Introduction to Brain Imaging

Human Brain Imaging NEUR 570

& BIC lecture series

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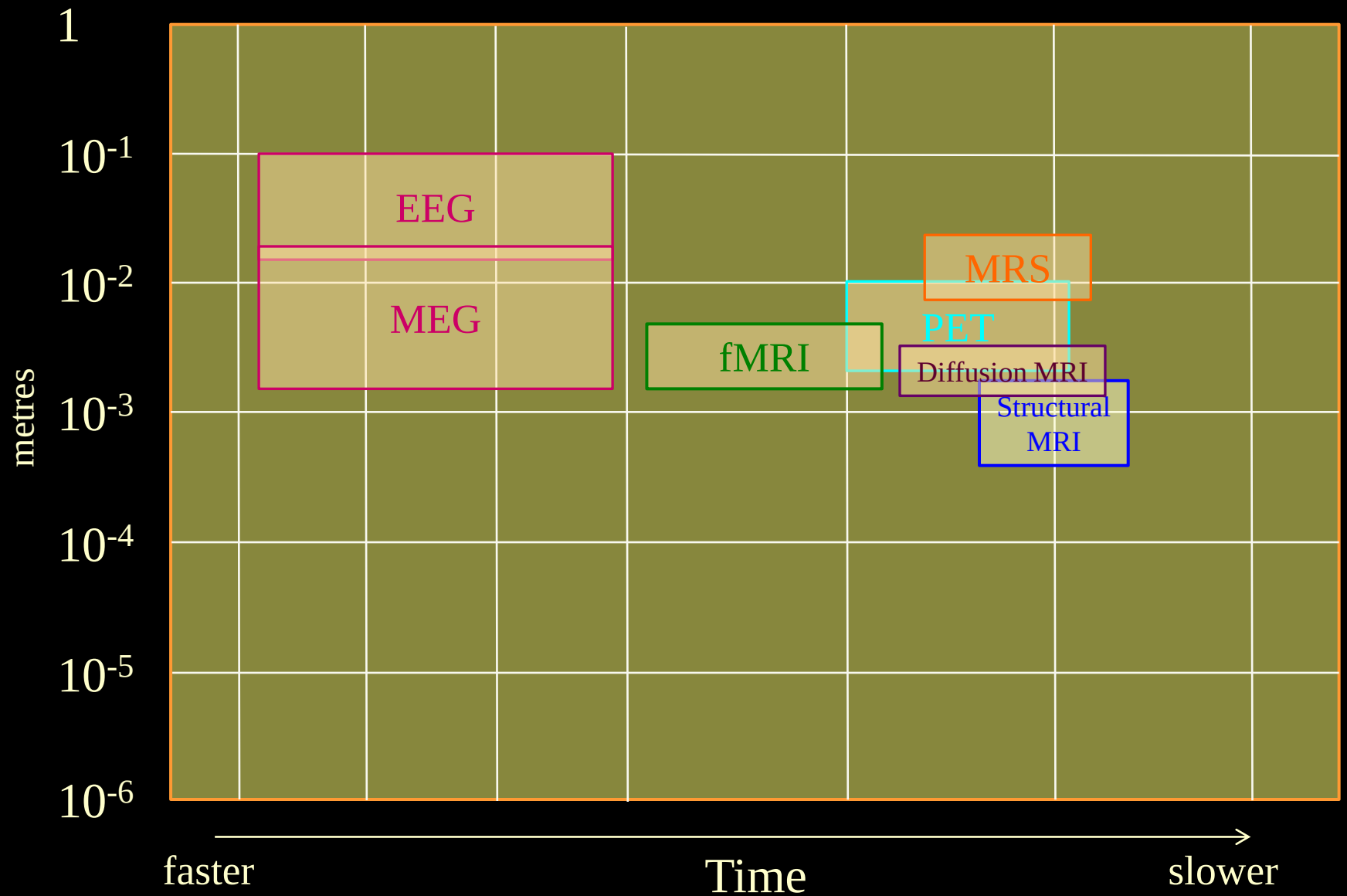
Various techniques available to image the human brain

Which technique should I use?

