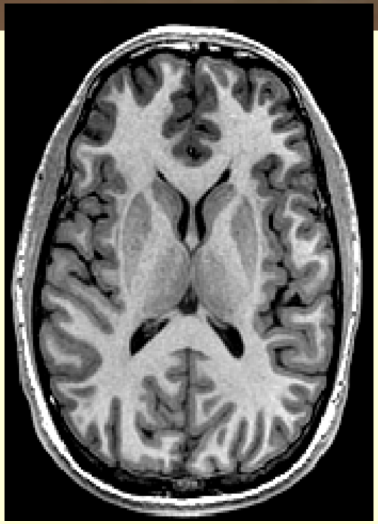
Surface Coil

Volume Coil

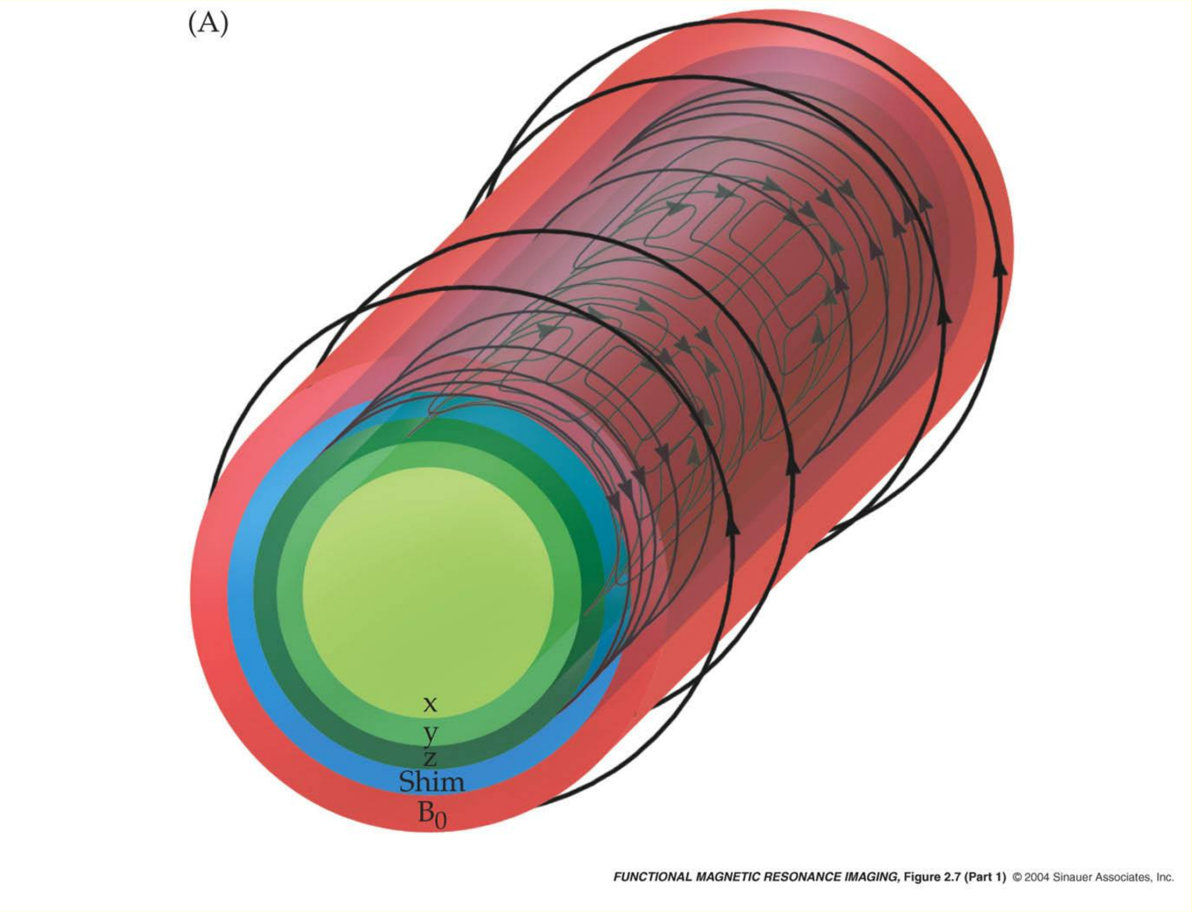



Phase-Array Coil

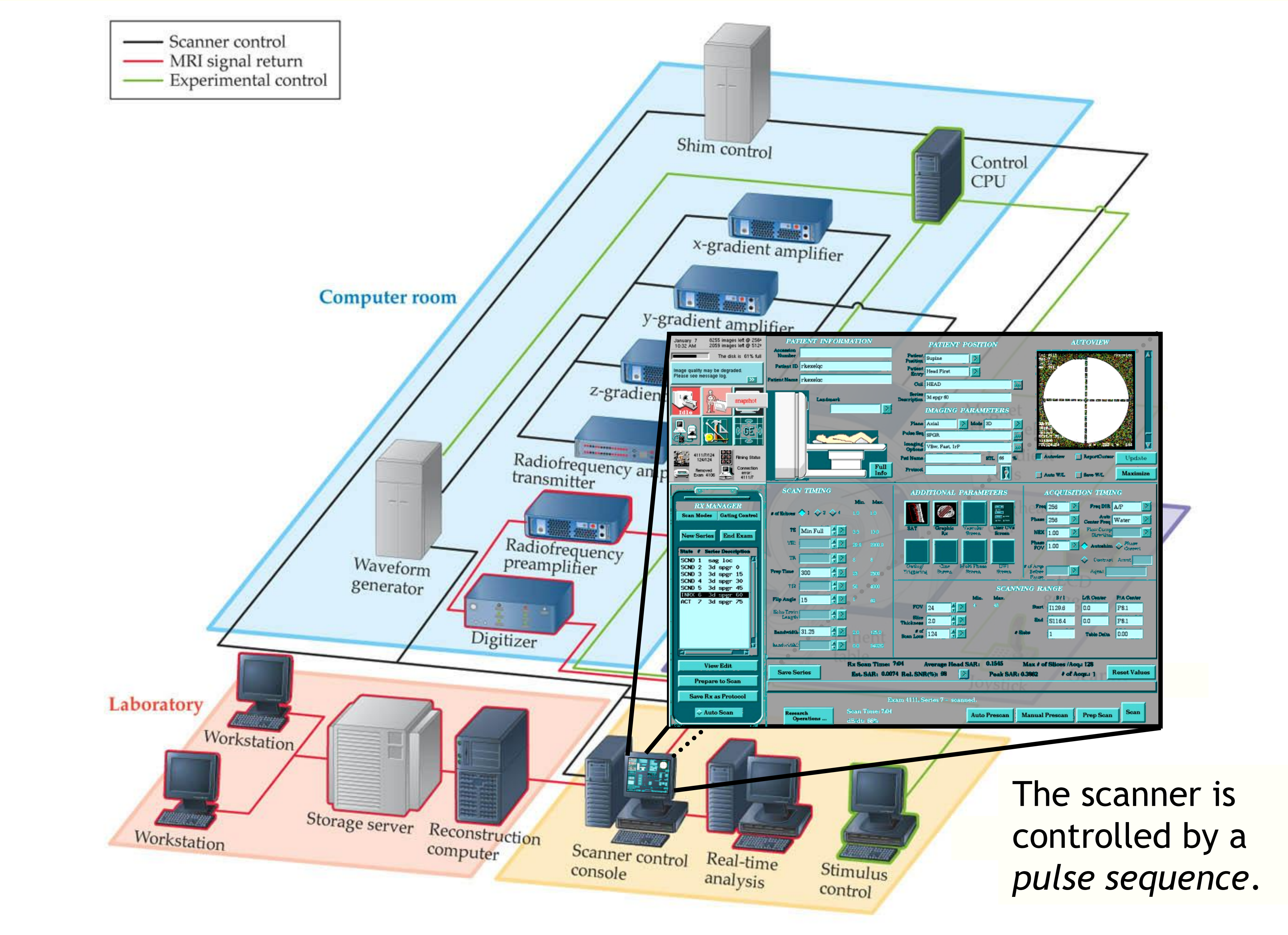



Electronic coils tuned to radio signals send energy into the brain and record an emitted “echo”.

