

# Machine Learning for Neuroimaging and Neuroscience

## *Lesson 1* *Introduction to* *data*



AGH UNIVERSITY OF SCIENCE  
AND TECHNOLOGY

# 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

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# Syllabus

14 sessions

- Lectures
- Laboratories
- Projects

Final grades 50% from laboratories and project

# Syllabus

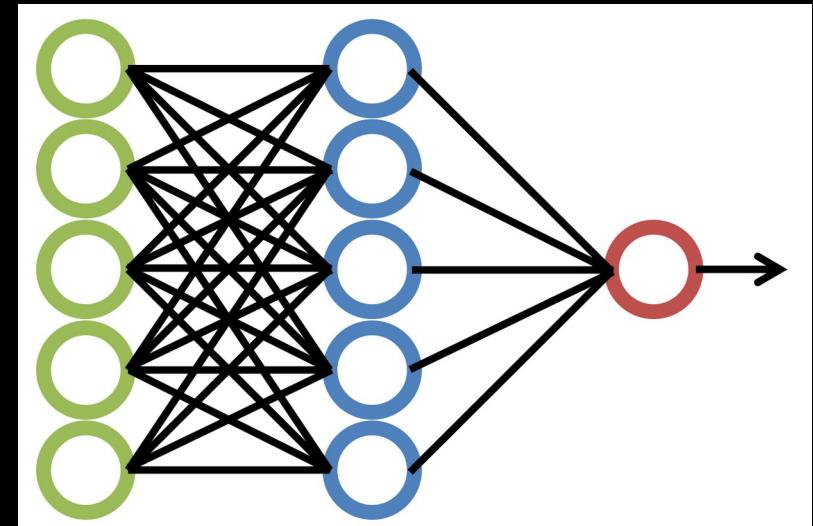
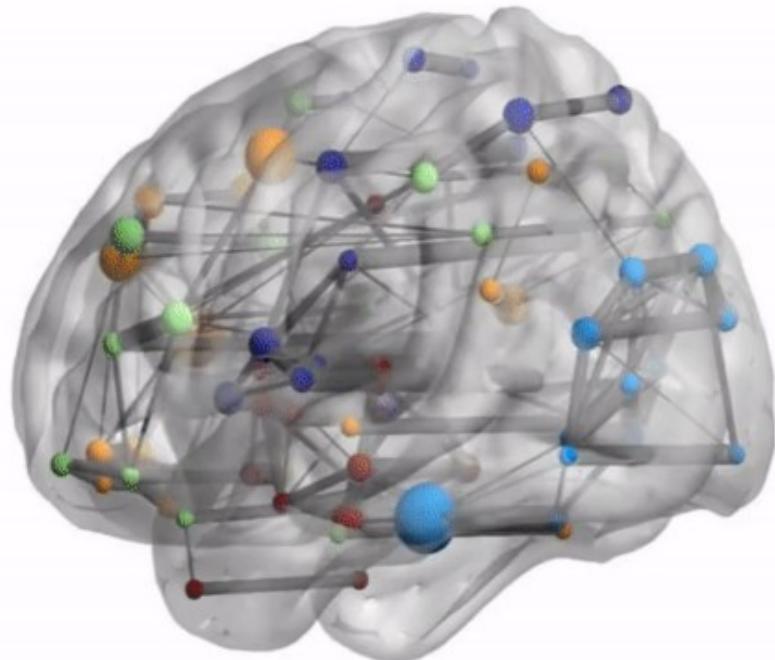
## Lectures

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



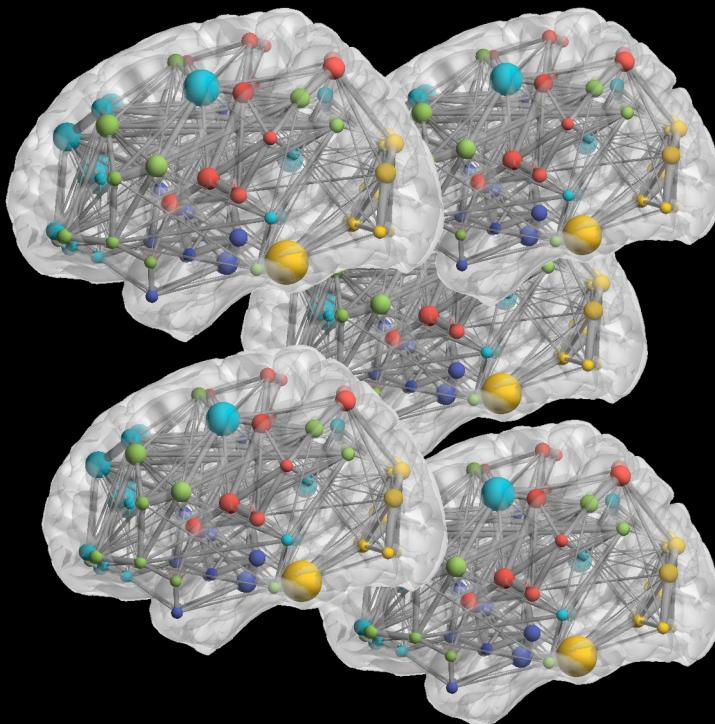
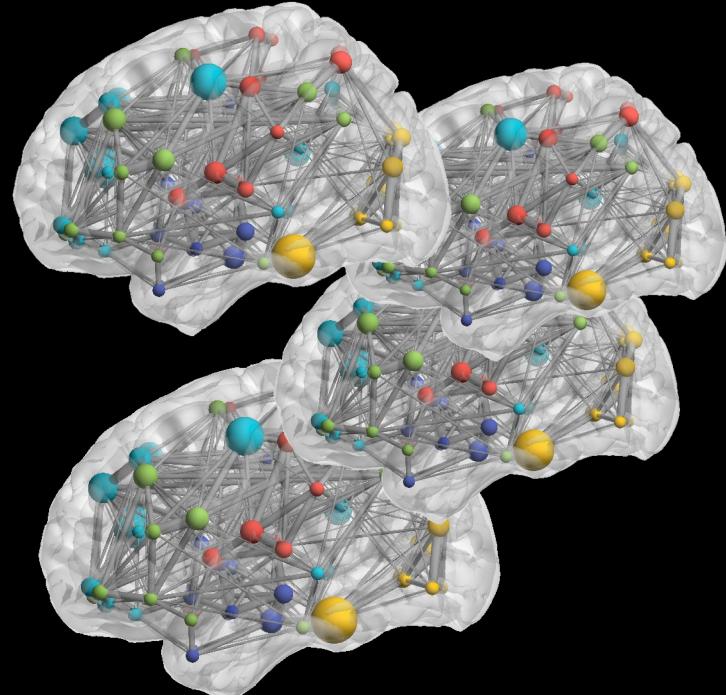
Alzheimer, Schizophrenia,...

Matched healthy control

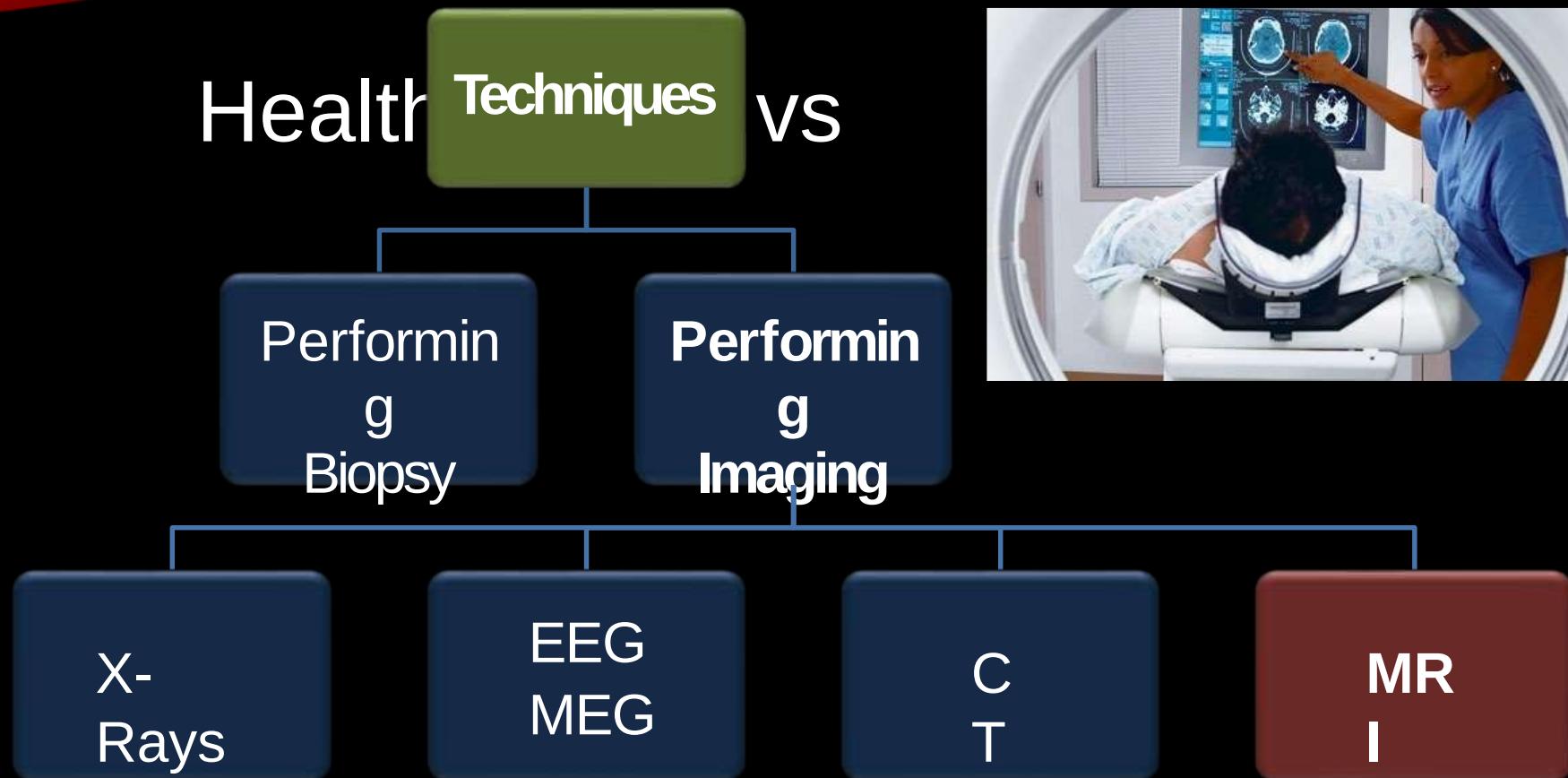
Healthy

vs

Alzheimer



# We can use different technologies and modalities



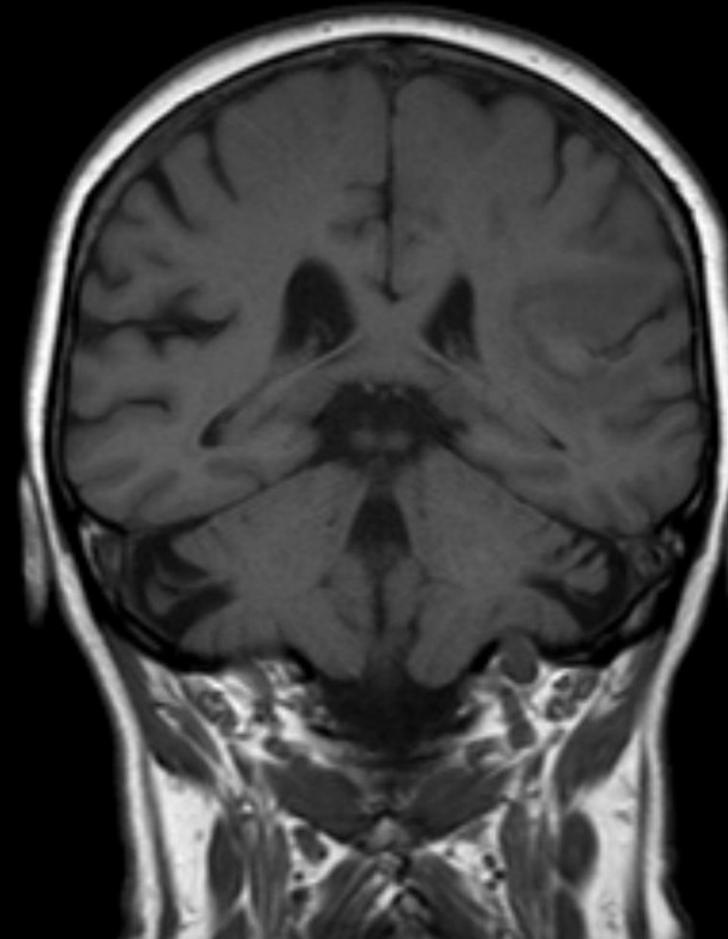
## We can use different technologies and modalities

