



MEDICAL IMAGE ANALYSIS & AI: SHEDDING LIGHT ON DEVELOPING HUMAN BRAINS

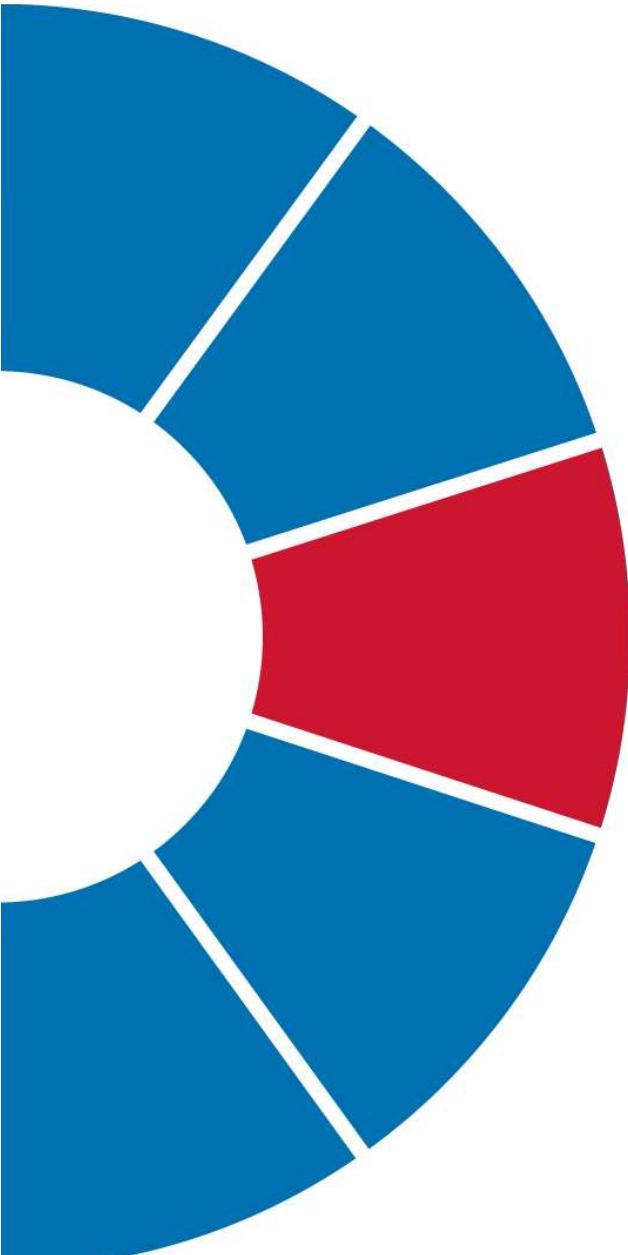
Hamza Kebiri, PhD

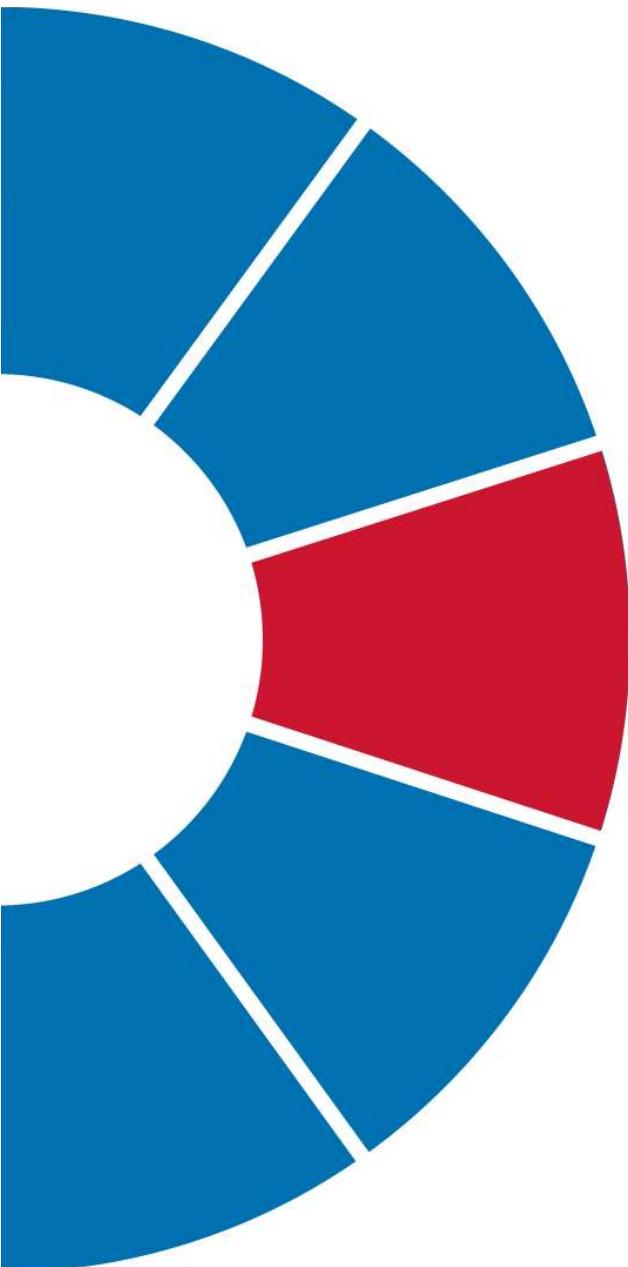
Medical Image Analysis Laboratory

Math & Maroc Association

09.03.2024



- 
- Medical Imaging
 - Machine Learning/Artificial Intelligence (ML/AI) in computer vision
 - ML in medical imaging
 - Two examples in the context of developing brains with diffusion magnetic resonance imaging (dMRI)



Medical Imaging

MEDICAL IMAGING



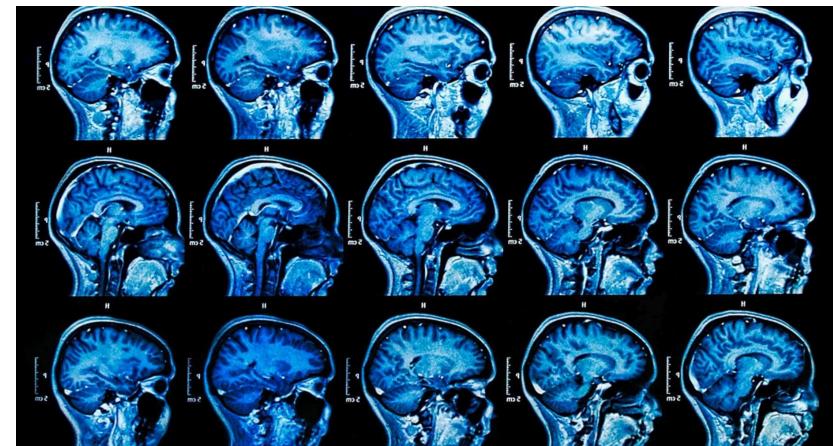
- Limited human senses
- Most of our serious health issues happen inside the body !
- How to look inside the body & brain, in a least invasive way ?



MEDICAL IMAGING



- Limited human senses
- Most of our serious health issues happen inside the body !
- How to look inside the body & brain, in a least invasive way ?