Different techniques have different spatial and temporal scales

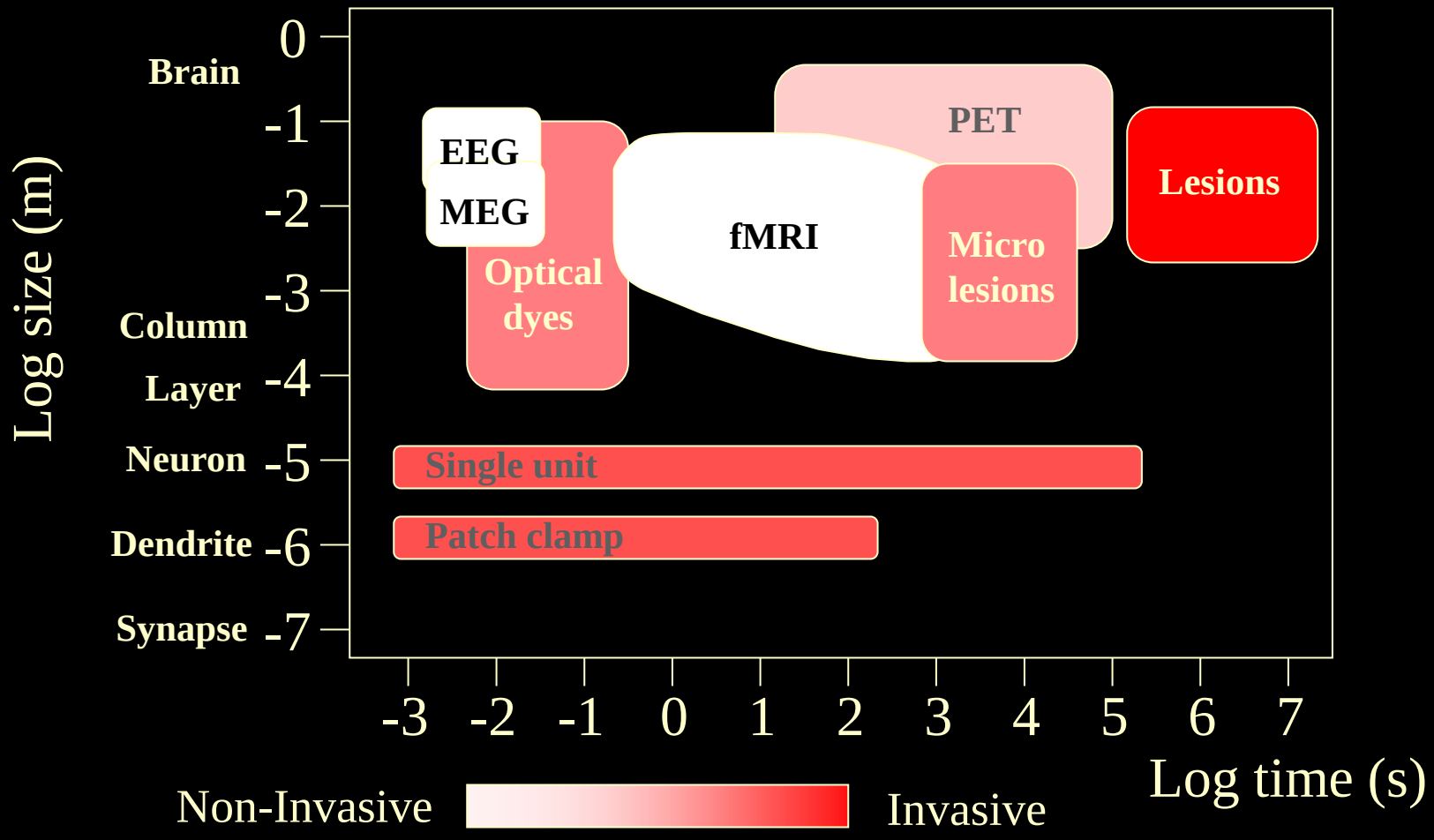


What do want to image?
(Or: what can we image?)

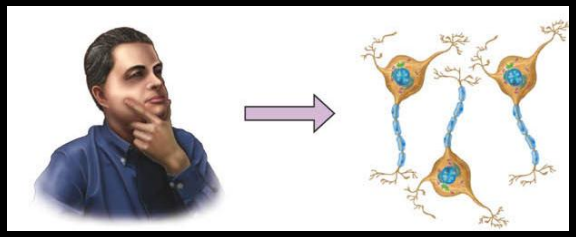
- Neuronal activity
- Brain metabolism
- Blood flow
- Anatomy gray and white matter
- Receptor density
- Brain biochemistry
- ....

i.e. STRUCTURE and FUNCTION of the brain

Functional mapping methods

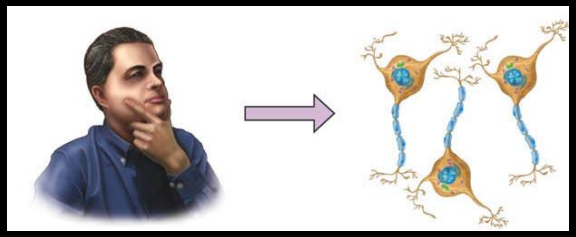


Imaging brain function in humans (ethically)



neuronal activity
- excitatory
- inhibitory

Imaging brain function in humans (ethically)



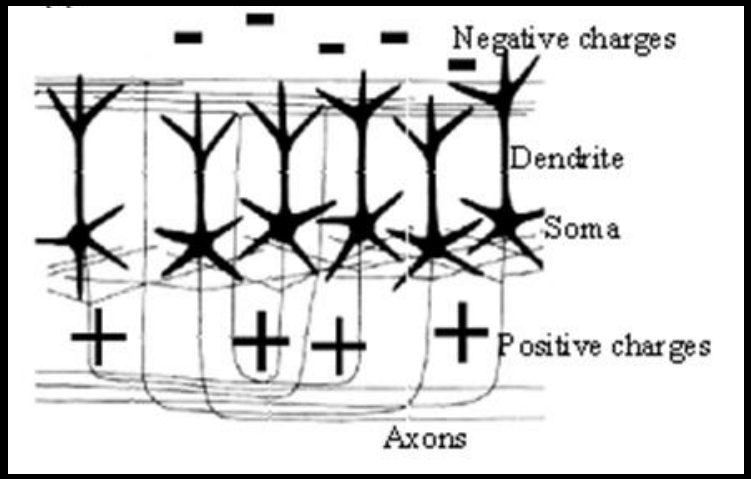
neuronal activity
- excitatory
- inhibitory

EEG

MEG

Electroencephalography (EEG)

- Record voltage fluctuations along the scalp
  - Summation of synchronous activity of thousands or millions of neurons with similar spatial orientation
  - Measure electrical activity at many points and mathematically infer the localization of the source
  - Clinical applications: epilepsy, coma/anesthesia/sleep
  - Research: event-related potentials



A Hydrocel Geodesic Sensor Net by Electrical Geodesics, Inc.
- image from Wikipedia

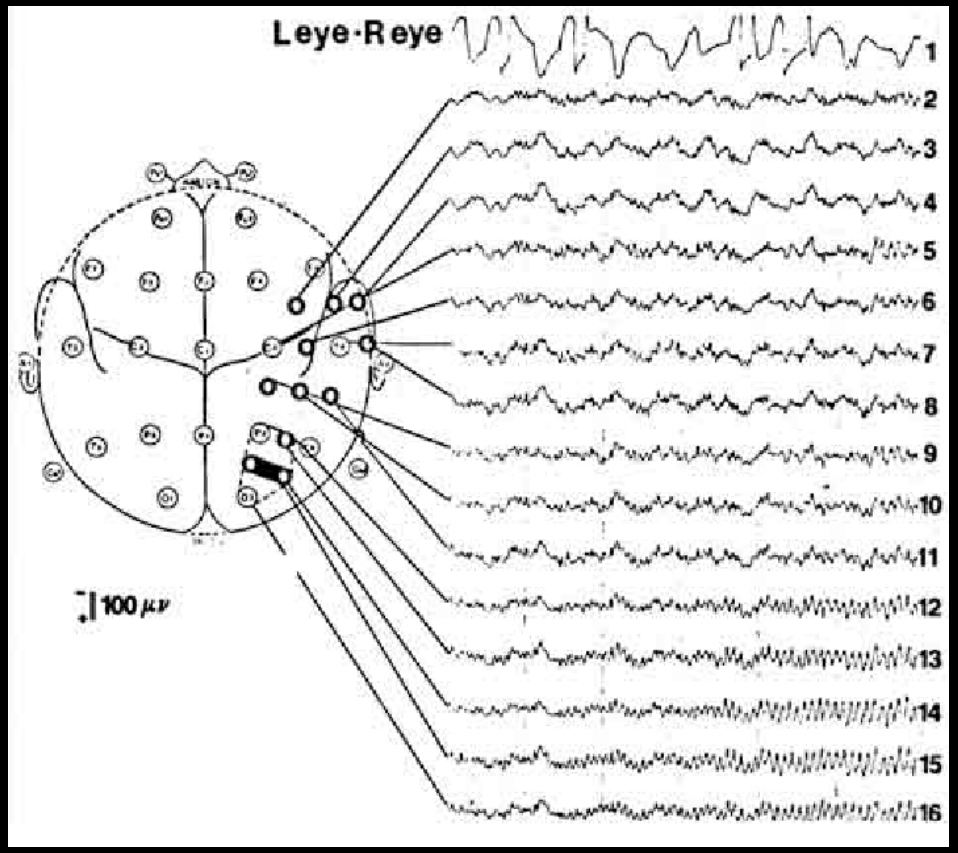
Electroencephalography (EEG)