- 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)

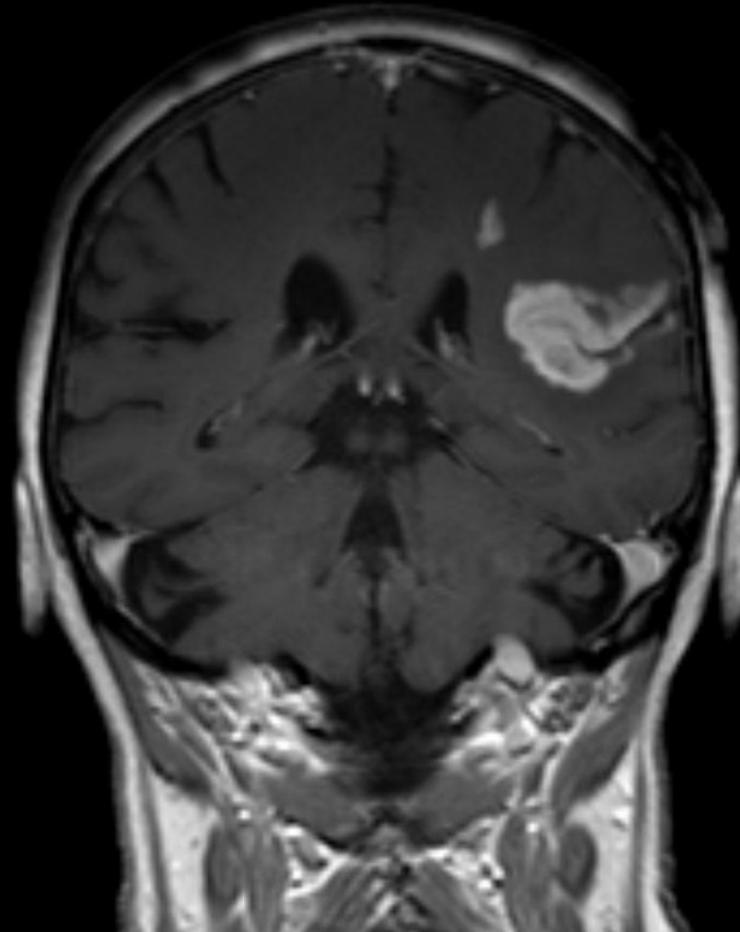
# Enhancement

- 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

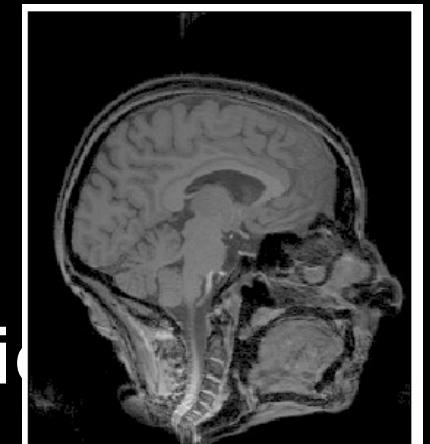
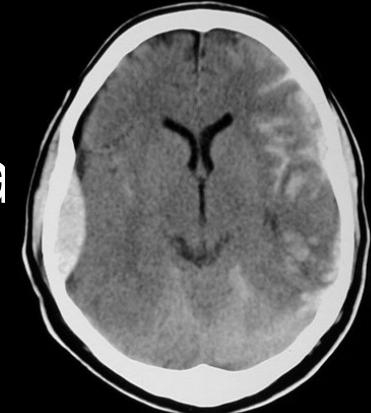


# No Enhancement

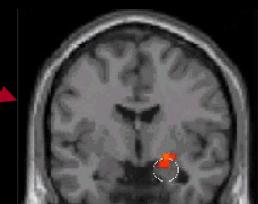
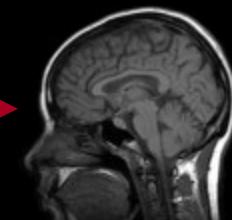
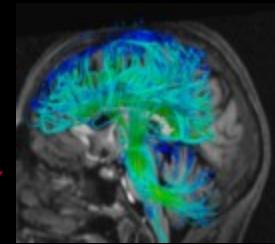


## Neuroimaging can take different forms

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



# MRI is cool



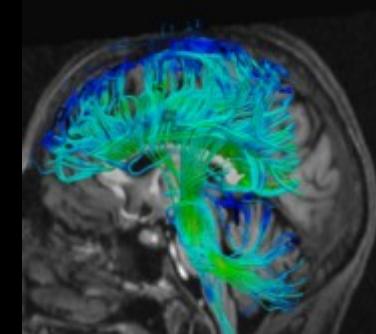
# How does research work?



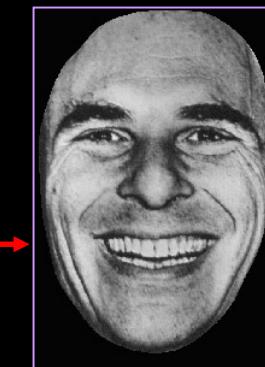
MRI Scanner



Process Data



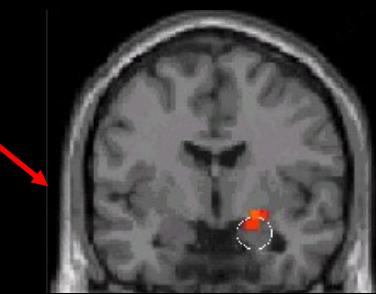
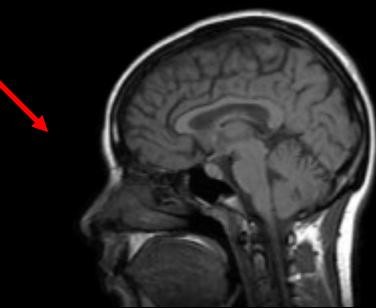
MRI Scanner



Stimulus  
(e.g. picture)



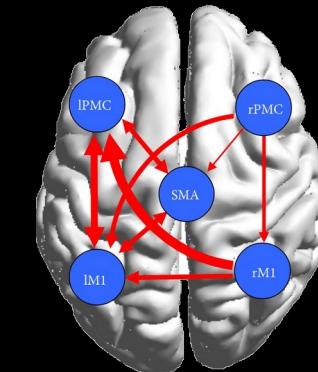
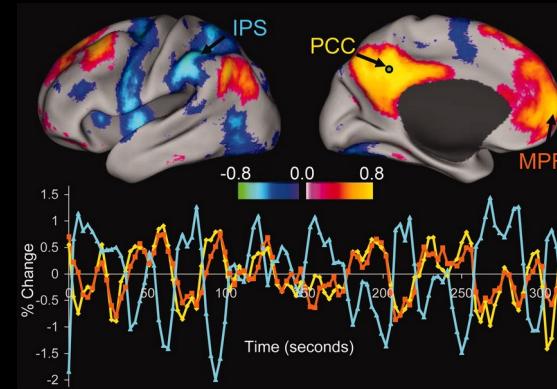
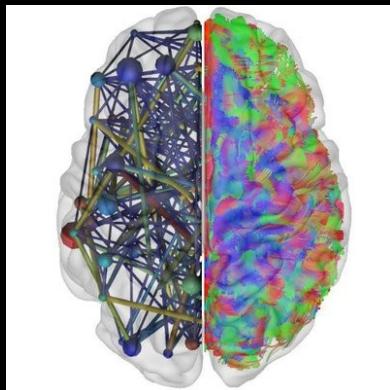
Process Data



There is more (e.g. MRA)



