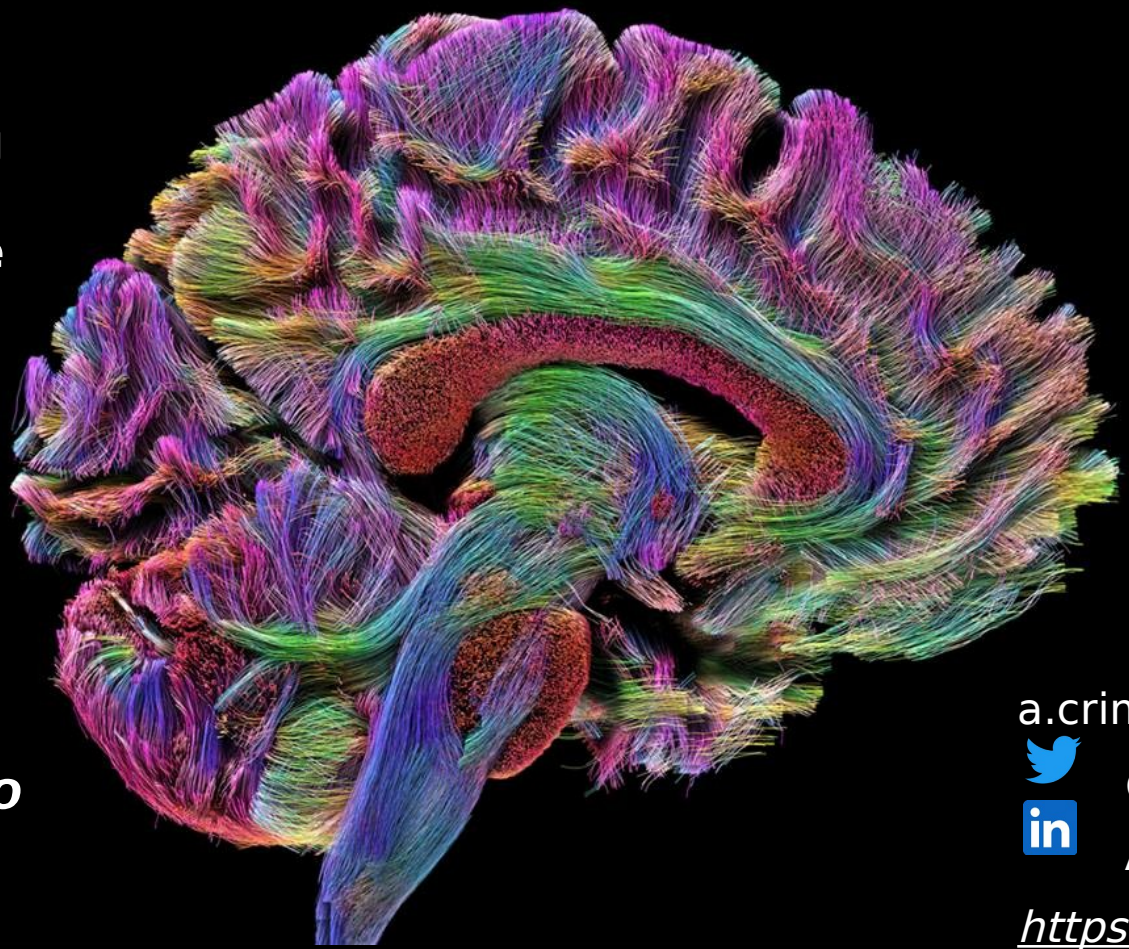
Machine Learning for Neuroimaging and Neuroscience



Lesson 1

Introduction to data

a.crimi@sano.science
@Dr_alex_crimi
Alessandro Crimi
https://bam.sano.science/

Objectives

At the end of this course, you SHOULD be able to

1. Master and explain fundamental aspects of data related to neuroimaging.
2. Write programs to perform statistical prediction or pattern recognition on neuroimaging or neuroscience.
3. Be able to design studies using statistics or machine learning in neuroimaging (e.g. diagnose/predict stroke, brain tumor, etc).

Contacts

a.crimi@sanoscience.org alecrimi@agh.edu.pl

c.koba@sanoscience.org

a.onicas@sanoscience.org

j.falcoroget@sanosciece.org

Syllabus

14 sessions

- Lectures
- Laboratories
- Projects

Final grades 50% from laboratories and project

Syllabus

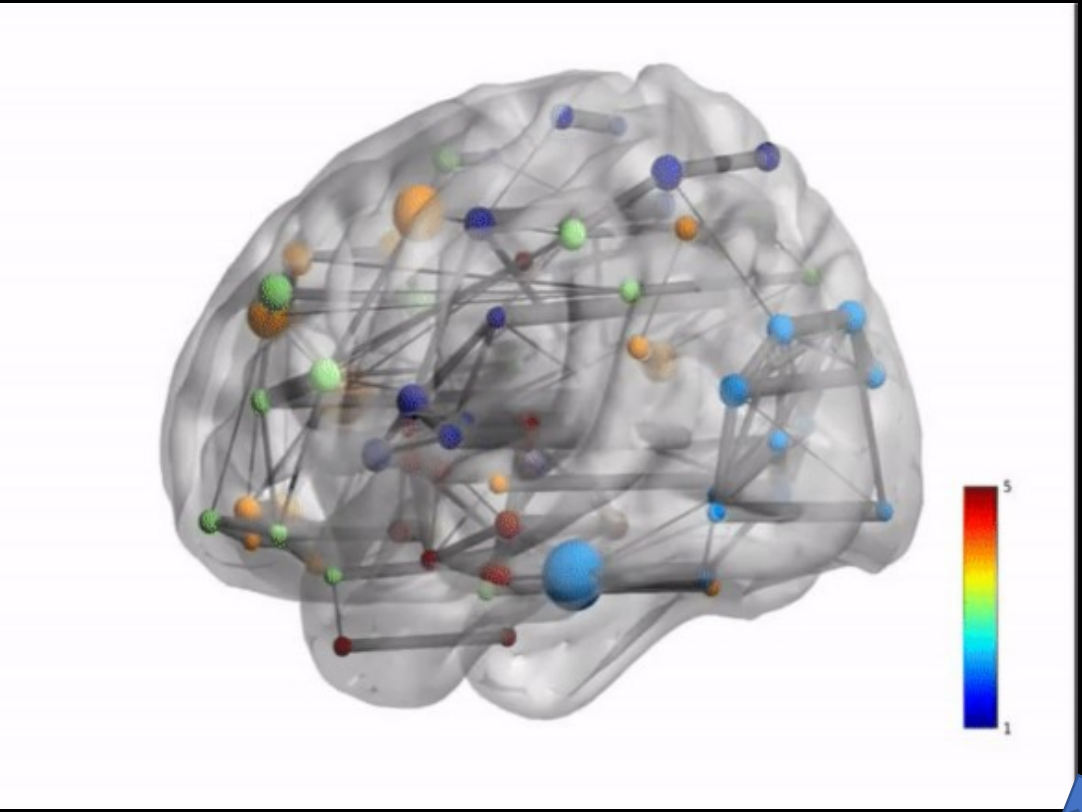
Lectures

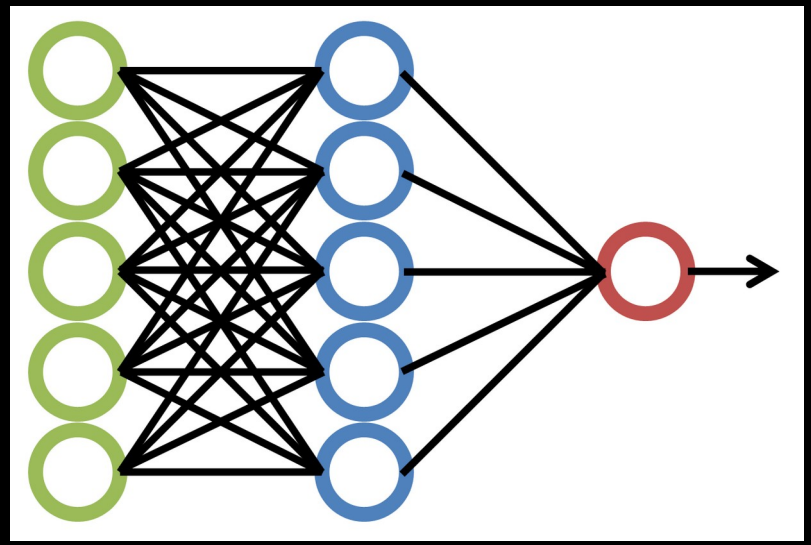
1. Introduction to neuroimaging data (date:)
2. Structural connectivity (date:)
3. Functional connectivity (date:)
4. EEG and wearables (date:)
5. Graph connectivity (date:)
6. Causality and effective connectivity (date:)
7. BCI & review (date:)

Lab plans (We alternate sessions of guided lab activities and assigned projects: from October 3rd until January 23rd 2024)

8. Data structures, tools, and brain tumor segmentation
9. From tractography to connectoma (MRTRIX & DiPy), fiber clustering
10. Classify functional connectome via oldschool machine learning tools
11. Graph convolutional networks on functional connectome EEG
12. Effective connectivity with Granger Causality
13. LSD vs non-LSD group comparison, free assignment