+ Millisecond-range temporal resolution

- Coarse spatial resolution ~ several centimeters

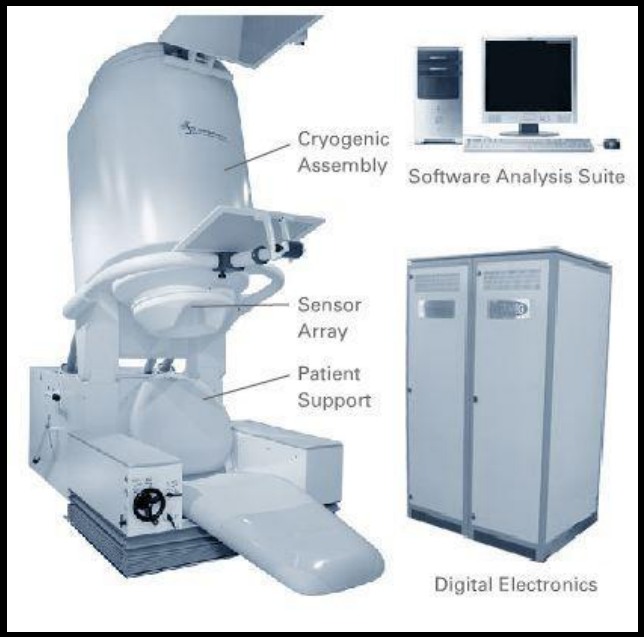
- Inverse problem: sources ambiguous

- Signal drop off with d^2: deep sources more difficult



Magnetoencephalography (MEG)

- Measures fluctuations of magnetic fields generated by neuronal currents
  - superconducting quantum interference device (SQUID) detectors
  - Measurement of very weak magnetic fields requires specially shielded rooms



Magnetoencephalography (MEG)

+ Millisecond-range temporal resolution

+ Higher spatial resolution than EEG (several mm to a few cm)

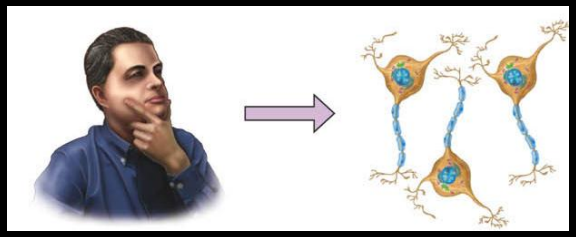
- Inverse problem: sources ambiguous

- Radial sources invisible

- Deep sources difficult (more than for EEG)

+ Deep sources difficult (i.e. superficial tangential sources less contaminated)

Imaging brain function in humans (ethically)