# Structural, functional & effective connectivity



## Structural/anatomical connectivity

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

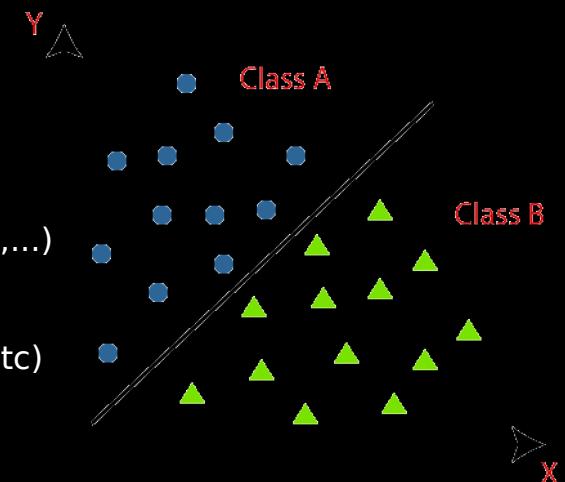
## Functional connectivity

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

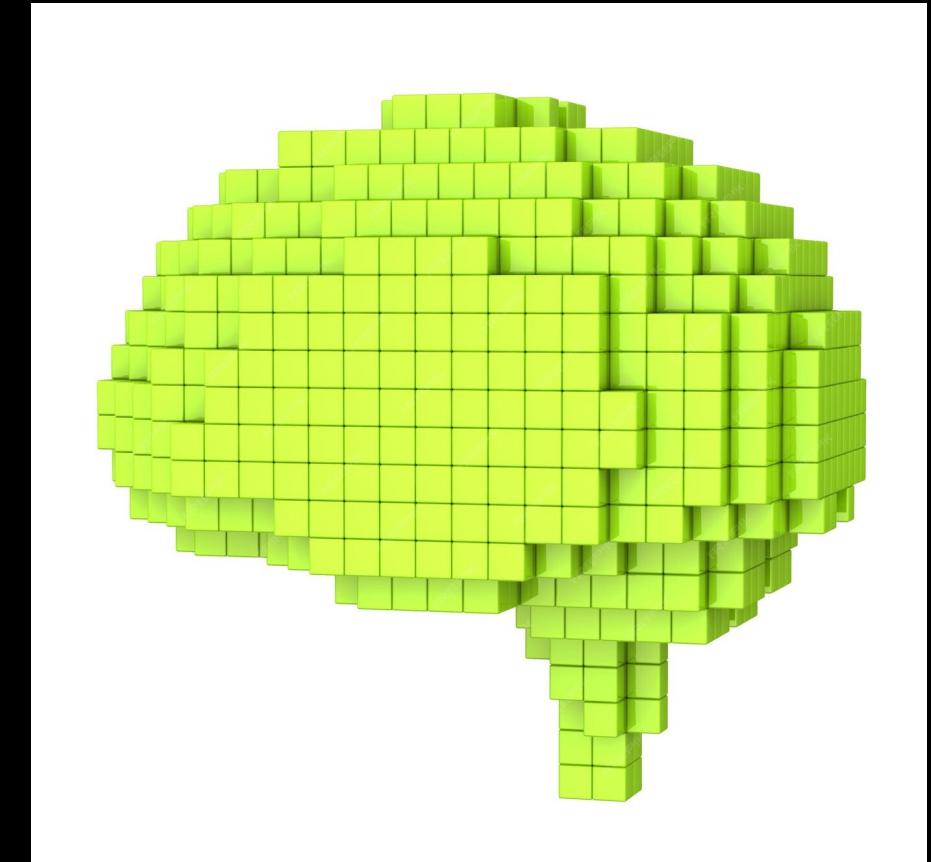
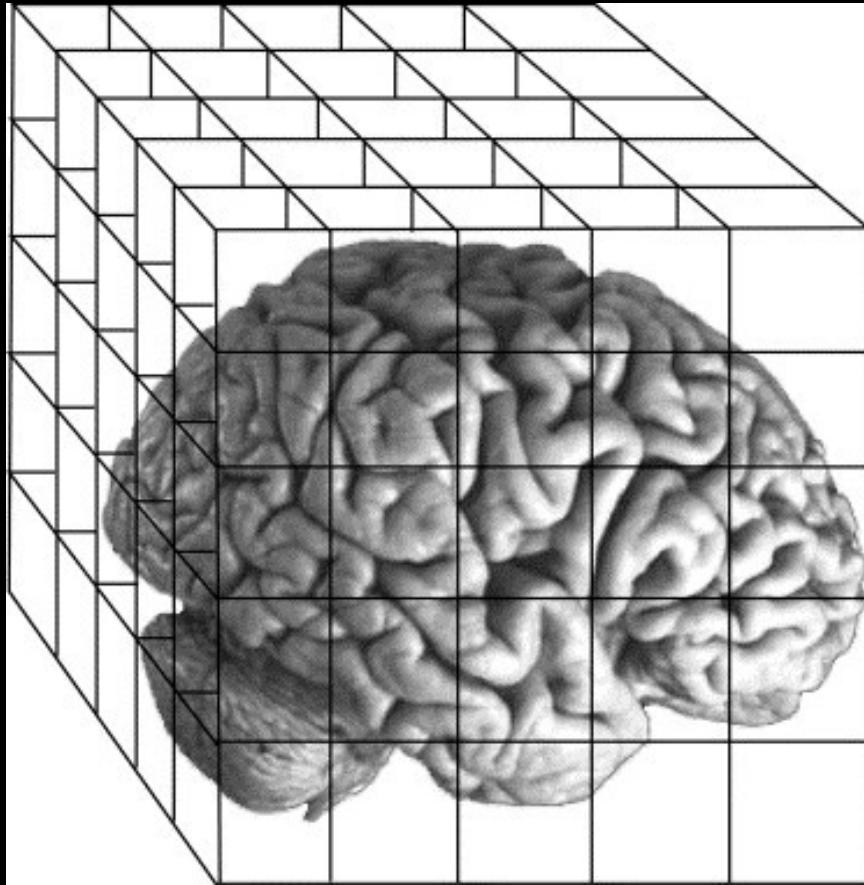
## Effective connectivity

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

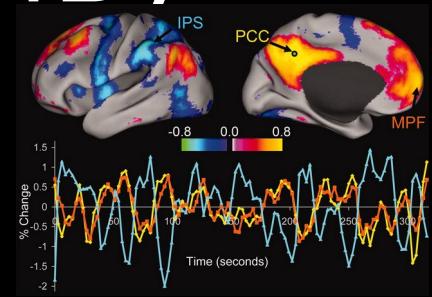
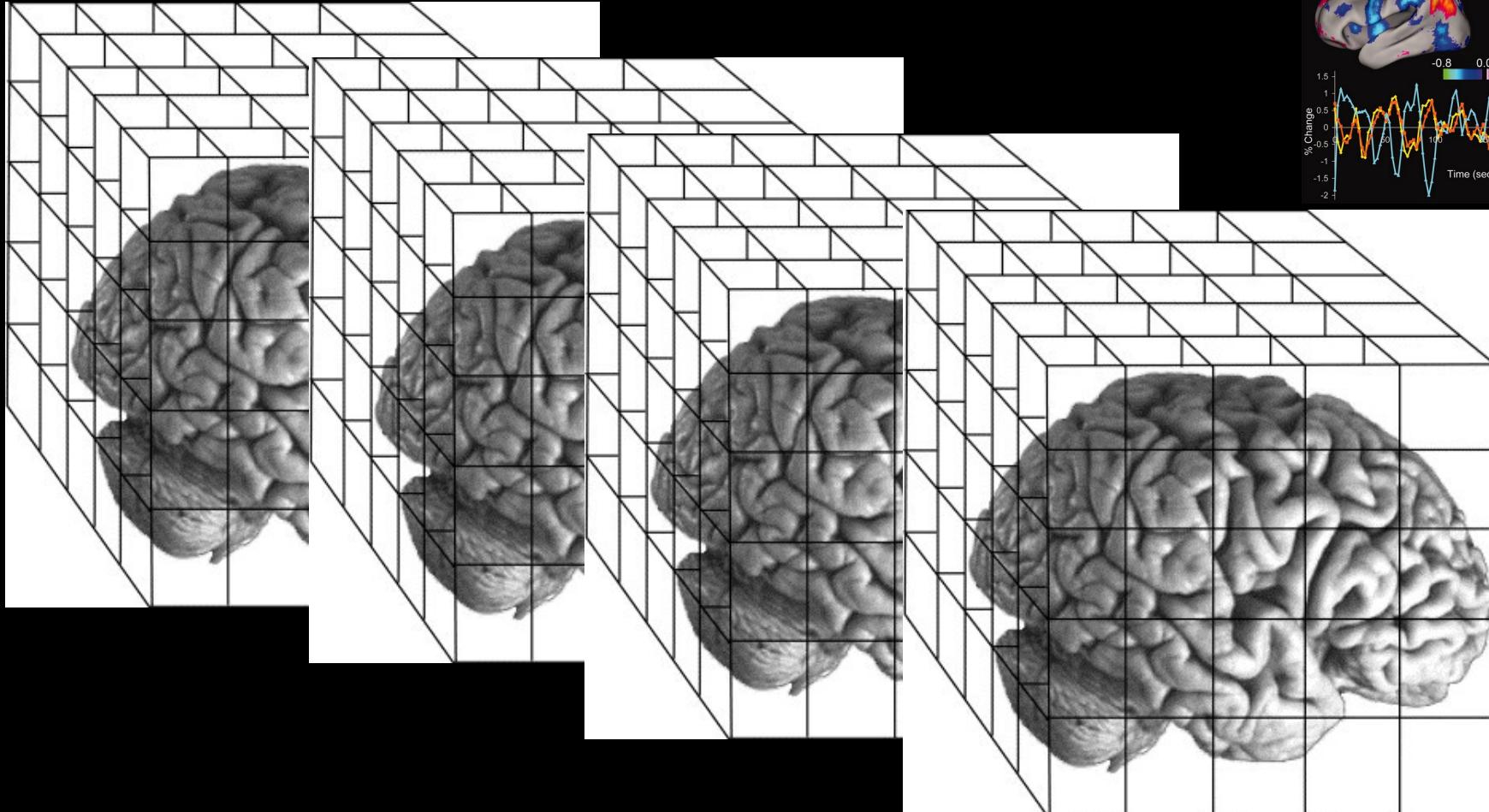
Nobody cares about **Morphological connectivity** ☺ ...



# Voxel (pixel in 3D)



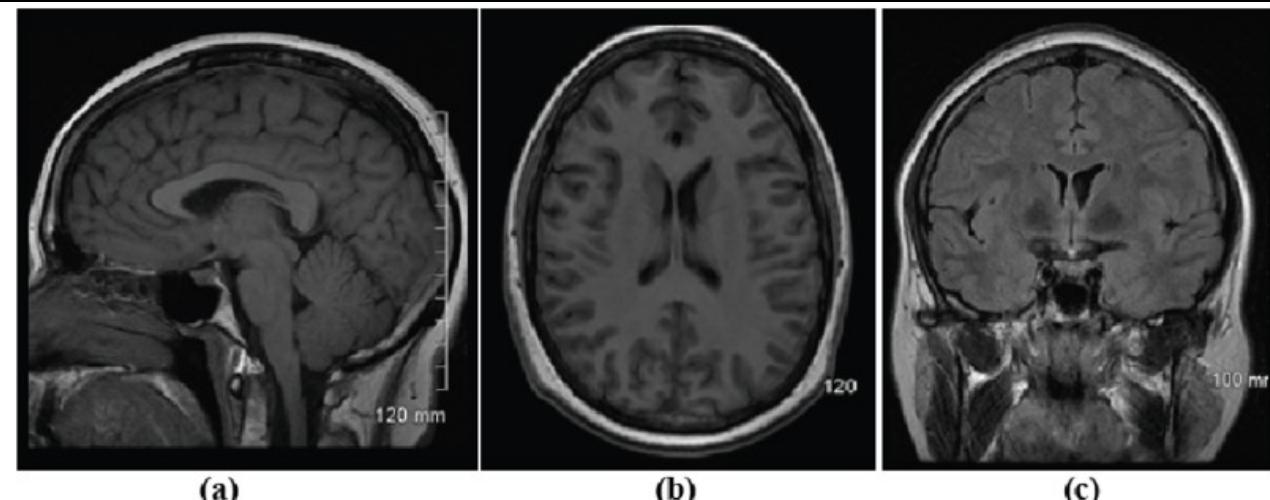
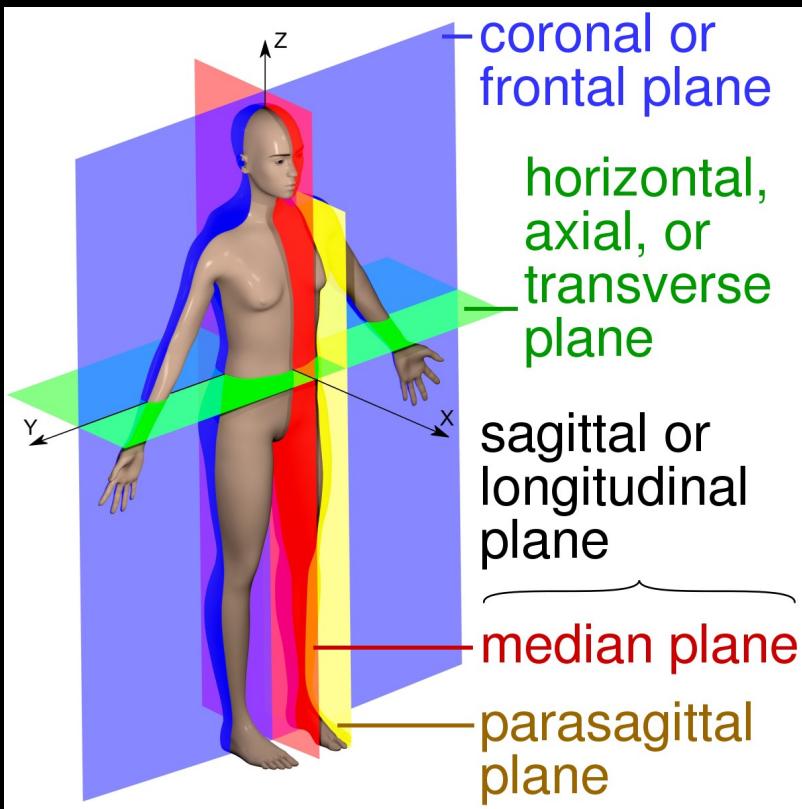
# fMRI/DTI Voxel (pixel in 4D)