Sources: Nvidia; Cooper et al., AJCR; twiniversity.com

MEDICAL IMAGING



■ Main modalities

- Computer Tomography (CT)
- Positron Emission Tomography (PET)
- Ultrasound (US)
- Magnetic Resonance Imaging (MRI)
- Single-Photon Emission Computed Tomography (SPECT)
- Fluoroscopy
- Mammography
- Angiography
- Magnetic Resonance Angiography (MRA)
- Near-infrared spectroscopy
- Elastography

MEDICAL IMAGING

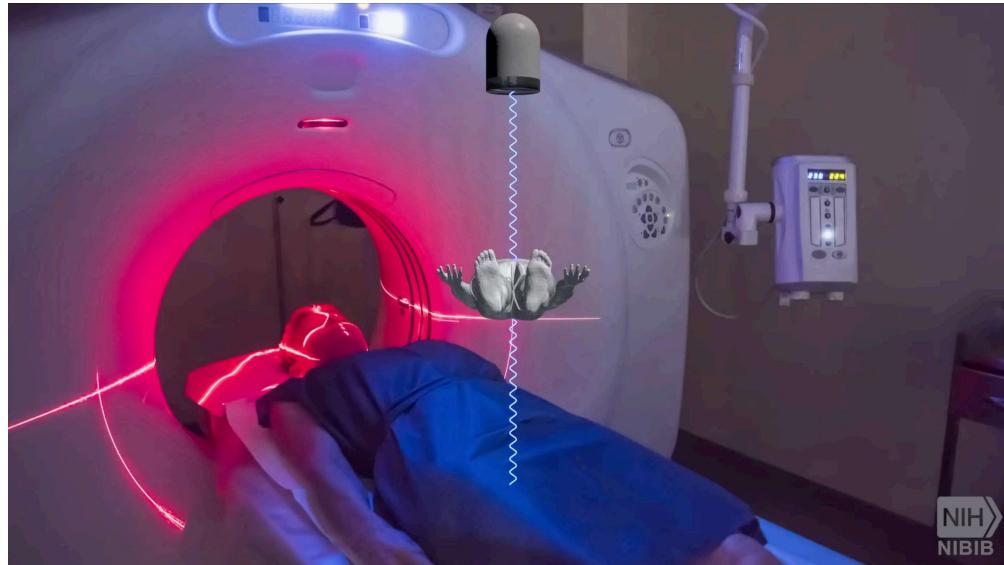
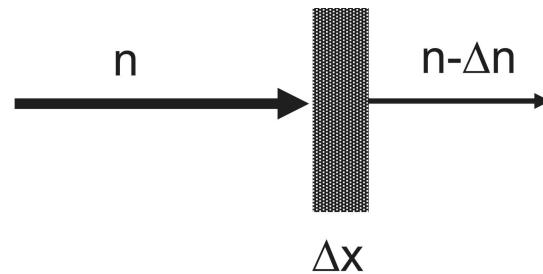


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COMPUTER TOMOGRAPHY

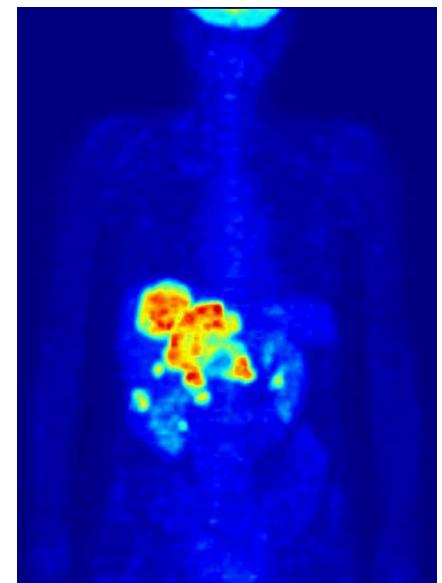
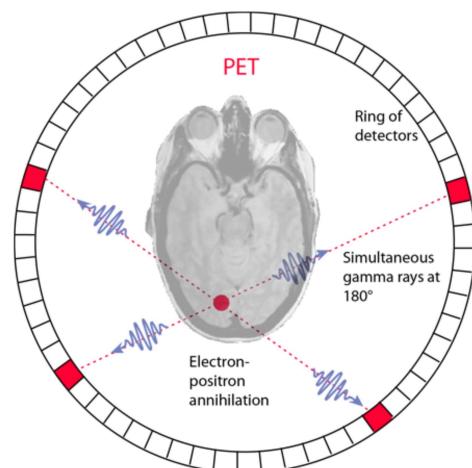
- X-ray based (transmitted)
- High contrast between air-tissue or bone-tissue
- Rapid scan with high spatial resolution
(limited only by radiation dose in humans)
- High radiations



Sources: NIH, Radiopedia

POSITRON EMISSION TOMOGRAPHY

- Gamma-ray based using specific radioactive *tracers*
- Tracer distribution in tissue
- Measures body/brain *function*
- Typical in oncology and neuroscience
- Typically sold as a PET/CT machine



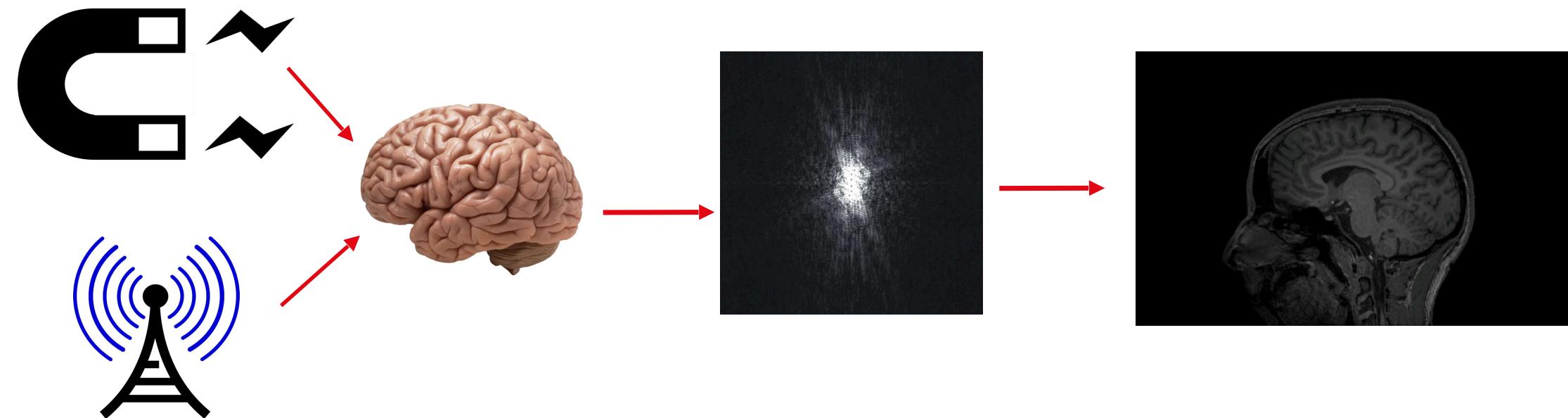
Sources: hyperphysics.phy-astr.gsu.edu, adapted from Wikipedia

ULTRASOUND

- Sound wave based (reflected back)
- Known for being the tool of reference for fetuses
- Rapid and least invasive assessment of tissue close to surface
- Safe and cheap