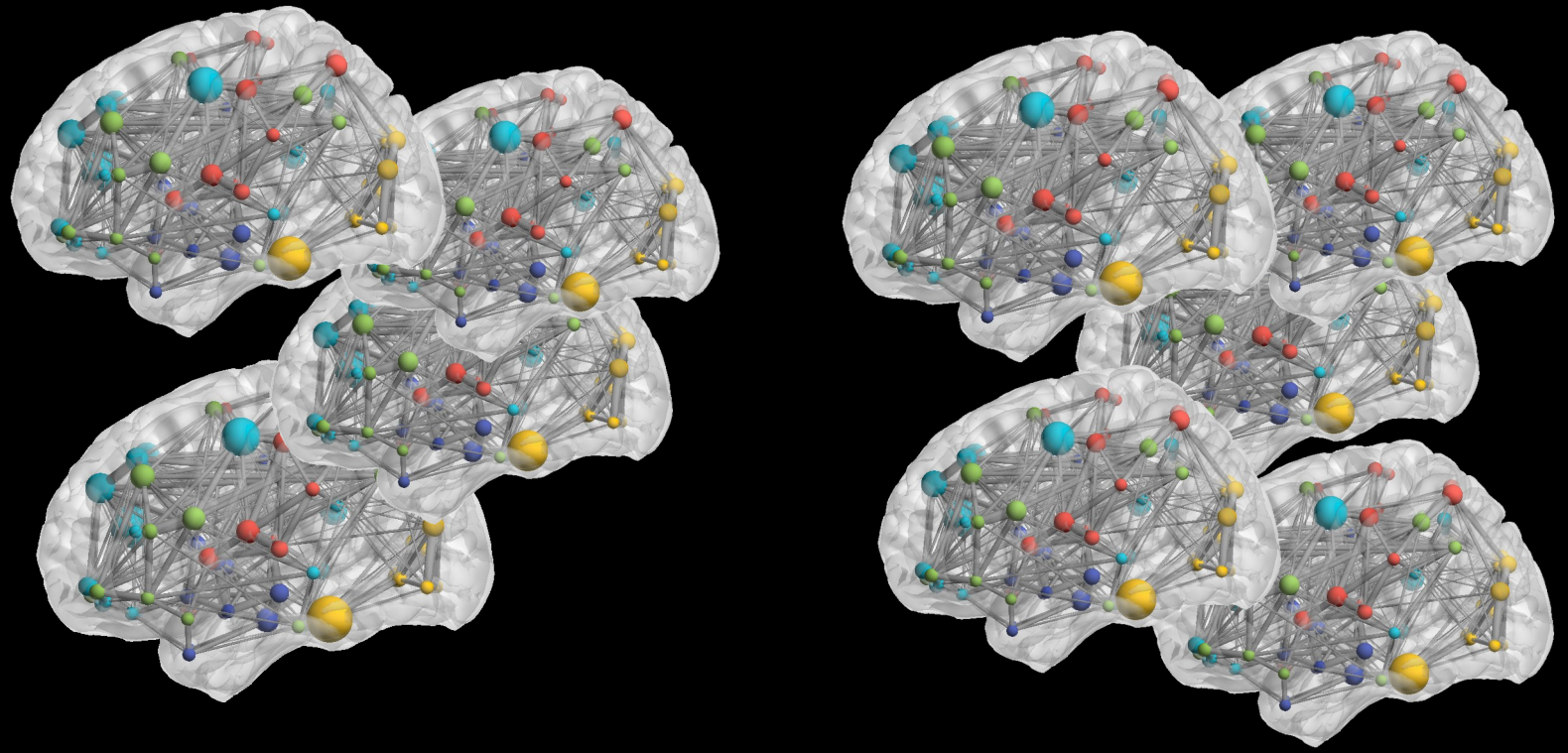
Welcome



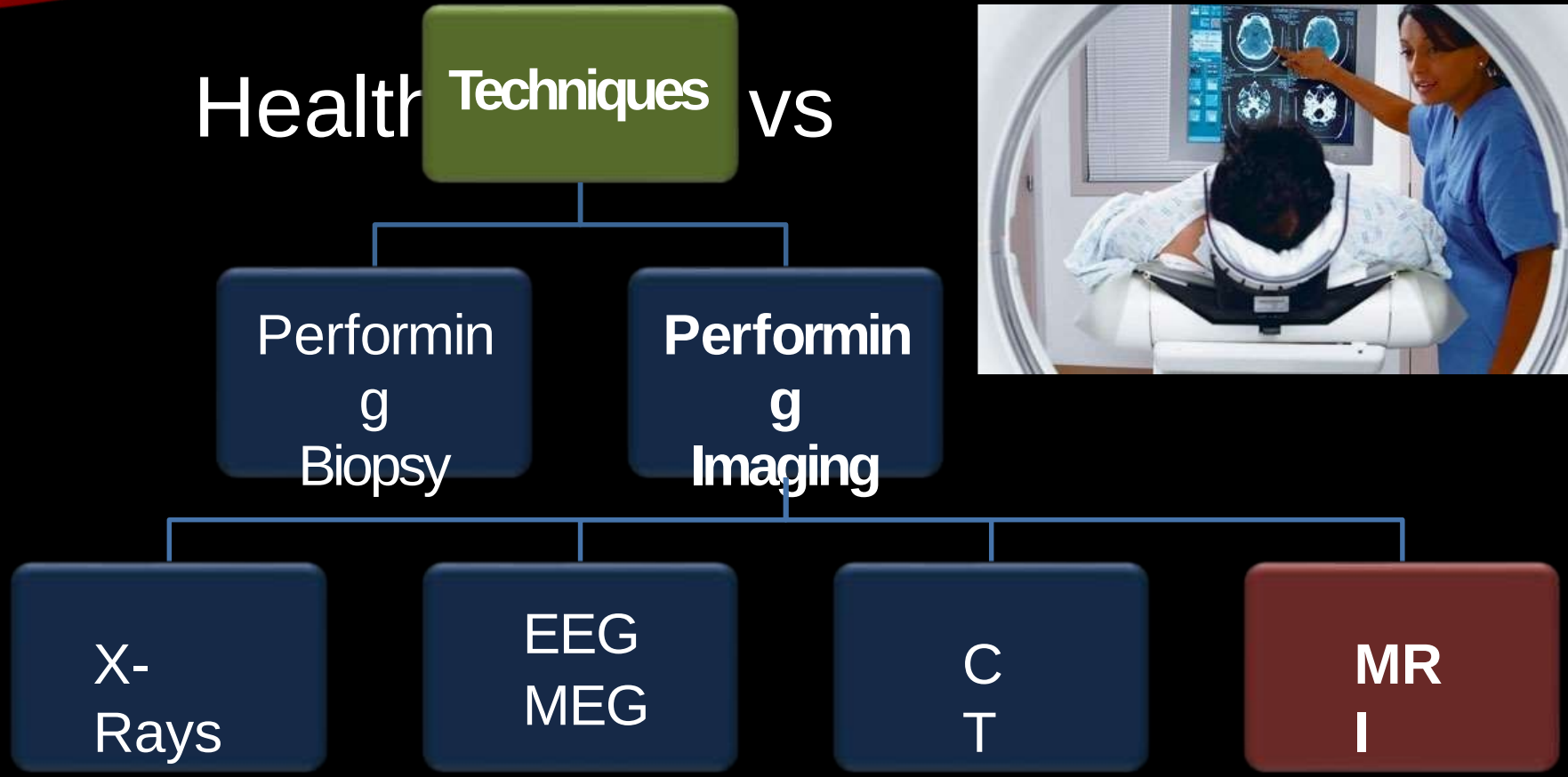


Alzheimer, Schizophrenia,... **Matched healthy control**

Healthy vs Alzheimer



We can use different technologies and modalities



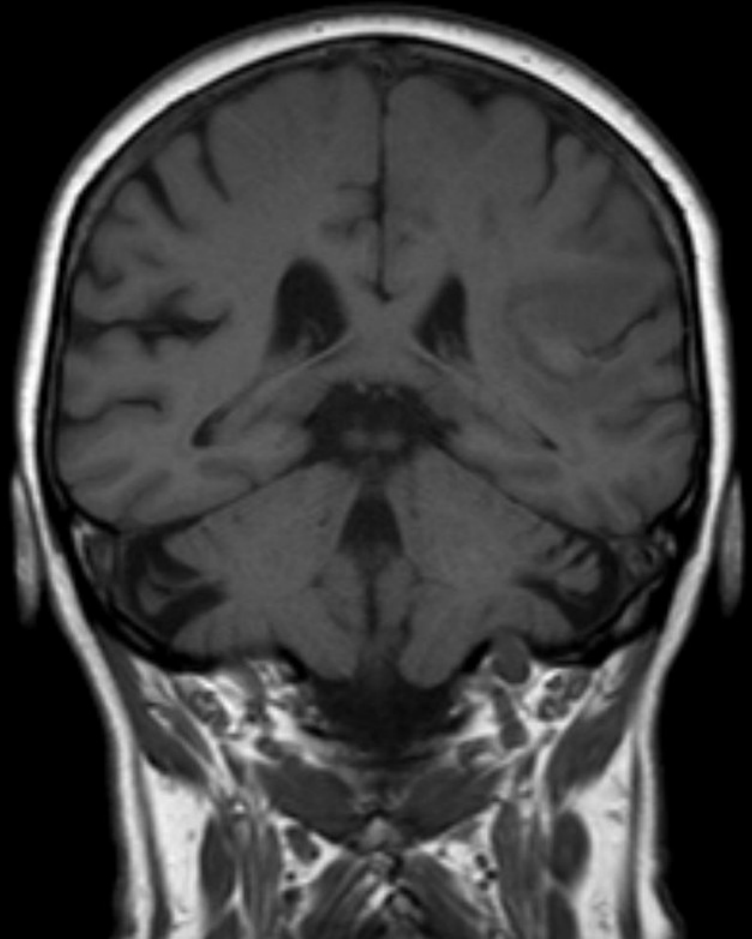
We can use different technologies and modalities

- CT (x-ray, ionizing radiation, with or without contrast)
- MRI (magnetic field and radio pulses, with or without contrast)
- EEG (detecting electrical signal)
- Ultrasound– rarely used
- PET and SPECT imaging (radioactive tracer)

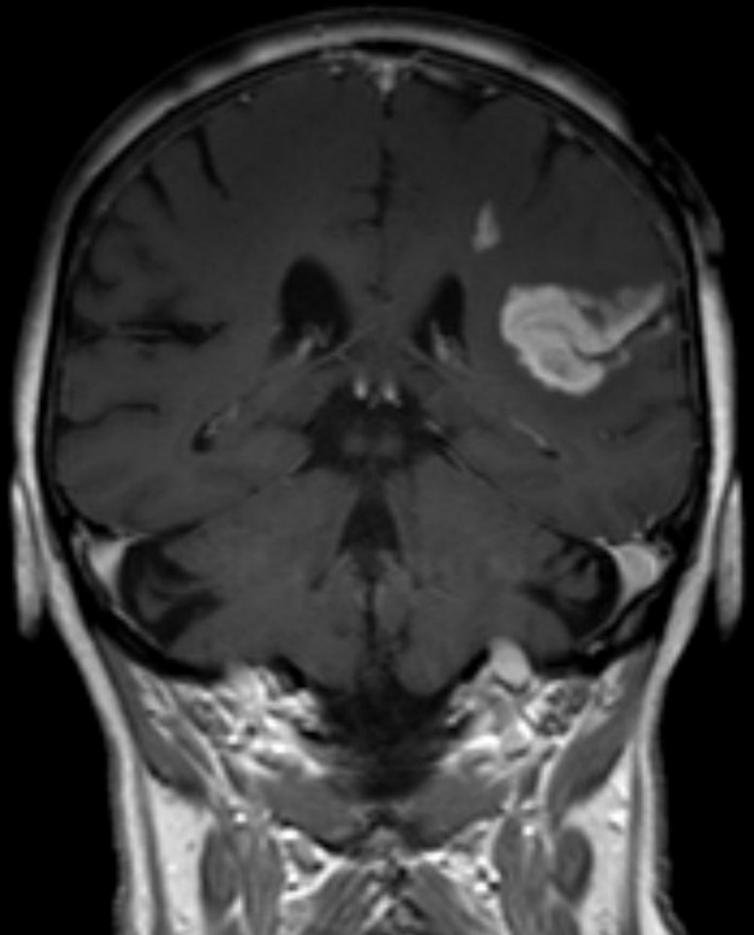
Enhancement

- Patients receive and injections or something
- Implies that contrast is visible
- Can be normal (e.g., blood vessels)
- Often pathologic– implies blood-brain barrier

No Enhancement

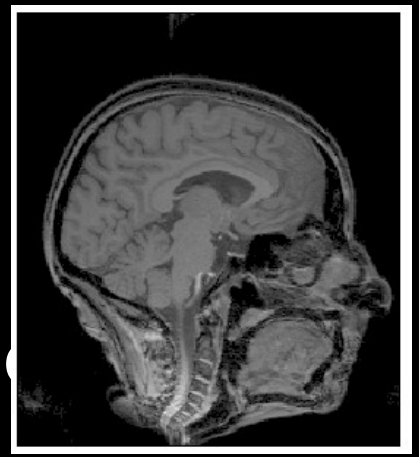


No Enhancement

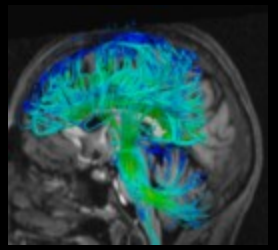


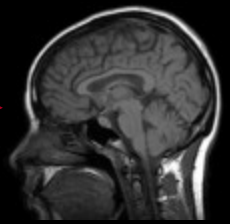
Neuroimaging can take different forms

- CT Pros and Cons
  - good for intracranial haemorrha or calcified lesions, quick
  - Cheap & dirty
- MRI Pros and Cons
  - superior tissue contrast and spatial resolution
  - expensive, noisy, claustrophobi



MRI is cool

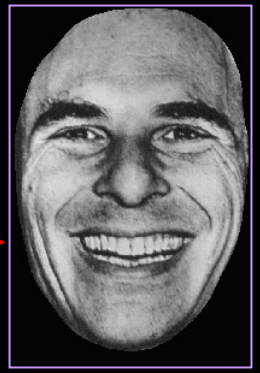




How does research work?