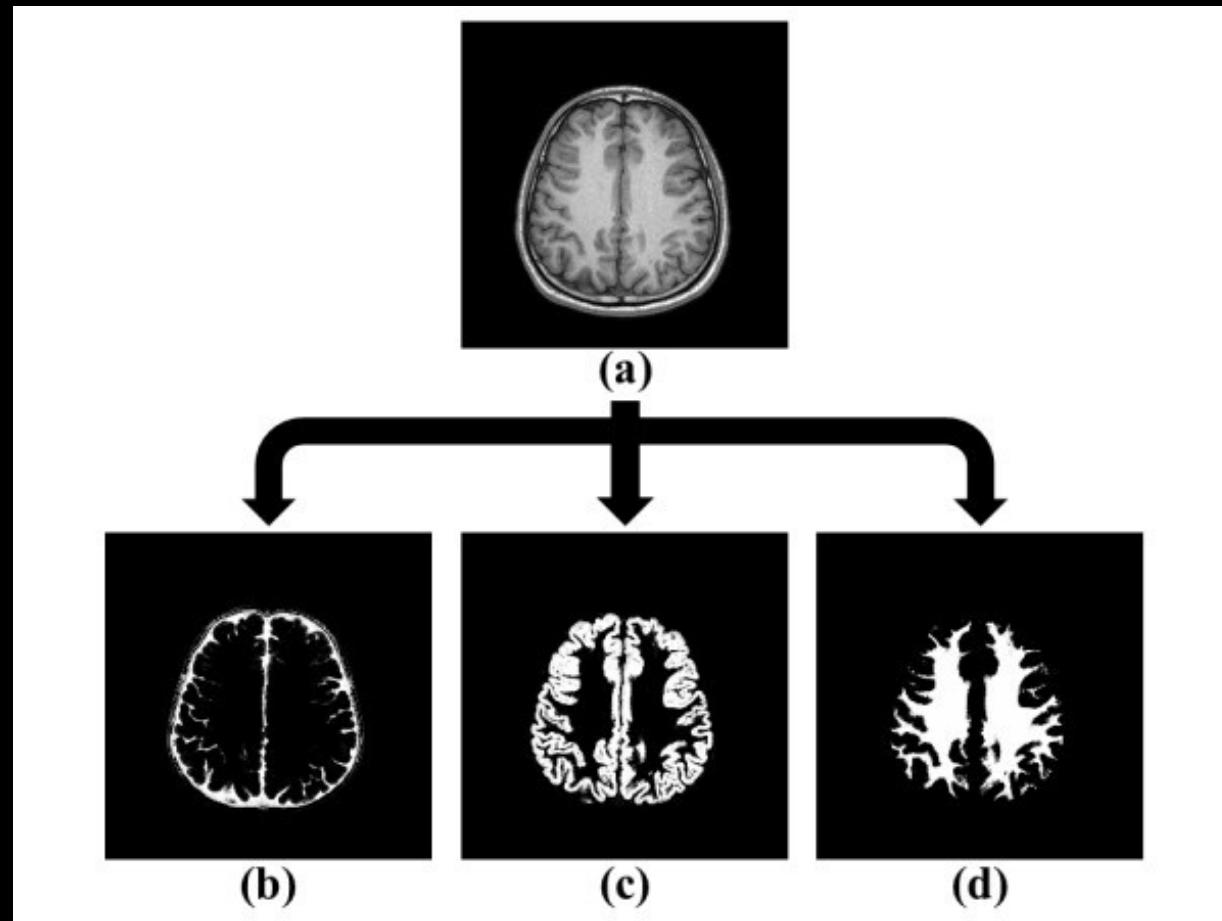
# Data format

1. Digital Imaging and Communications in Medicine (**DICOM**) 2D
2. Neuroimaging Informatics Technology Initiative (**NIFTI**) 2D, 3D or 4D

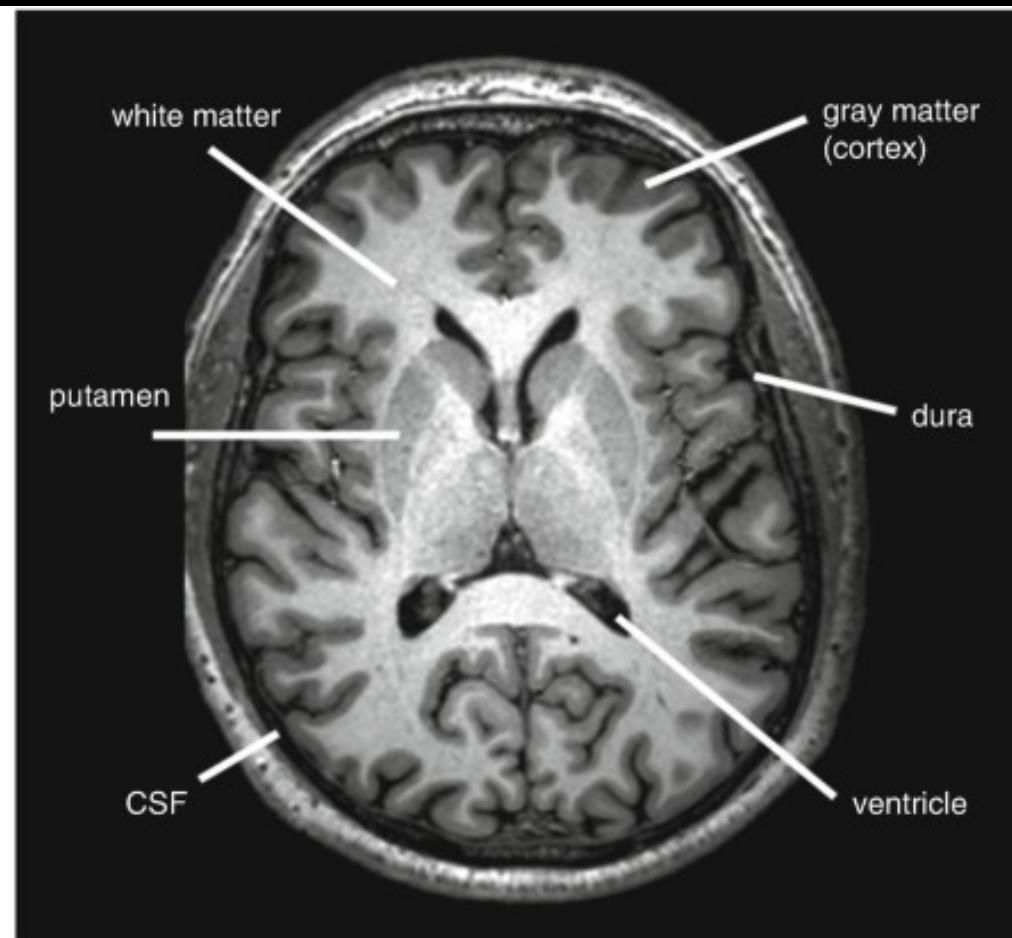
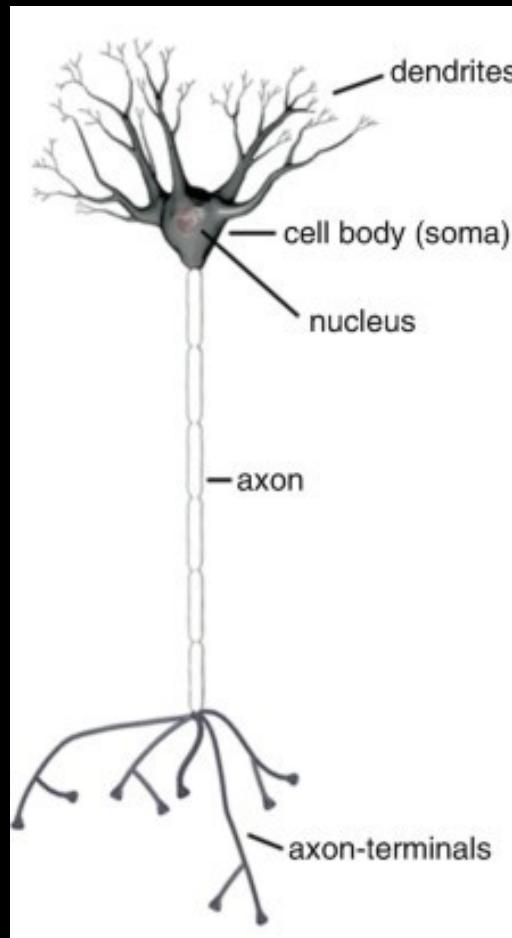
# Planes



