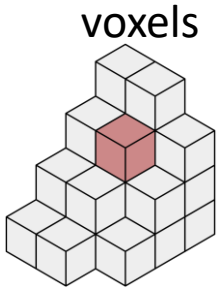
CS 463/516
Medical Imaging

Lecture 1

Medical Imaging

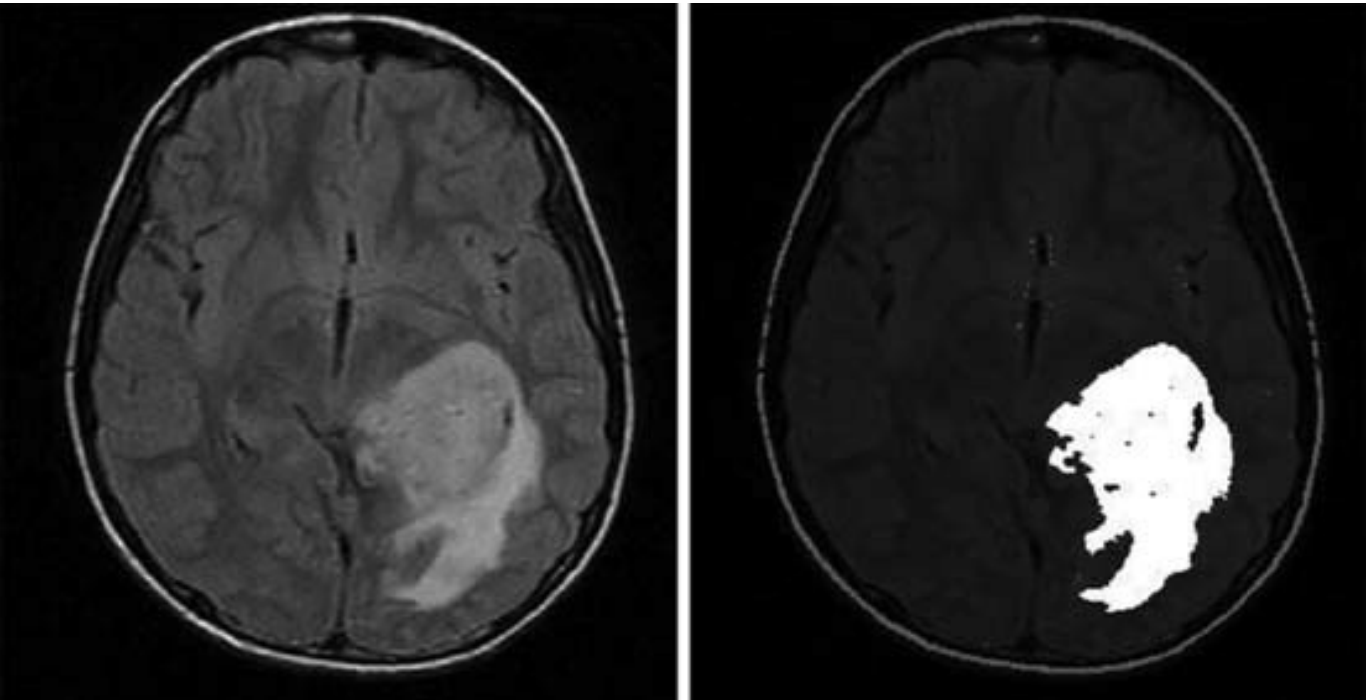


- Medical image:
  - typically 3-dimensional digital image composed of volumetric elements called ‘voxels’
- Many contrasts exist
  - Contrast between biological tissues
  - Molecular composition contrast
  - Functional (time-varying) contrast
- Extracting info from image:
  - Health of the subject
  - Differences between subjects
  - Differences across time

Applications

- A) Locate and identify tumor (segmentation)
- B) Trace connections between different brain areas (tractography)

A)



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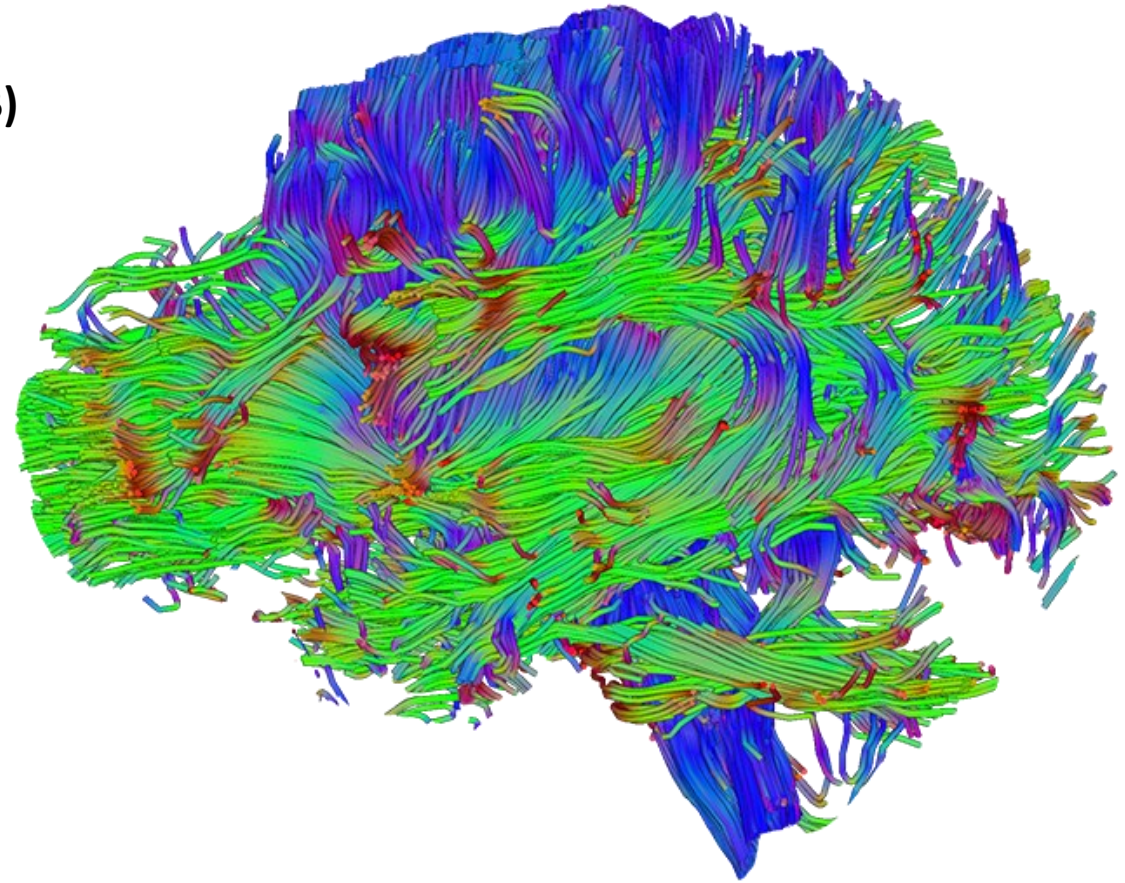
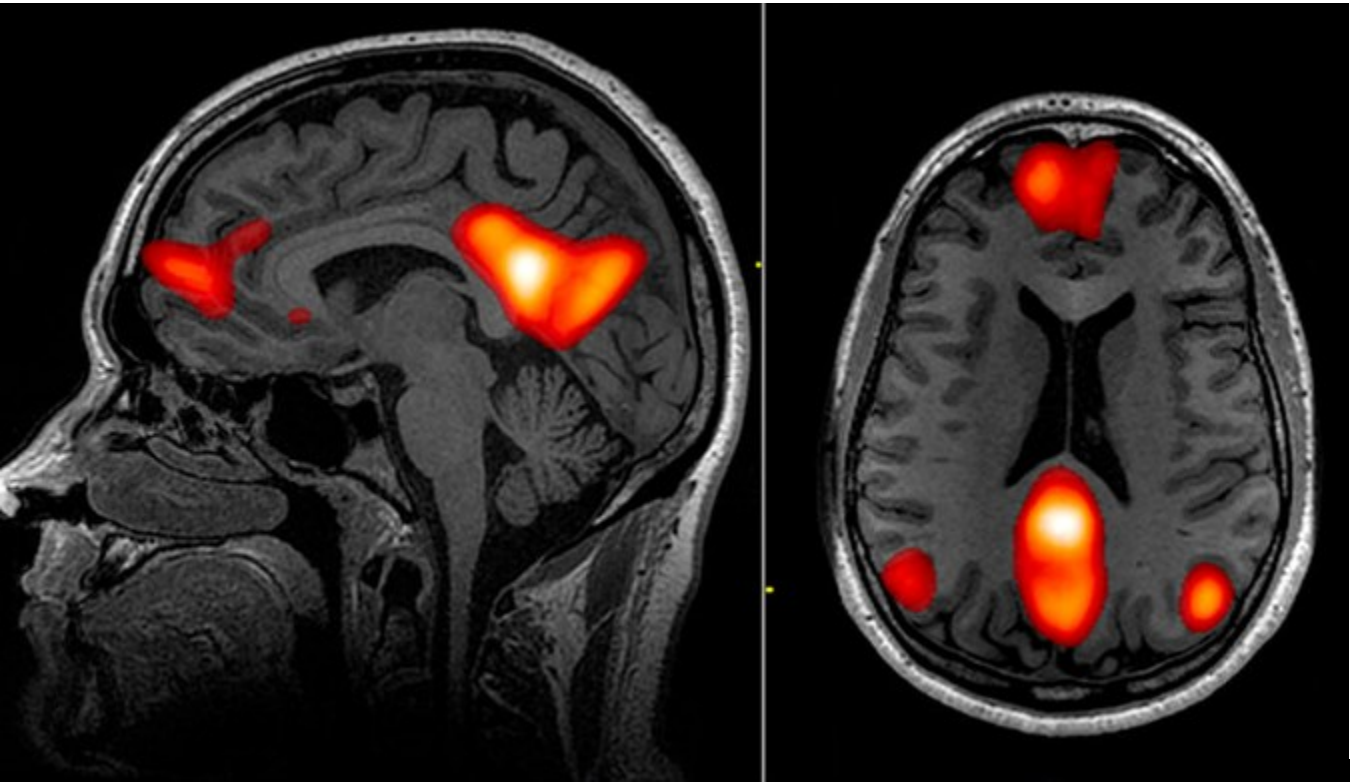


