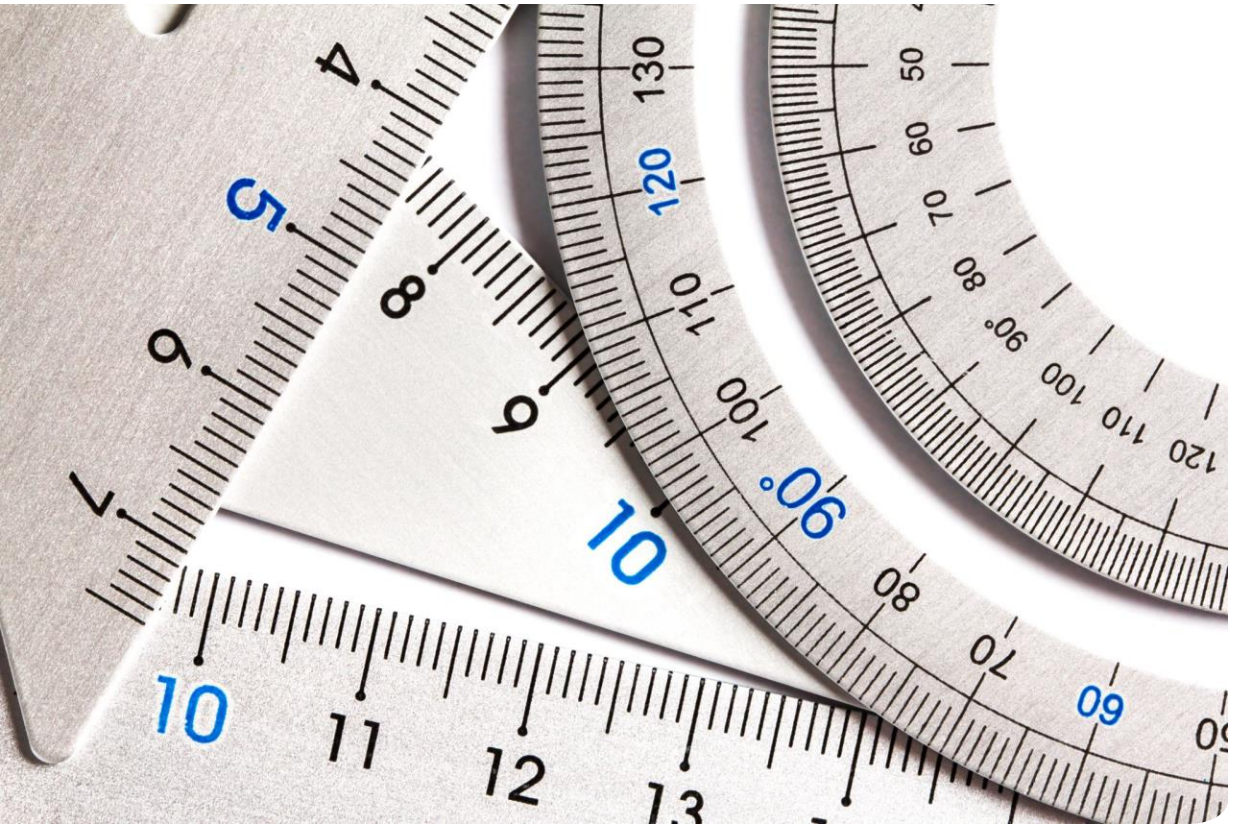


Measurement – Indirect Approaches

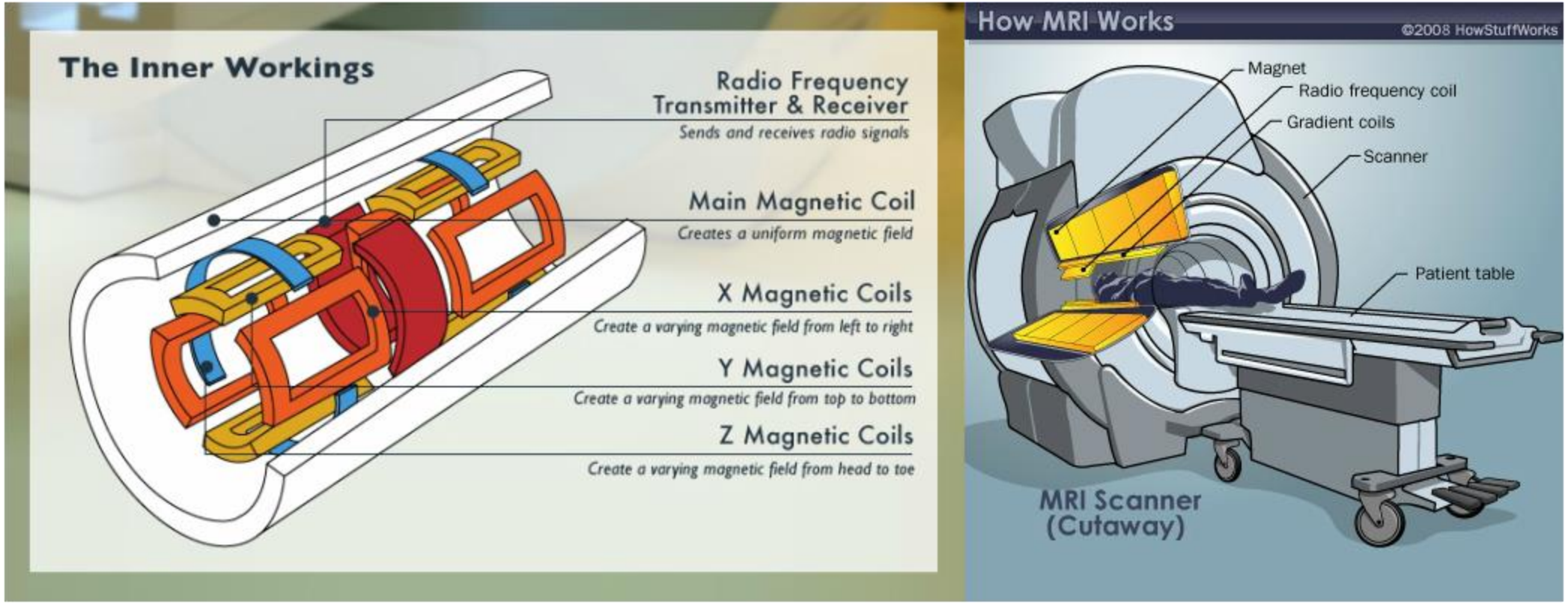
9/12/2024

Indirect approaches to neuroimaging

- The brain requires an enormous amount of blood flow to operate
- Despite making up only 2% of body weight, the brain consumes over 20% of the oxygen supply
  - **Ischemic stroke** – when a blood clot blocks or reduces blood flow to the brain, leading to neural cell death
- Different tissues have different atomic compositions, or different structural properties that influence the flow of water
- Neuroscientists have learned how to leverage small things like these to make accurate inferences about the brain's structure and function

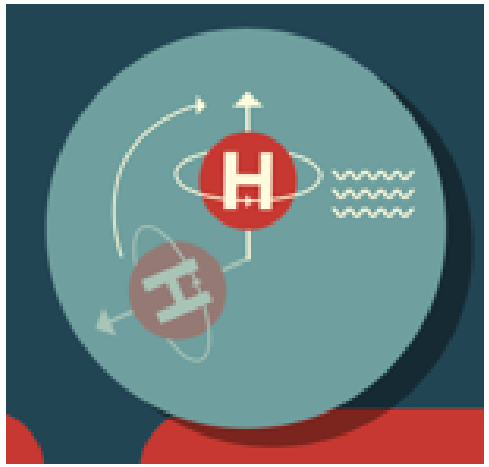
Magnetic Resonance Imaging (MRI)

- MRI machines use a combination of a very strong magnet, precisely controlled radiofrequency (RF) pulses, and a receiver coil to generate detailed 3D images of complex fields
  - **Voxel** – a single bit of information in a 3D image, like a 3D pixel