MRI



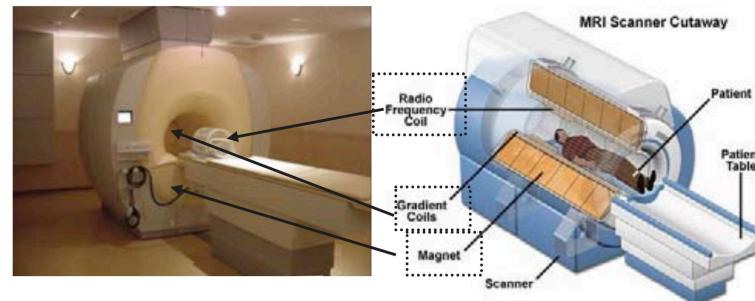
Courtesy of Dr. Thomas Yu

MRI

- Principle: manipulation of magnetic properties of protons (mainly water protons)

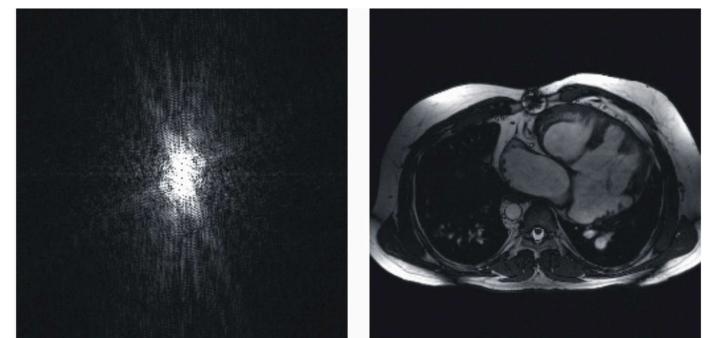
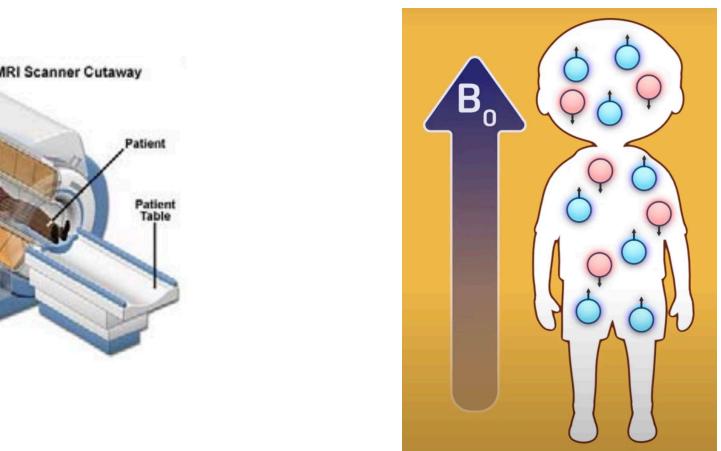
- Components

- Magnet
 - RF coils
 - Gradient coils



- Rich in contrast!

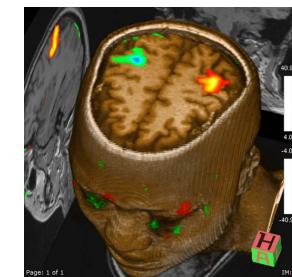
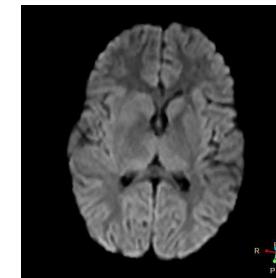
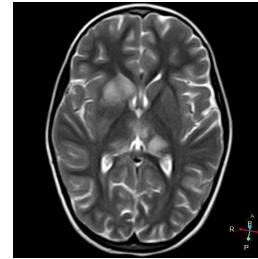
- Good for soft tissue contrast
 - Signal-to-noise dependent on B_0 (1.5/3 Tesla)
 - Not quantitative! (Unlike other modalities such as CT, PET, etc.)
 - Highly dependent on acquisition parameters (*MRI sequences*)
 - Can be hard to interpret
 - Expensive (~1M\$/Tesla)



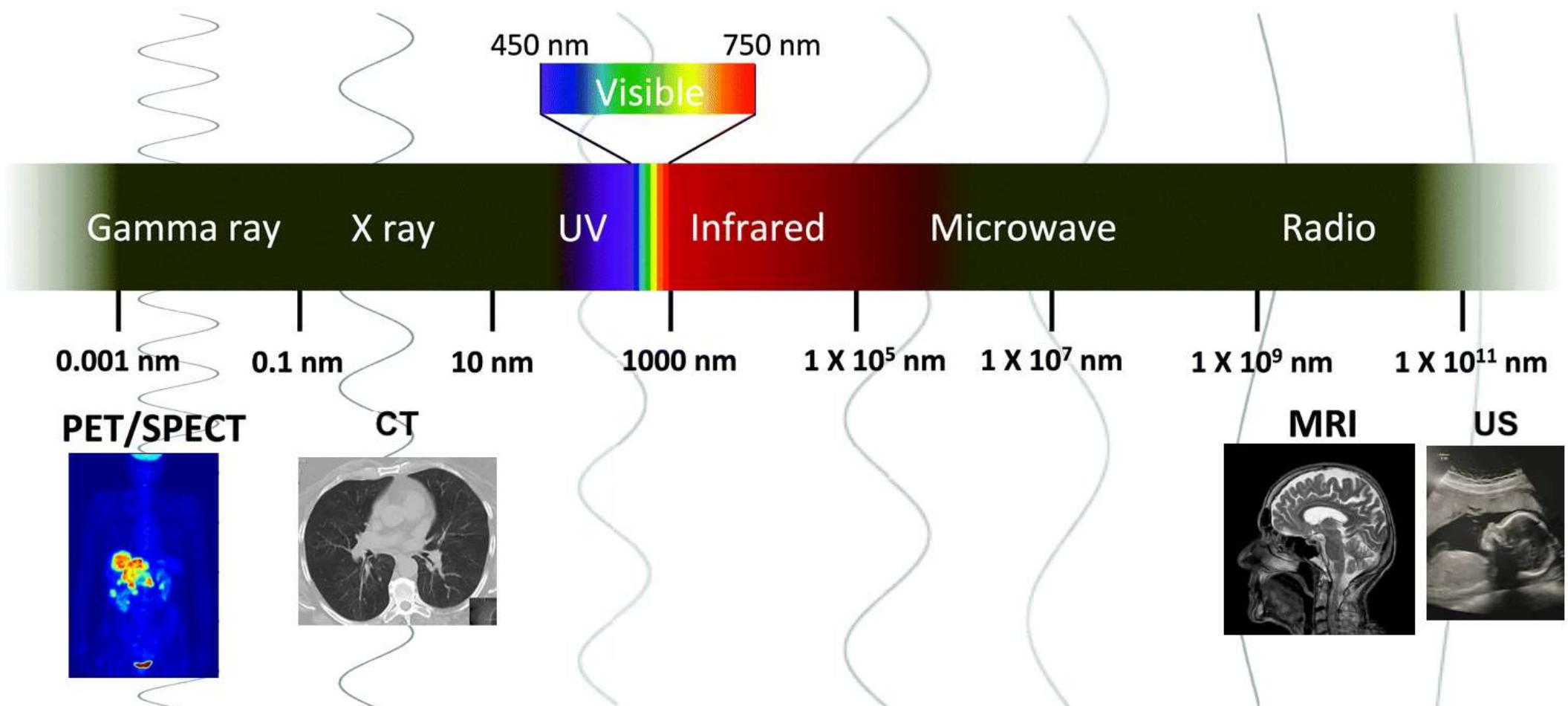
Sources: Fundamentals of biomedical Imaging EPFL course; John Hopkins Radiology; Moratal et al., BIIJ 2008

MRI CONTRASTS

- T1-T2
 - Inherent tissue properties
 - Structural information
- Diffusion MRI (dMRI)
 - Water molecules displacement
 - Structural information
 - Brain white matter information
- Functional MRI (fMRI)
 - Measures cerebral blood flow through time
 - Indirect functional activity
- Perfusion MRI, Proton Density, FLAIR, Spectroscopy, etc.