MRI Scanner

MRI Scanner

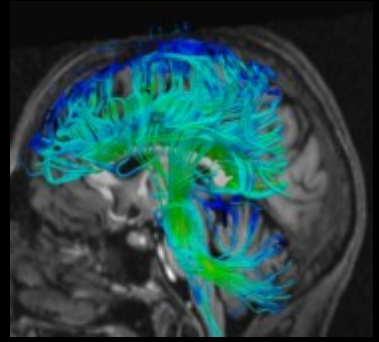


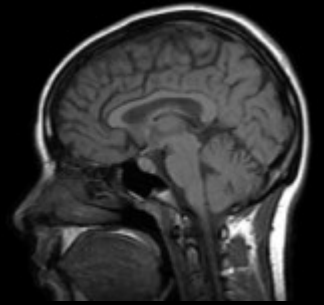
Stimulus

(e.g. picture)

Process Data

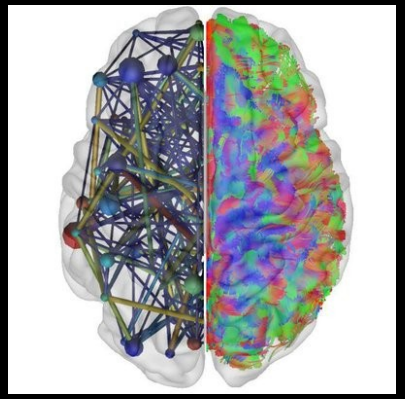
Process Data

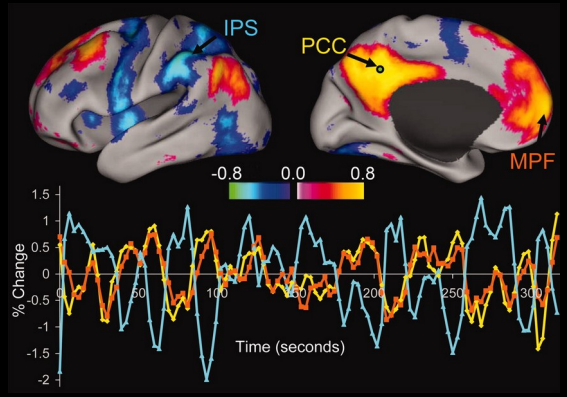


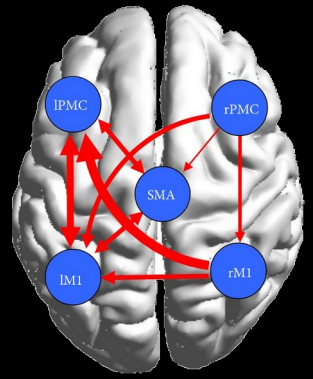


There is more (e.g. MRA)

Structural, functional &A effective connectivity





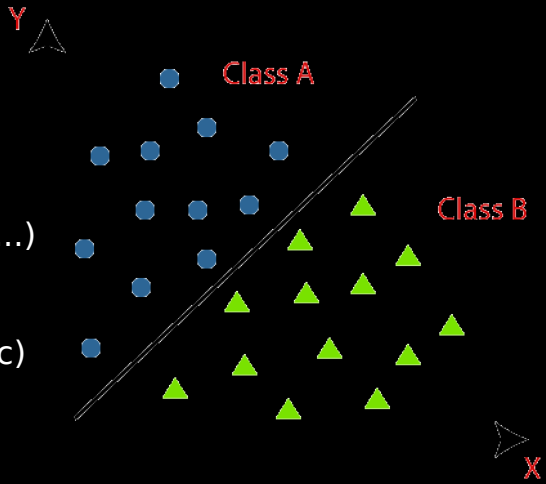


Structural/anatomical connectivity
= presence of axonal connections / white matter tracks (eg, DWI, AAV tracers)

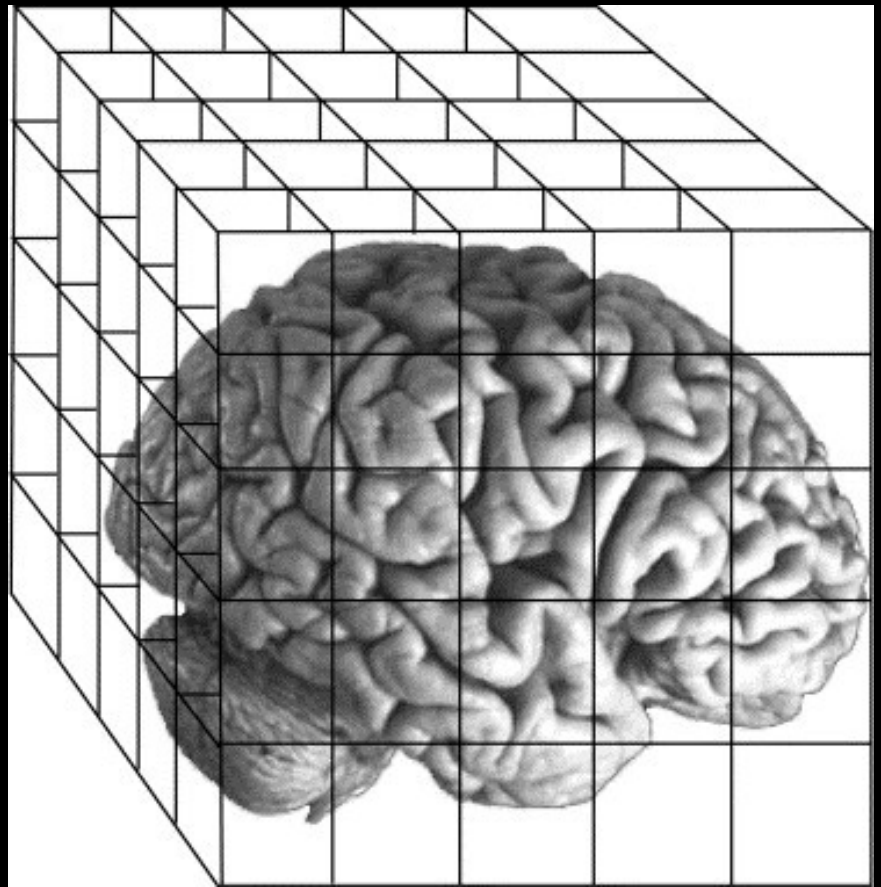
Functional connectivity
= statistical dependencies between regional time series (eg, Pearson correlation, ICA,...)

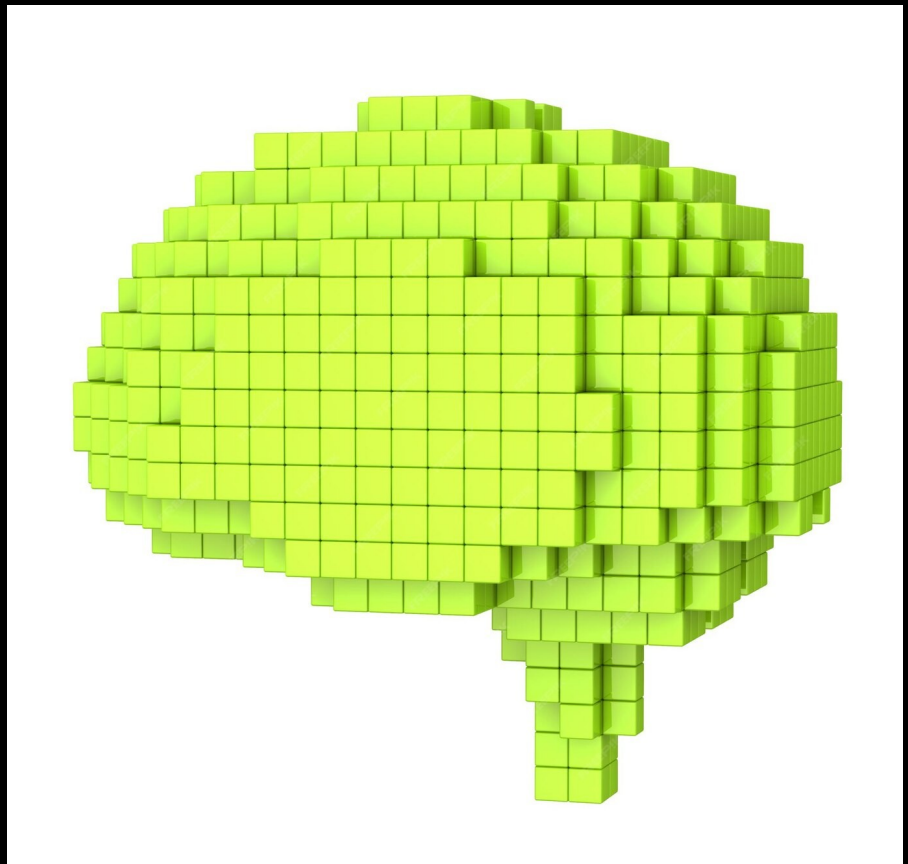
Effective connectivity
= causal (directed) influences between neuronal populations (eg, DCM, Granger C., etc)

Nobody cares about **Morphological connectivity** ☹ ...

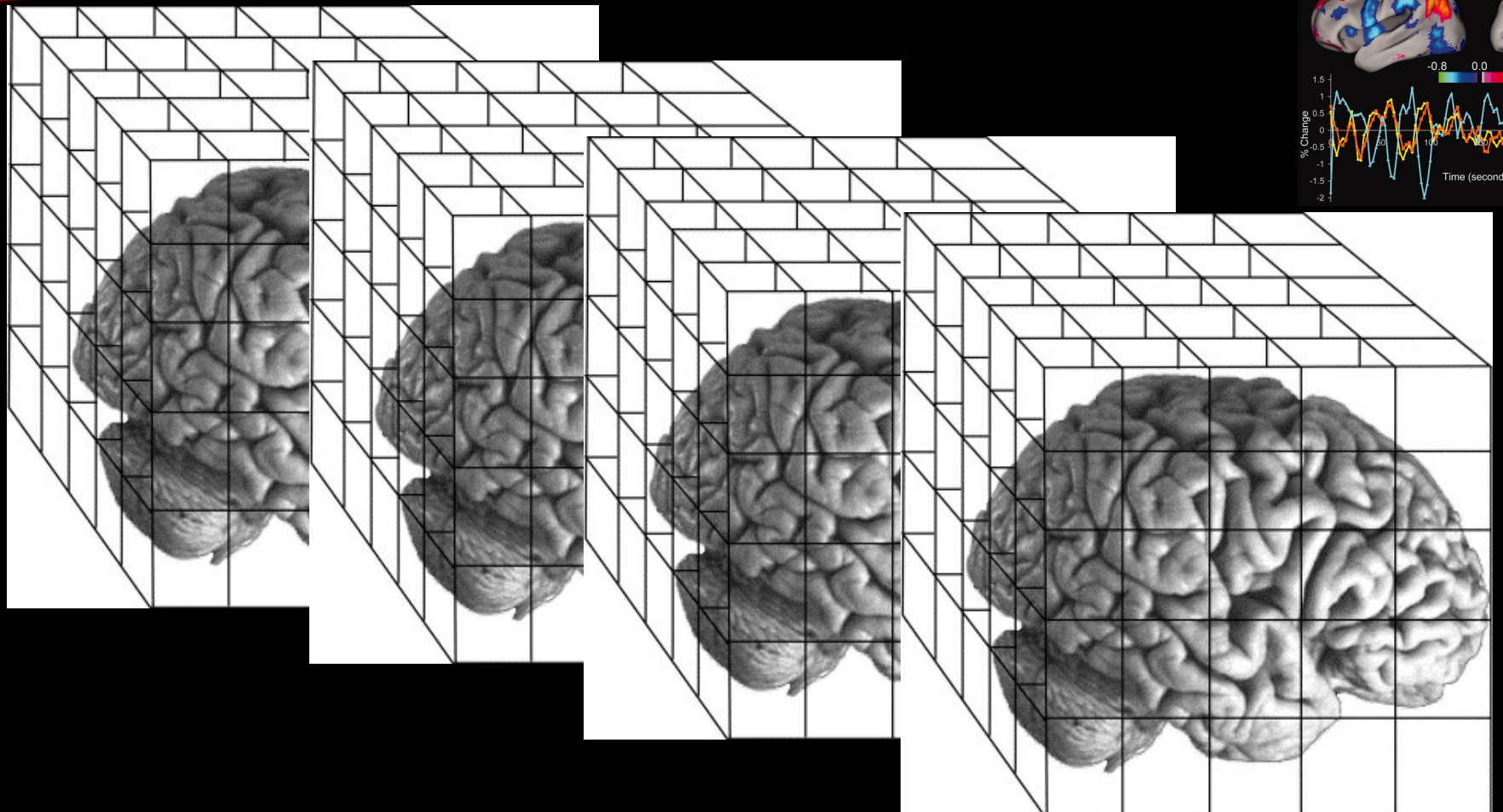


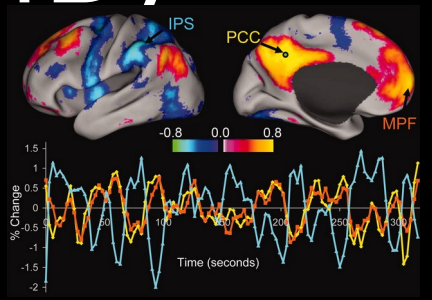
Voxel (pixel in 3D)





fMRI/DTI Voxel (pixel in 4D)