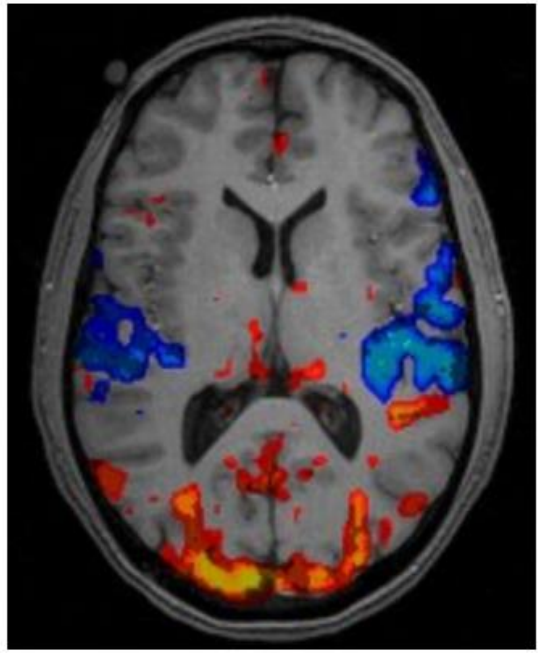
How MRI works

- Different tissues/fluids (grey/white matter, cerebrospinal fluid) have different magnetic properties because they are composed of different concentrations of protons (hydrogen atoms, from H_2O, water)
- Transmitter coils briefly excite the protons with RF pulses, causing them to all align in orientation with the external magnetic field
- After the pulse, the protons return to their original orientation (**relaxation**), emitting their own RF pulse as a kind of echo, which is detected by receiver coils
  - But that echo will be unique depending on the tissue type (they will have different **relaxation times**), allowing us to differentiate tissue types
- Different types of RF pulses are designed to detect specific types of tissue
  - Grey/white matter, CSF, blood flow, blood oxygenation
  - Advanced MR-spectroscopy techniques can even "tag" specific neurotransmitters by a magnetic field for detection



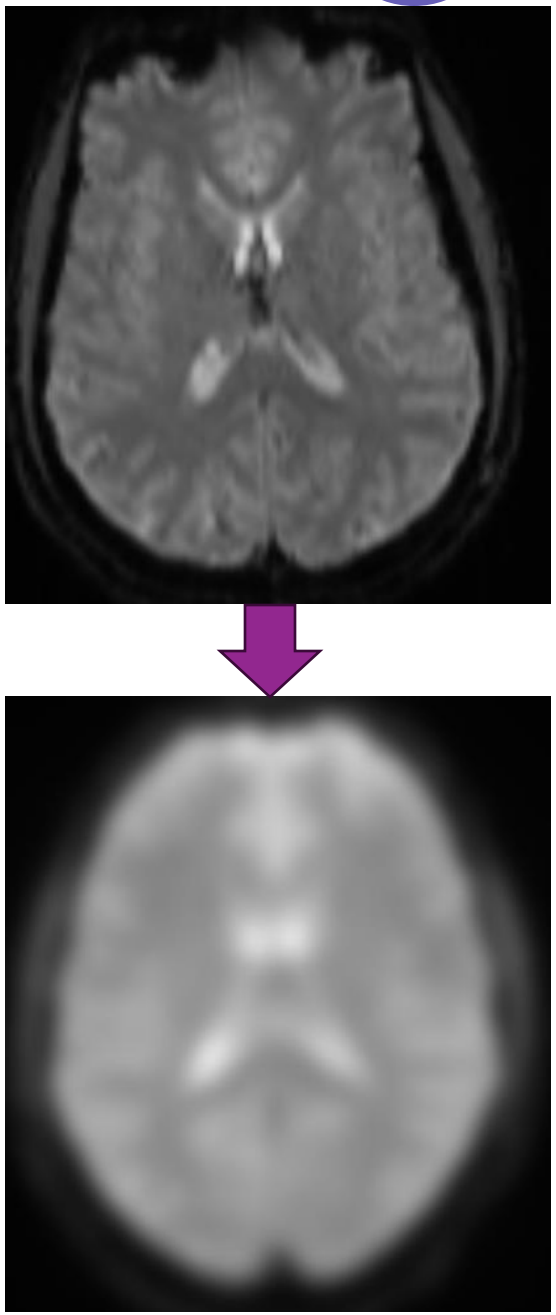
Functional MRI (fMRI)