# 3. Imaging: Gradient Coils



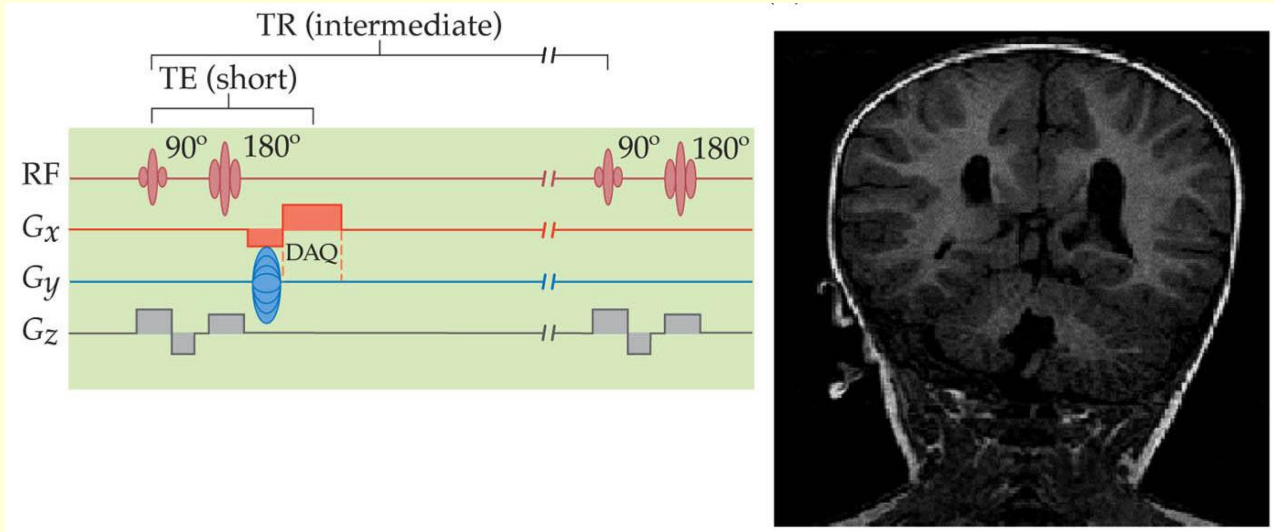

Three gradient coils are used, one in each of the cardinal directions. These allow spatial encoding of the MR signal.



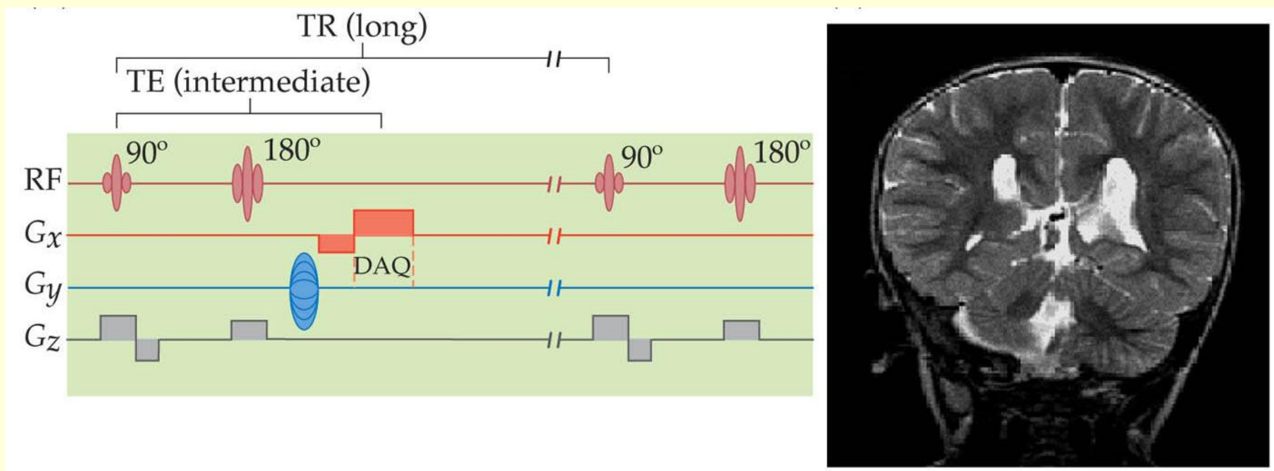

The scanner is controlled by a *pulse sequence*.

# Pulse Sequences

$T_1$




$T_2$




- Recipes for controlling scanner hardware
- Allow MR to be extremely flexible

# 4. MRI in Detail

# Synopsis of MRI

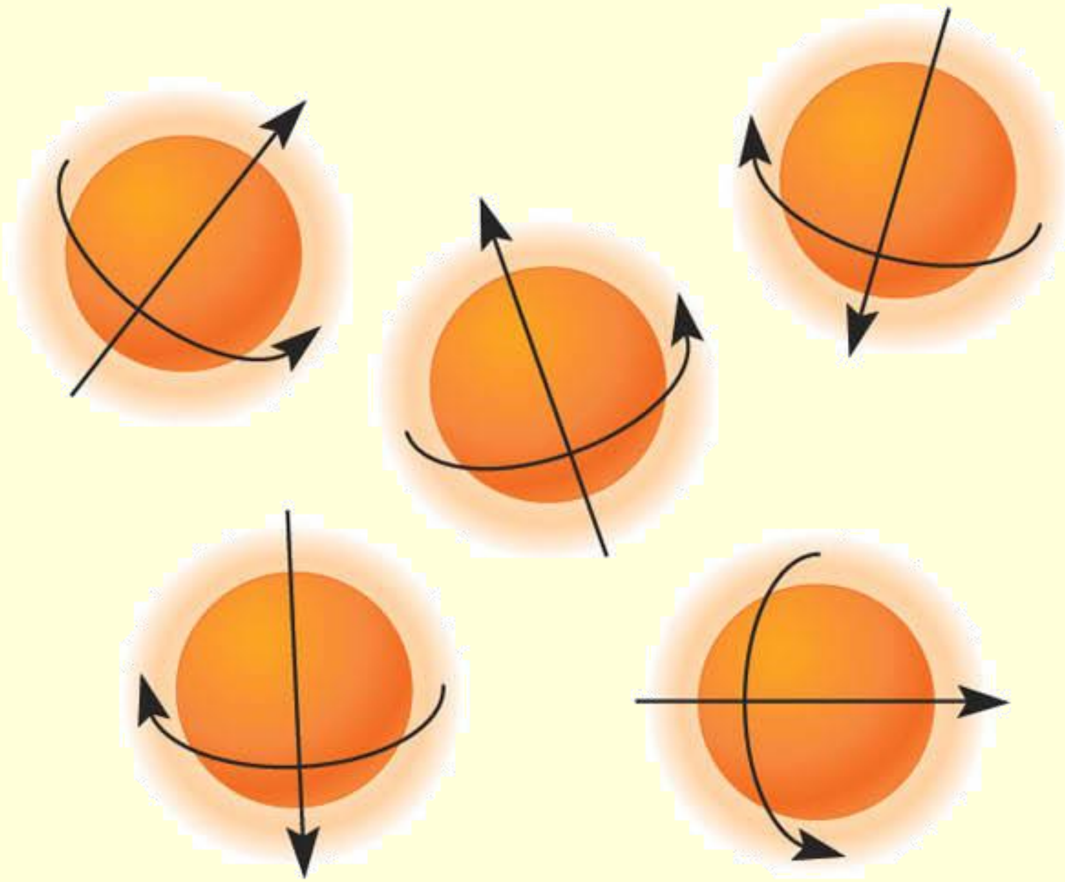
M: Put subject in strong magnetic field

R: Transmit radio waves into subject, turn off transmitter, receive radio waves emitted by subject's brain. This is the MR signal.

I: Modulate the strength of the magnetic field slightly over space.