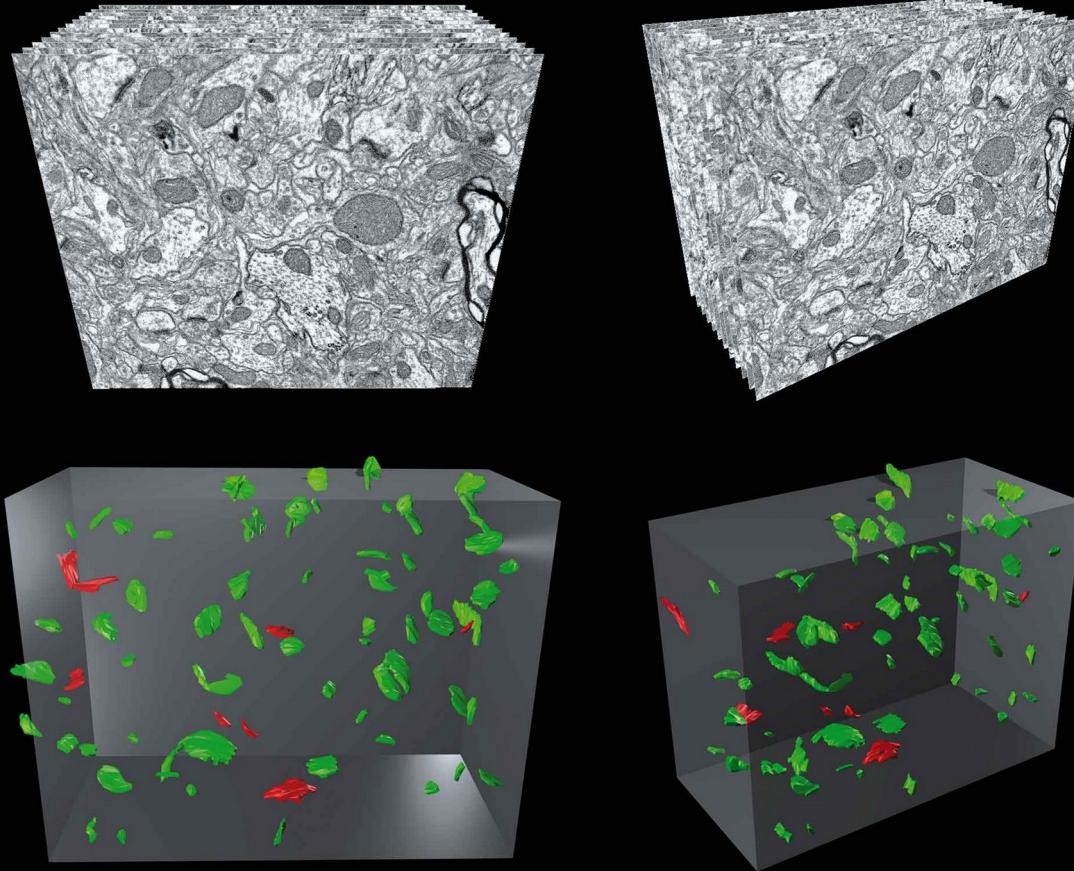
# What we usually see in an MRI



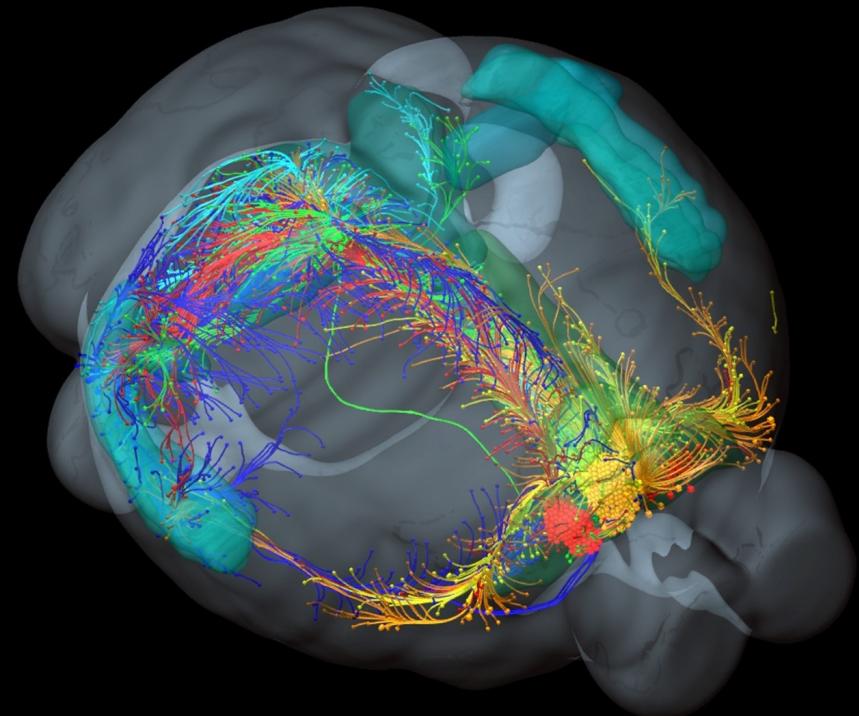
# What we usually see in an MRI



# Electron microscopy slices



# Adeno-associated virus tractography

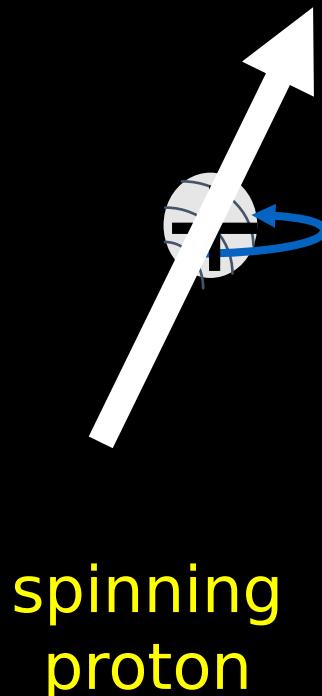


Oh et al. Nature 2014

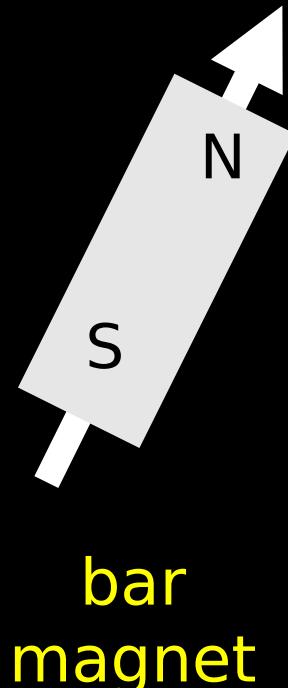


# Break

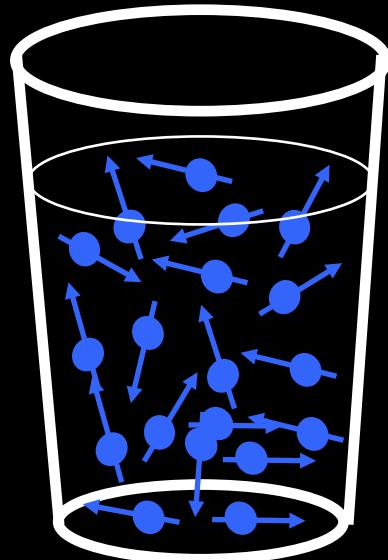
# Magnetic Resonance Imaging



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

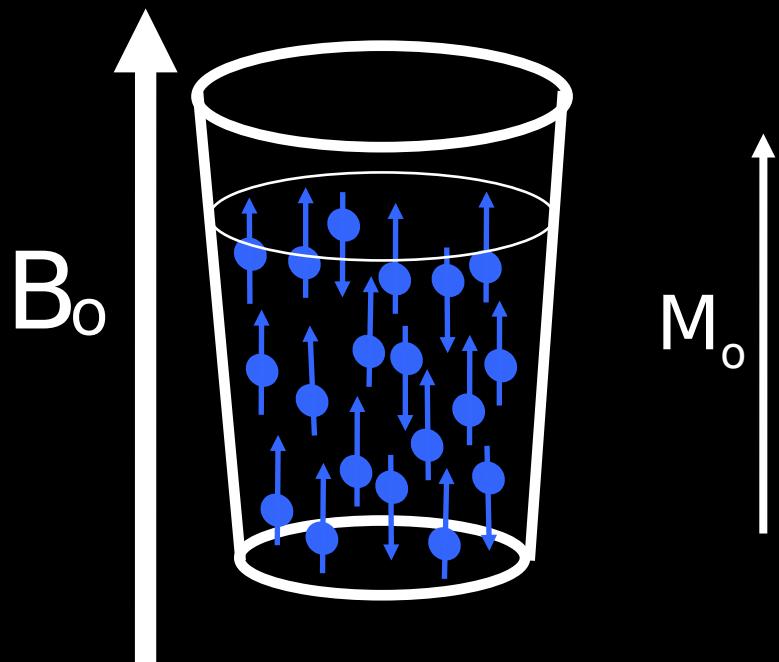


Randomly oriented  
protons



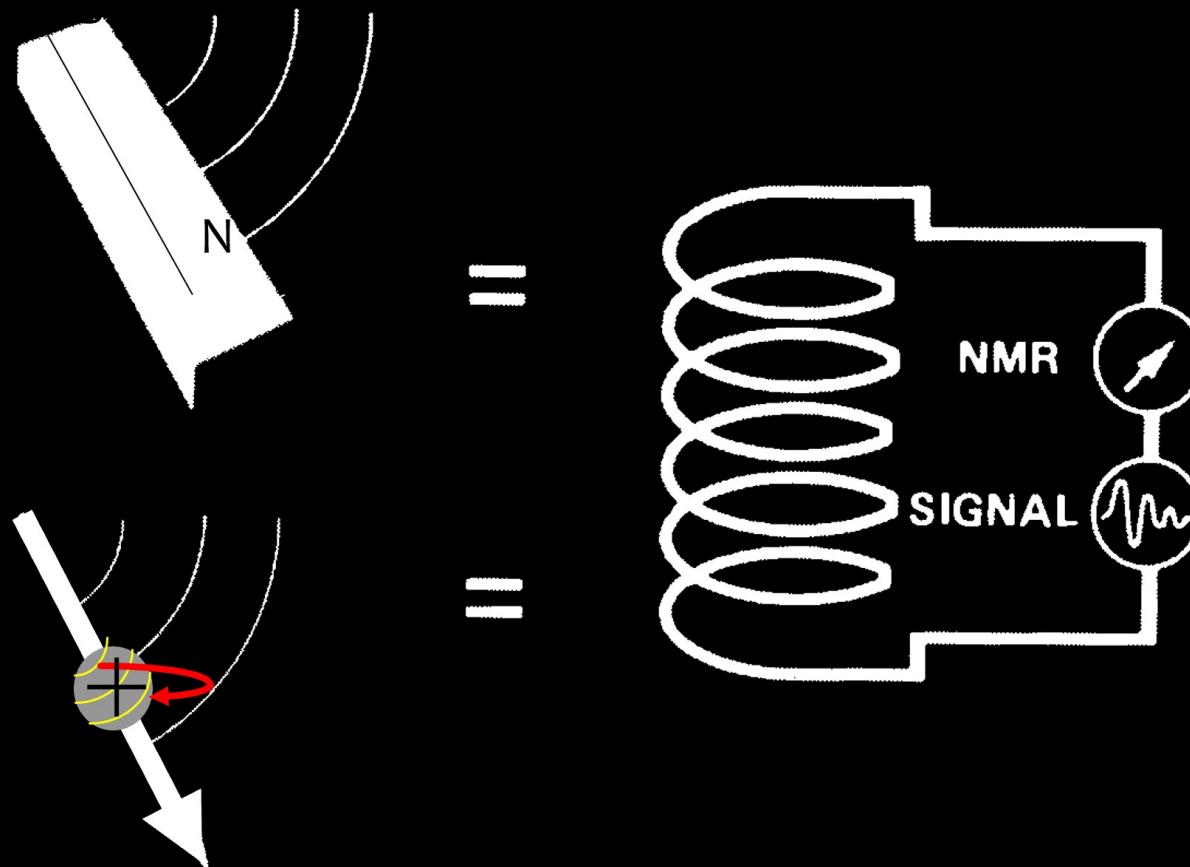
net magnetic  
moment is *zero*

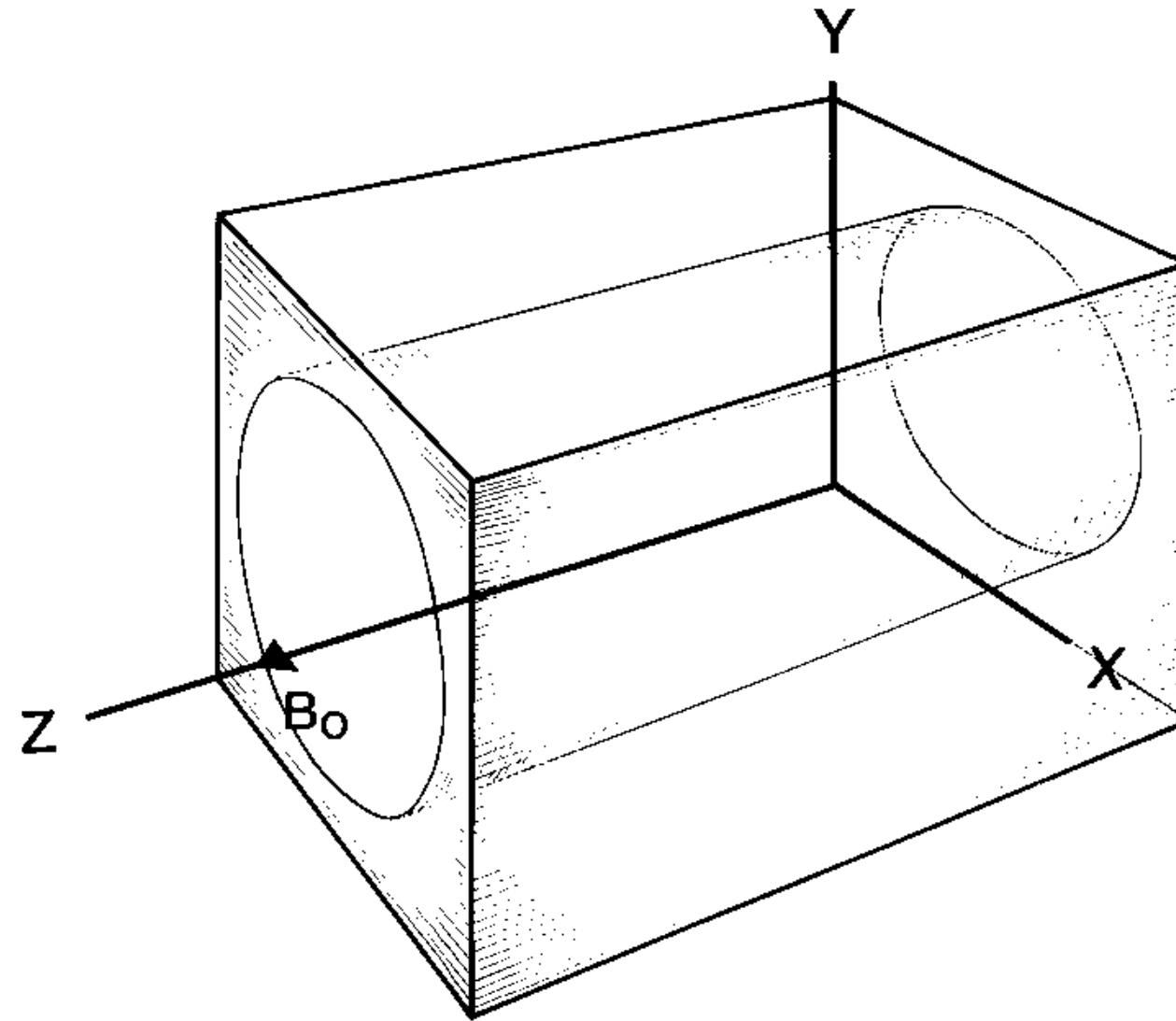
Protons aligned with a  
strong magnetic field

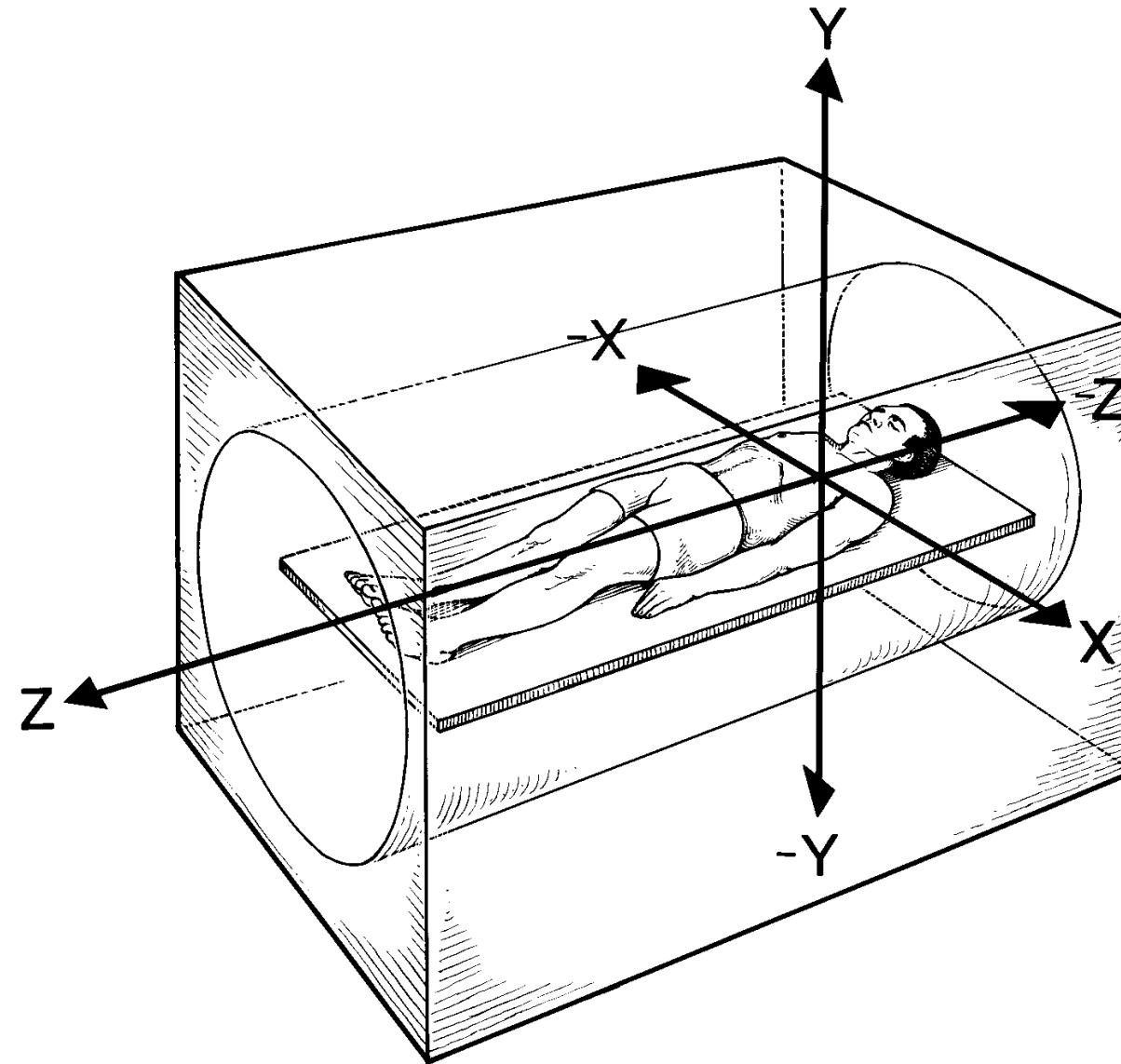


net magnetic moment  