ELECTROMAGNETIC SPECTRUM

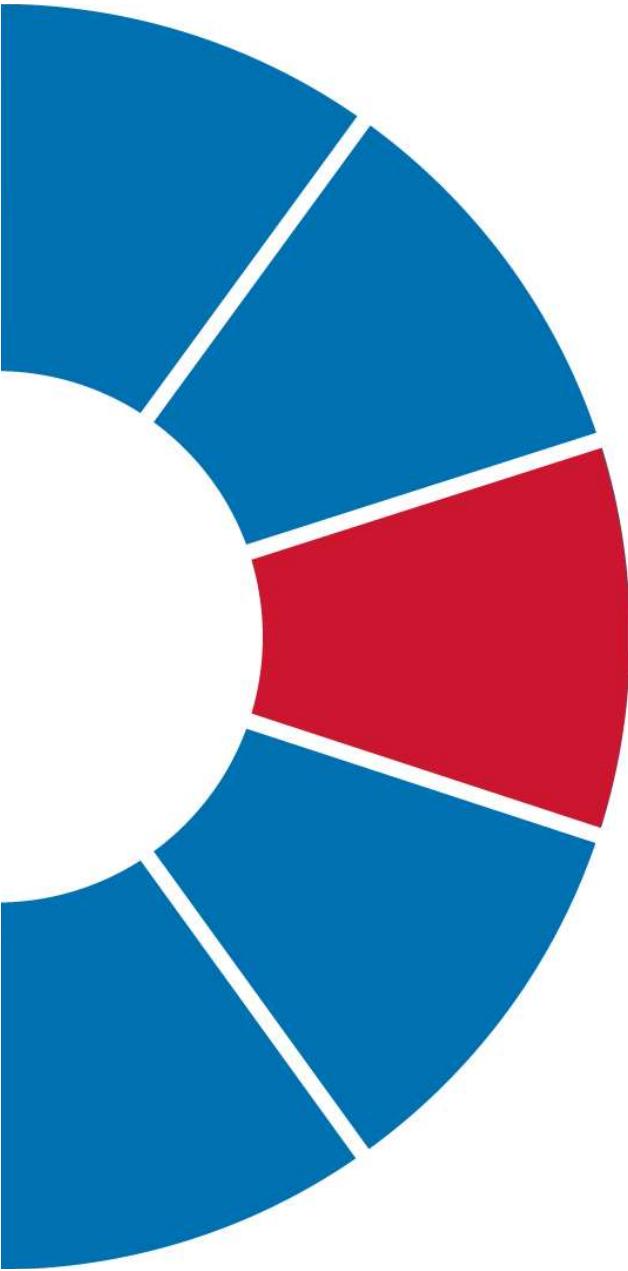


Sources: adapted from Chan and Almutairi, Material Horizons, 2016; Wikipedia; internationalimagingcongress.com

MEDICAL IMAGING DEALS WITH.. IMAGES

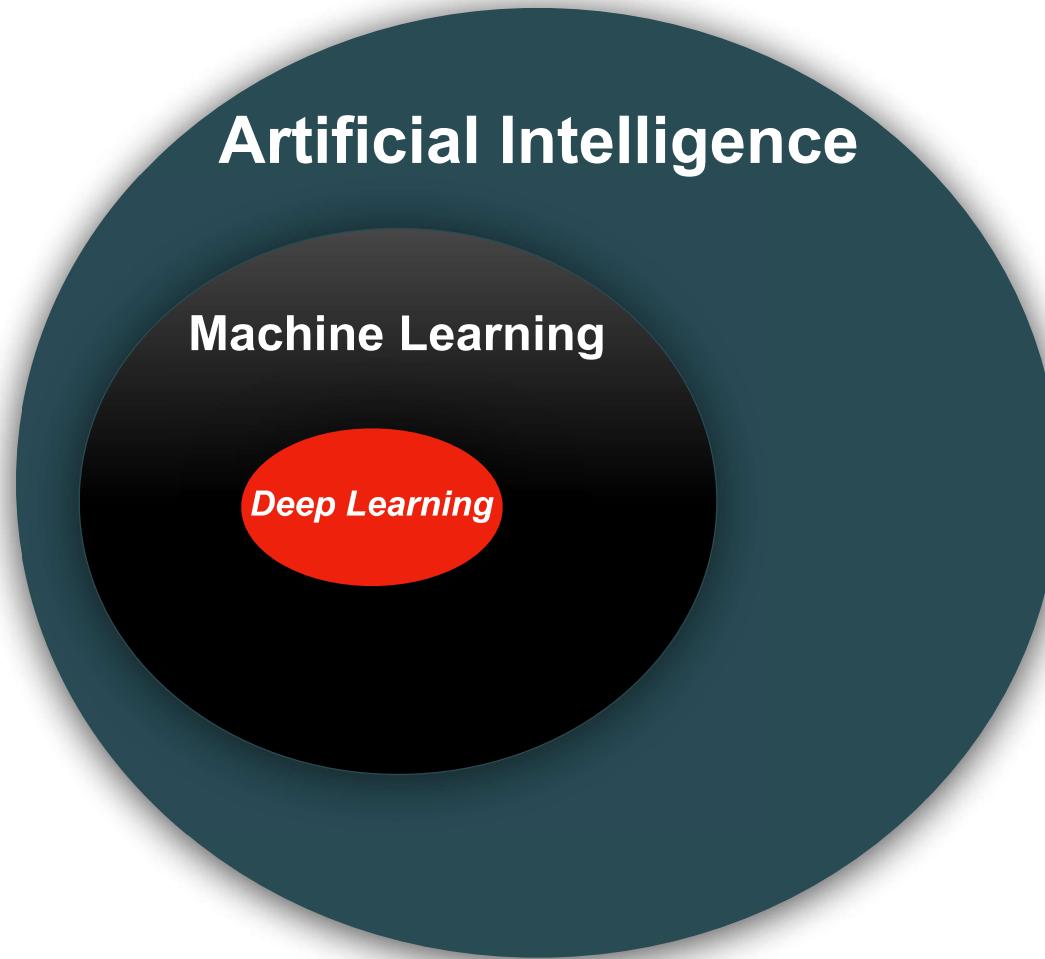
- AI revolution in image processing!
 - Generation
 - Detection
 - Captioning
 - Etc.