M

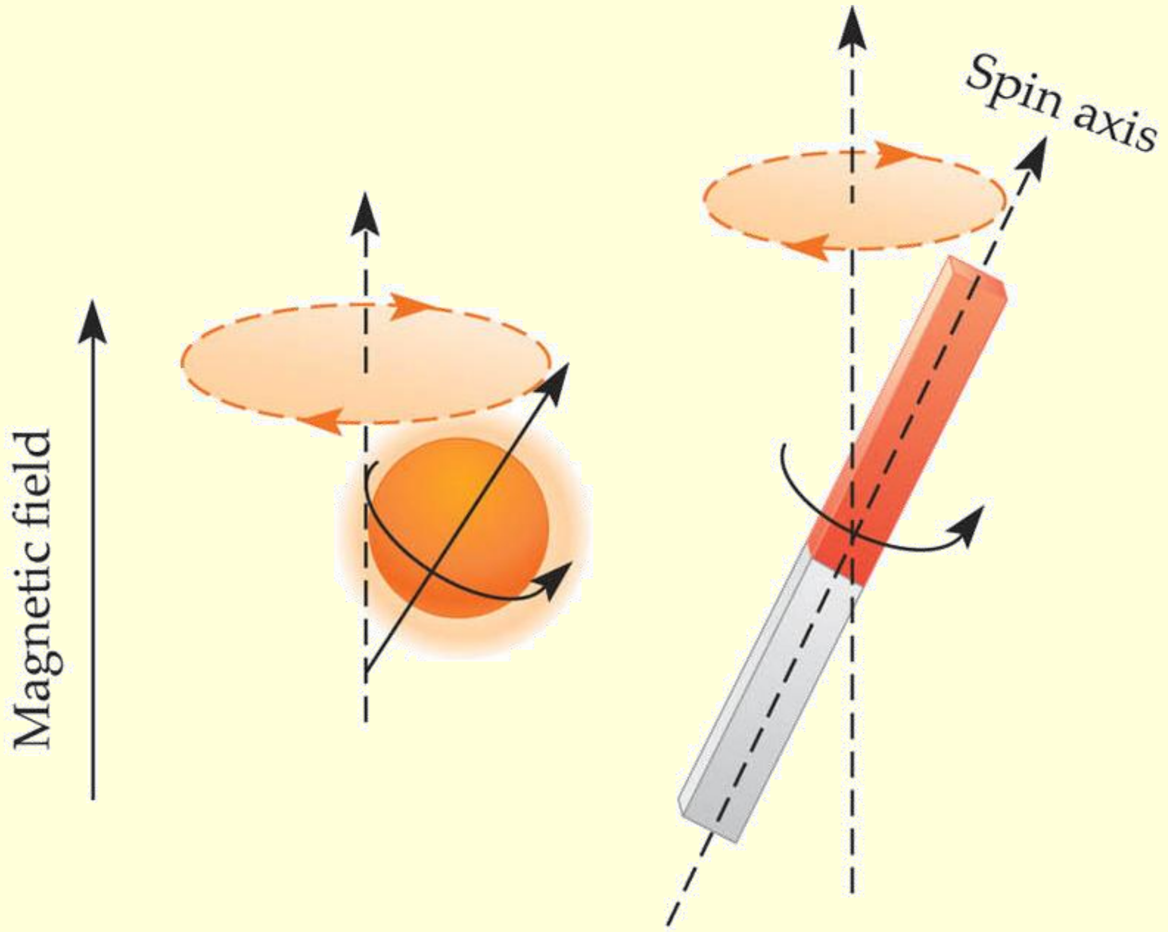
# Protons in no magnetic field



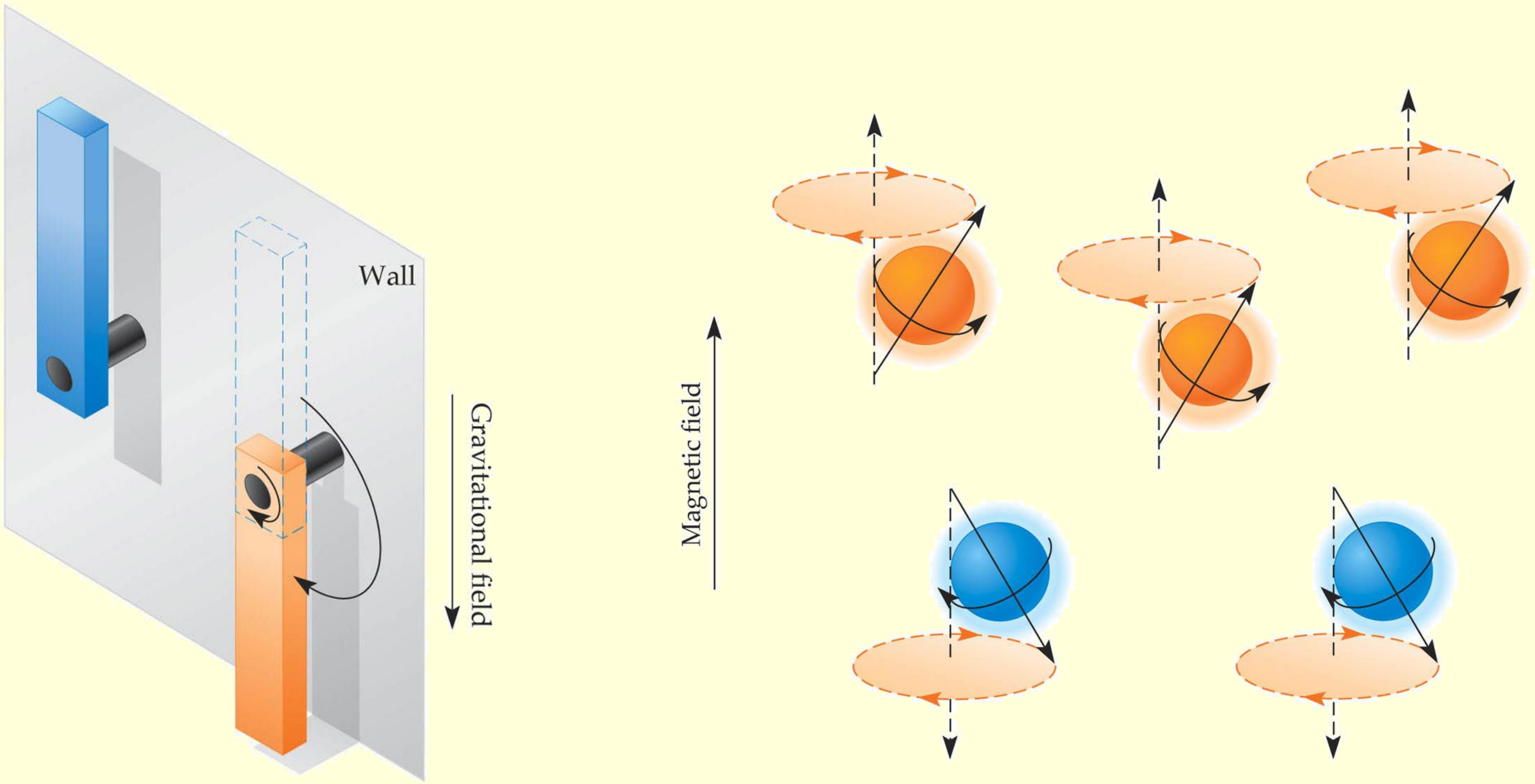
**In the absence of a strong magnetic field, the spins are oriented randomly.**

**Thus, there is no net magnetization (*M*).**

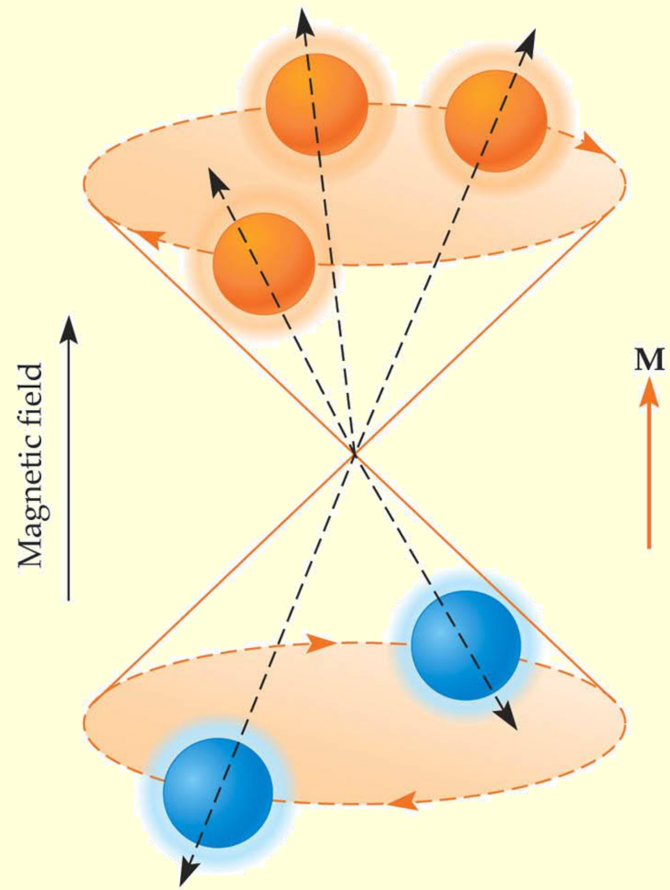
# Protons align with a magnetic field…



# In a magnetic field, protons can take *high*- or low-energy states




FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 3.5 © 2004 Sinauer Associates, Inc.