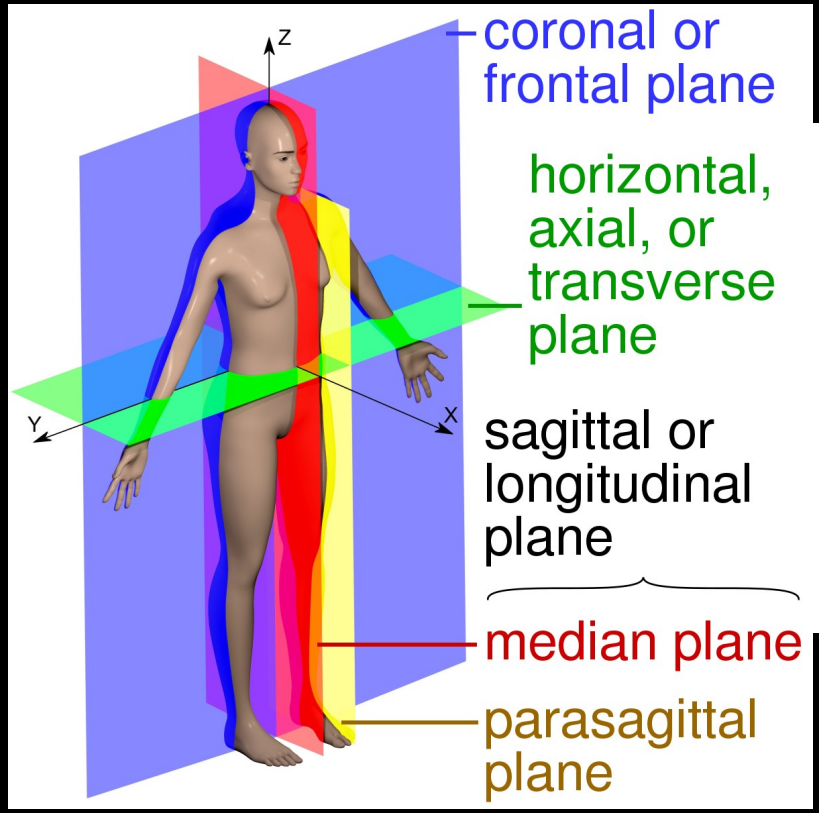


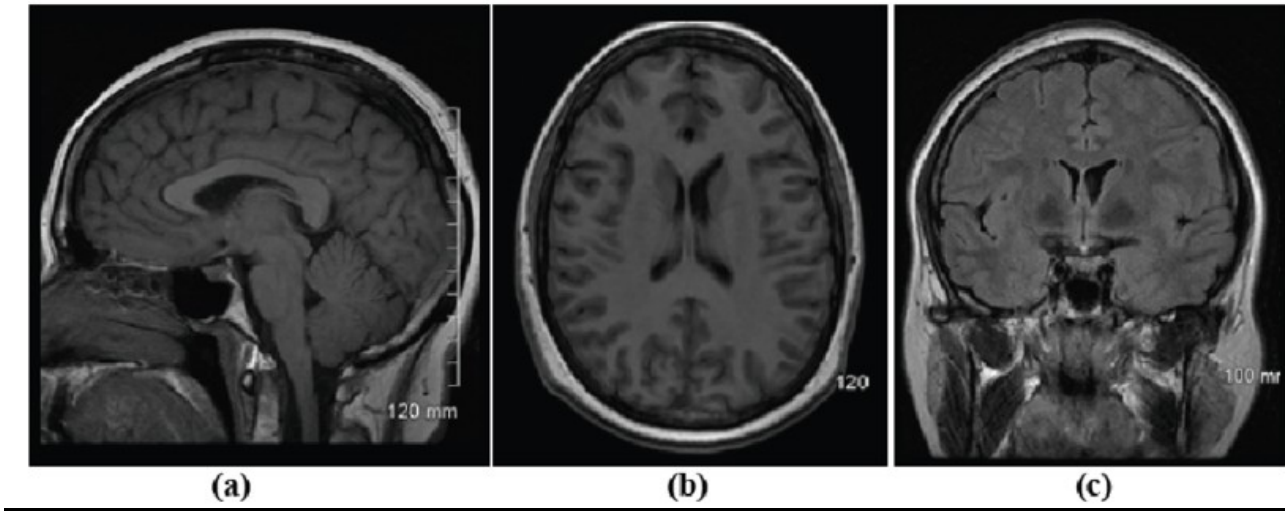
Data format

1. Digital Imaging and Communications in Medicine (**DICOM**) 2D

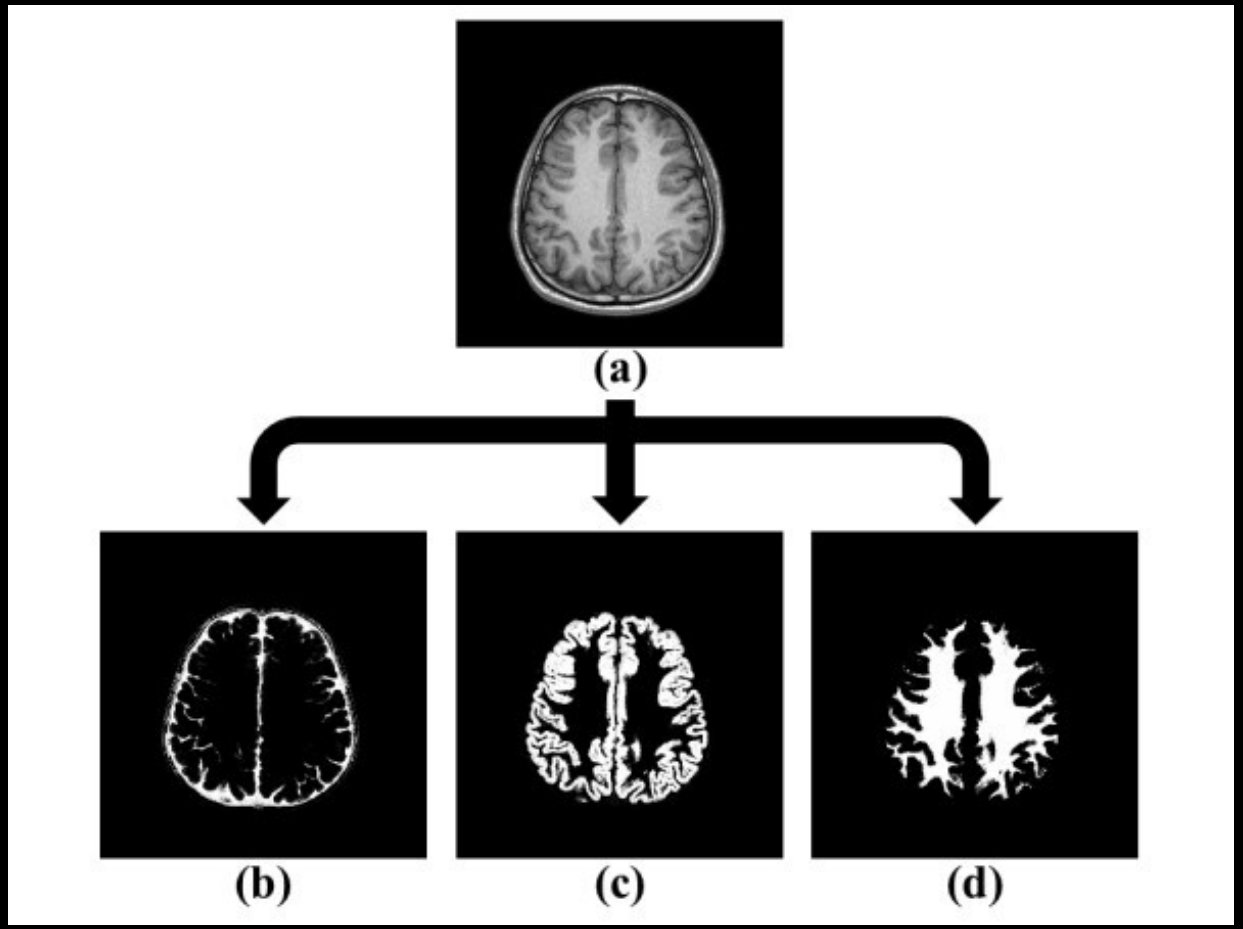
2. Neuroimaging Informatics Technology Initiative (NIFTI) 2D, 3D or 4D

Planes

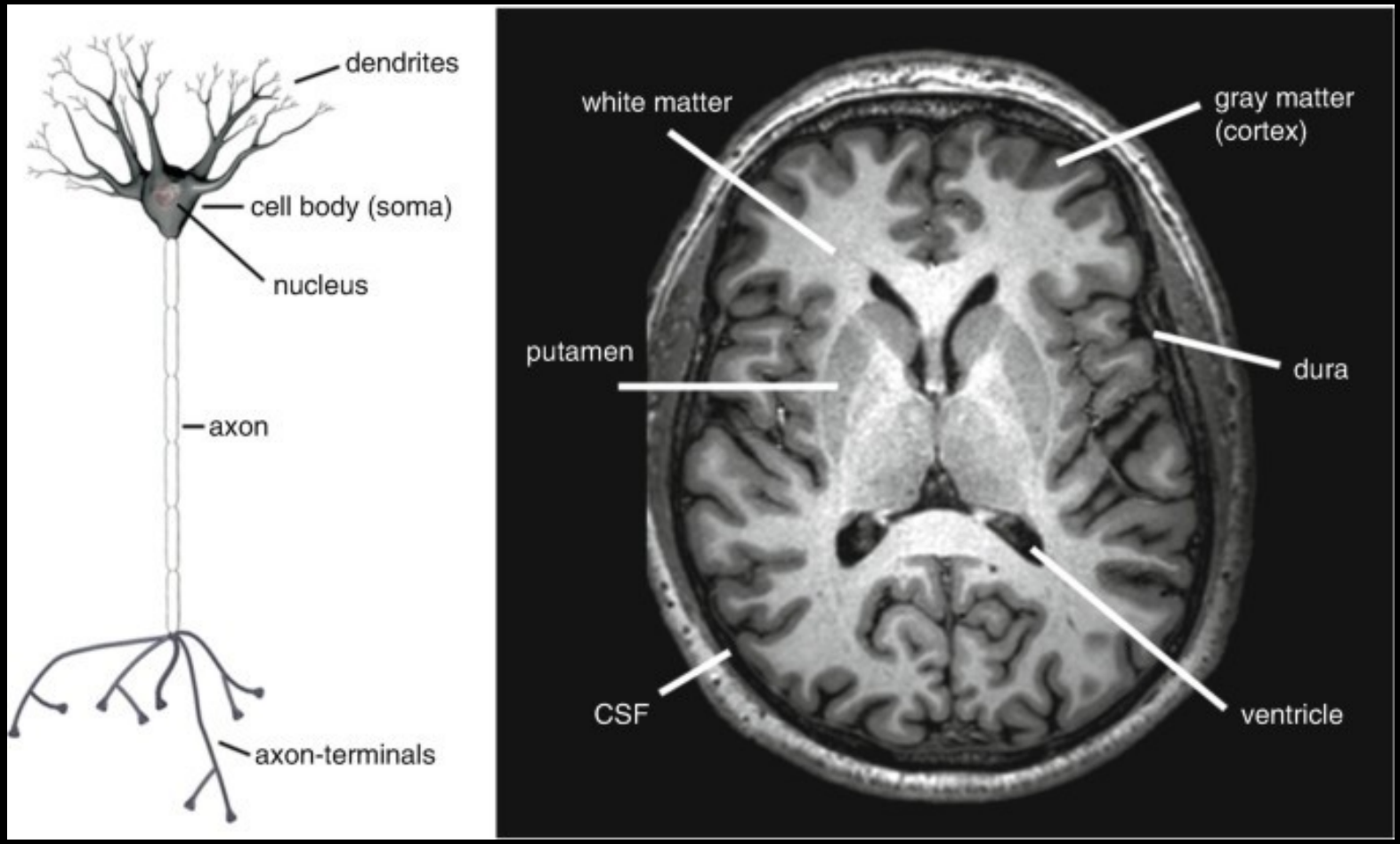

Z
Y
X
coronal or frontal plane
horizontal, axial, or transverse plane
sagittal or longitudinal plane
median plane
parasagittal plane


120 mm
120
(a)
(b)
(c)