is *positive*

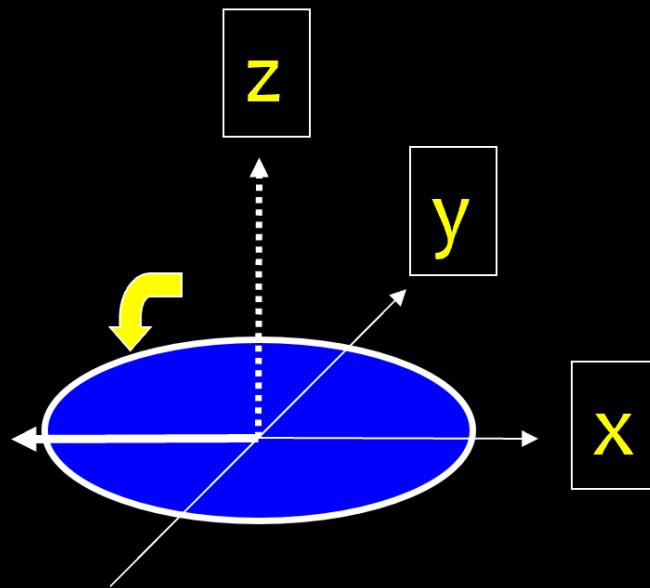
# MRI measurement







# 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 ( $B_0$ ) 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 ( $M_0$ )

Transverse relaxation occurs much faster than Longitudinal relaxation

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

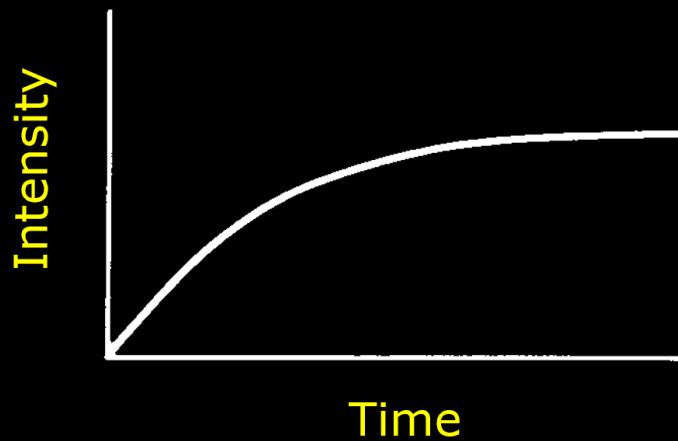
# Main Tissue Contrast Controls

Echo Time (TE) - time after  $90^\circ$  RF pulse until readout.  
Determines how much transverse relaxation will occur before reading one row of the image.

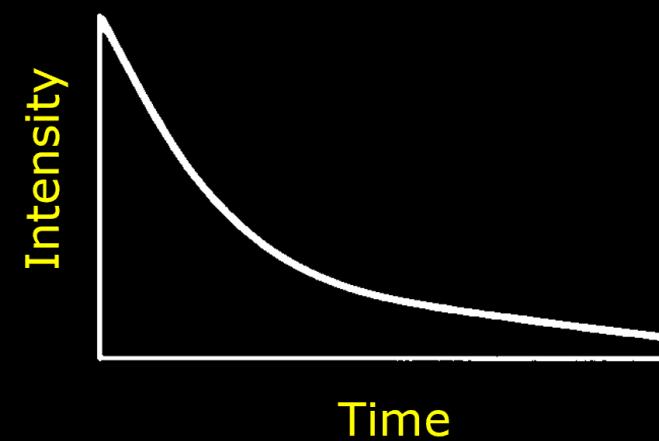
Repetition Time (TR) - time between successive  $90^\circ$  RF pulses. Determines how much longitudinal relaxation will occur before constructing the next row of the image.