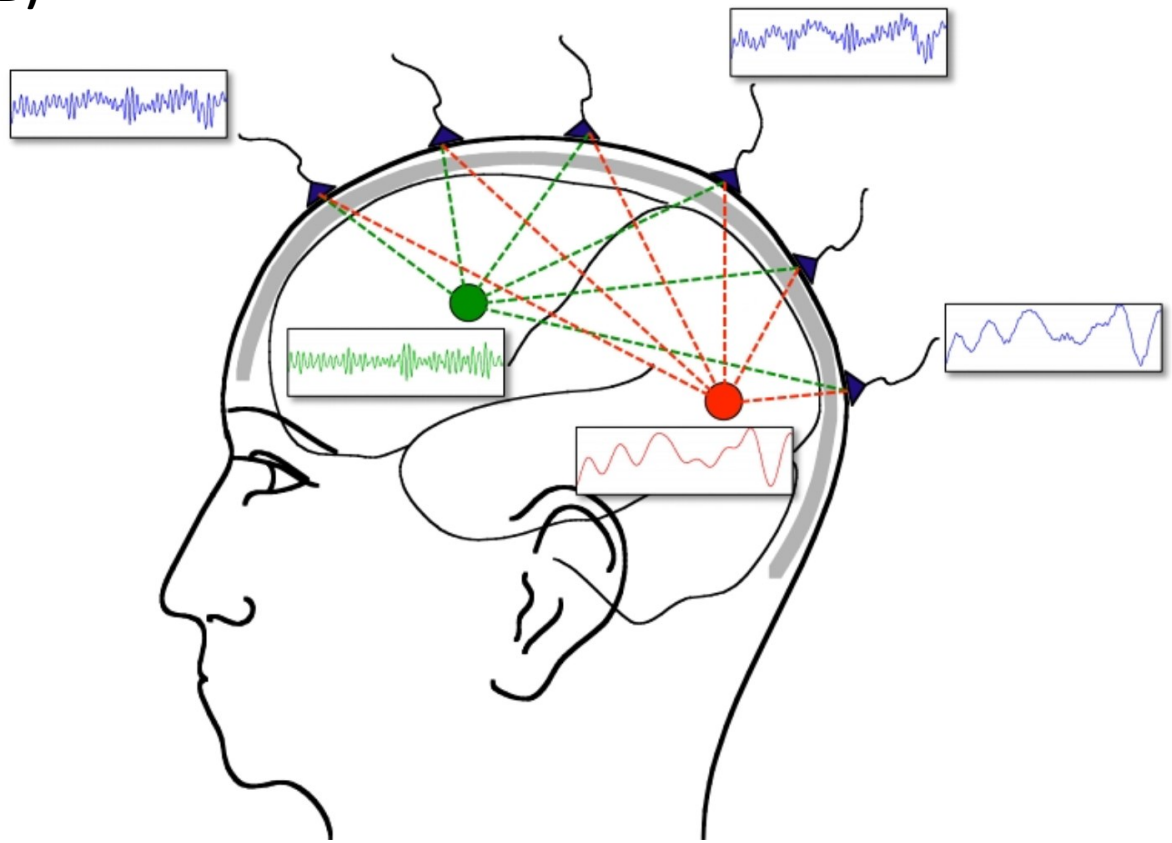
Applications

- C) Decode a person's thoughts from blood flow patterns (fMRI)
- D) Localize source of evoked neuronal membrane fluctuations (EEG)

C)

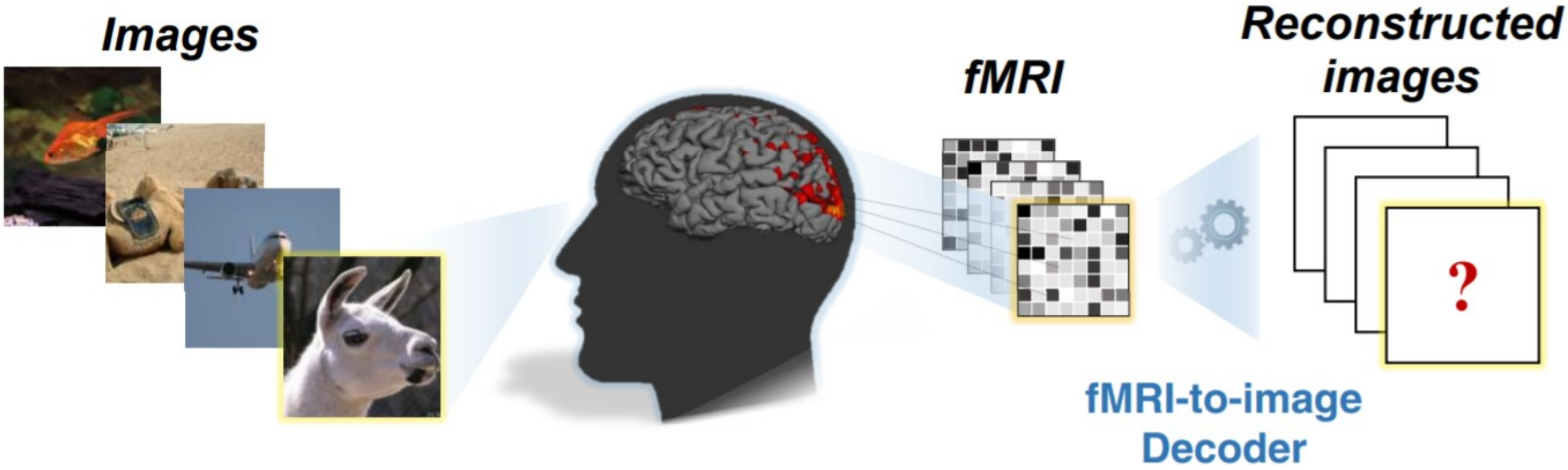


D)