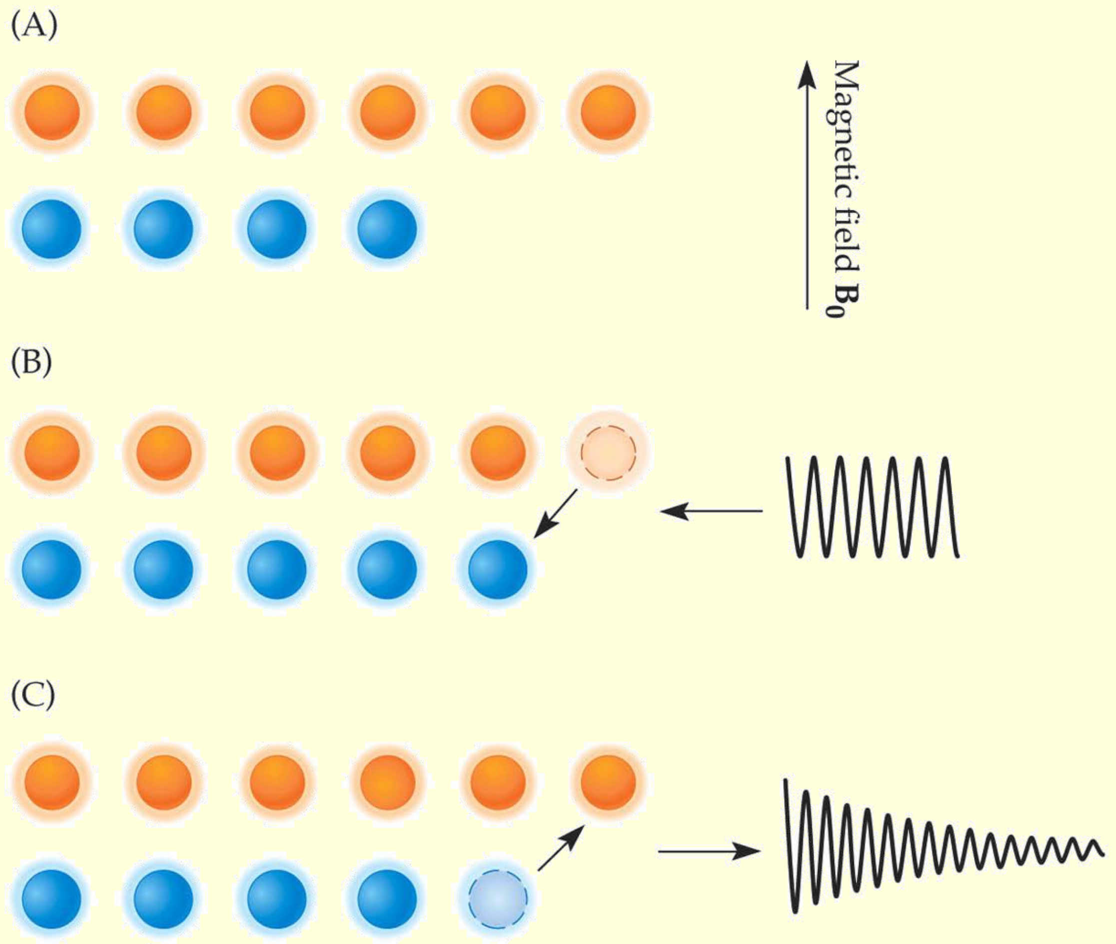



FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 3.7 © 2004 Sinauer Associates, Inc.

**The difference between the numbers of protons in the high-energy and low-energy states results in a net magnetization (M).**