# Main Tissue Contrast Controls

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



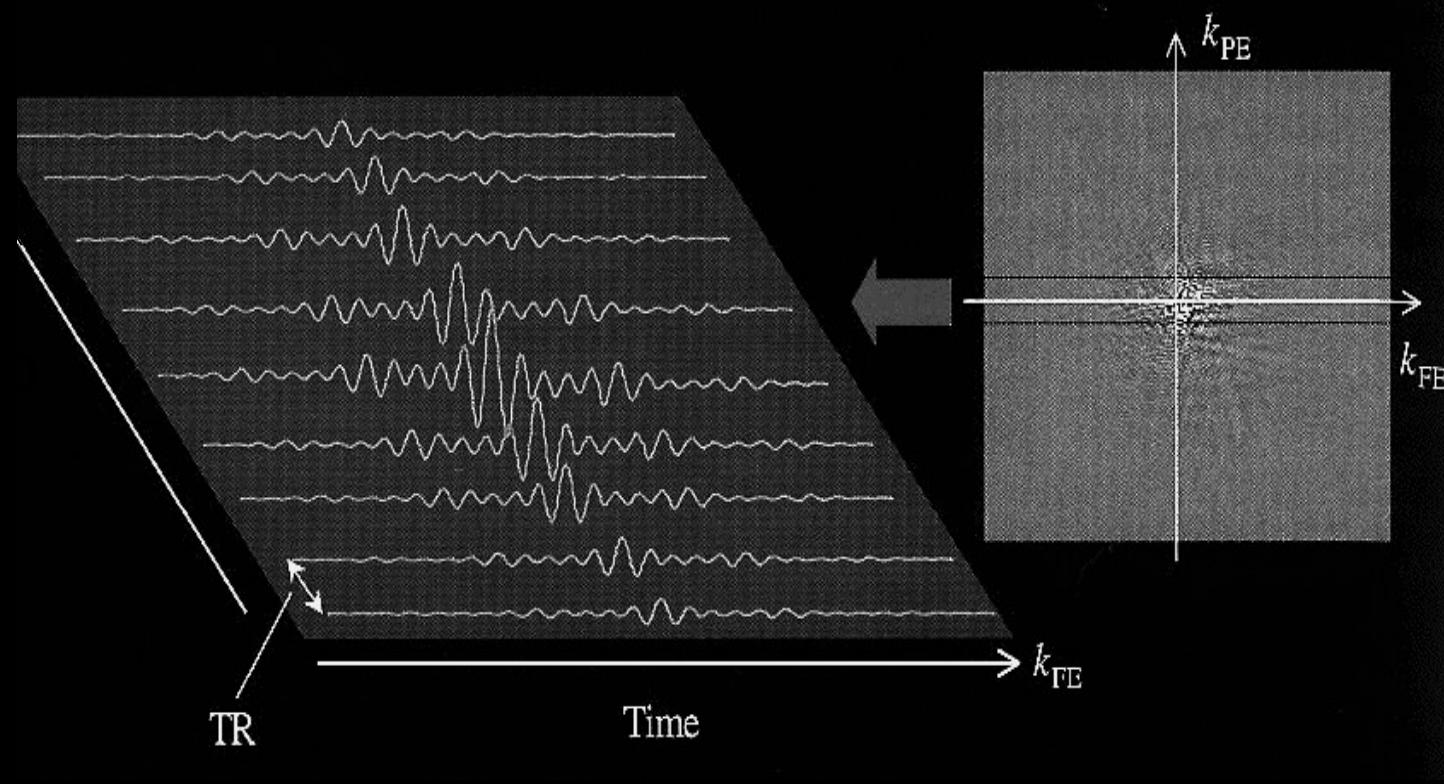
T1 Curve



T2 Curve

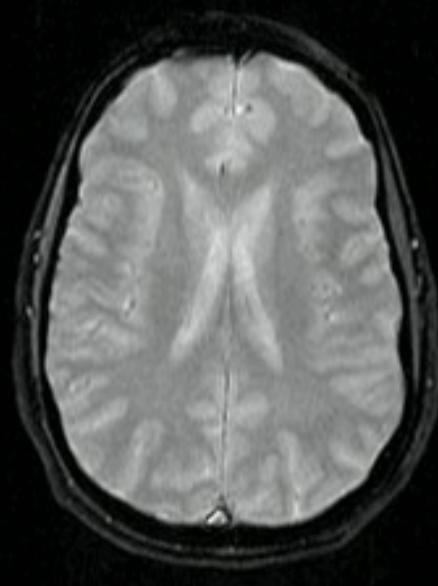
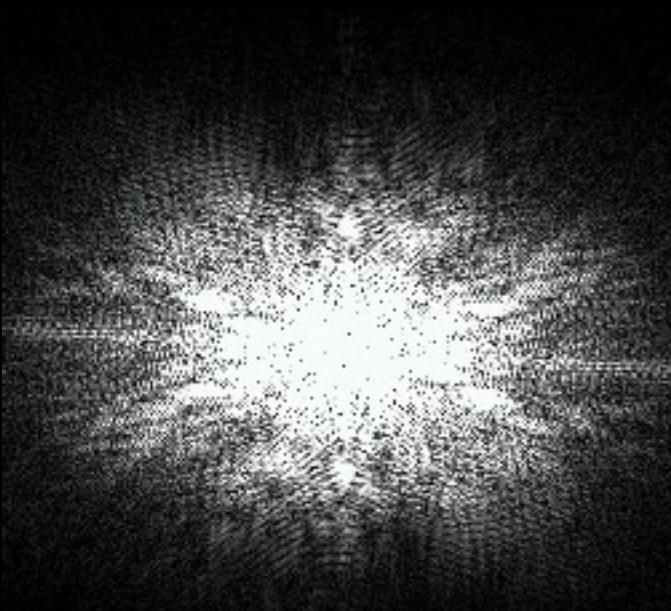
# k-space

Signal

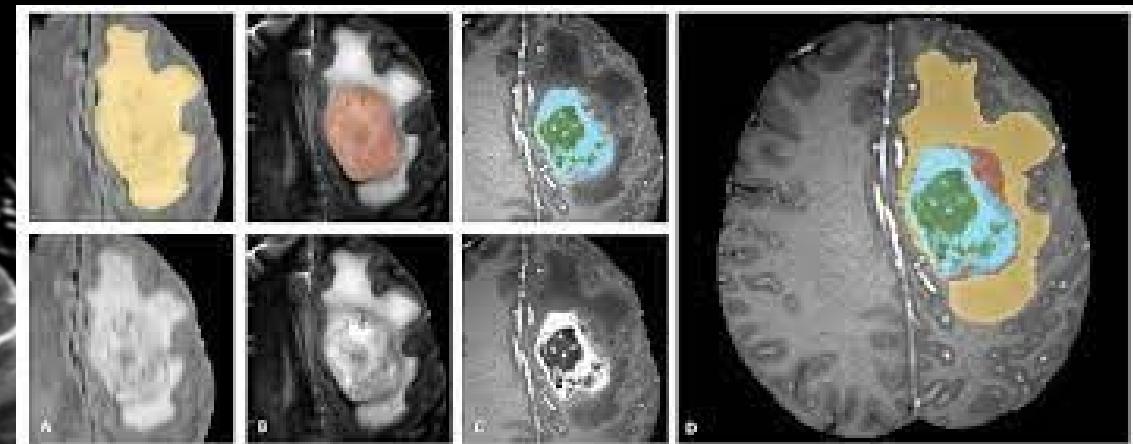
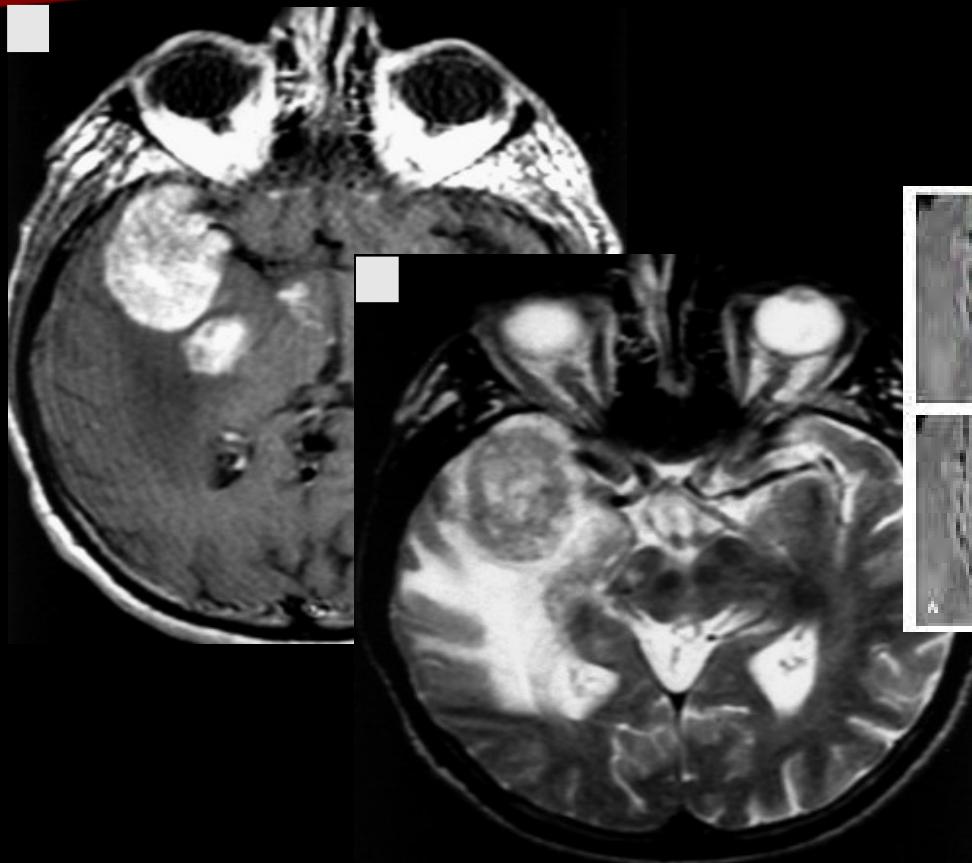


# Images From k-space

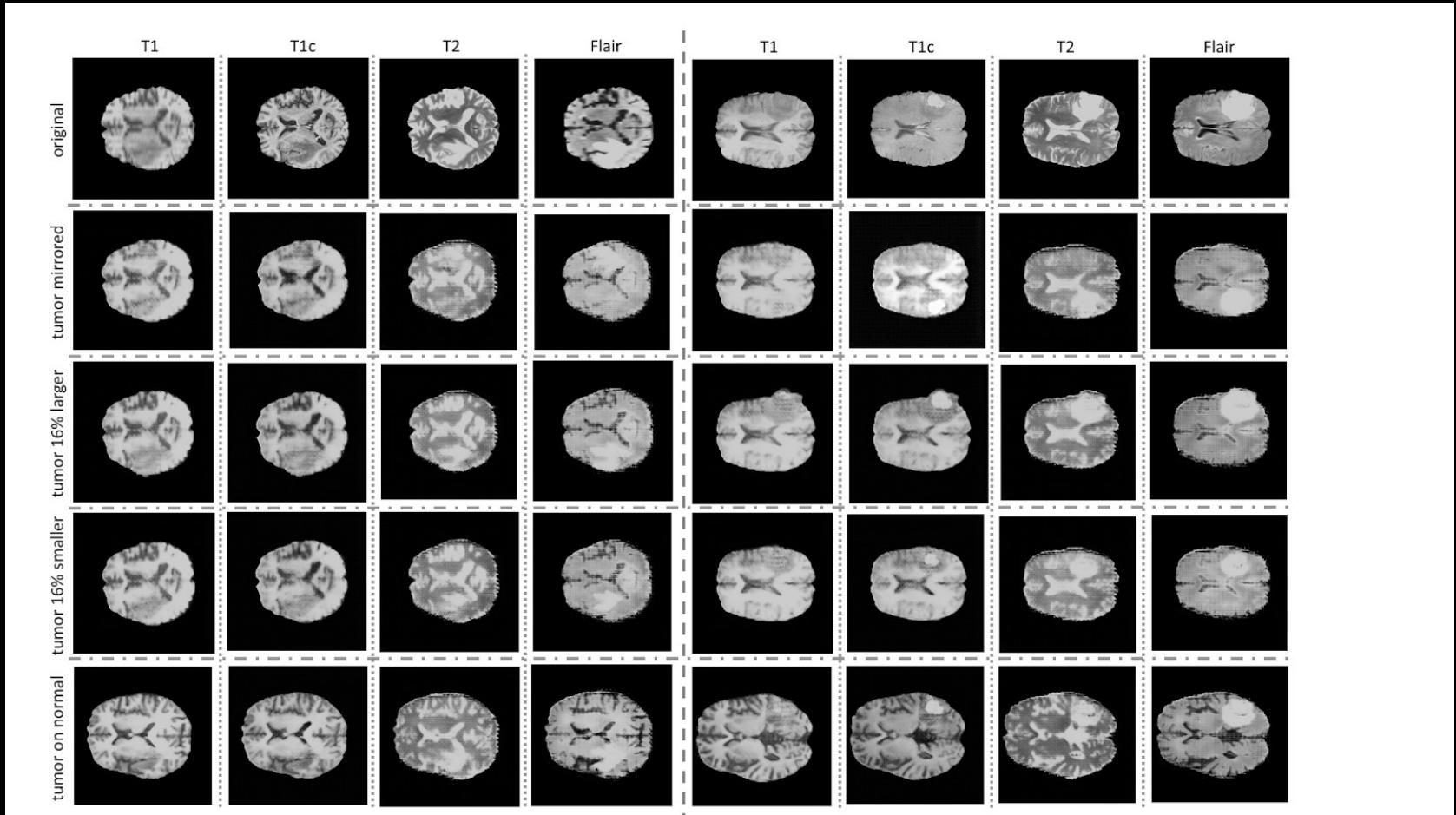
K-space is turned into an image using  
a Fourier Transformation