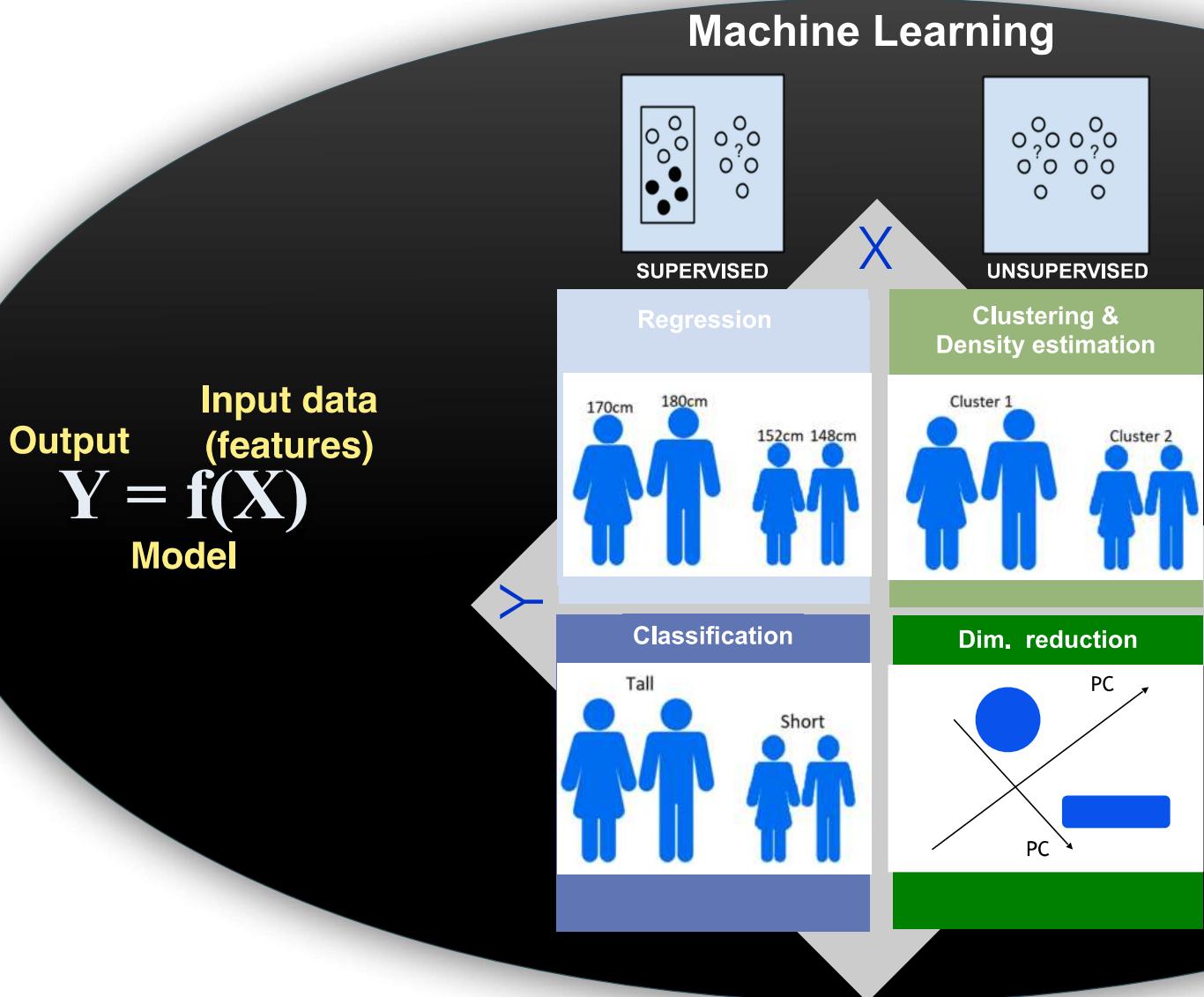


MACHINE LEARNING IN COMPUTER VISION

MACHINE & DEEP LEARNING

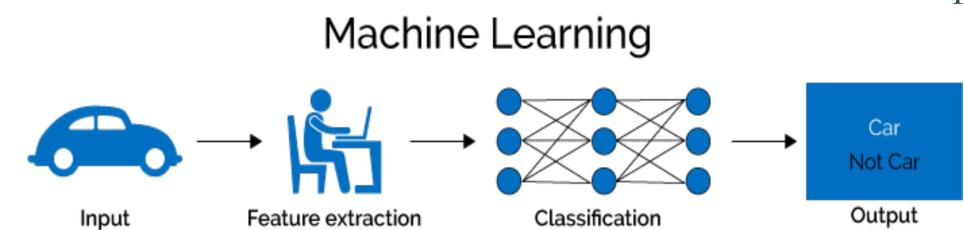
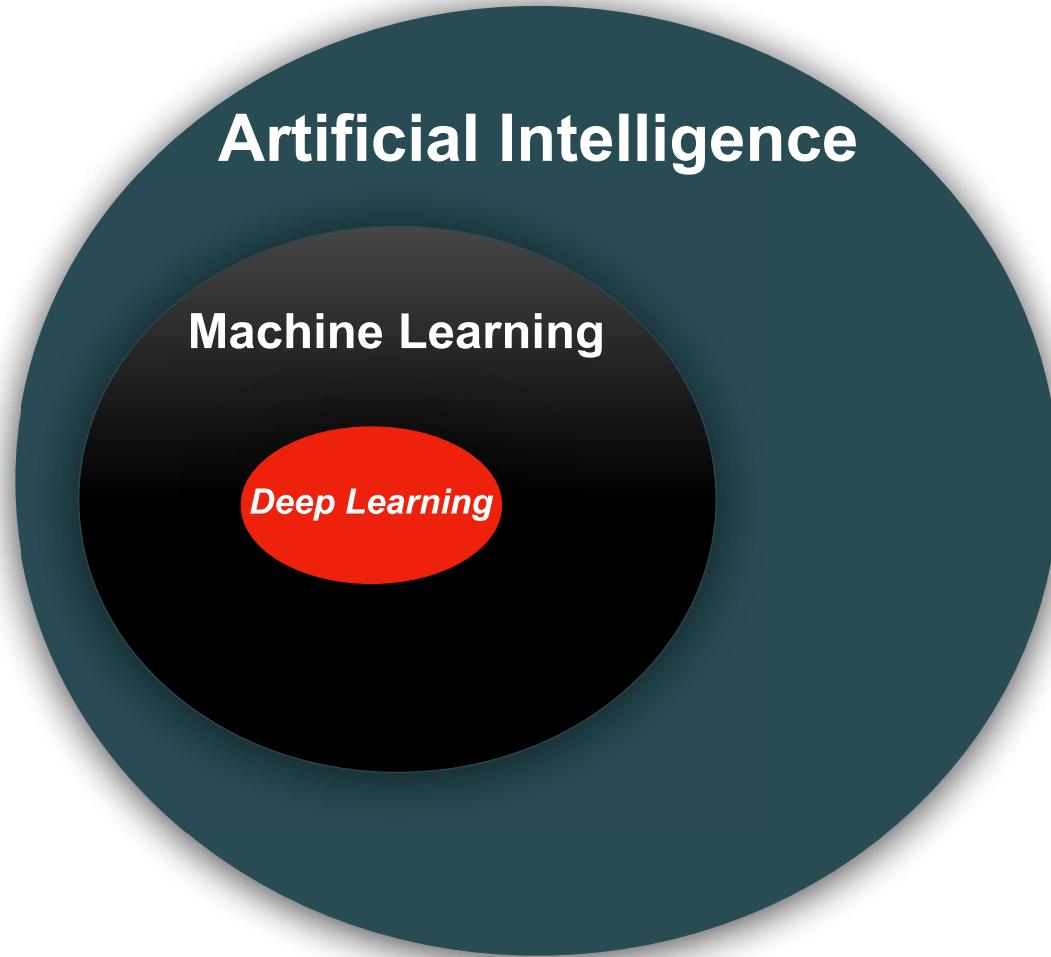