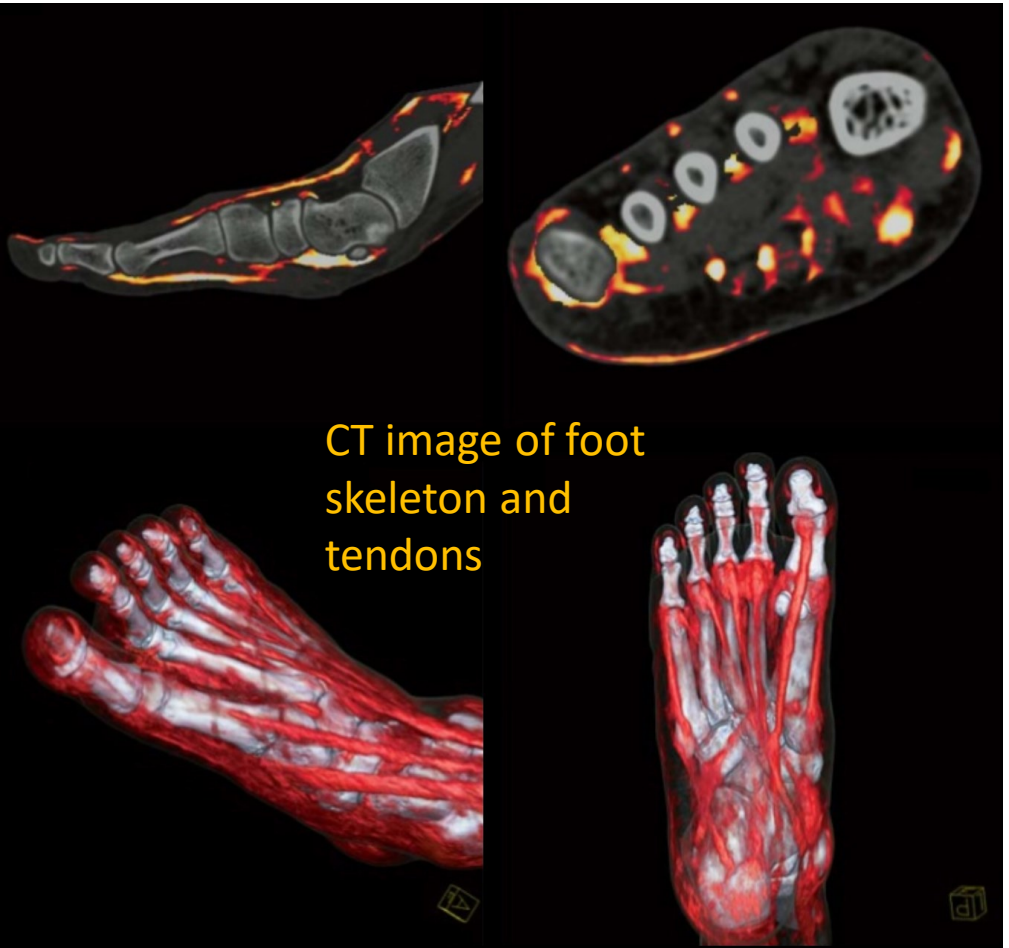
Applications: mind reading

- Using deep learning to decode someone's thoughts from functional MRI (fMRI)

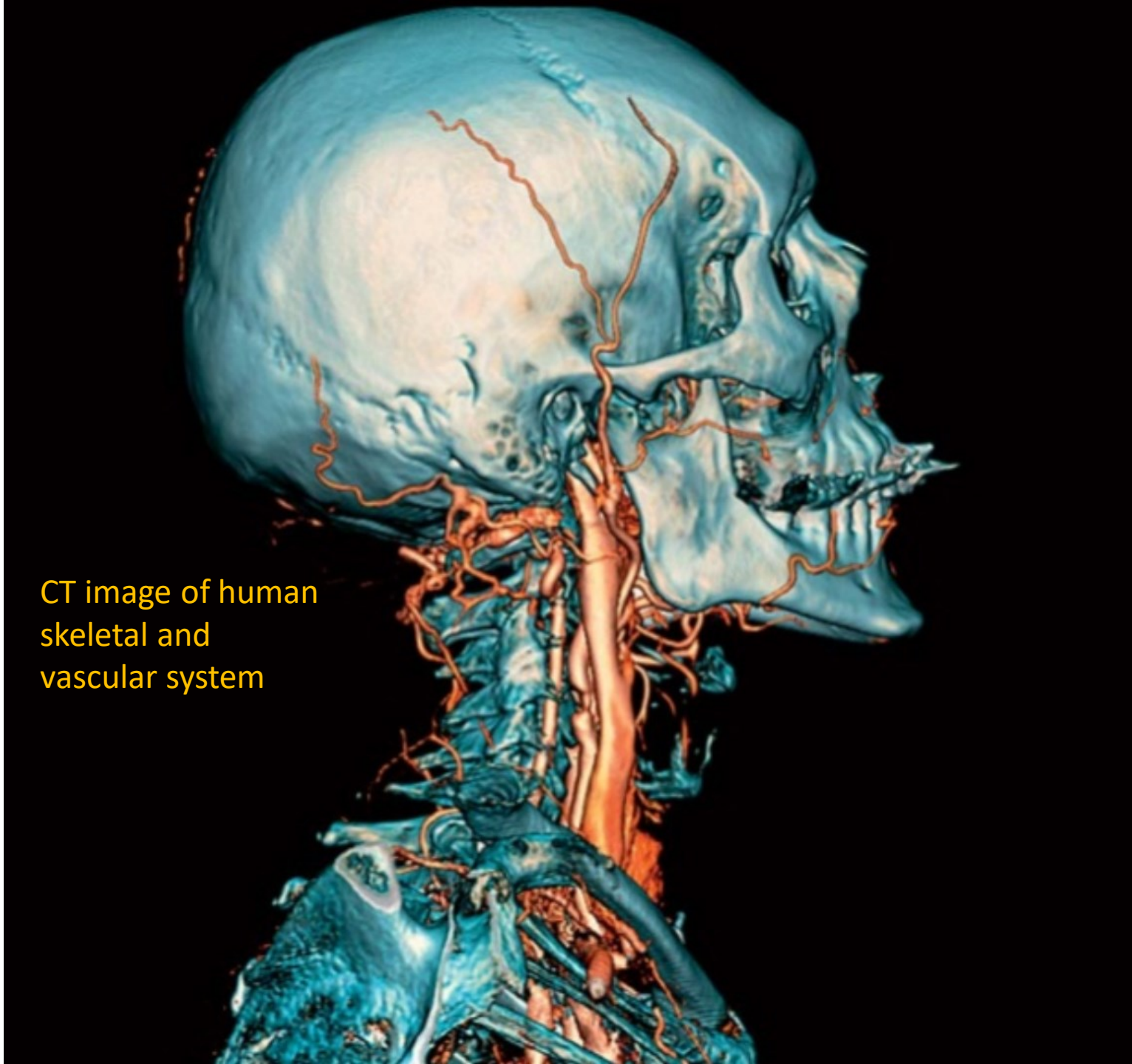


http://papers.nips.cc/paper/8879-from-voxels-to-pixels-and-back-self-supervision-in-natural-image-reconstruction-from-fmri

Applications: high resolution imaging of vasculature, skeleton, and tendons



CT image of foot skeleton and tendons



CT image of human skeletal and vascular system

Applications: and more

- **Big data, big data from small data**
  - UK biobank https://www.ukbiobank.ac.uk/
    - Images and health data from over 500,000 participants
  - Human Connectome Project https://www.humanconnectome.org/
    - Large MRI database with ~8,500 participants, many different studies
  - OpenNeuro https://openneuro.org/
    - Collection of brain MRI datasets from across the globe, ~10,000 participants
  - Aggregating many small studies (big data from small data)
- **Machine learning**
  - A survey on deep learning in medical image analysis: https://arxiv.org/abs/1702.05747
- **Studies of human**
  - https://onlinelibrary.wiley.com/doi/full/10.1002/acn3.50927

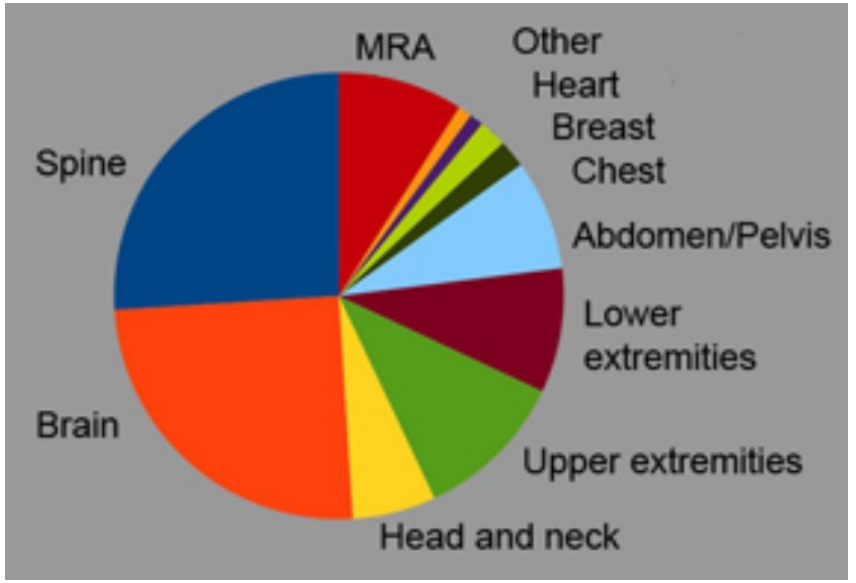
What we will cover in this course

- All the primary imaging modalities, with a focus on MRI
  - Computed Tomography (CT) and X-ray imaging
  - Magnetic Resonance Imaging (MRI)
  - Ultrasound
  - Positron Emission Tomography (PET)
  - Electroencephalography (EEG) and Magnetoencephalography (MEG)
- Common image processing problems specific to medical imaging
  - Denoising and artifact removal
  - Image registration
- Advanced processing pipelines (applications)
- Visualization of medical images (basic computer graphics)

https://www.magnetic-resonance.org/ch/21-01.html

Magnetic Resonance Imaging (MRI)

- Magnetic Resonance Imaging (MRI)
- Worldwide: around 50,000 machines. 5,000 machines sold every year
  - 366 machines in Canada
- ~14 machines satisfies needs of 1,000,000 people
- Clinical:
  - Brain and spine make >50% of all MRI scans
  - Breast, heart, and interventional make <5%
  - Mostly 3-Tesla and 1.5-Tesla field strength
- Research
  - Trend towards ultra-high field machines (7+ Tesla)
  - Basic neuroscience and psychology research
  - Used in animals and with other modalities (PET, EEG)
  - Development of faster and more robust scans