- Functional MRI measures the amount of oxygen in the blood as an indirect measure of neural activity
- **Blood oxygen level dependent (BOLD) signal**:
  - Neural activity (target we are interested in)
    → cellular metabolism, which consumes oxygen
      → blood oxygen levels (which we estimate from the MR image)
- Temporal resolution: about 2 seconds to get a single BOLD image
  - Record many images over a period of minutes
  - Can have time-locked events (like a stimulus)
- Lower spatial resolution than structural MRI
- The BOLD signal is the canonical way to make inferences about brain activity, based on **signal change (%)**
  - Responsible for most "brain blob" figures that you see
  - Researchers will highlight (blobs) where the significant effects are



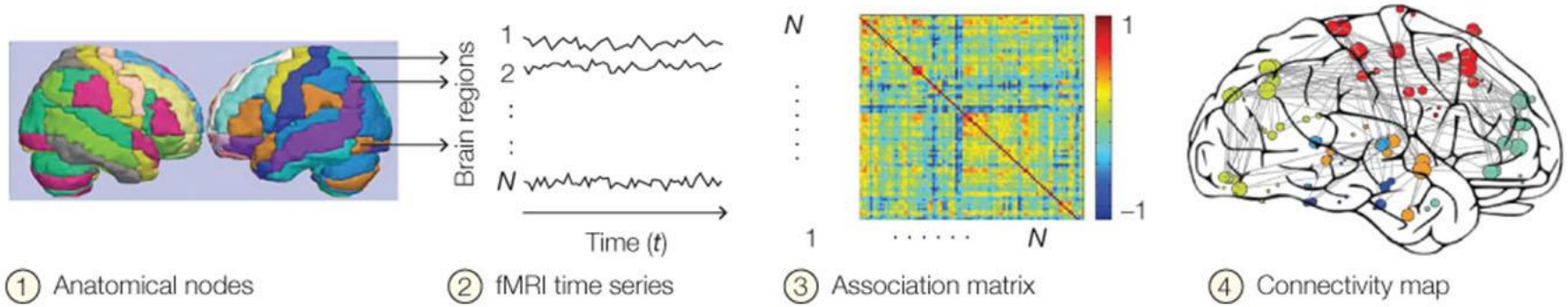
fMRI Analysis

- MRI data requires *many steps* of preprocessing to perform meaningful analysis.
  - Correcting for small recording time differences between each voxel, detecting and correcting subtle motion of head, fitting image to an idealized space so you can compare across subjects, smoothing to reduce artifactual noise
- You can compare voxels to each other across space and time
  - A typical 5-minute BOLD scan: 192×256×256 (spatial dimension) × 300 (5 minutes of scanning) = 3,774,873,600 voxels
  - You can make the analysis simpler by grouping voxels together into nodes or regions-of-interest (ROIs) to inspect how a whole region is behaving on average
- You typically need a control task to compare to your experimental trial (this comparison is called a **contrast**)