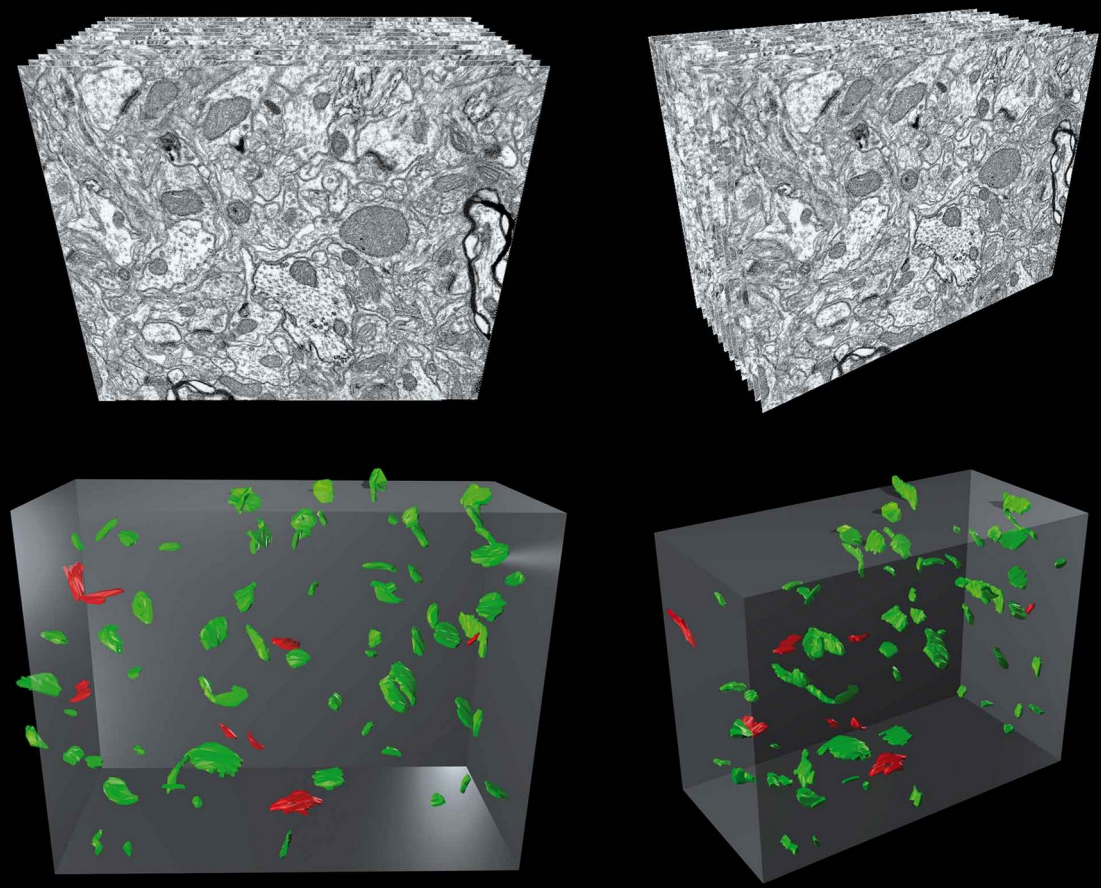
What we usually see in an MRI



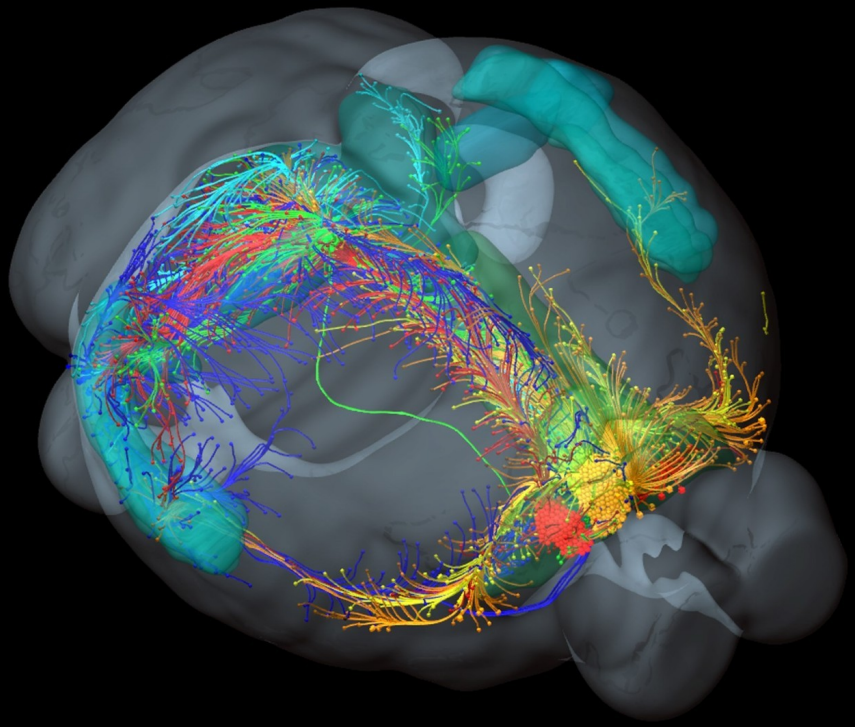
What we usually see in an MRI



Electron microscopy slices



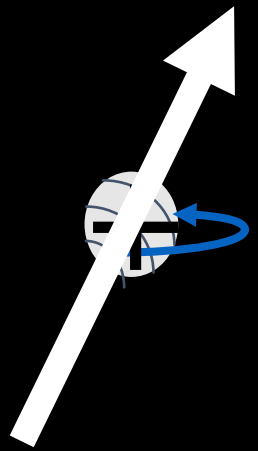
Adeno-associated virus tractography



Oh et al. Nature 2014

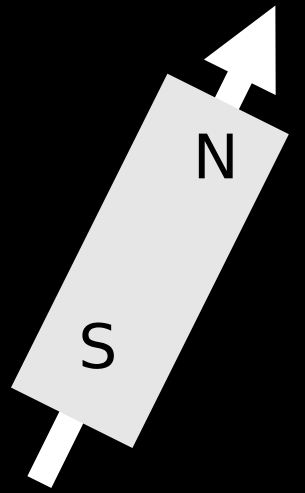
Break

Magnetic Resonance Imaging



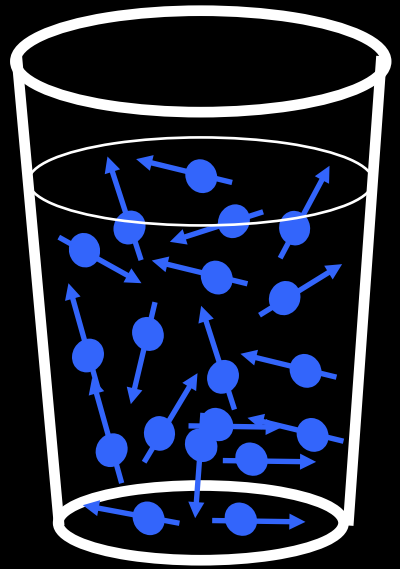
spinning proton

- Hydrogen protons spin producing a magnetic field
- A magnetic field creates an electrical charge when it rotates past a coil of wire



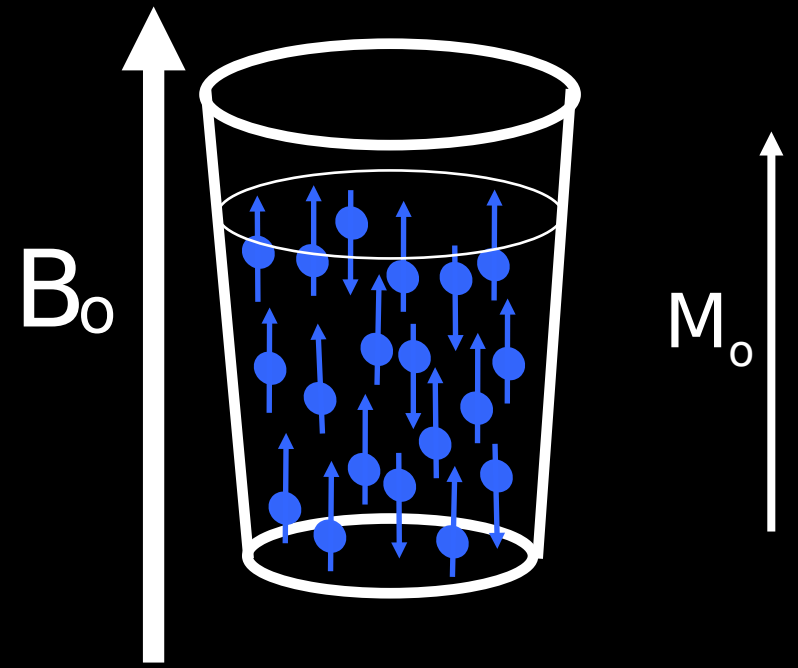
bar magnet

Randomly oriented protons



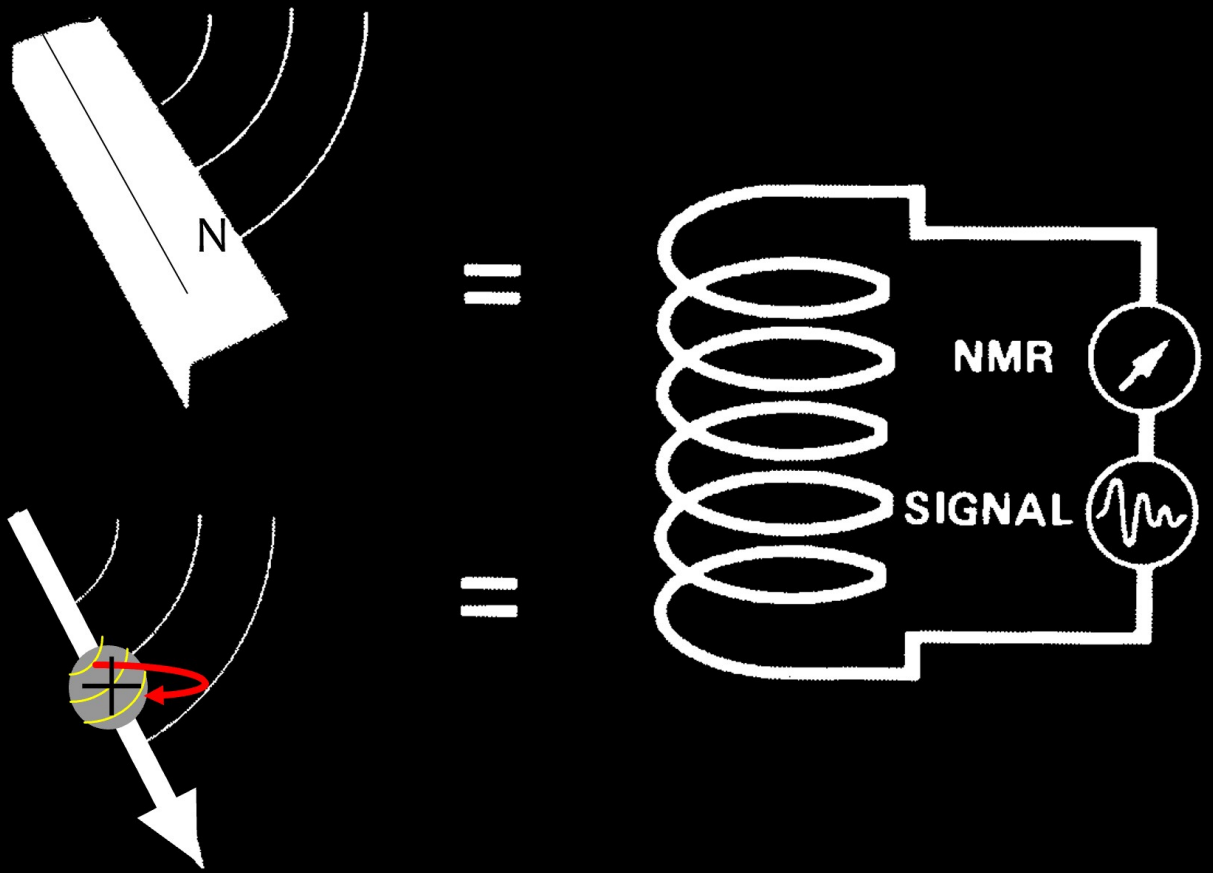
net magnetic moment is *zero*

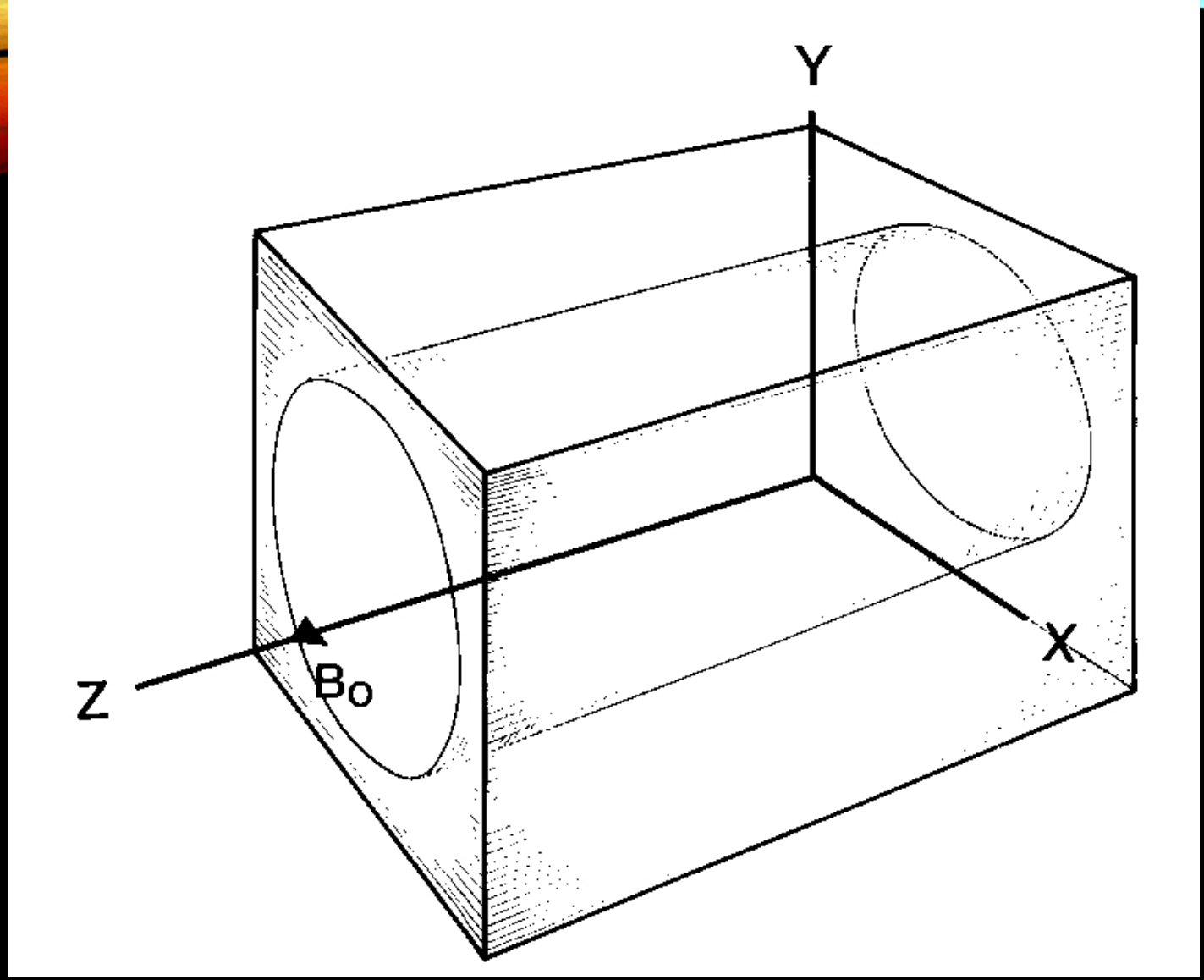
Protons aligned with a strong magnetic field