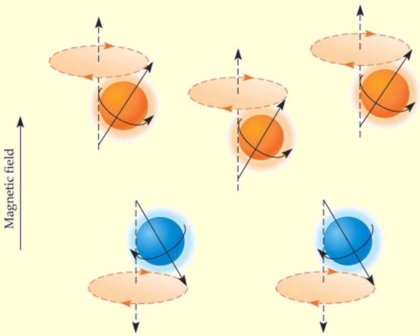

R

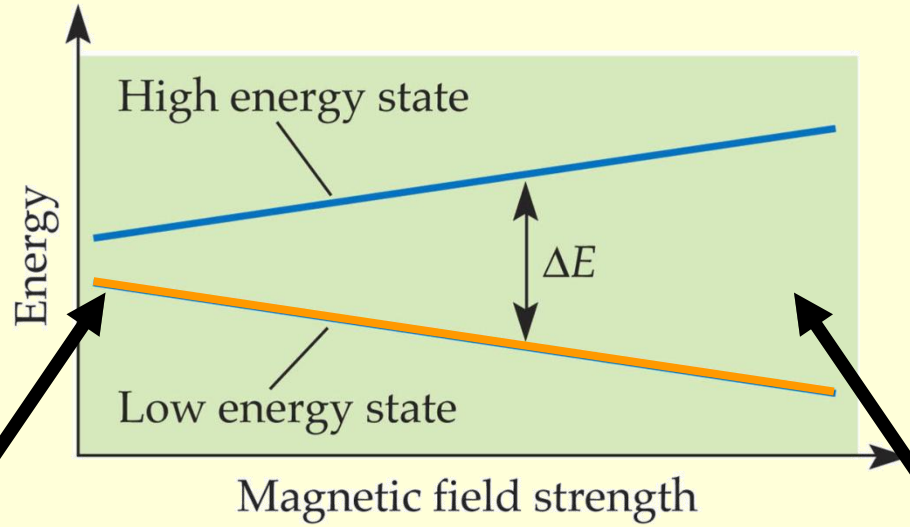
# Excitation: Conceptual Overview




FUNCTIONAL MAGNETIC RESONANCE IMAGING, Figure 3.9 

# Energy states: Magnetic field effects

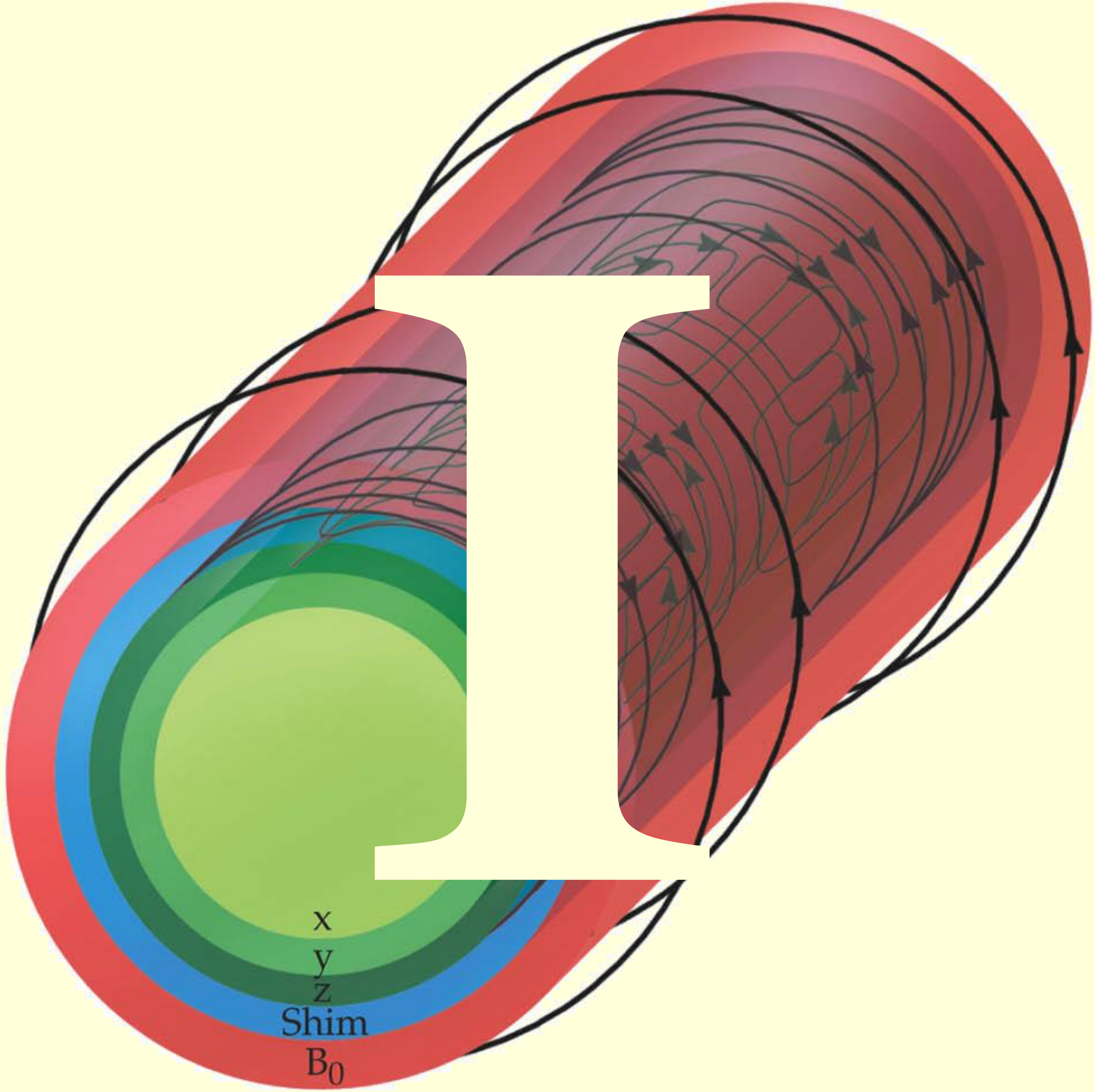


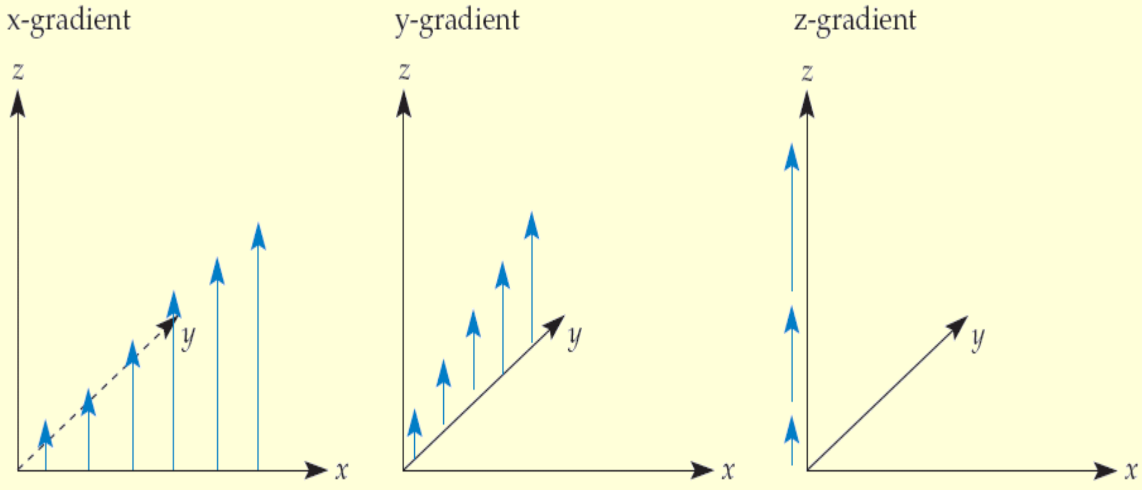

When the magnetic field is weak, little energy is required for a proton to change between high and low states (ΔE is small).

But, when the magnetic field is strong, much more energy is required (ΔE is large).

Thus, protons in the lower-energy state tend to stay in that state


I
x
y
z
Shim
$B_0$

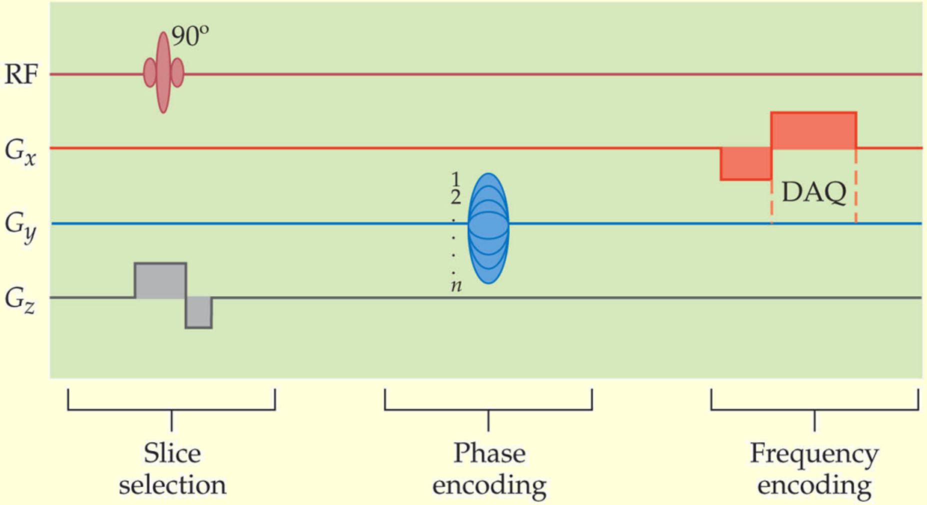
# Gradients change the Strength, not Direction of the Magnetic Field