DEEP LEARNING FOR COMPUTER VISION TASKS



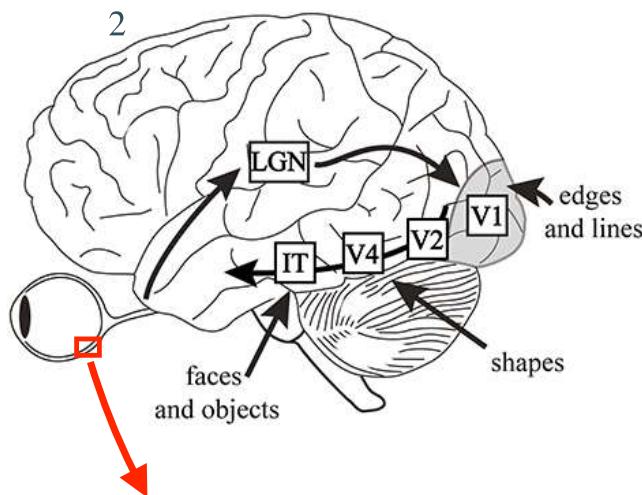
Courtesy of Dr. Meritxell Bach Cuadra

DEEP LEARNING FOR COMPUTER VISION TASKS

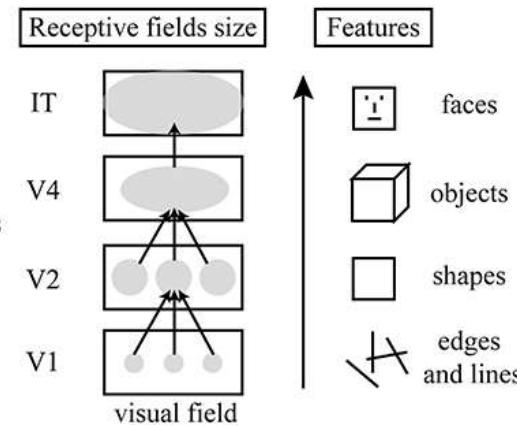
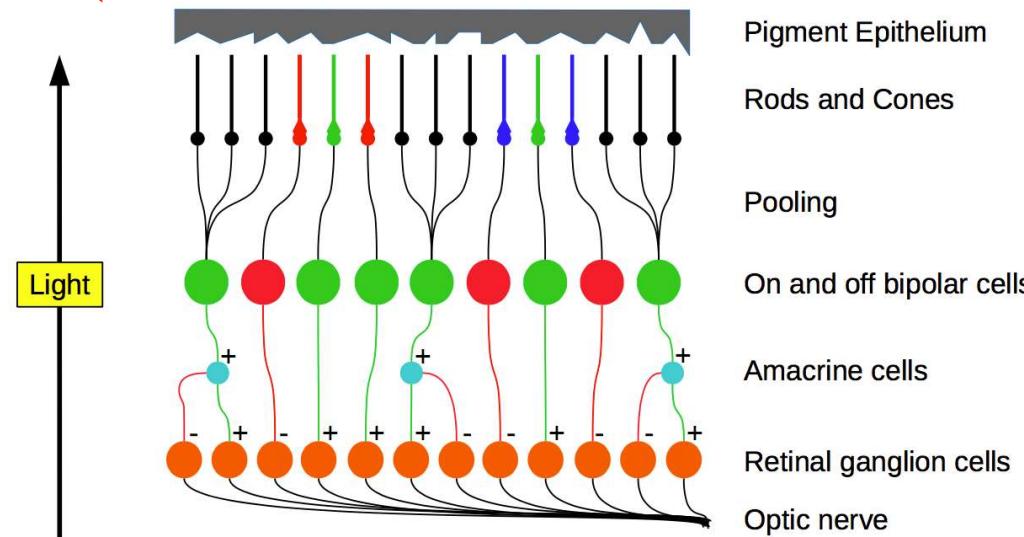


CONVOLUTIONAL NEURAL NETWORKS FOR COMPUTER VISION TASKS: BIOLOGICAL INSPIRATION

Higher level processing



Information processing in the retina



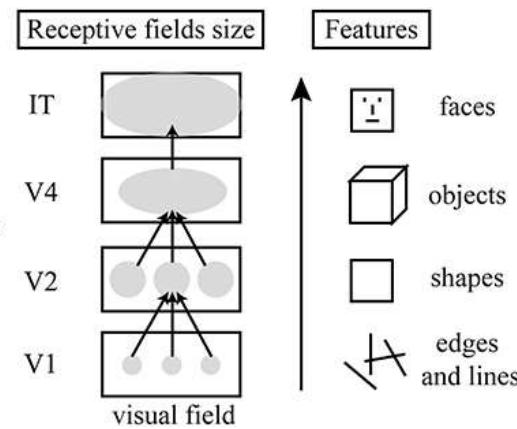
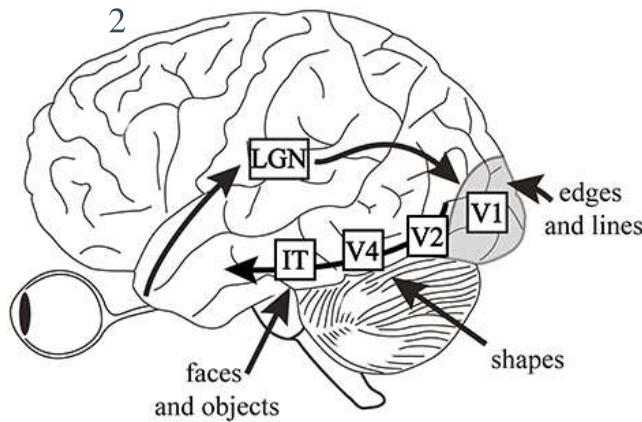
Deep Learning