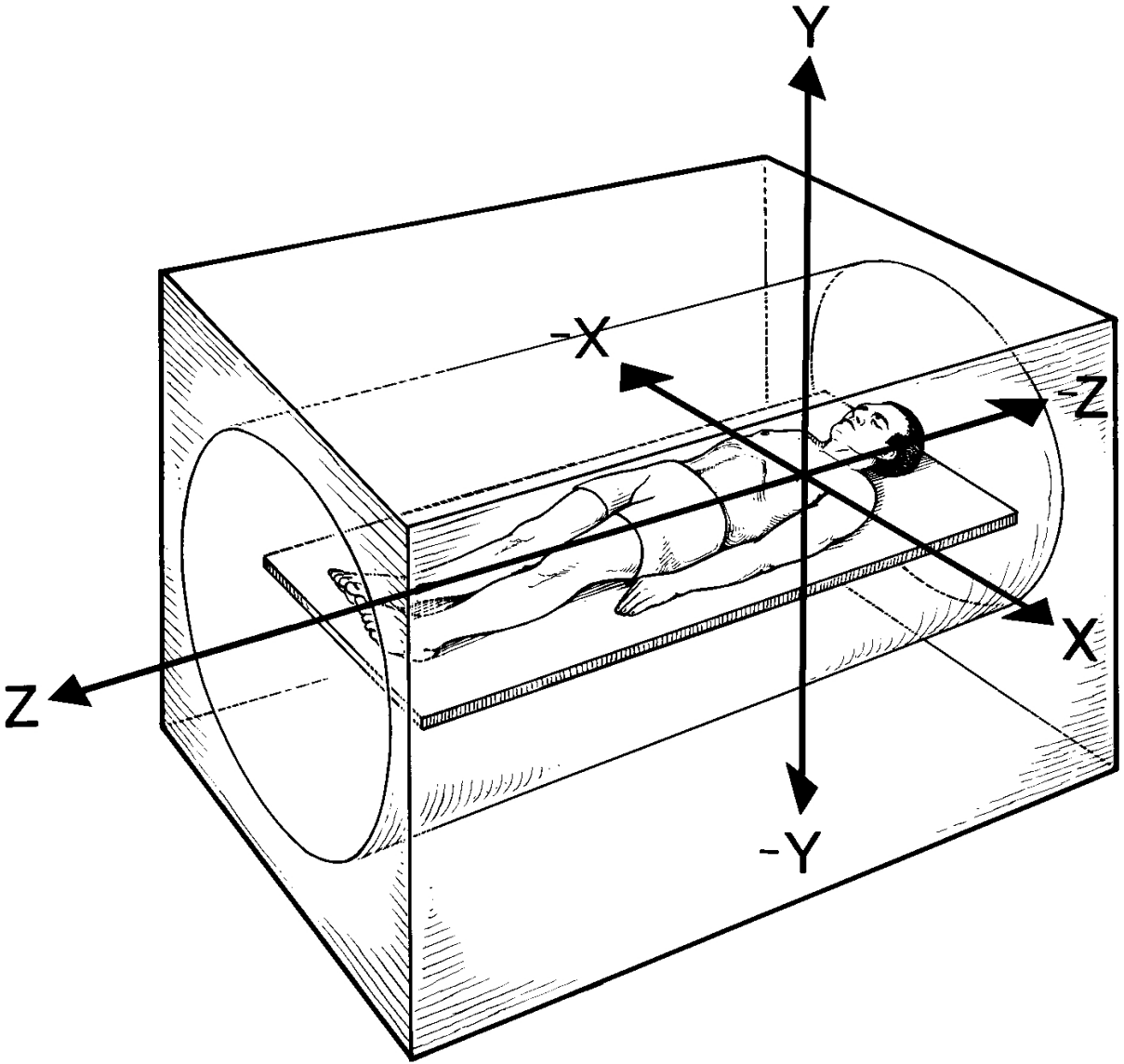


net magnetic moment is *positive*

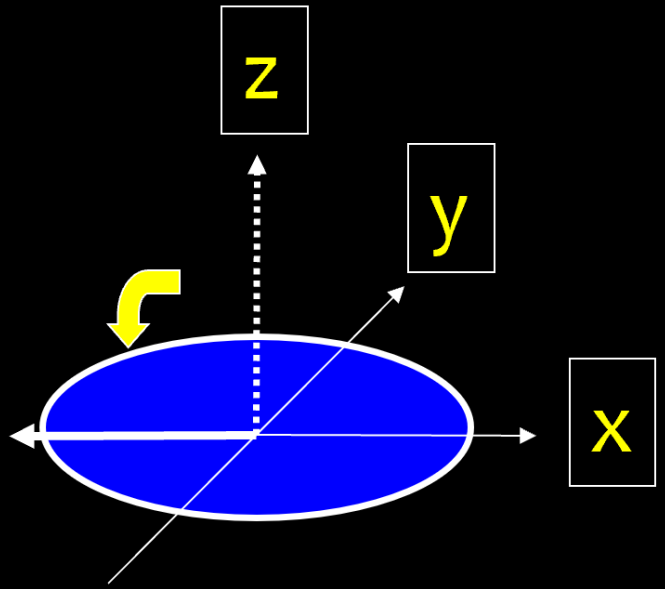
MRI measurement




Y
X
Z
Bo


Y
-X
-Z
Z
X
-Y

Flip Angle - Degree of Deflection from Z-axis



90° Radiofrequency Pulse used to "tip" protons into X-Y plane.

The MRI Measurement
(Up to this point)

In the presence of the static magnetic field

- Protons align with the field
- Protons precess about the magnetic

Briefly turn on RF pulse

- Provides energy to tip the protons at least partially into the imaging plane

What happens to the protons next?

Relaxations

Longitudinal – precessing protons are pulled back into alignment with main magnetic field of the scanner (B_o) reducing size of the magnetic moment vector in the x-y plane

Transverse – precessing protons become out of phase leading to a drop in the net magnetic moment vector (M_o)

Transverse relaxation occurs much faster than Longitudinal relaxation

Tissue contrast is determined by differences in these two types of relaxation

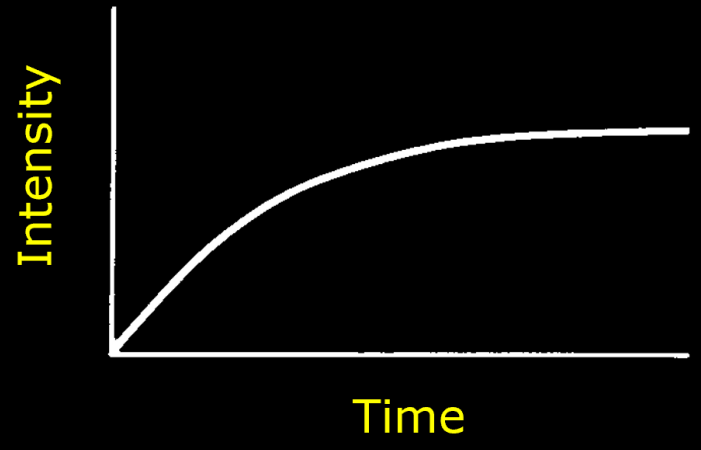
Main Tissue Contrast Controls

Echo Time (TE) – time after 90^{o} RF pulse until readout. Determines how much transverse relaxation will occur before reading one row of the image.

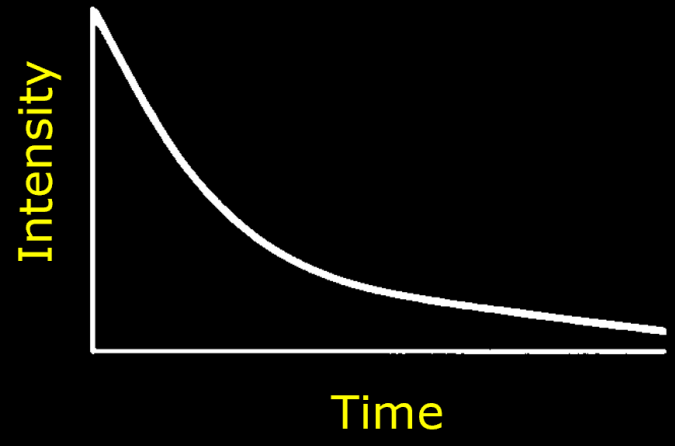
Repetition Time (TR) – time between successive 90^{o} RF pulses. Determines how much longitudinal relaxation will occur before constructing the next row of the image.

Main Tissue Contrast Controls

Every tissue has a different affect on longitudinal (T1) and transverse (T2) relaxation.