neuronal activity
- excitatory
- inhibitory

metabolic response
- ↑ glucose consumption
- ↑ oxygen consumption

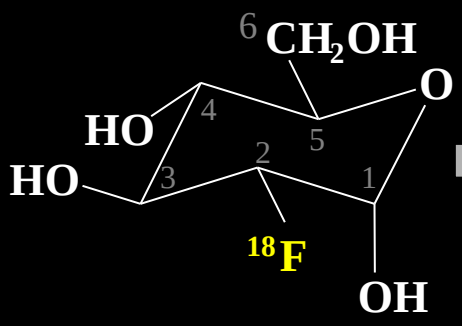
FDG PET

$CMRO_2$ MRI

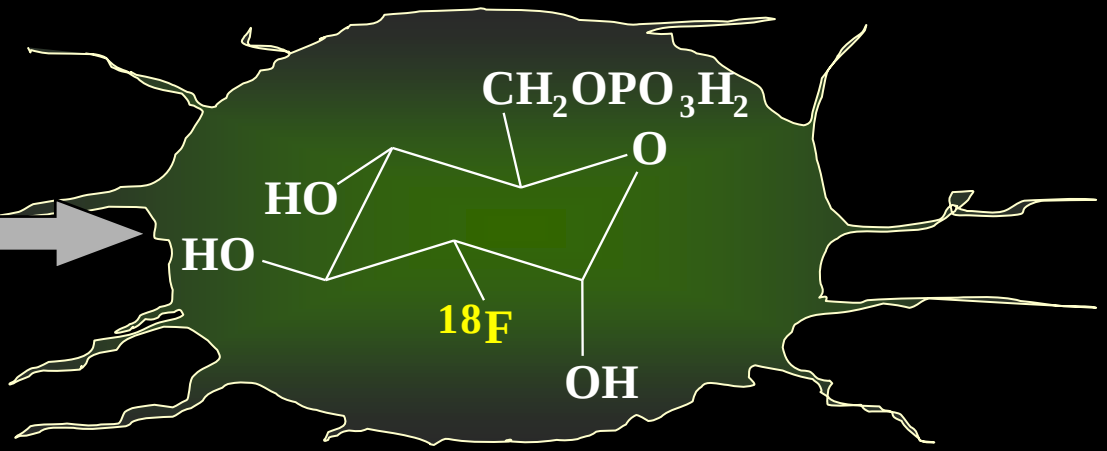
EEG

MEG

2-[^{18}F]Fluoro-Deoxy-Glucose



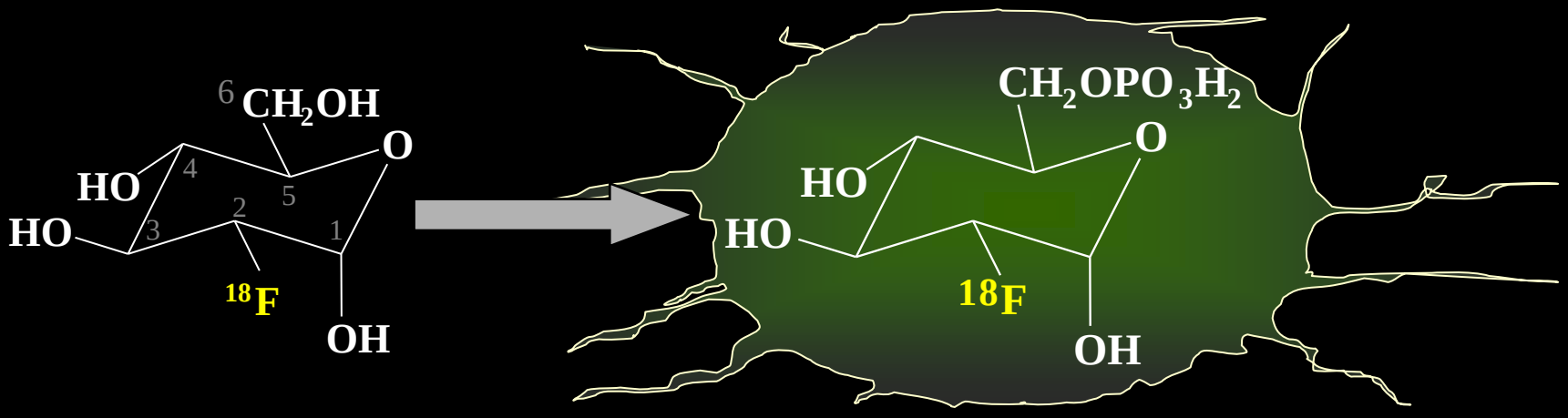
2-[18F]FDG-6-phosphate



no substrate for glucose-phosphate-isomerase: accumulates in cell

2-[^{18}F]Fluoro-Deoxy-Glucose

2-[18F]FDG-6-phosphate



Imaging of glucose uptake

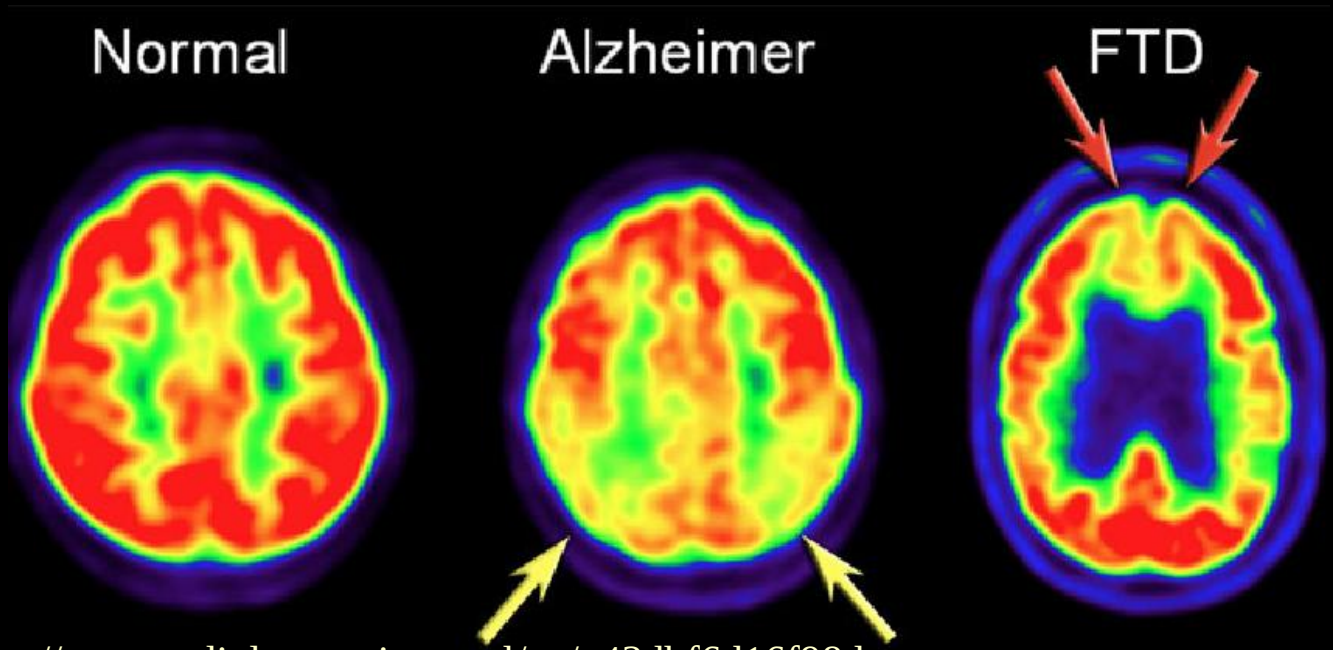


Image from http://www.radiologyassistant.nl/en/p43dbf6d16f98d

Positron emission tomography

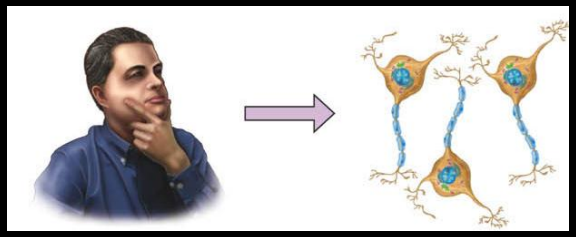
\+ Very specific: label what you want (i.e. what your radiochemist can do)

+/ - Spatial resolution (depends e.g. on radioisotope), several millimeters to centimeters

\- Poor temporal resolution (depends on radioisotope), minutes to hours)

\- Requires radioactive tracer and its injection

Imaging brain function in humans (ethically)



neuronal activity
- excitatory
- inhibitory

metabolic response
- ↑ glucose consumption
- ↑ oxygen consumption

FDG PET

EEG

MEG

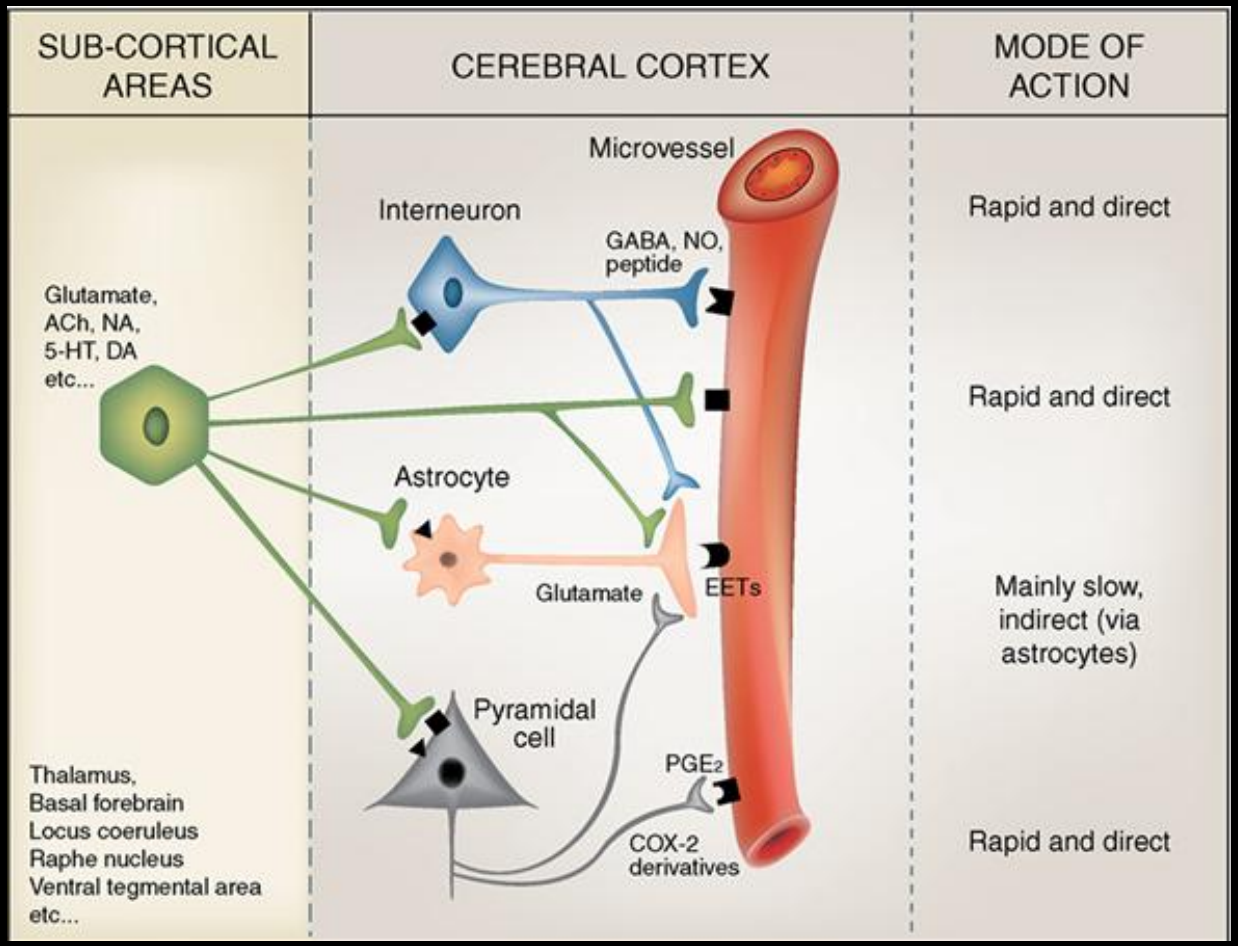
hemodynamic response
- ↑ blood flow
- ↑ blood volume
- ↑ blood oxygenation