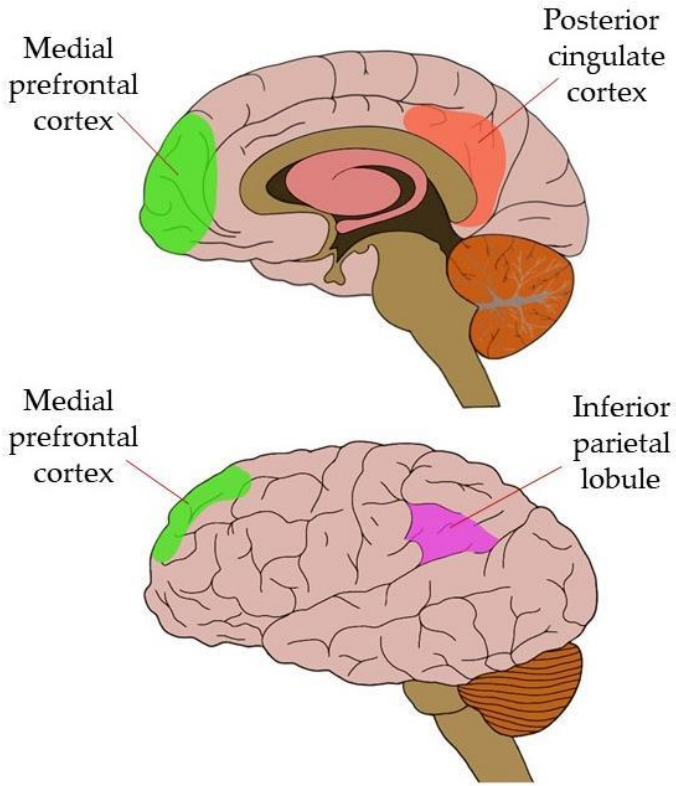
fMRI Functional Connectivity

- When regions show a highly-correlated signal change across time, they are said to be **functionally connected**.
- Especially when these are distant regions of the brain, it implies that they are communicating with each other to work in tandem
- **Functional networks** can be differentiated based on a functional connectivity analysis
- A matrix of connectivity scores can be used to create a **connectivity map** of brain activity (also known as a **connectome**)



Resting-state Functional Connectivity

- When you ask people to do nothing in the scanner, they don't do nothing
  - They think, they plan for the future, they remember the past, they rehearse and retell stories to themselves, they mind-wander
  - Brain activity remains highly organized during this time
- **Intrinsic** brain activity – ongoing, spontaneous activity that arises without any external stimuli or task, reflecting a "default mode" of operation and self-organization
  - Includes (but not exclusively!) the **default mode network (DMN)**
- **Extrinsic** brain activity – activity that is evoked by sensory input, cognitive demands, motor outputs, or some other external event, usually reflecting an active engagement with the world
- The intrinsic activity of a given individual, as seen in the functional connectivity map of their resting state activity, can reflect a lot about their mood, personality, and cognition
  - Each person has a unique "brain fingerprint" or "connectome fingerprint" that reflects their unique self – their past, their habits, their predilections



Key regions of the DMN

MRI

Pros

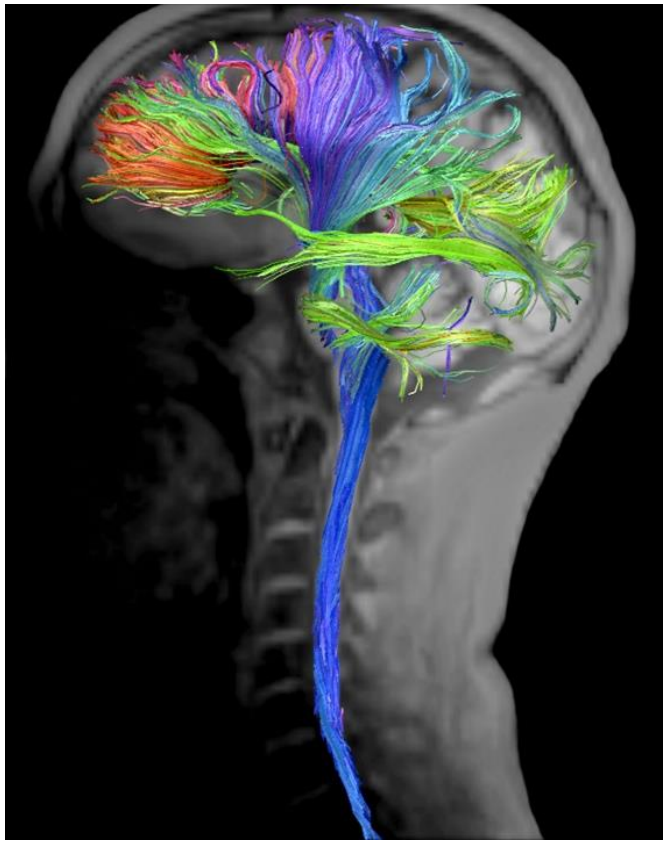
- Good spatial resolution (as good as roughly 1 mm)
- Noninvasive
- Has advanced cognitive neuroscience far more than any other single tool over the last few decades
- Methods keep improving to get clearer and more detailed impressions of brain structure and activity

Cons

- Middling temporal resolution (roughly 2 seconds)
- Expensive, loud, and inconvenient
- Requires massive multimillion dollar machine with dedicated technicians
- Data are only indirect inferences about brain structure and activity