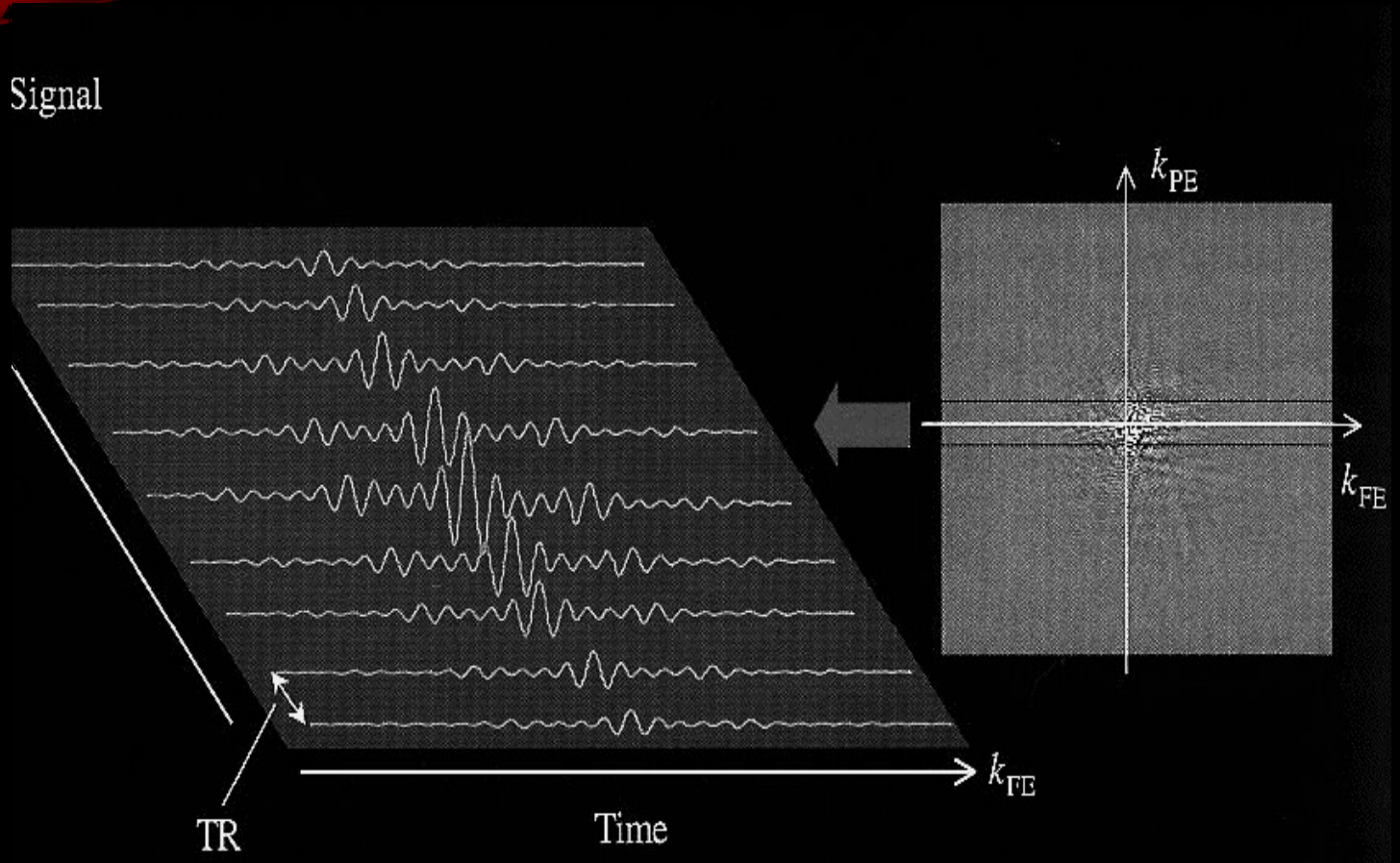


T1 Curve



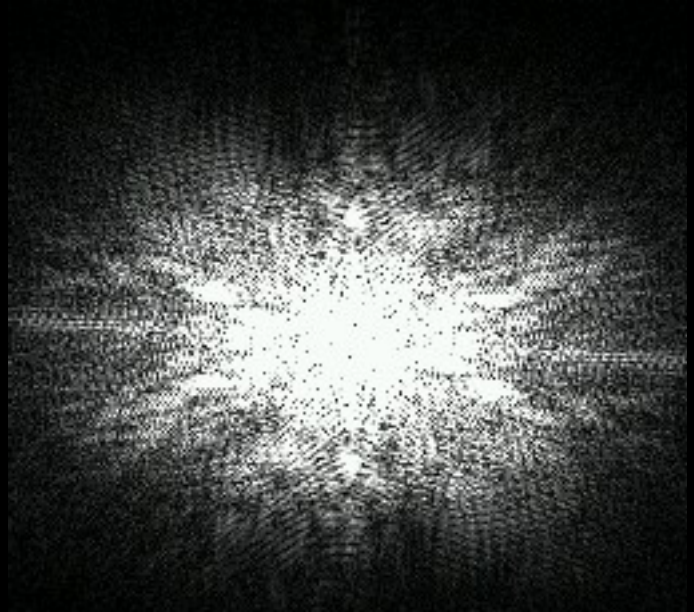
T2 Curve

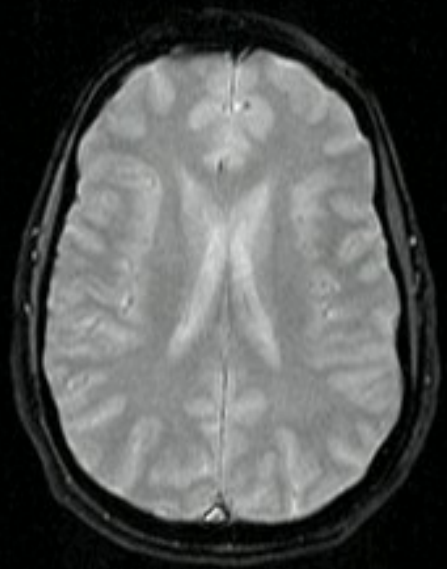
k-space



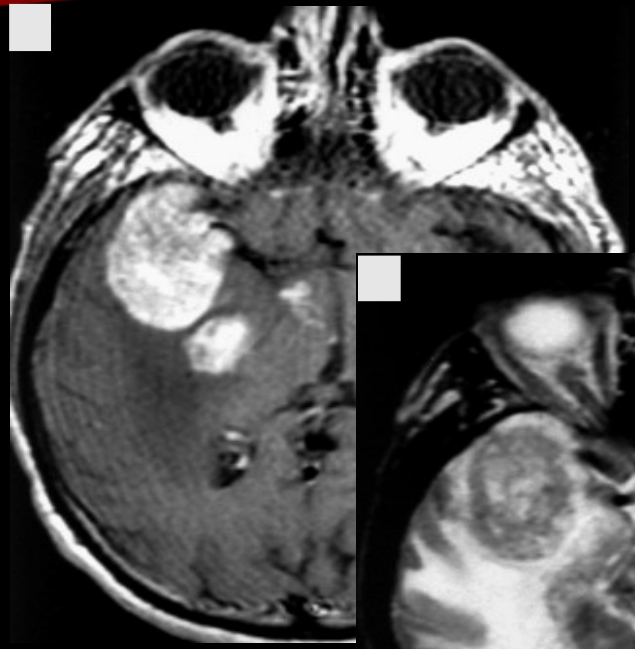
Images From k-space

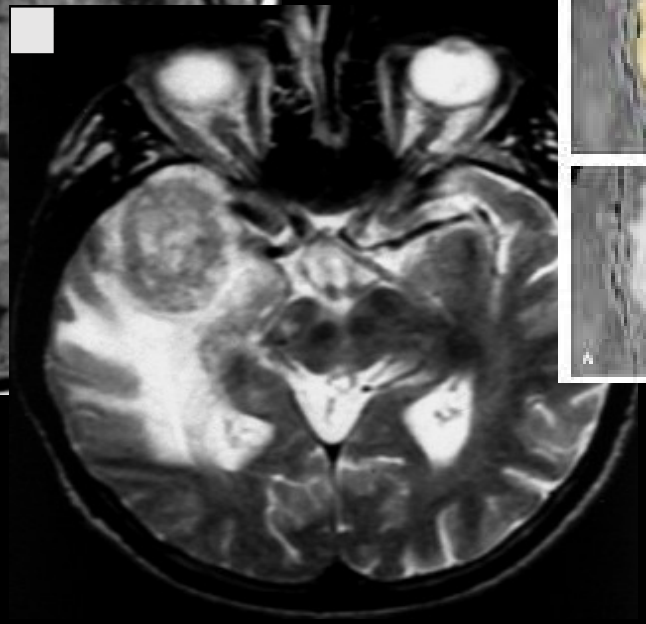
K-space is turned into an image using a Fourier Transformation