$H_2{}^{15}O$ PET

NIRS

fMRI

Neurovascular coupling



EETs: epoxyeicosatrienoic acids

Cauli and Hamel, Frontiers in Neuroenergetics, 2010

BOLD fMRI

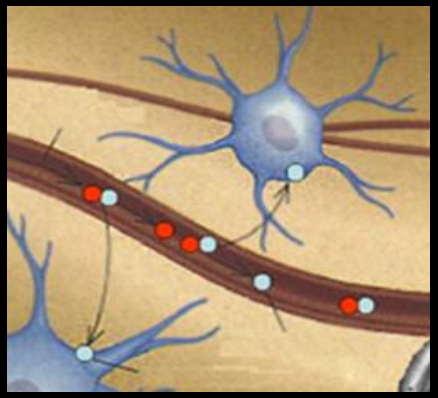
- The workhorse of functional imaging techniques based on hemodynamics

- BOLD: Blood Oxygenation Level-Dependent
  - Sensitive to small changes in T2* resulting from the difference in magnetic properties of
    - Deoxyhemoglobin
    - Oxyhemoglobin

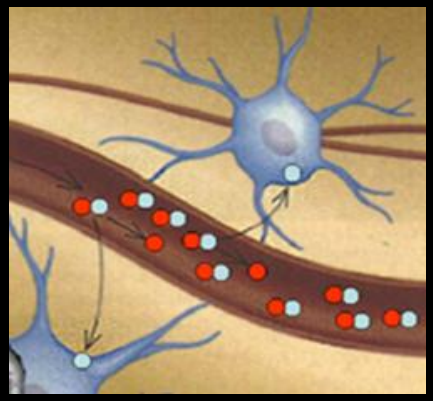
BOLD fMRI

Neuronal activation =>

- Increased local (capillary) blood flow: far in excess of increased local oxygen demand
- Increased ratio oxyHg:deoxyHg
- Increased signal on T2*-weighted images



Resting state



Activated state

CBF
CBV
Oxy-Hb
Deoxy-Hb
OxyHb/DeoxyHb

Astolfi et al., Int J of Bioelectromagnetism, 2006: 6 (2)

Task fMRI

47*9=?

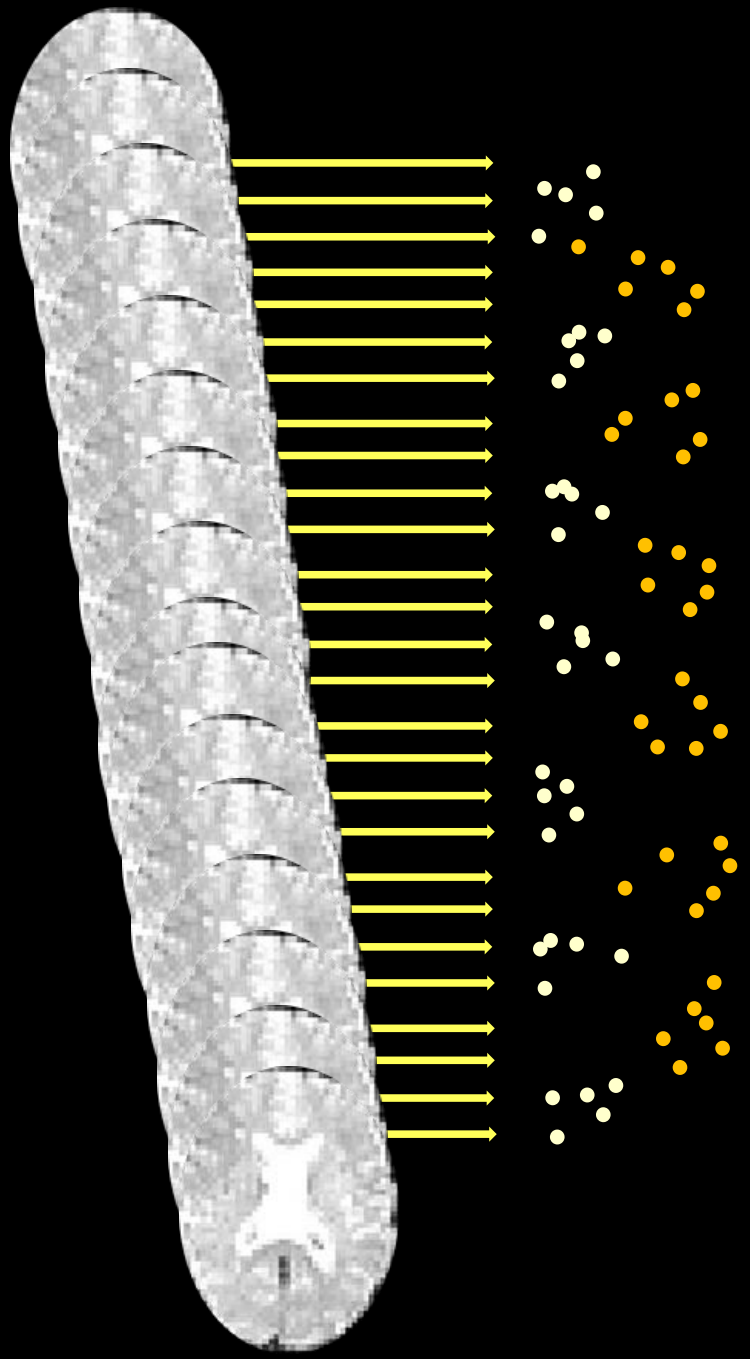
45*3=?