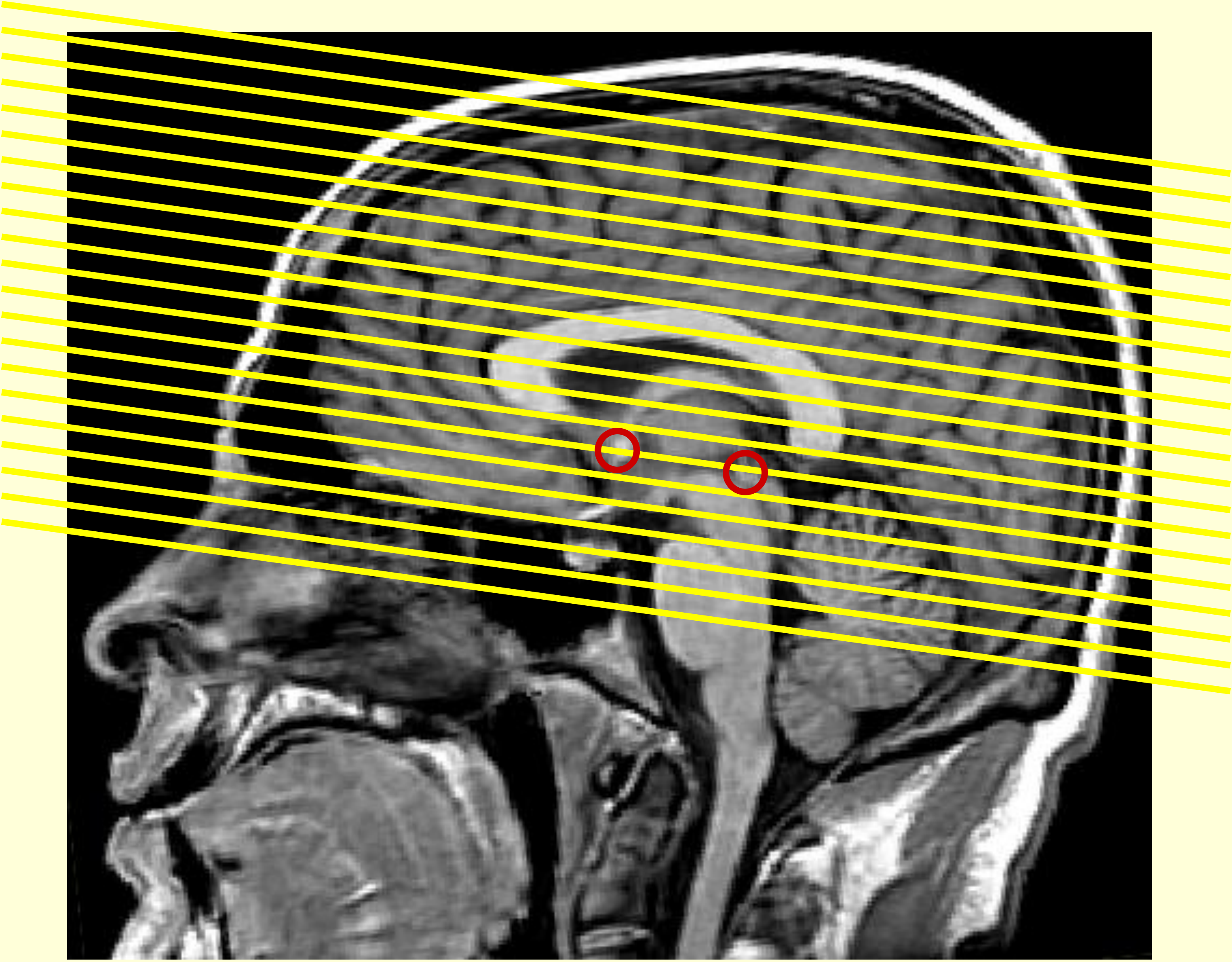
# Parts of 2D Image Formation

- Slice selection
  - Linear z-gradient
  - Tailored excitation pulse

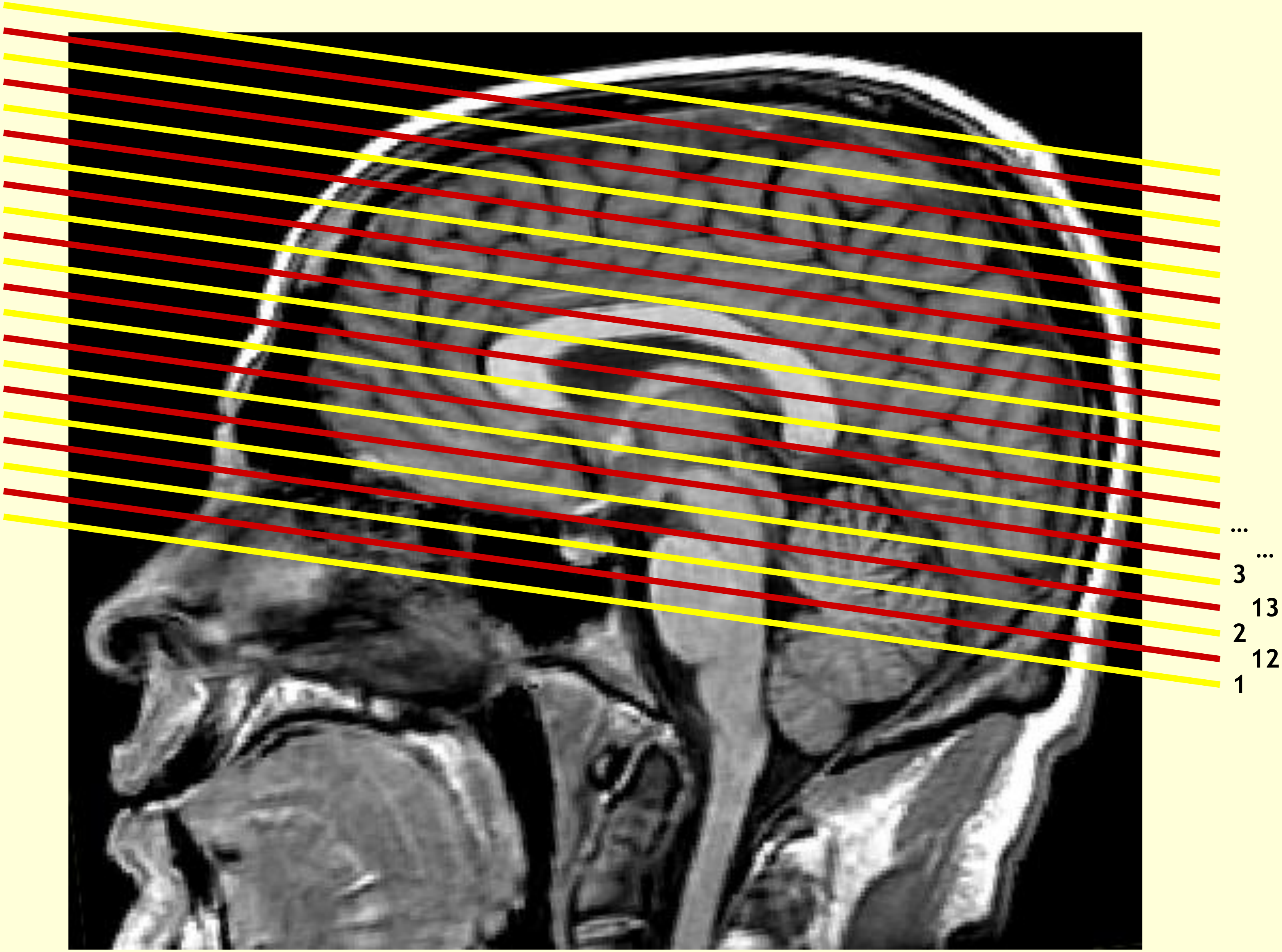
- Spatial encoding within the slice
  - Frequency encoding
  - Phase encoding