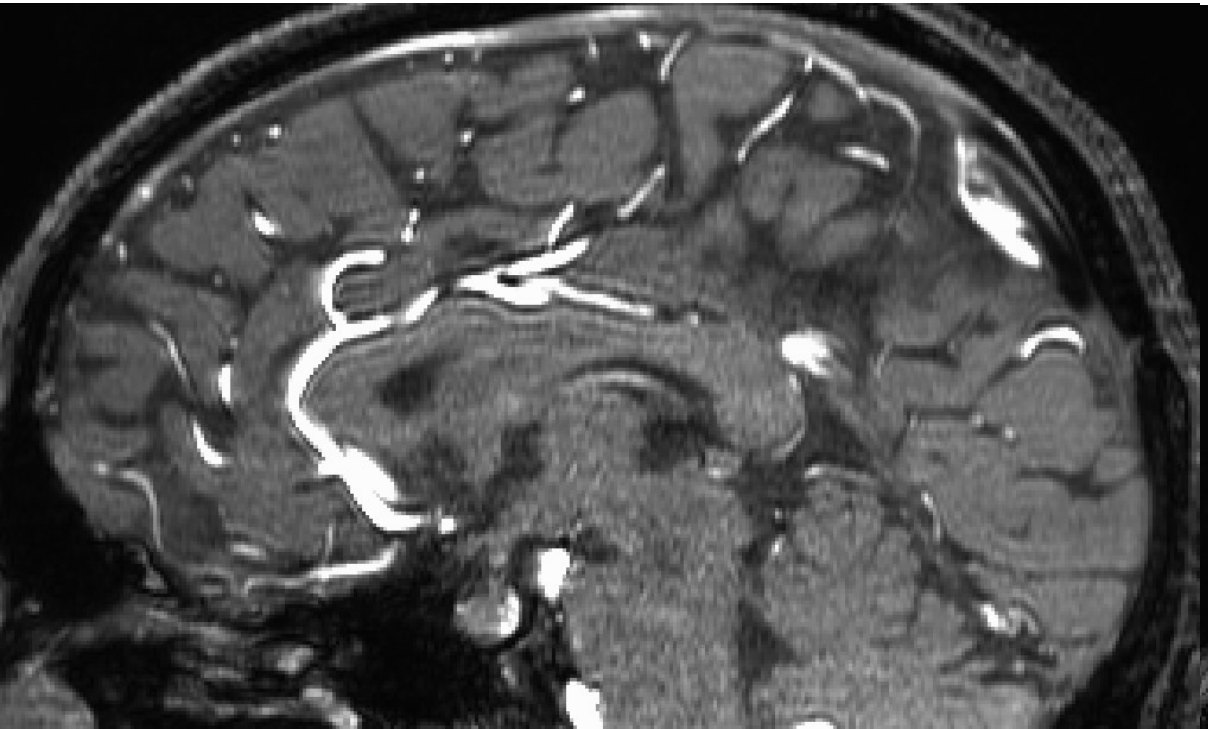


MRI scan type distribution

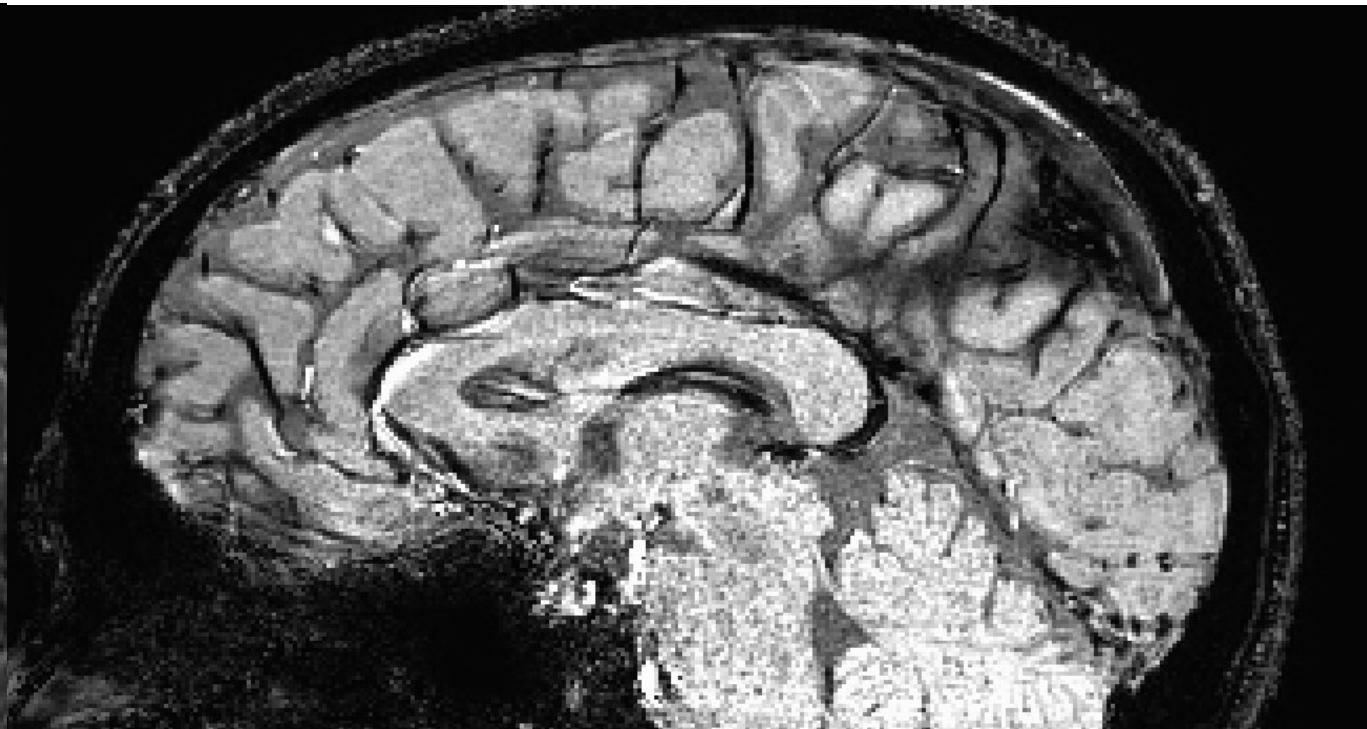
MRI captures high resolution soft tissue contrast

- Example: arterial (TOF) and venous (SWI) vasculature in same human participant (myself)
- MRI can be made sensitive to a wide range of biological tissues by simply tweaking the acquisition parameters

TOF



SWI



https://www.cancer.gov/about-cancer/diagnosis-staging/ct-scans-fact-sheet

Computed Tomography (CT)

- Computed Tomography (CT) more widely used than MRI (cheaper and faster)
- 561 machines in Canada alone (up from 419 in 2007)
- Over 80 million CT scans per year in the US (despite concerns about radiation)
- Clinical:
  - Trauma patients (CT is fast)
  - Detect tumors and blood clots, edema
  - Detect cancer in chest, abdomen, pelvis, lung, liver, kidney, and other areas
  - Radiotherapy pre-planning
  - Skeletal X-ray, mammography, dental X-ray
- Research:
  - Reduce radiation from scan
  - Higher quality images (increased volume coverage, higher SNR, higher resolution)
  - K-edge imaging, multi-source imaging