42*5=?

45*6=?

47*7=?

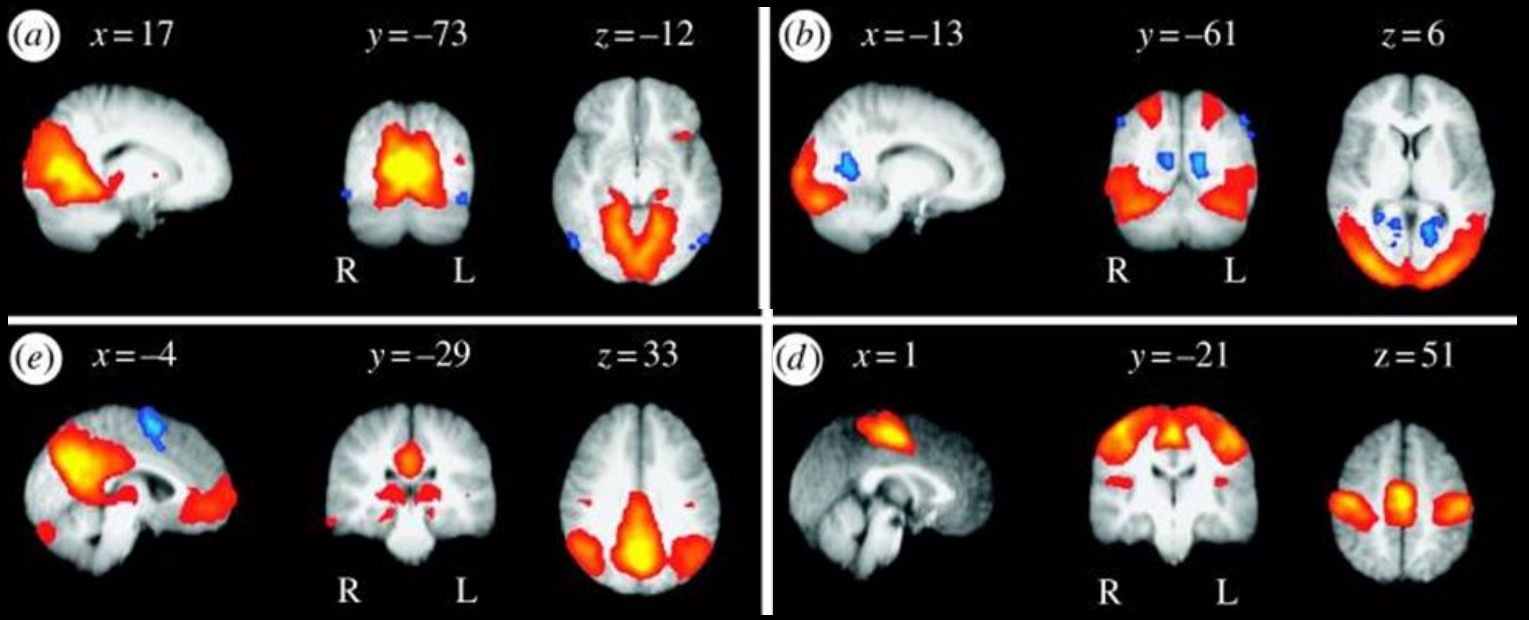
43*4=?



- Detects changes in neuronal activation due to some task or stimulus
  - Studies of normal brain function
  - Studies of altered brain function in patients
    - Need to consider effects of pathology on the signal
      - Vascular changes
      - Blood flow/volume, perfusion/diffusion

Resting state fMRI

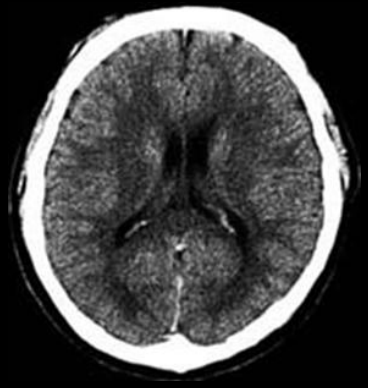
- Task-free or “resting state” analyses to find spatial patterns of temporally-correlated BOLD signal changes
  - Thought to reveal distinct cortical networks



Beckmann et al., Philos Trans R Soc Lond B Biol Sci. 2005;360(1457):1001-13.

Imaging brain structure in vivo

- MRI
- MRI
- MRI
- CT…
- PET with specific tracers (i.e. 18F-flumazenil)



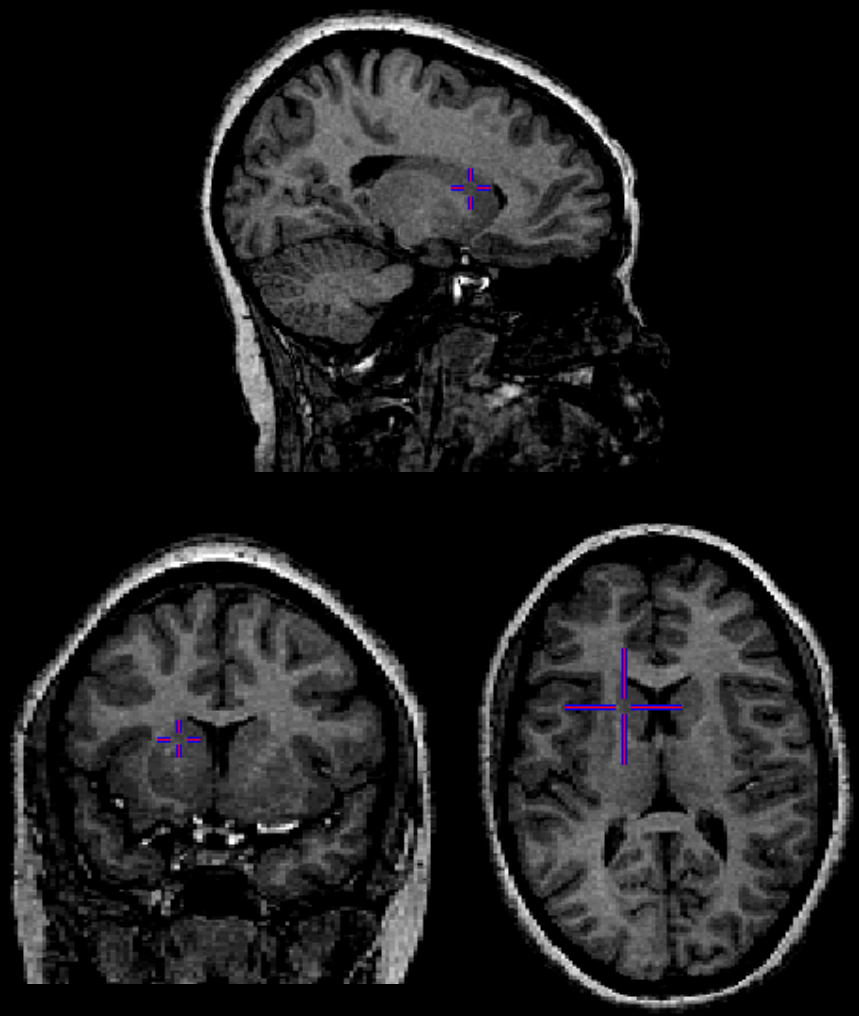
http://thebrain.mcgill.ca/flash/capsules/outil_bleu13.html#ctscan