*Convolutional
Neural Networks¹*

[1] LeCun et al., Neural Computation 1989

CONVOLUTIONAL NEURAL NETWORKS FOR COMPUTER VISION TASKS: BIOLOGICAL INSPIRATION

Higher level processing



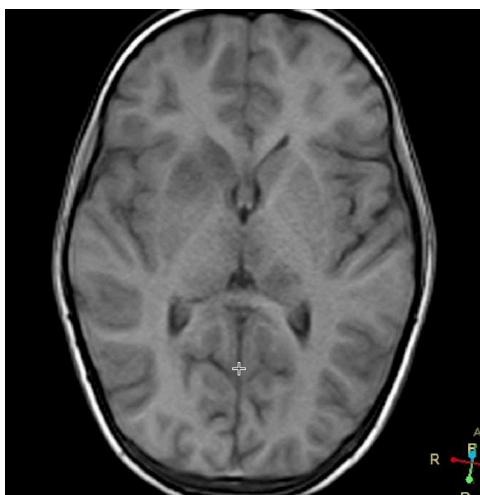
Deep Learning

*Convolutional
Neural Networks¹*

- Processing is divided into several consecutive layers
- Neurons process only a small subpart of the available information
- Neurons in each layer combine their inputs to higher order features
- Many neurons perform the same task for different parts of the input

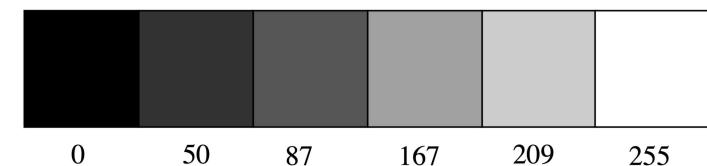
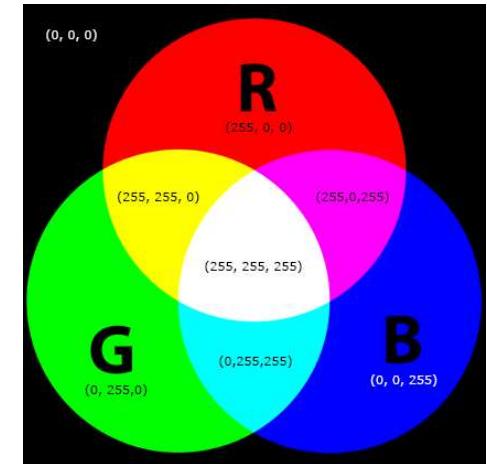
[1] LeCun et al., Neural Computation 1989

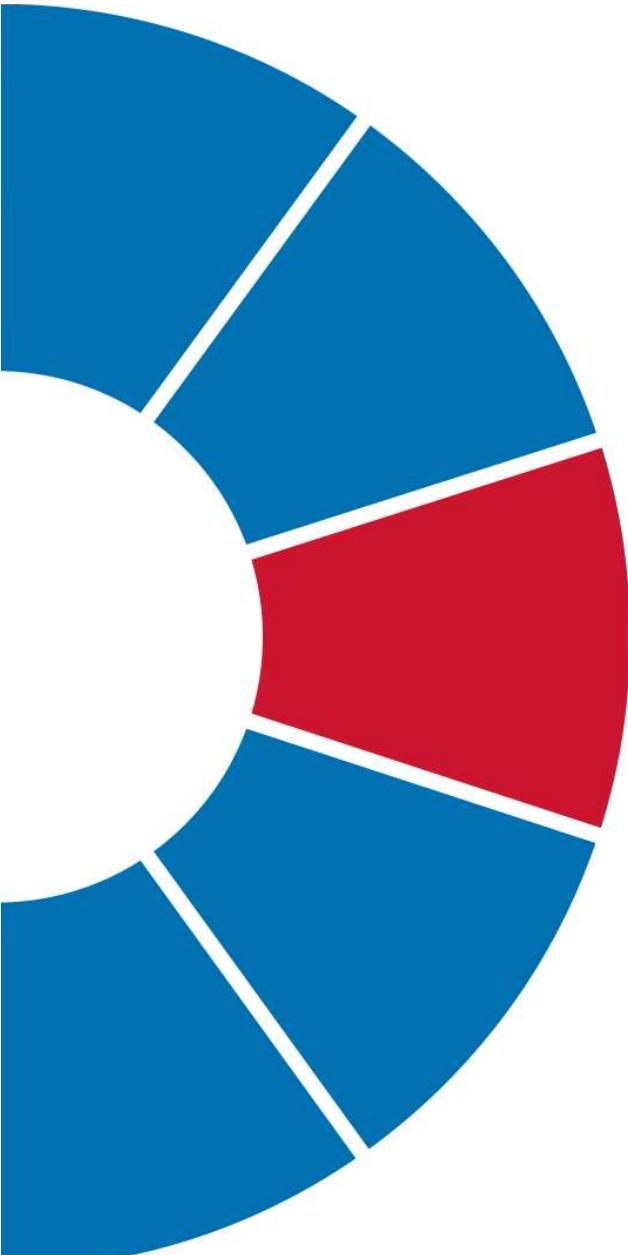
« IMAGES ARE JUST NUMBERS »



Radiopedia.com

Pixel (picture element)
=
number(s) in a computer





Machine learning in medical imaging (MRI)

APPLICATION OF ML IN MEDICAL IMAGE ANALYSIS

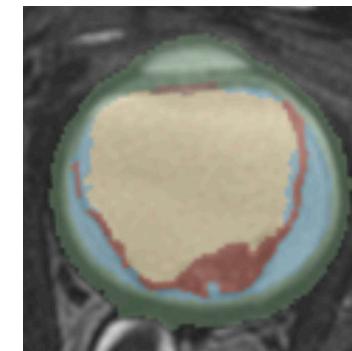
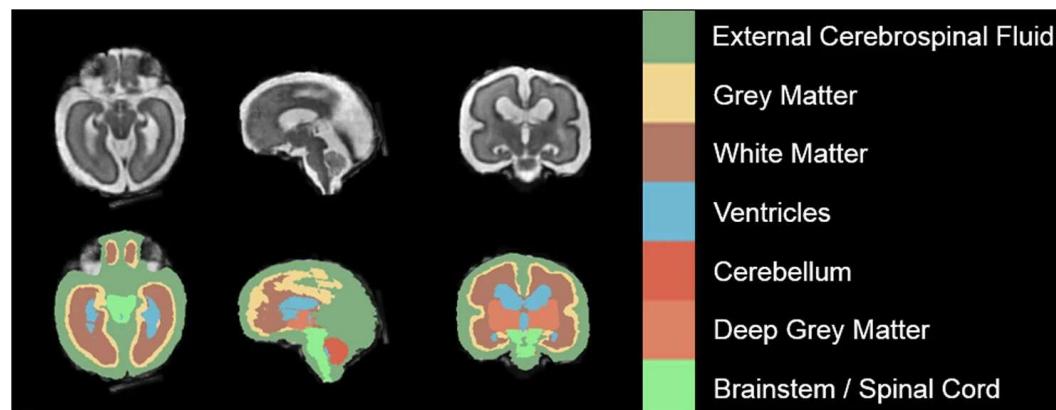
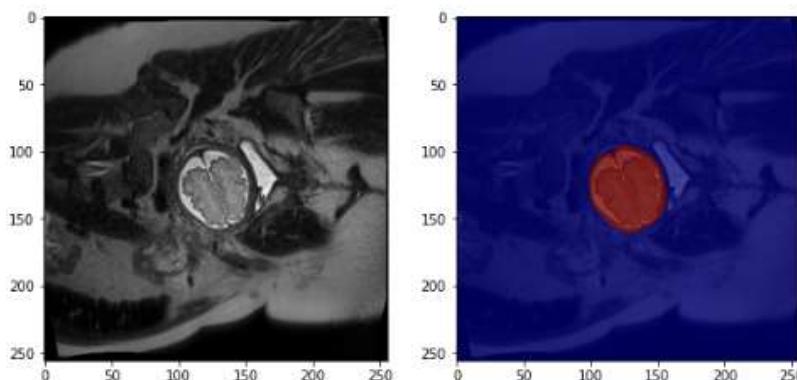