Computed tomography (CT) scanner

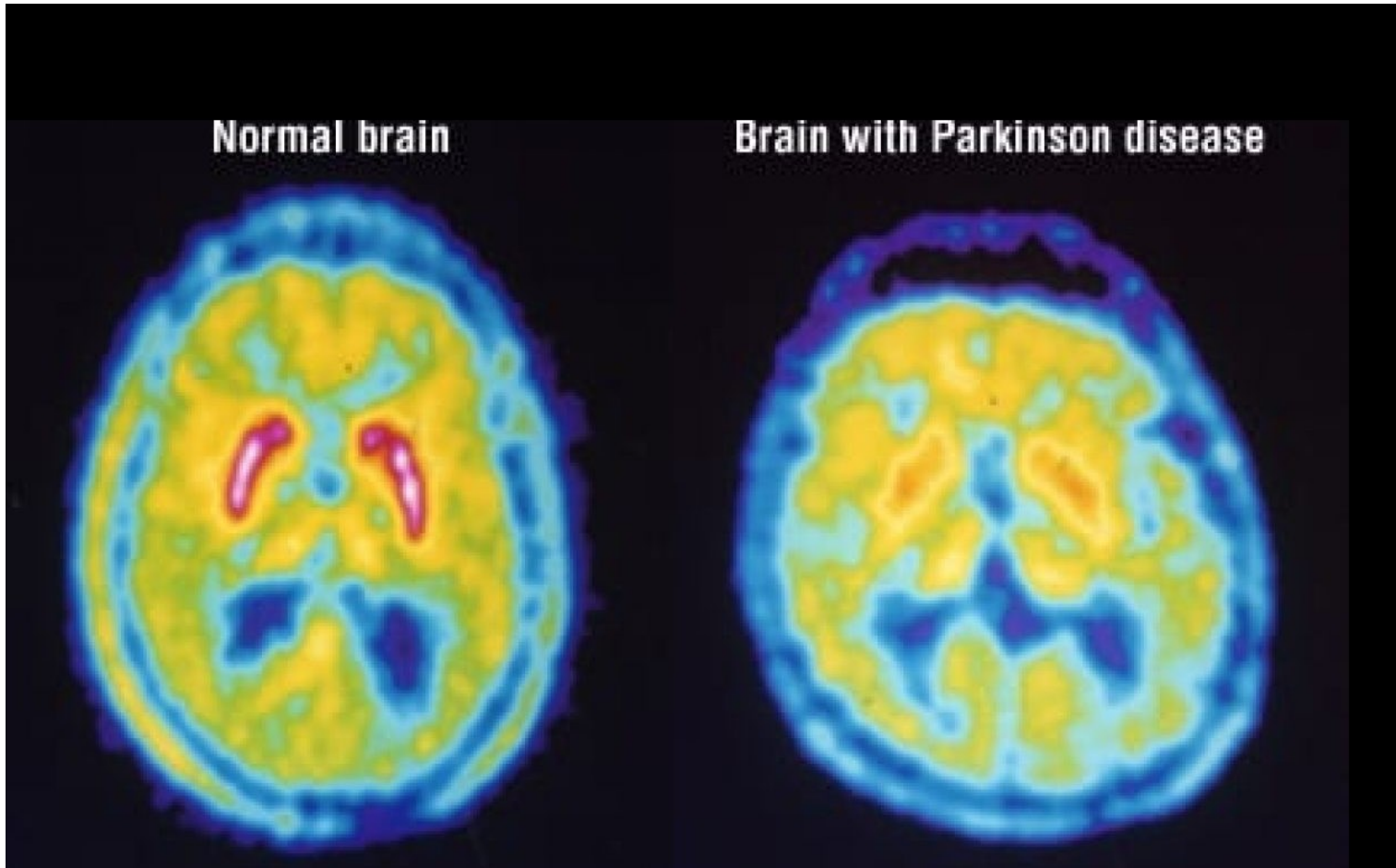
Ultrasound

- Cheapest and most portable of imaging modalities, ultrasound machine cost $20,000-$100,000
- Clinical
  - Can visualize muscles, tendons, and internal organs
  - Emergency ultrasound increasingly used for trauma and surgery
  - Echocardiography, fetal imaging
- Research
  - Low-intensity focused ultrasound stimulation
    - Blood-brain barrier manipulation
    - Modulating brain activity

Ultrasound of fetus in womb at 12 weeks of pregnancy

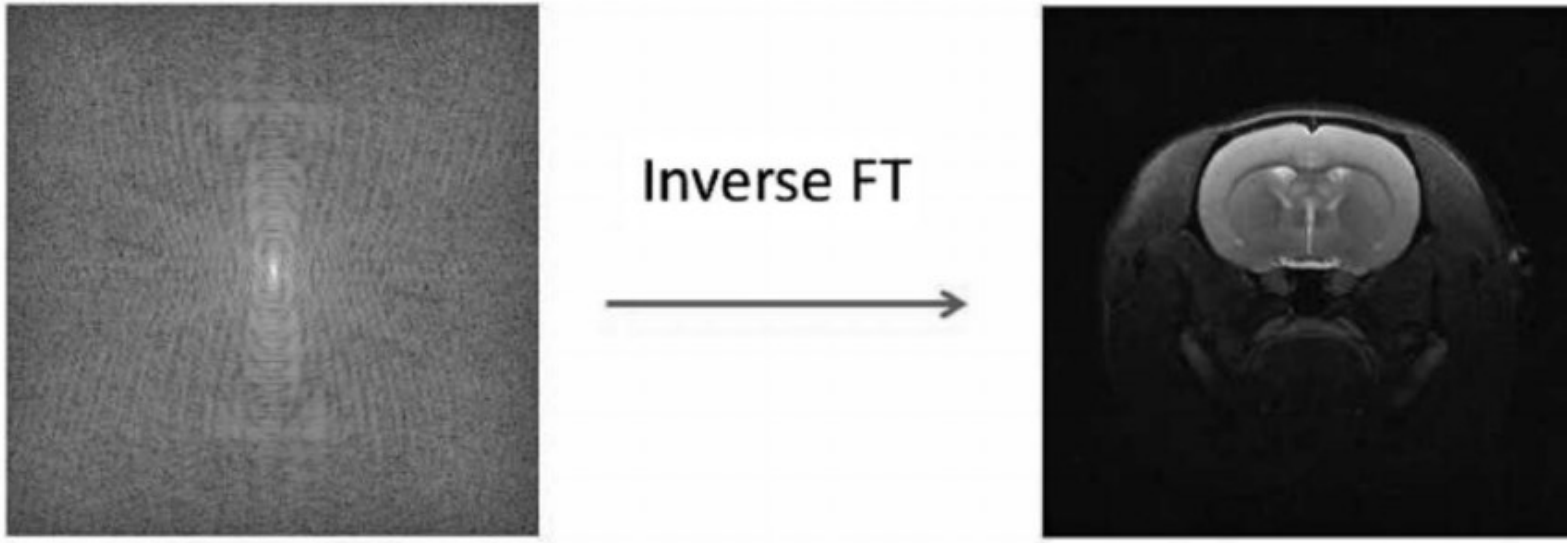
Positron Emission Tomography (PET)

- Observe metabolic processes using radioactive tracers
- Expensive and requires on-site cyclotron
- Clinic:
  - Oncology (cancer)
    - Detect tumor and metastases
    - Hodgkins lymphoma
    - Lung cancer
- Research
  - Neuroimaging, metabolic brain activity
  - Small animal imaging



Acquisition and Reconstruction

- Magnetic Resonance image acquired in ‘k-space’
- K-space transformed to image space using Inverse Fourier Transform (FT)
- Other modalities are acquired in their own space, or directly in image space
  - Radon transform for CT, coincidence detection for PET
  - Course will cover all the main transforms
  - Will also look at advanced MRI acquisition sequences (simultaneous multi-slice echo-planar imaging)



Denoising and artifact removal

- Medical images are often contaminated by noise and artifacts
- Head motion during scan systematically alters image
- High resolution datasets suffer from low signal-to-noise ratio
- Will look at ways to improve image quality and reduce artifacts