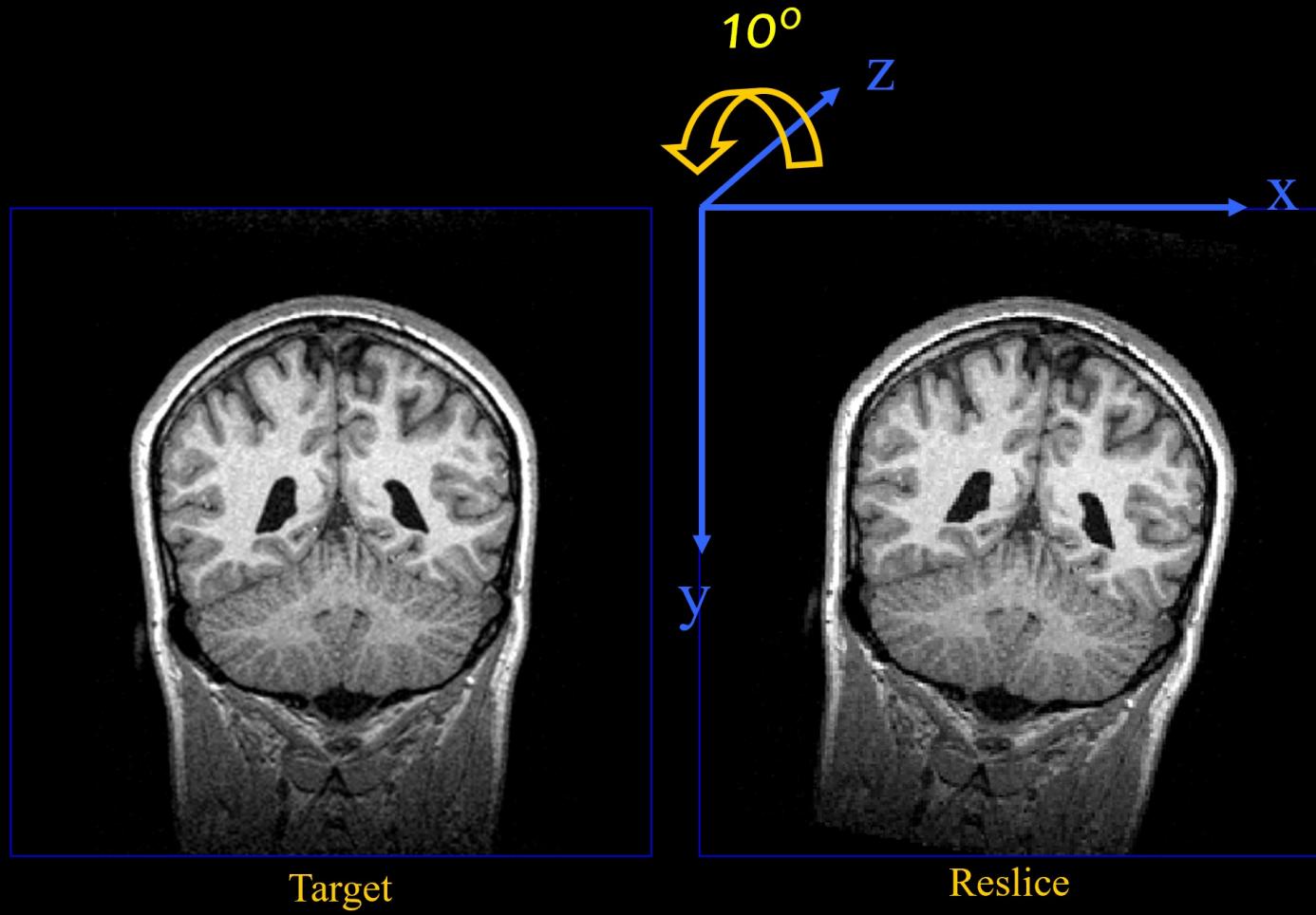
# Just structural



# GAN TUMOR



# Registration

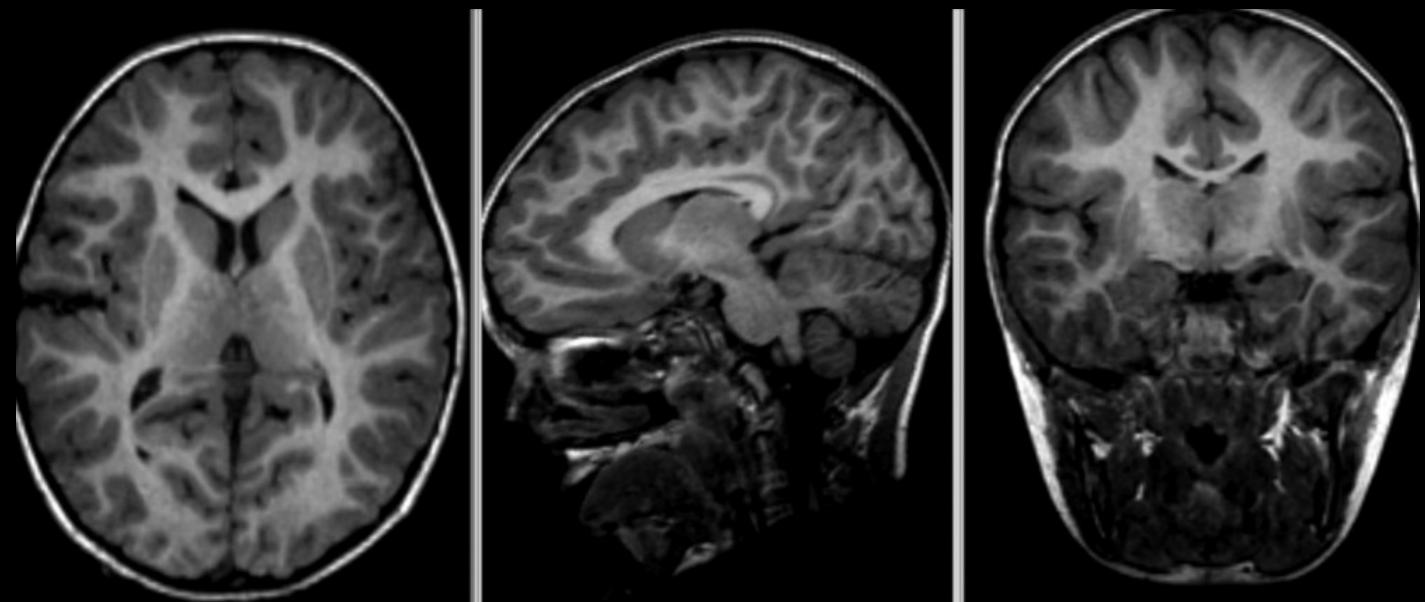
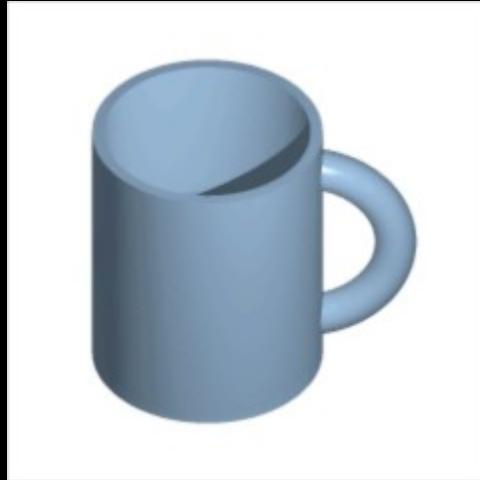


# Registration

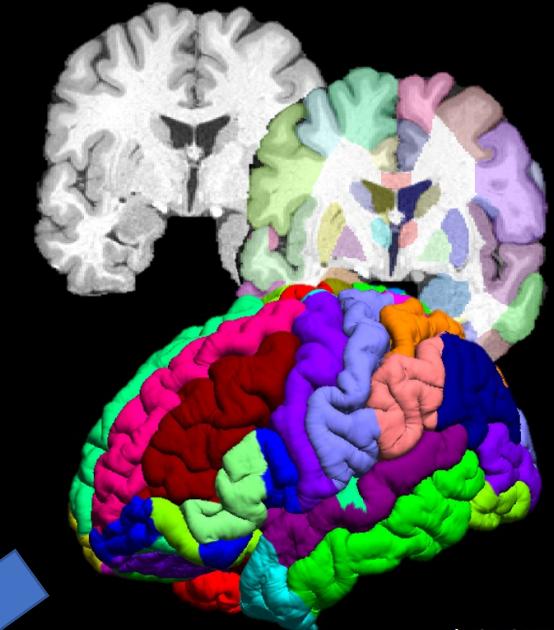
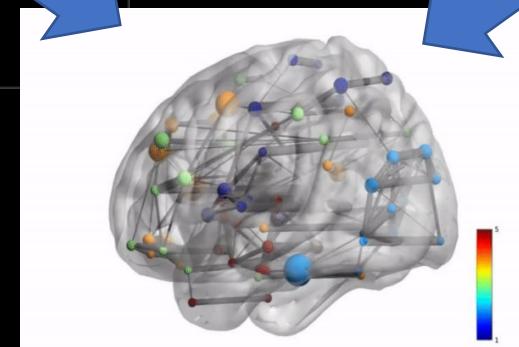
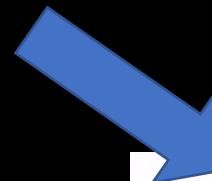
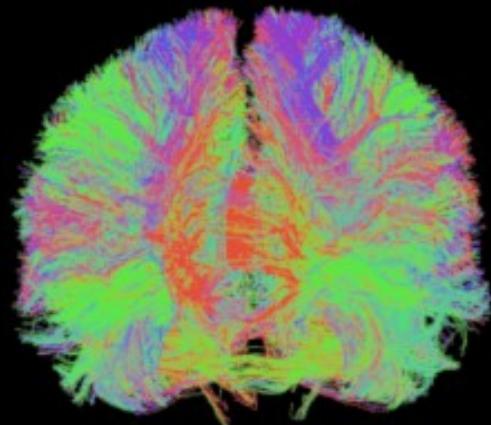
Reasons:

- 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



[brainsuite.org](http://brainsuite.org)

# 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