Structural MRI

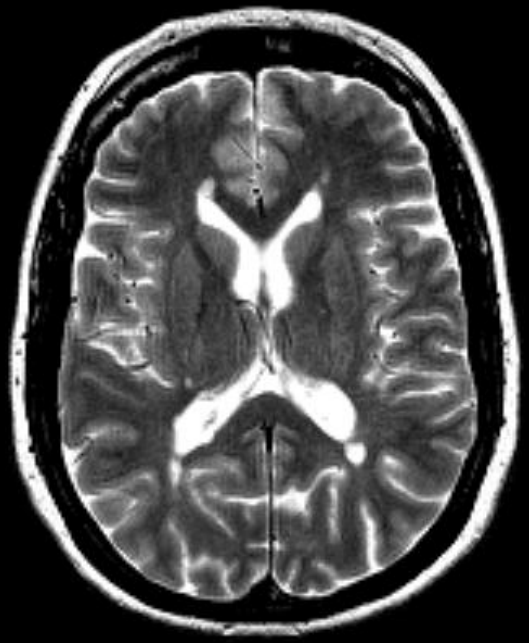
- Wide variety of contrasts available
  - T1-weighted
  - T2-weighted
  - Proton density (PD)-weighted
  - …

T1-weighted

- Good WM/GM contrast
- Used for segmentation and volumetry of brain tissues or structures
  - Voxel-based morphometry (VBM)
  - Cortical Thickness Analysis



T2-weighted

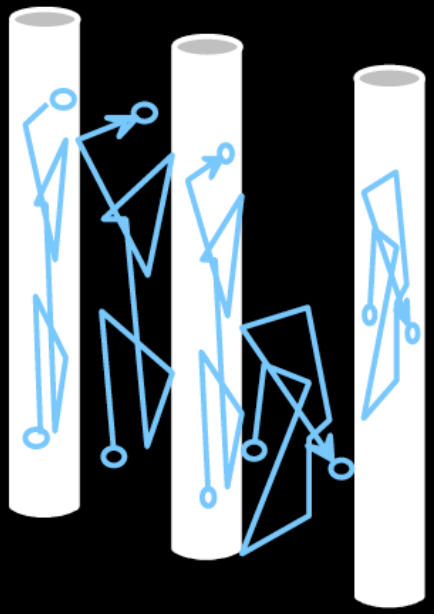


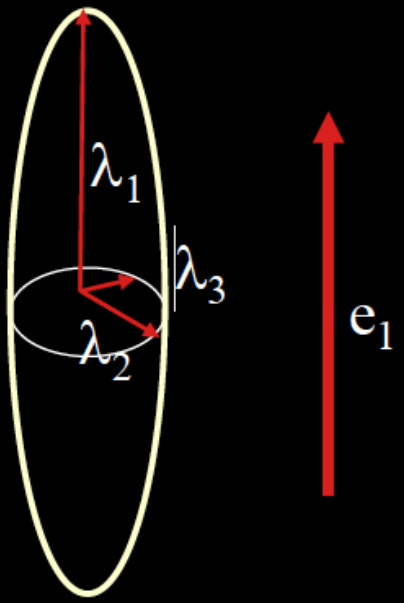
- Visualize pathology with high sensitivity
  - Not specific for a particular pathological process
- Aid in tissue/lesion segmentation

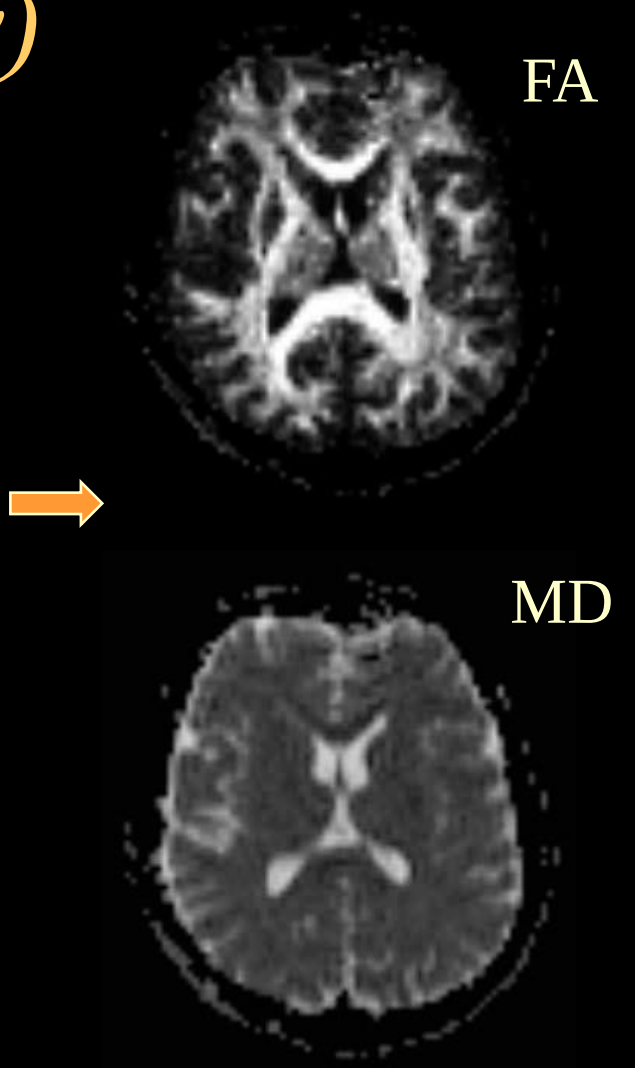
Diffusion-weighted imaging

- E.g. Diffusion Tensor Imaging
  - Quantifies the magnitude and direction of hindrance to water diffusion caused by axons, myelin membranes and surrounding structures
    - Informs about tissue microstructure