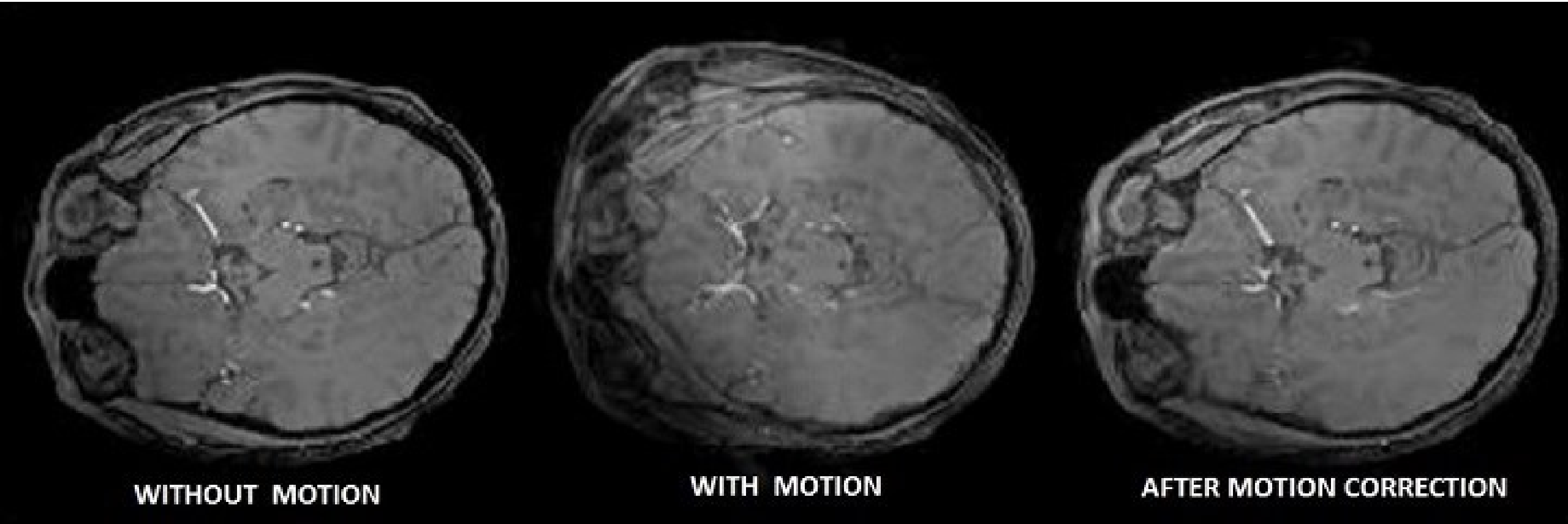
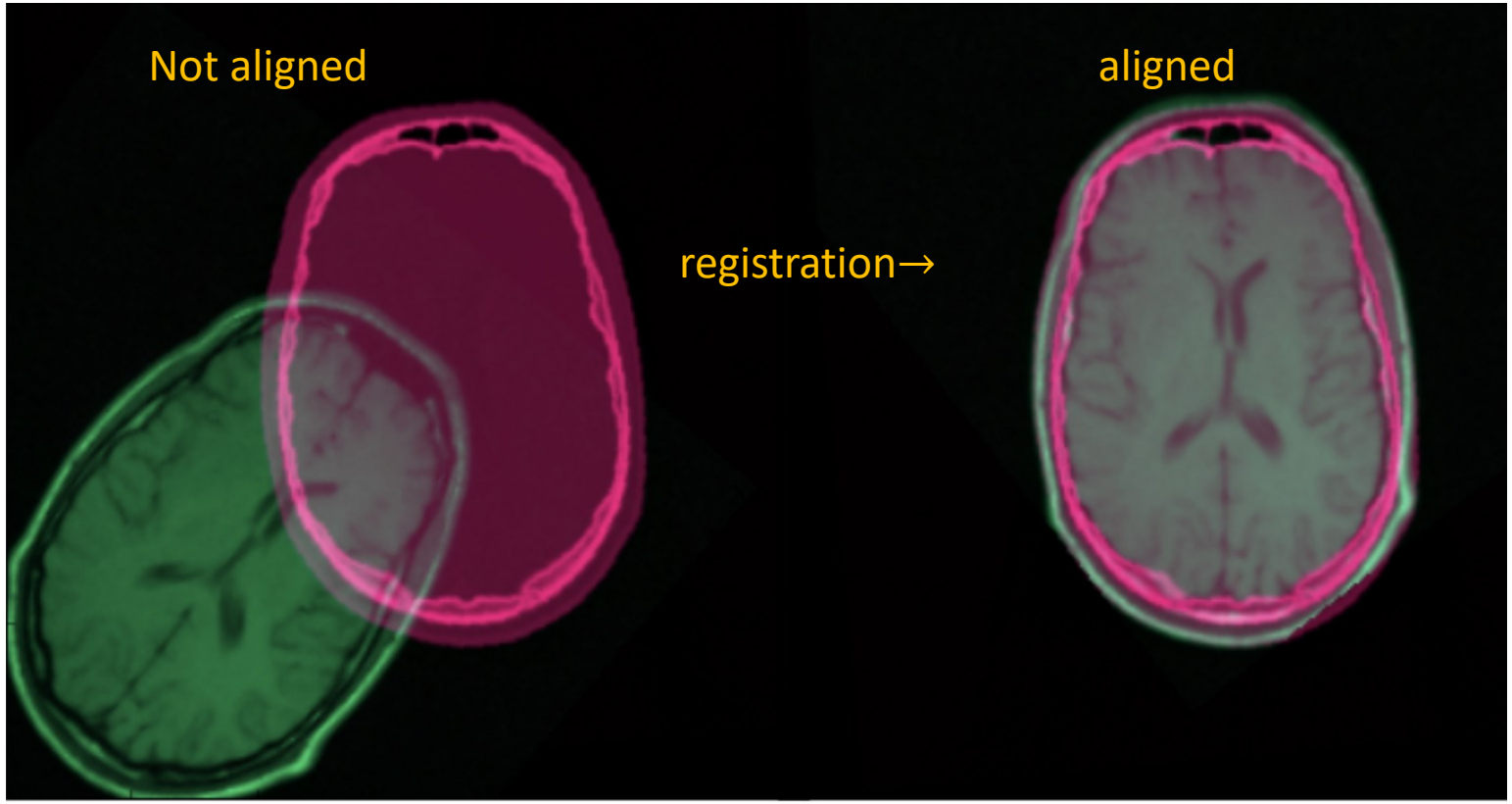


Image Registration

- Medical images are acquired in different people and using different modalities
  - MRI, FMRI, CT, PET, etc… all images have different contrast/resolution
- Need a way to analyze all the images in same ‘space’
- Will look at how to align images using affine transformations and numerical optimization

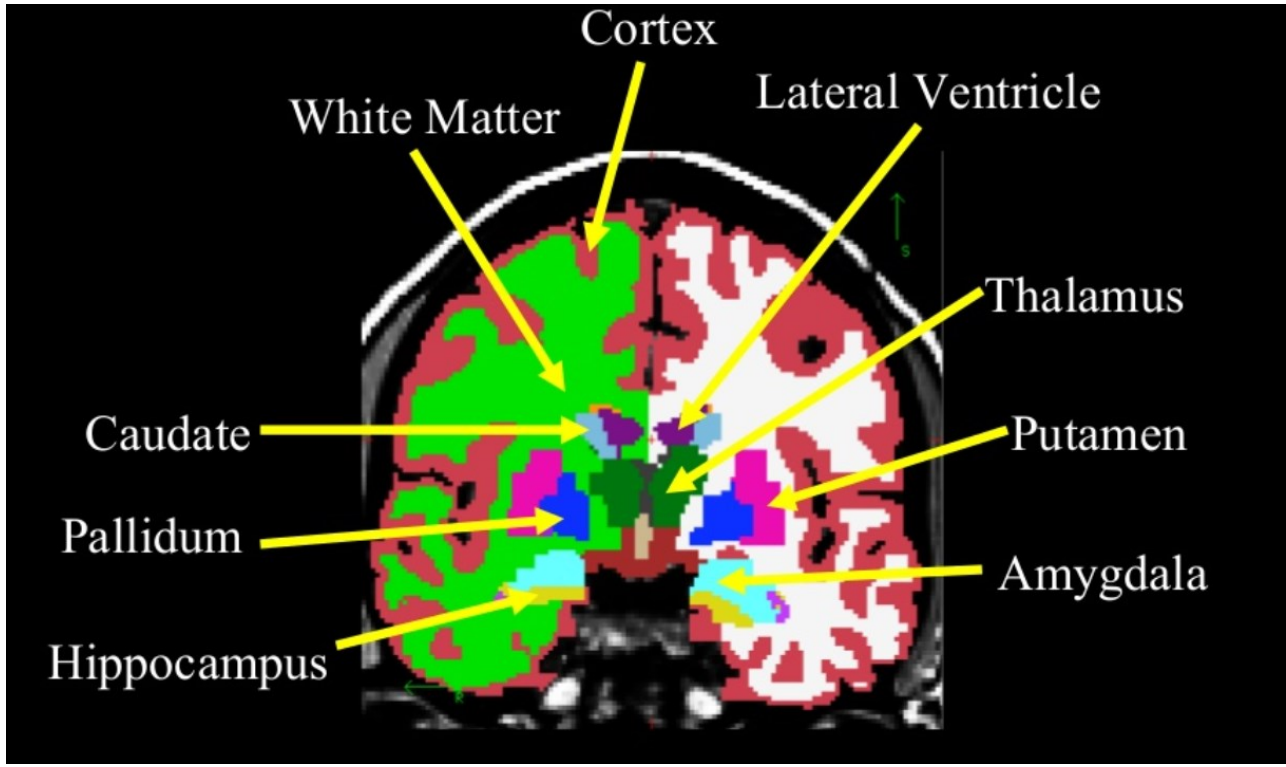
CT

MRI



Segmentation

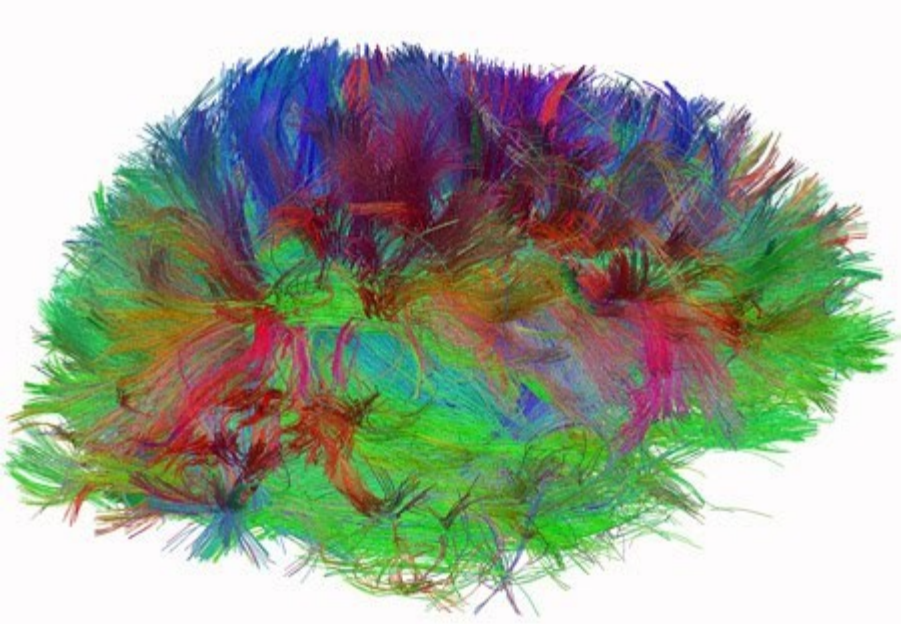
- Image segmentation: one of the most useful, and difficult tasks
- Requires expert knowledge and large datasets
- Machine learning leading to rapid advances in segmentation accuracy
- Example: BRATS challenge
  - http://braintumorsegmentation.org/
  - Segment brain tumor from MRI
- We will cover a range of segmentation methods and problems