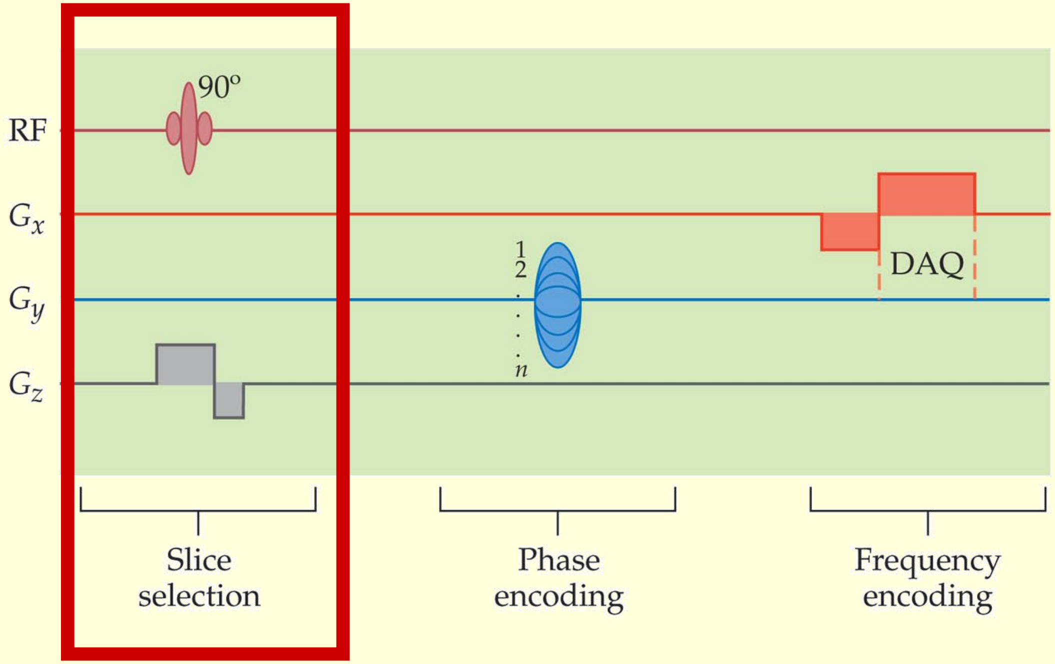


# Slice Selection



# Interleaved Slice Acquisition

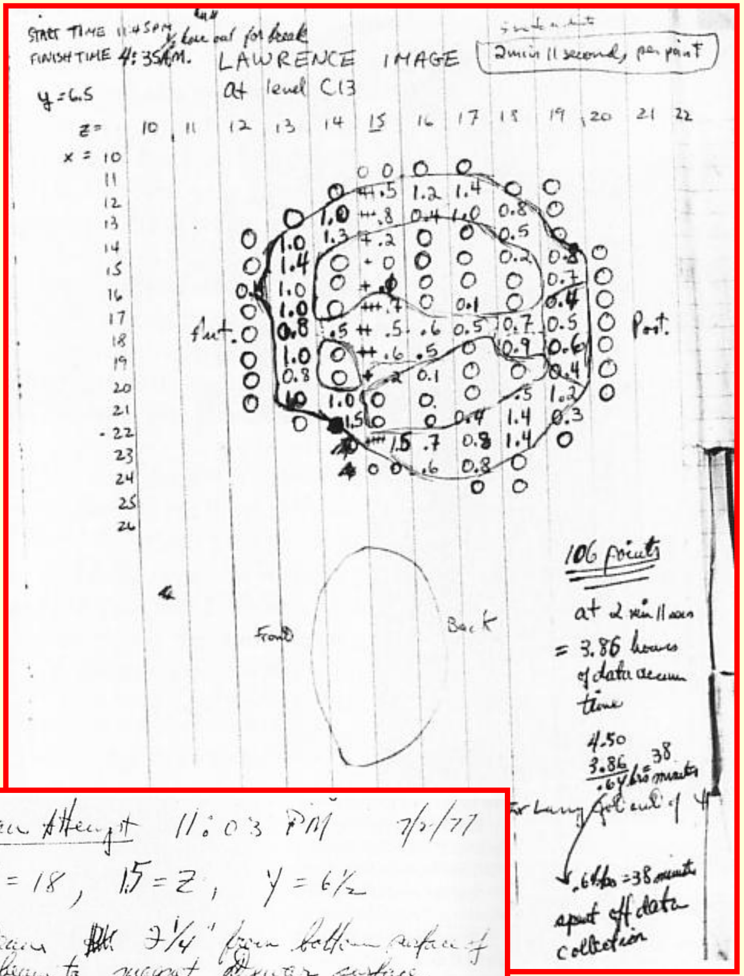


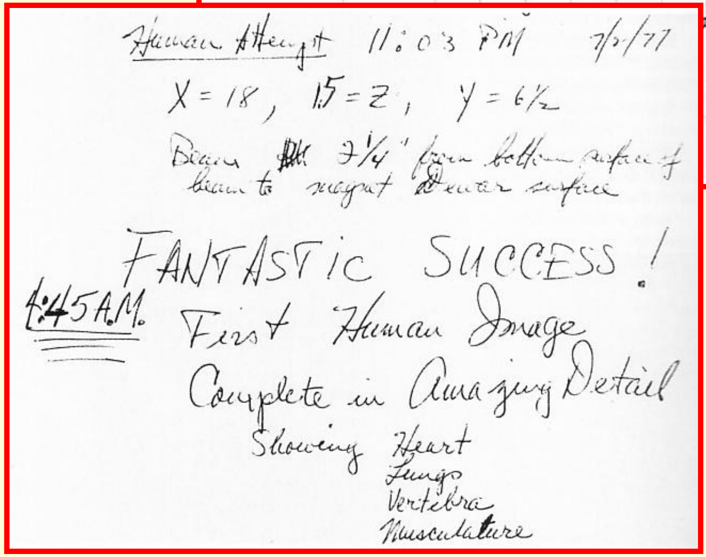

90°
RF
$G_x$
$G_y$
$G_z$
1
2
n
DAQ
Slice selection
Phase encoding
Frequency encoding