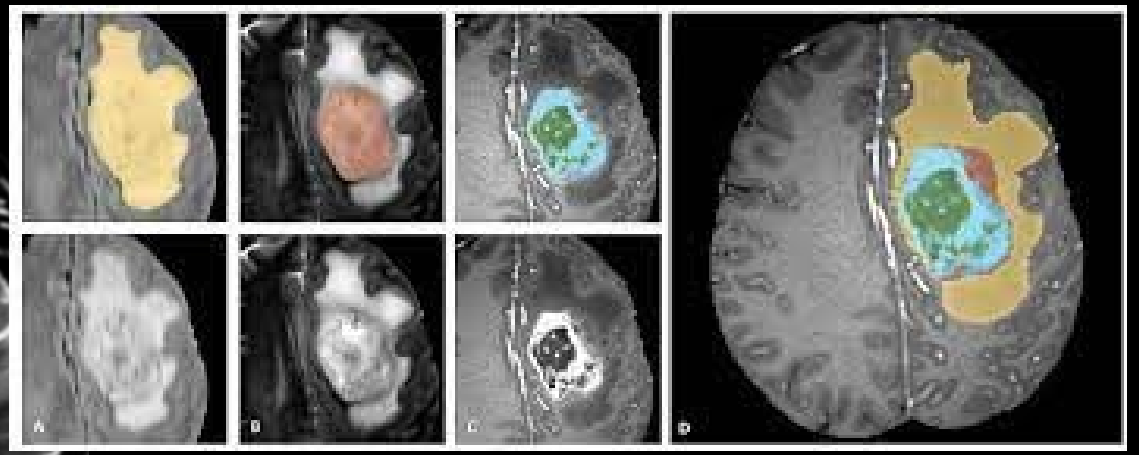




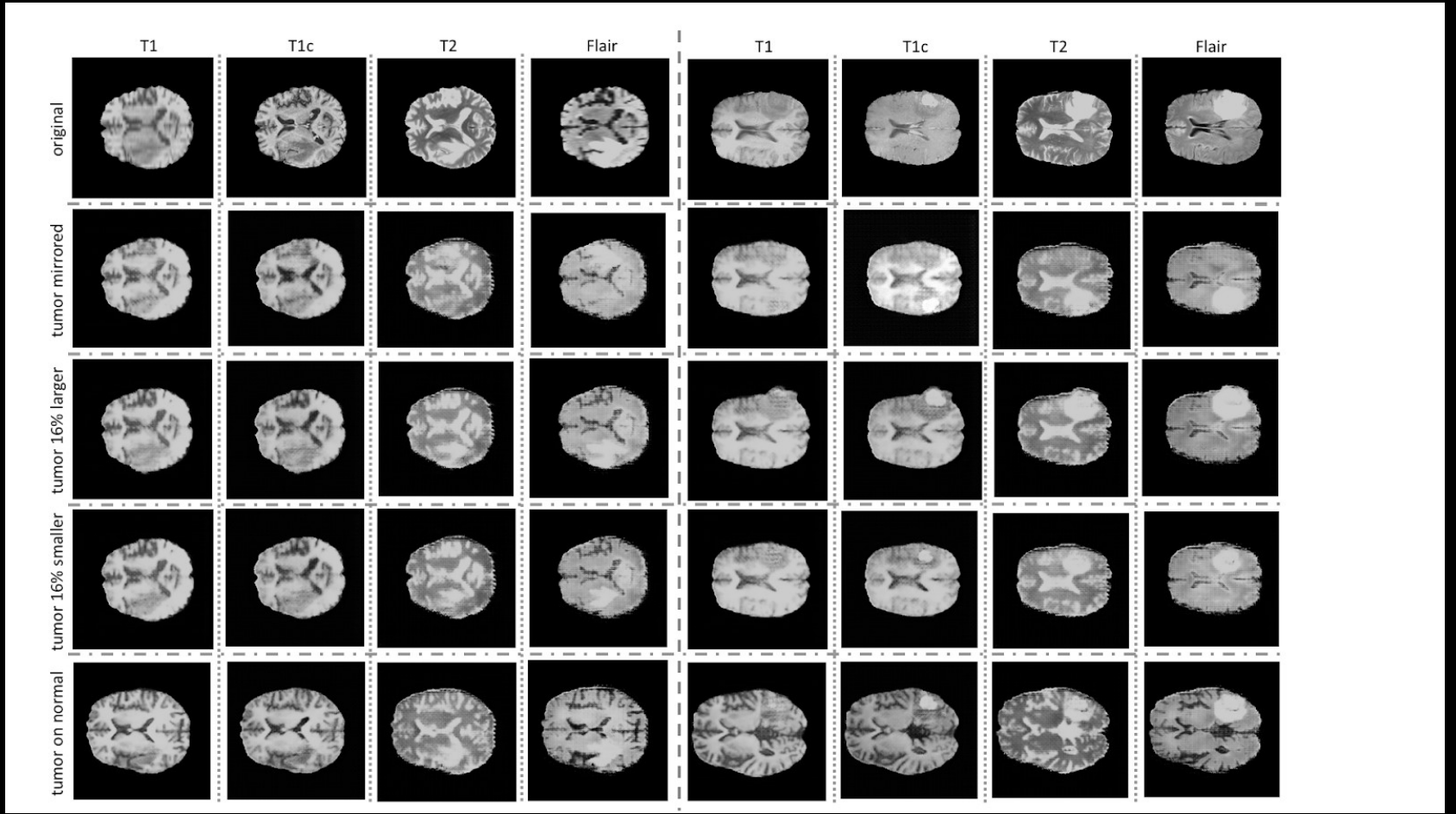
Just structural



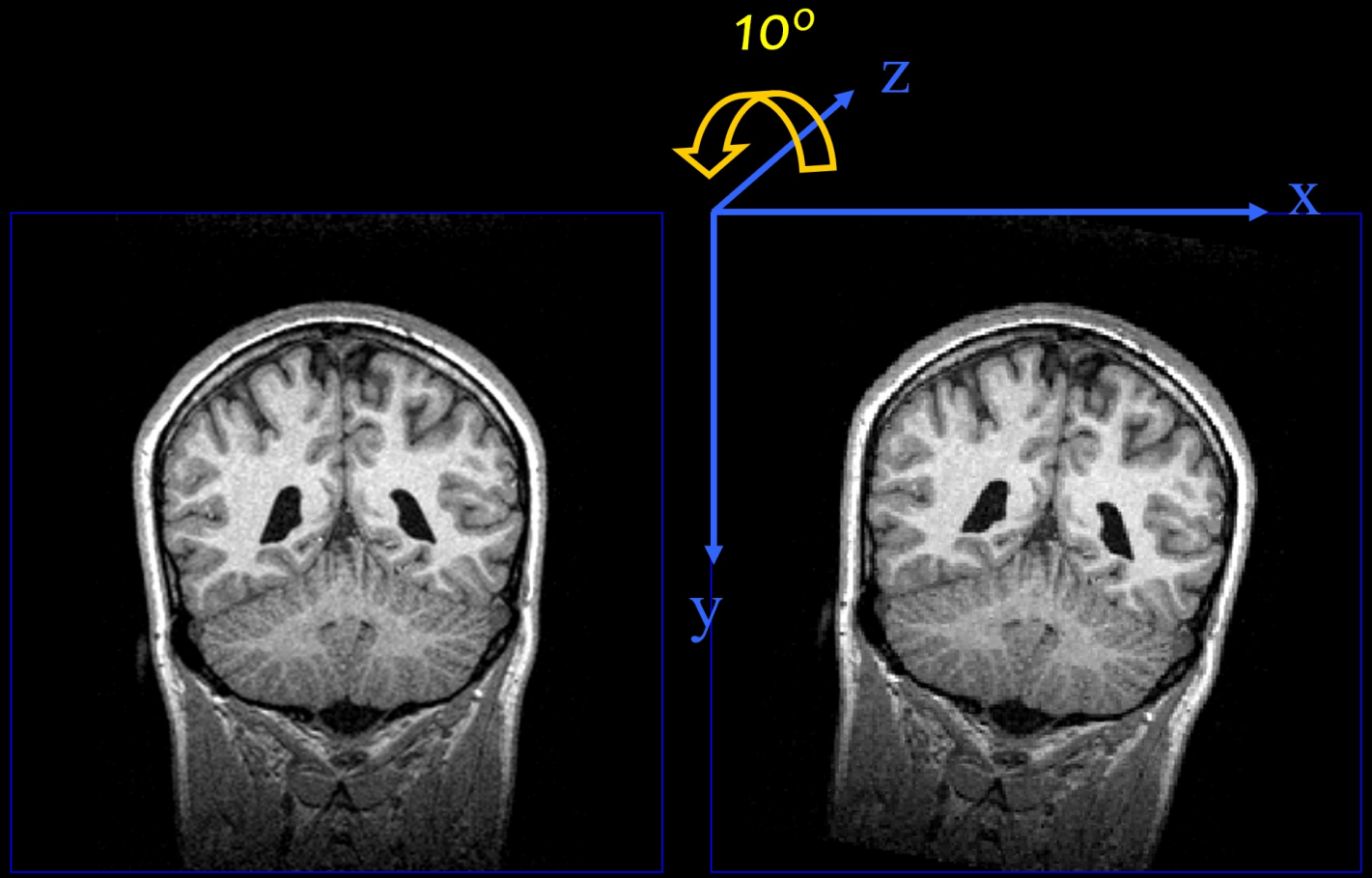




GAN TUMOR


T1
T1c
T2
Flair
T1
T1c
T2
Flair
original
tumor mirrored
tumor 16% larger
tumor 16% smaller
tumor on normal

Registration

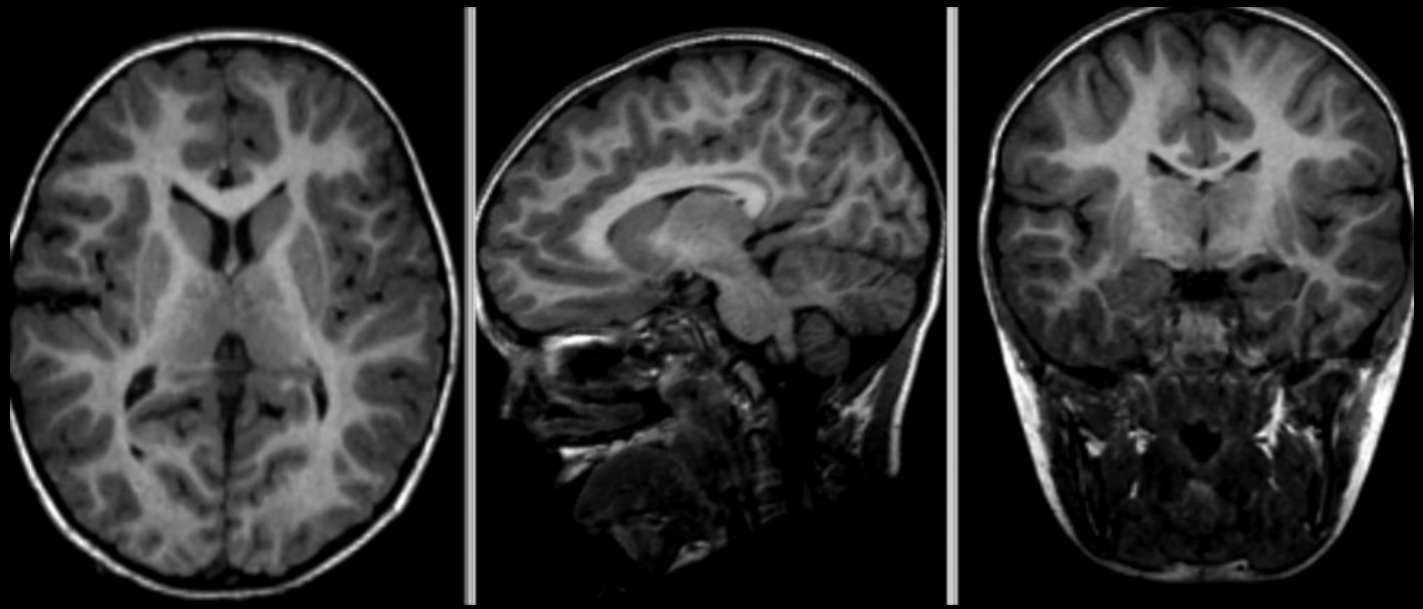


Registration

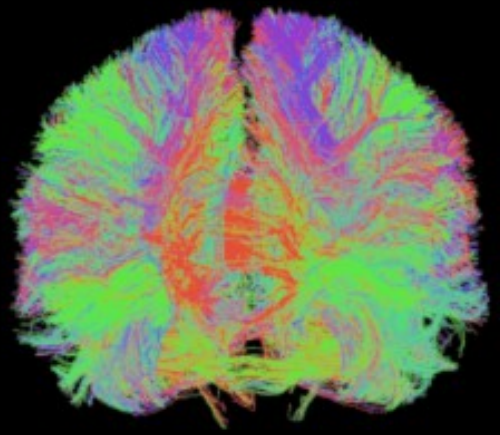
Reasons:

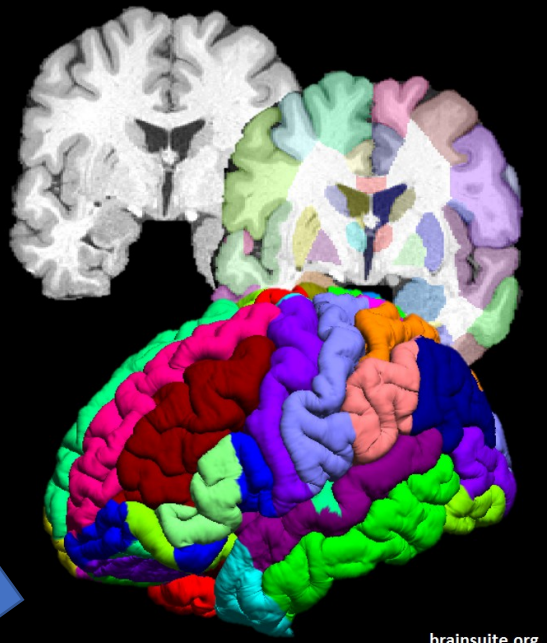
- To have consistent data
- in fMRI people move, breath or have cardiac pulsation (those will be micro-registrations called motion corrections)

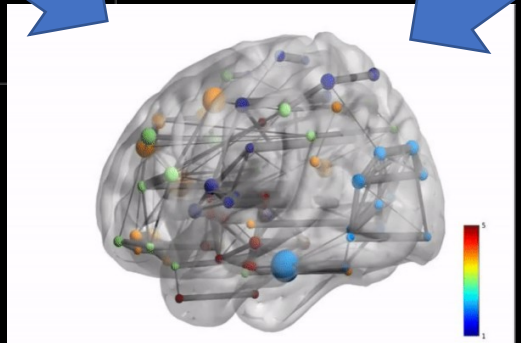
Non-linear registration



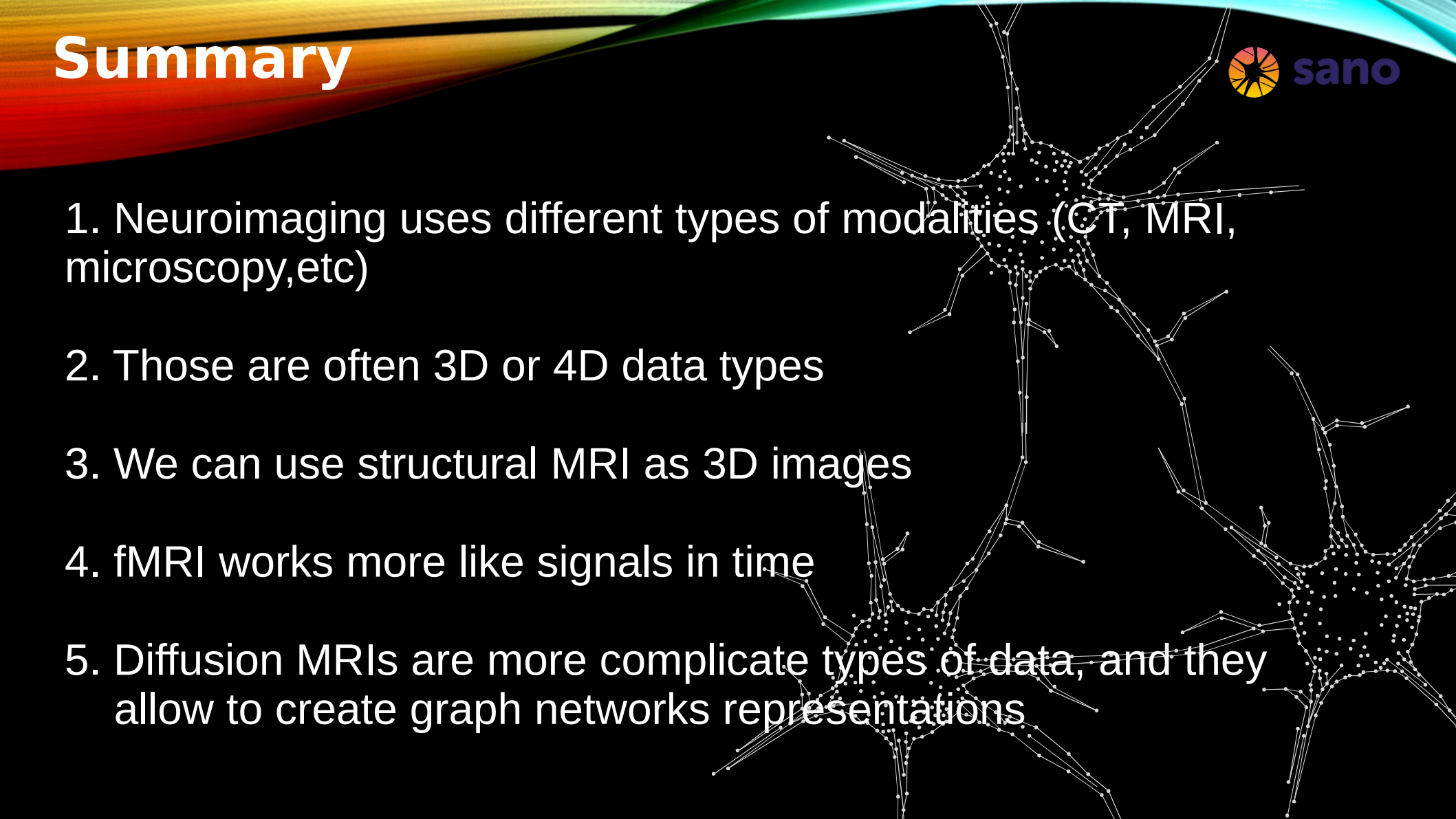
Structural Connectivity







Summary



1. Neuroimaging uses different types of modalities (CT, MRI, microscopy,etc)

2. Those are often 3D or 4D data types

3. We can use structural MRI as 3D images

4. fMRI works more like signals in time

5. Diffusion MRIs are more complicate types of data, and they allow to create graph networks representations