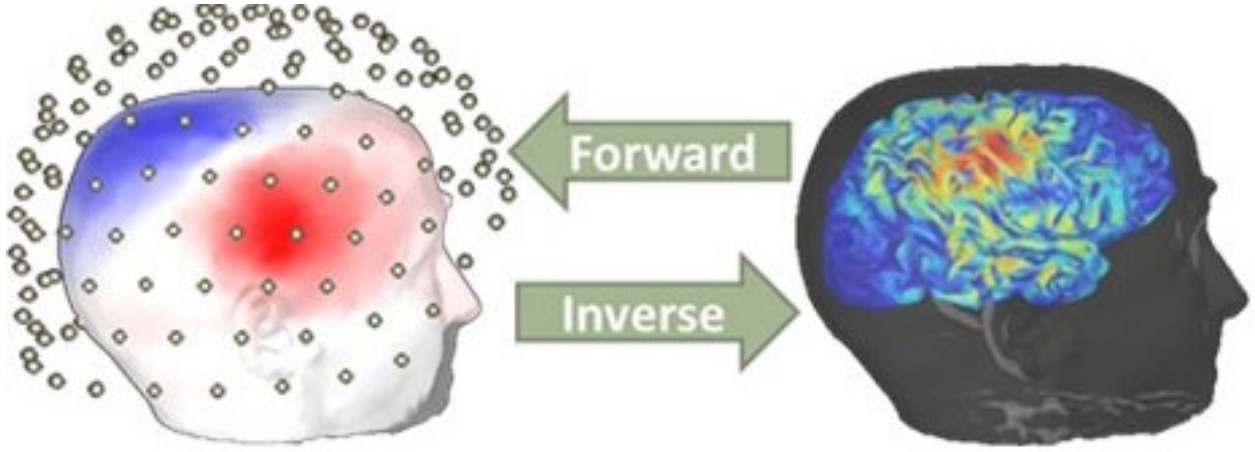
Advanced processing

- Will cover:
  - a) Diffusion tractography (Diffusion MRI)
  - b) Inverse/forward modeling (EEG and MEG)
  - c) Structural and functional connectivity (fMRI, MRI)
  - And more! (deep learning, group analysis, etc.)

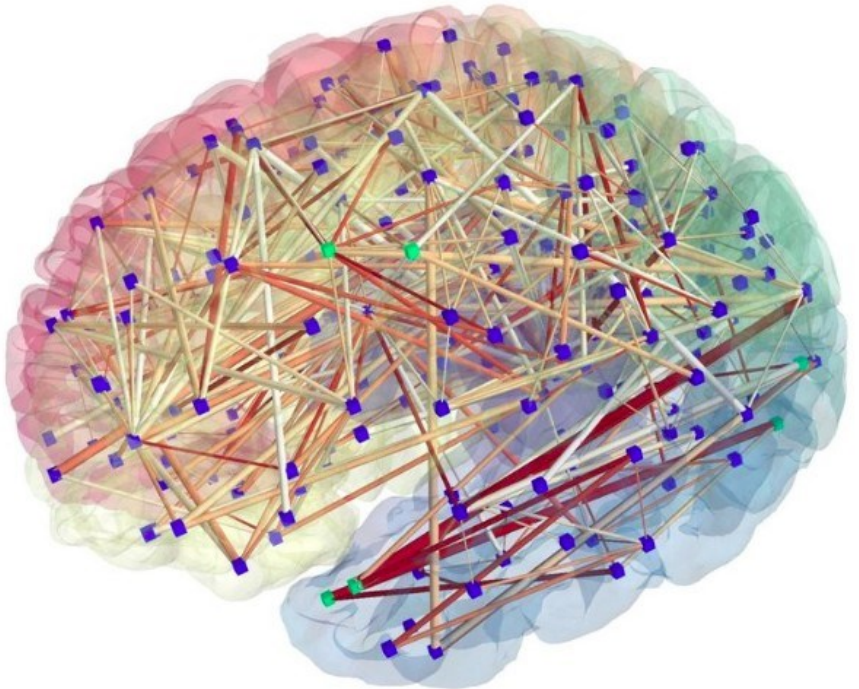
a)



b)

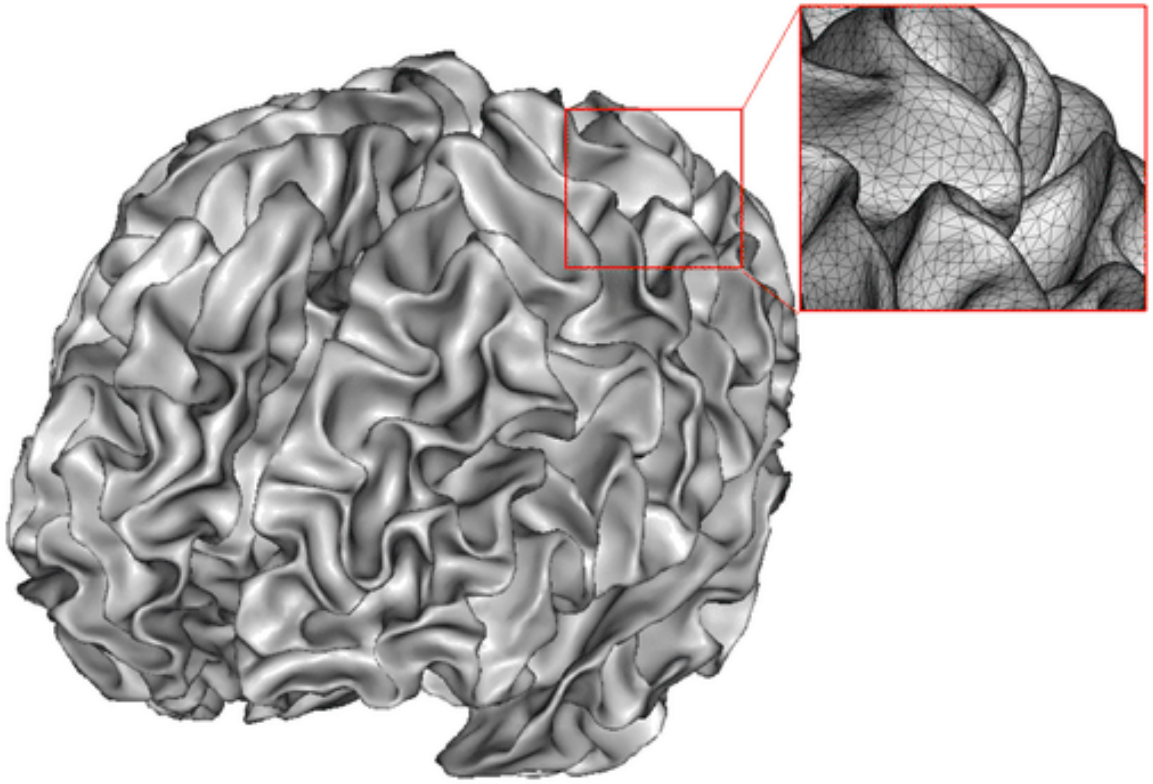


c)



Visualization

- Visualizing images is key for both researcher and clinician
- We will use **unity** to write our own surface and volume rendering software
  - Can then build to multiple platforms including mobile, desktop, AR, and VR



What you will need for this course

- 1) programming ability
  - 4 assignments. 3 in python, 1 in C#. Need to know basic coding.
  - Working with multidimensional arrays in numpy.
- 2) basic maths
  - Most of the math for the course can be learned along the way, however…
  - Need basic understanding of linear algebra and calculus (gradients, vectors, matrices, etc.)
- 3) work ethic
  - Assignments will be challenging, and solutions are not available online
  - My Ph.D. was in medical imaging, so I can design assignments nobody has ever seen ☺

What you will gain from this course

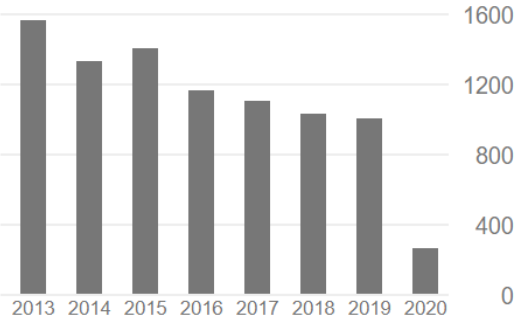
- The course is primarily image processing
  - Image reconstruction
  - Image denoising
  - Image registration
  - Image segmentation
- You will become an expert in numpy (python)
  - Will also use matplotlib, nibabel, scikit-learn, scipy and pandas
- Will learn how to apply machine learning to solve problems using real-world datasets
- Will also gain some signal processing and computer graphics experience

My research lineage

What is a ‘citation’? Citations are whenever someone publishes in peer-reviewed academic journal or conference, and ‘cites’ one of your papers (makes a reference to your paper).
Typically, more citation = better researcher, but there are many confounding factors.