DTI: Directionality (fractional anisotropy) and 'amount' of diffusion (mean diffusivity)



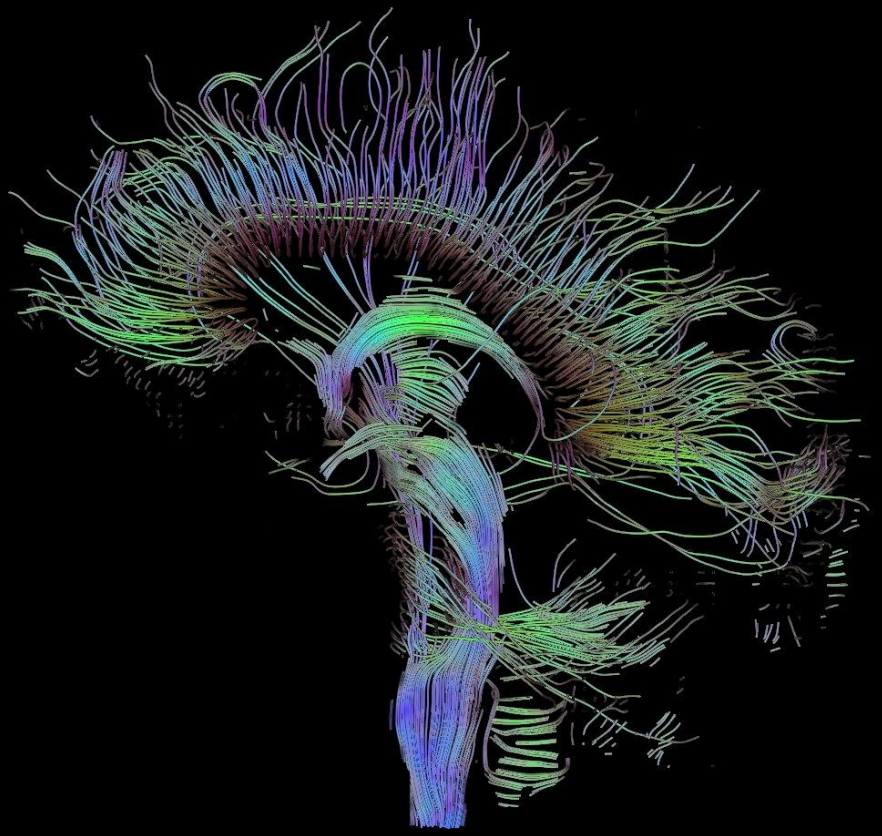




Images courtesy of Dr. Jennifer Cambell, BIC

DTI: tractograpy

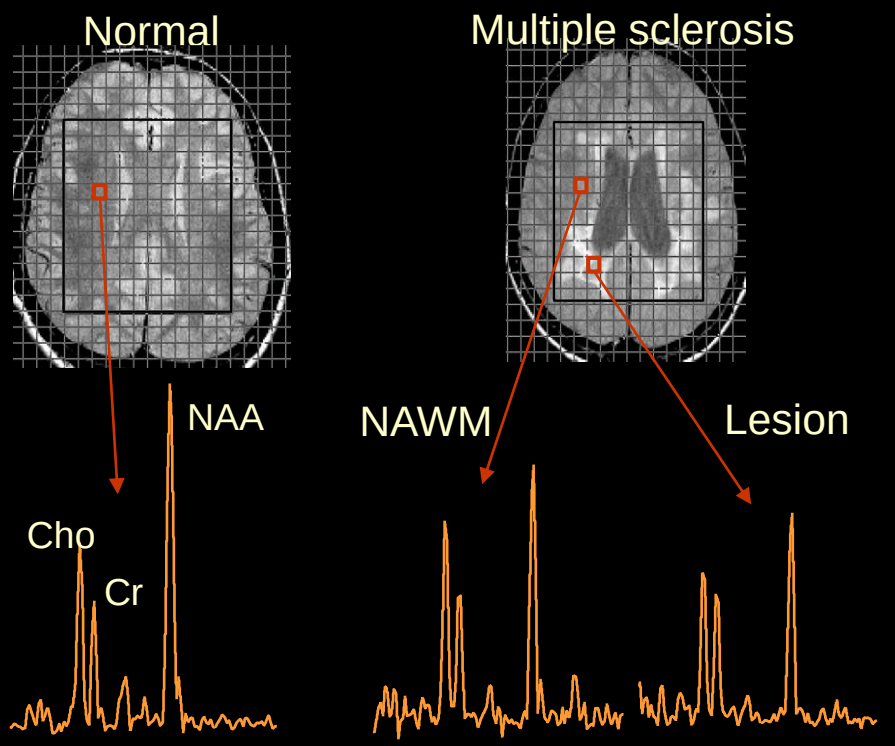
- Visualize white matter tracts
- Estimate connectivity between brain areas



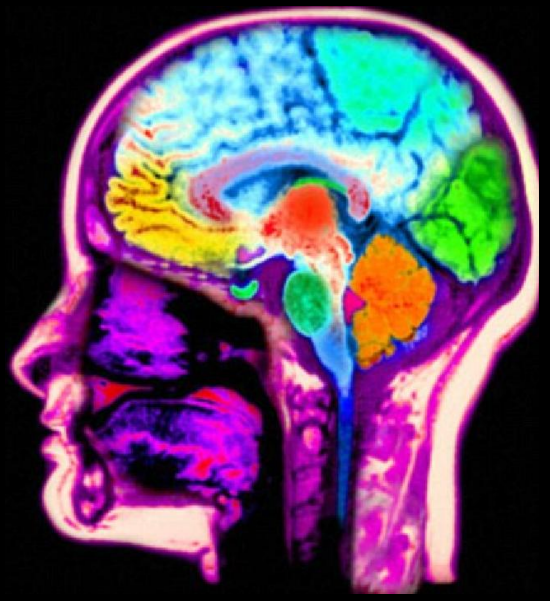
From Wikipedia Commons

Biochemical information: magnetic resonance spectroscopy (MRS)

- Provides biochemical information complementary to structural information from MRI
- A number of metabolic products can be measured, e.g. N-acetylaspartate (NAA), choline, creatine, lactate…
- Large body of work using NAA as a marker of neuroaxonal integrity
- Low spatial resolution (centimeters)
- Low temporal resolution (minutes)



- Many brain imaging modalities available
  - Different strengths and weaknesses
  - Provide different types of information
  - Can combine data from complementary techniques for a multimodal approach



Which technique should I use?

Which technique should I use?

- ALWAYS start with the biological question!
  - Which imaging technique provides the information I need?

Dreamstime.com

Questions?