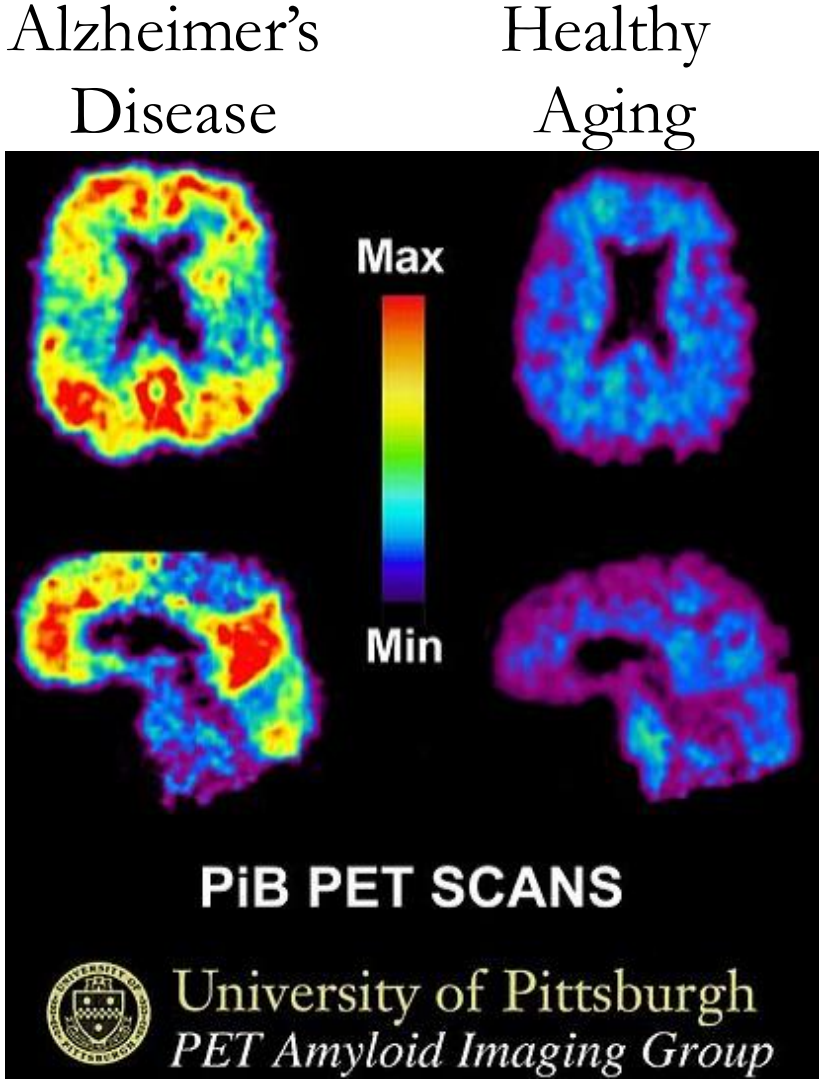
Diffusion Tensor Imaging (DTI)

- An MRI sequence and analysis technique that measures the directionality of the flow of water molecules in different parts of the brain
- The flow of water molecules is more directional in white matter tracts because axons create barriers that force the water to flow in the direction of the fibers/tracts
  - **Fractional anisotropy** – a key metric that quantifies how organized the diffusion of water is, allowing inferences to be made about the organization of the white matter
- Allows for accurate imaging of the "wiring" of the brain - **tractography**



Positron Emission Tomography (PET)

- A machine that measures the distribution of radioactive drugs (called **tracers**) that are injected into a patient's vein to see where they go
- Different types of tracers can be used that travel to brain to bind to receptors or get taken up into cells
- The PET machine detects the gamma rays that the tracers emit
- Can track glucose metabolism, neurotransmitters, beta amyloid (to diagnose Alzheimer's disease)



Lesions

- If the brain is damaged in a specific location, we can make **causal inferences** about the impact of that location on function
- **Lesion-network mapping** – test people with differing brain lesions on the same tasks and link their performance to the lesions' effects on brain wiring