Rachid Deriche (Maxime’s Ph.D. supervisor)

	All	Since 2015
Citations	27158	5994
h-index	75	34
i10-index	220	106



Maxime Descoteaux (my Ph.D. supervisor)

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Citations	7091	4461
h-index	40	32
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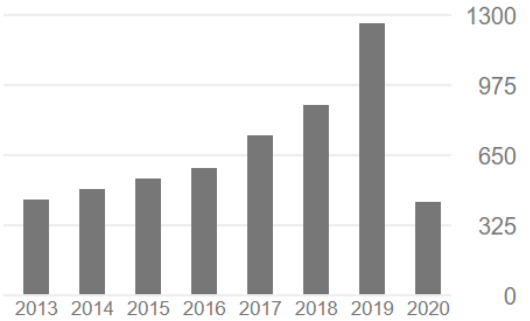

Nikos Logothetis (Kevin’s Ph.D. supervisor)

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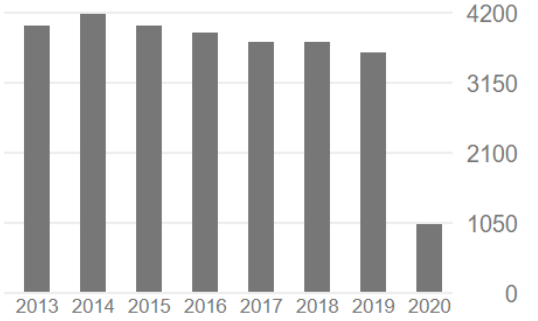
i10-index	342	266



Kevin Whittingstall (my Ph.D. supervisor)

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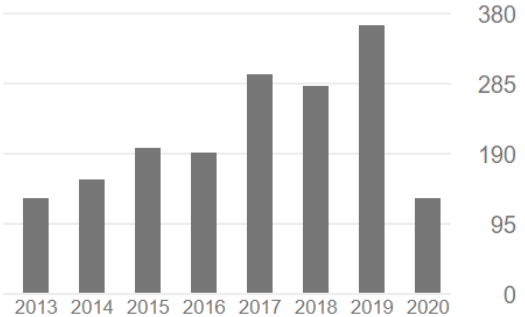
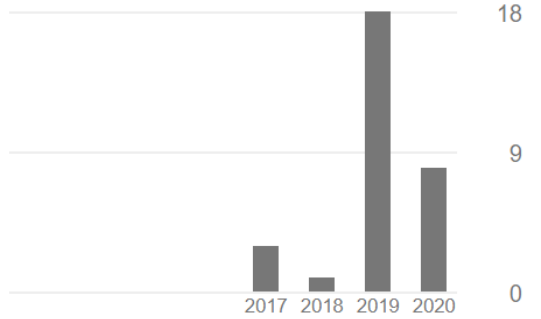
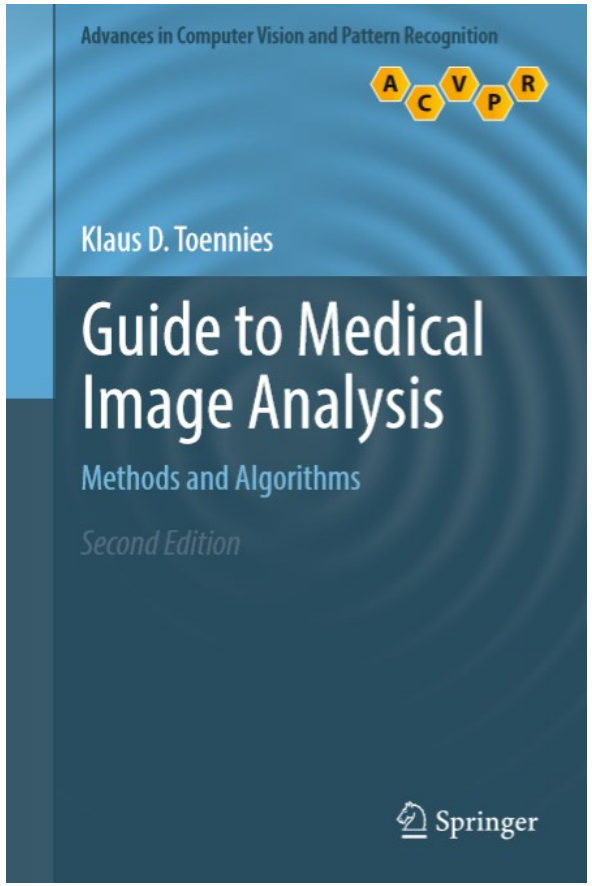
i10-index	38	37



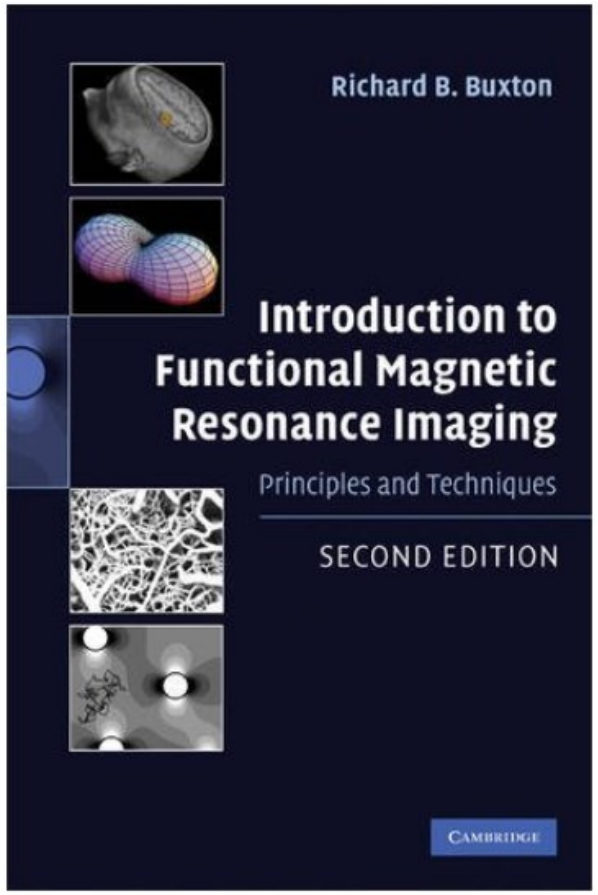
	All	Since 2015
Citations	31	31
h-index	4	4
i10-index	0	0

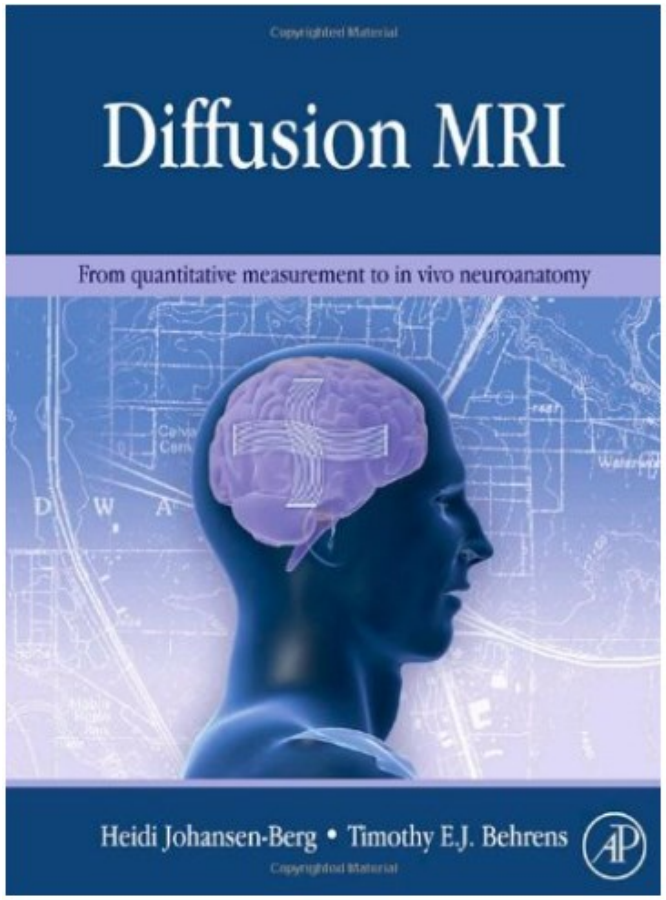


resources



Good overview





More specialized topics