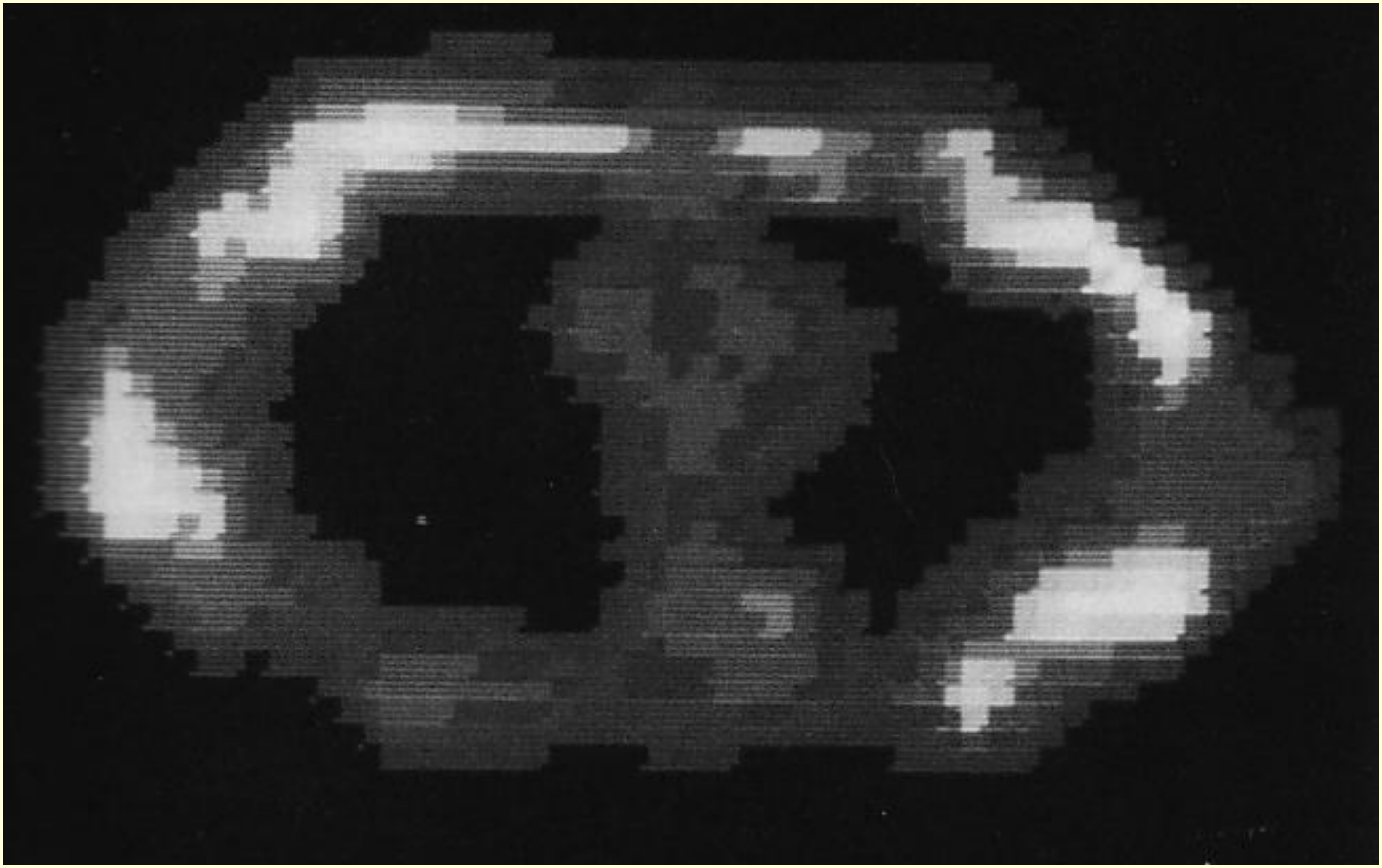
# Spatial Encoding

# Early Human MR Images (Damadian)
# How not to spatially encode

© Fonar Corporation

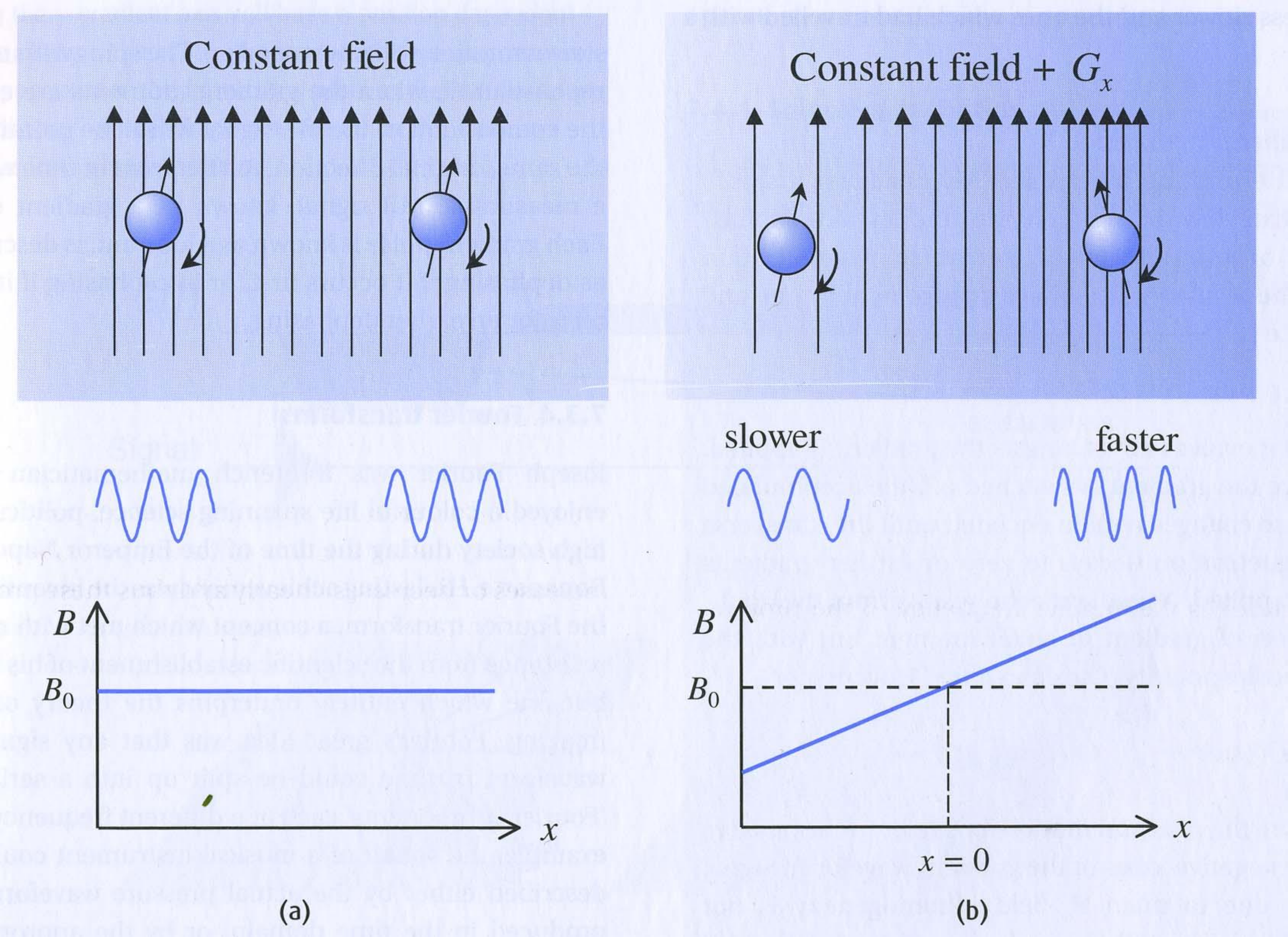




Human Attempt 11:03 PM 7/2/77
X = 18, 15 = Z, Y = 6½
FANTASTIC SUCCESS!
4:45 A.M. First Human Image
Complete in Amazing Detail
Showing Heart
Lungs
Vertebra
Musculature

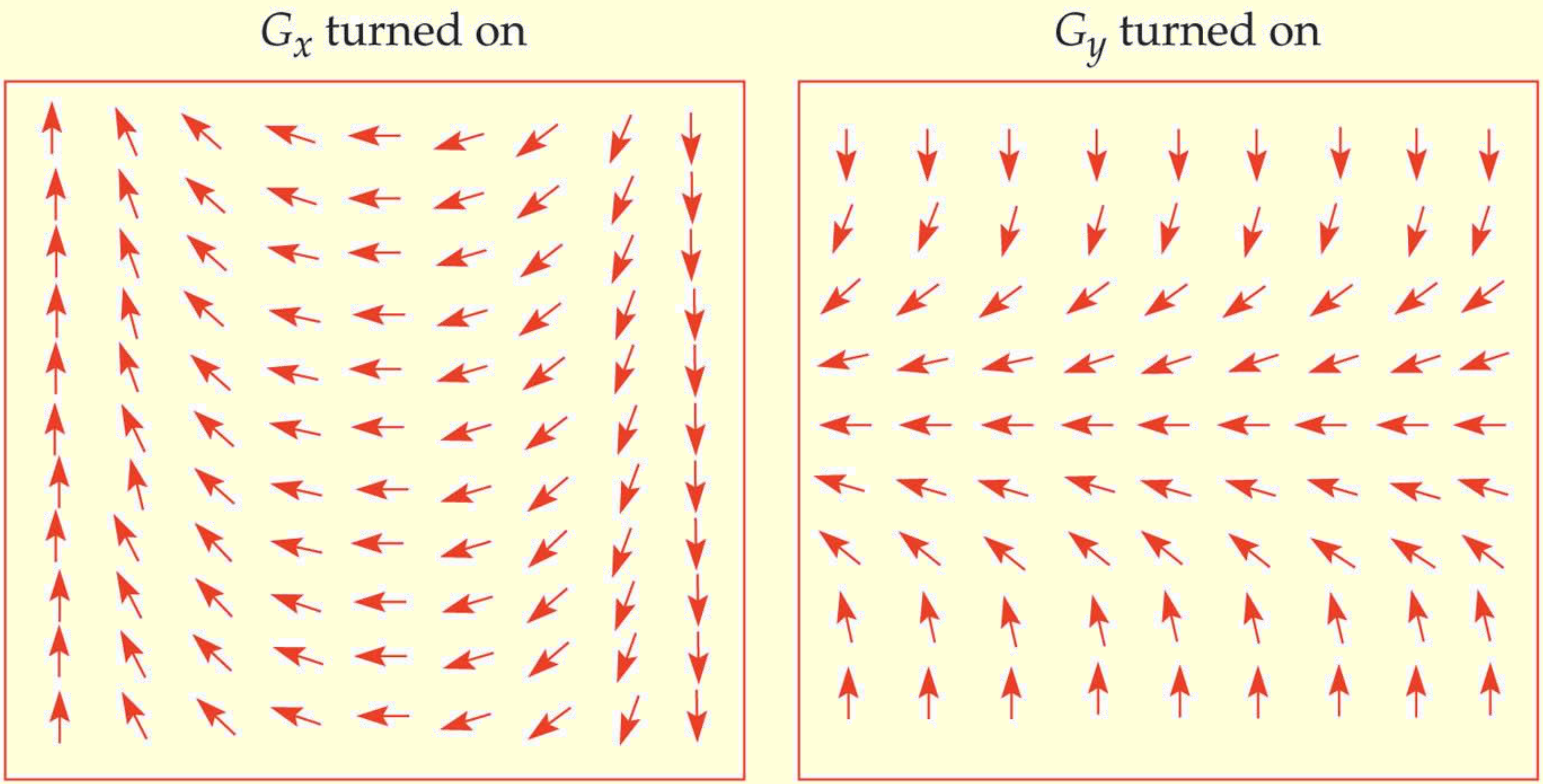


Mink5 Image – Damadian (1977)

# What does a varying magnetic field cause?



# Effects of Gradients on Phase



# Why manipulate frequency and phase?

- By combining frequency and phase encoding
  - Each voxel in each slice will have a unique phase-frequency combination.
  - With Fourier Analyses we can distinguish these components from one another
  - This allows us to determine where signal originates

# Summary of Key Concepts

- Contrast
  - quantitative difference between two values
  - our ability to distinguish differences in anatomy and function
- Spatial Resolution
  - Typical anatomicals ~1mm
  - Typical functionals ~4mm
- Temporal Resolution
  - Typically a few seconds
- <u>Functional</u> Resolution
  - ability to distinguish the function(s) of a region
  - depends as much on fMRI as exp design

# Summary of MRI

- MRI requires a strong (homogenous) magnetic field
- We measure changes in the system by perturbing it
- We can localize signal by uniquely encoding voxels with frequency and phase encoding.

# Additional Resources

- Overview of MRI
  - http://www.sinauer.com/neuroscience4e/animations1.1.html
- MRI physics
  - http://www.mri-tutorial.com
  - www.simplyphysics.com

# Questions?