- Segmentation
- Localization
- Classification
- Registration
- Synthesis

SEGMENTATION

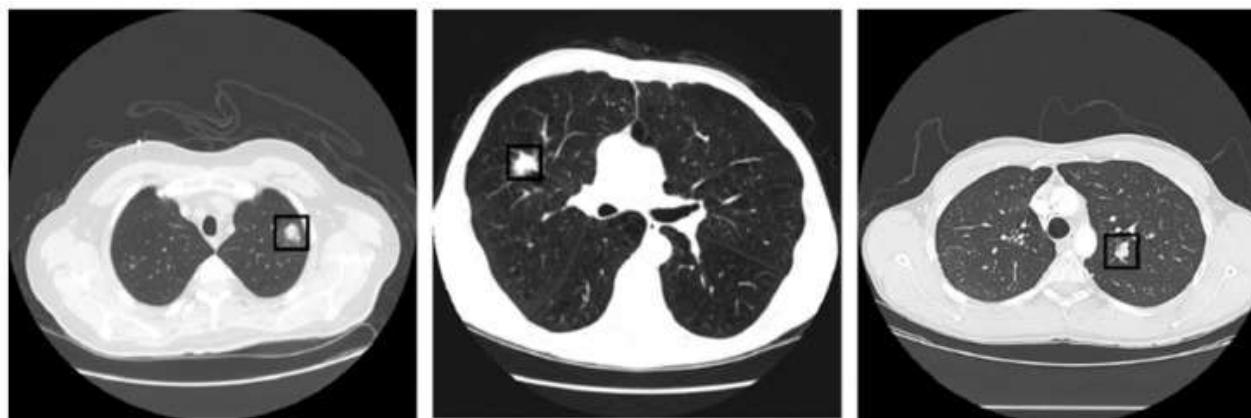
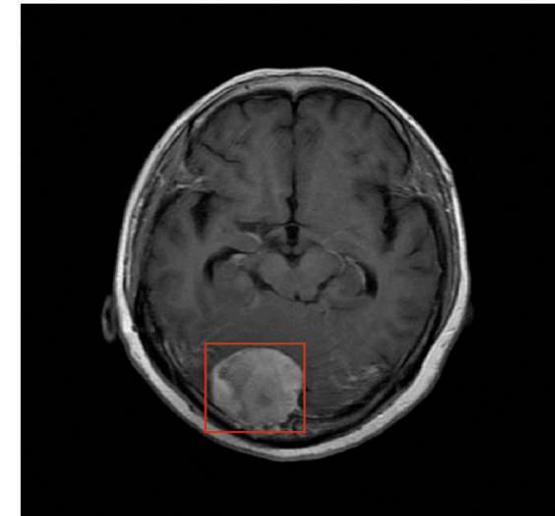
- Assign a label to each pixel/voxel (binary or not)

- Typically using a U-Net architecture
 - Brain/non-brain
 - Brain regions
 - Tumor/non-tumor
 - Etc.



LOCALIZATION

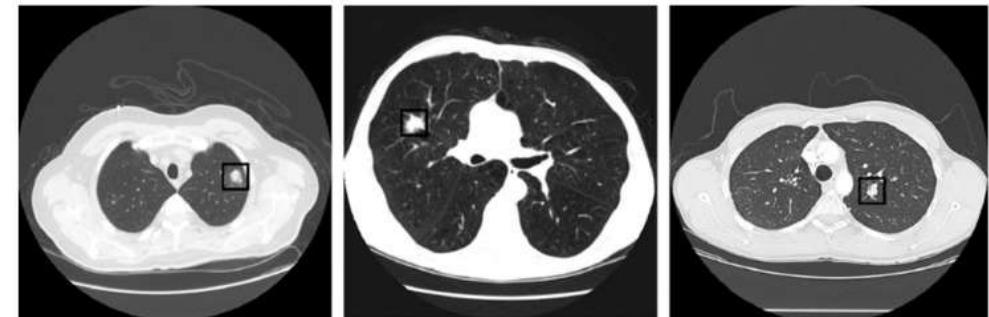
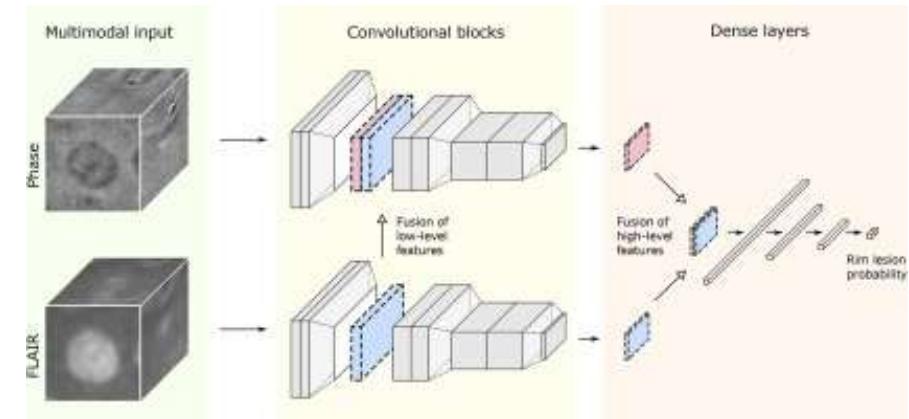
- Identifying the position of an object (involving *bounding boxes*)
 - Brain localization in an US
 - Tumour localization
 - Nodule localization in a CT scan



CLASSIFICATION

- Assign a label to each image (binary or multiple)

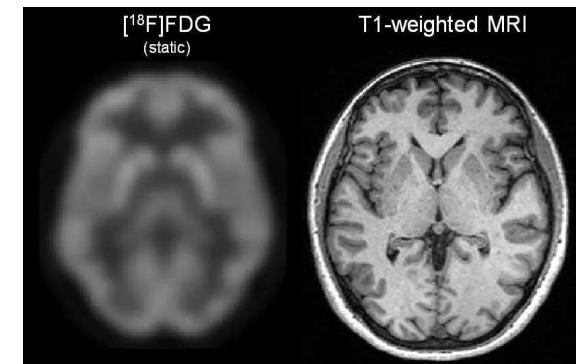
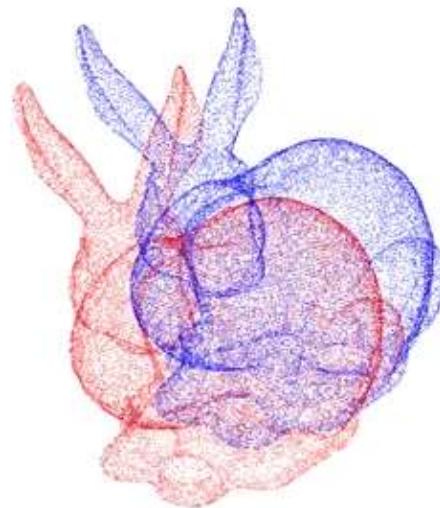
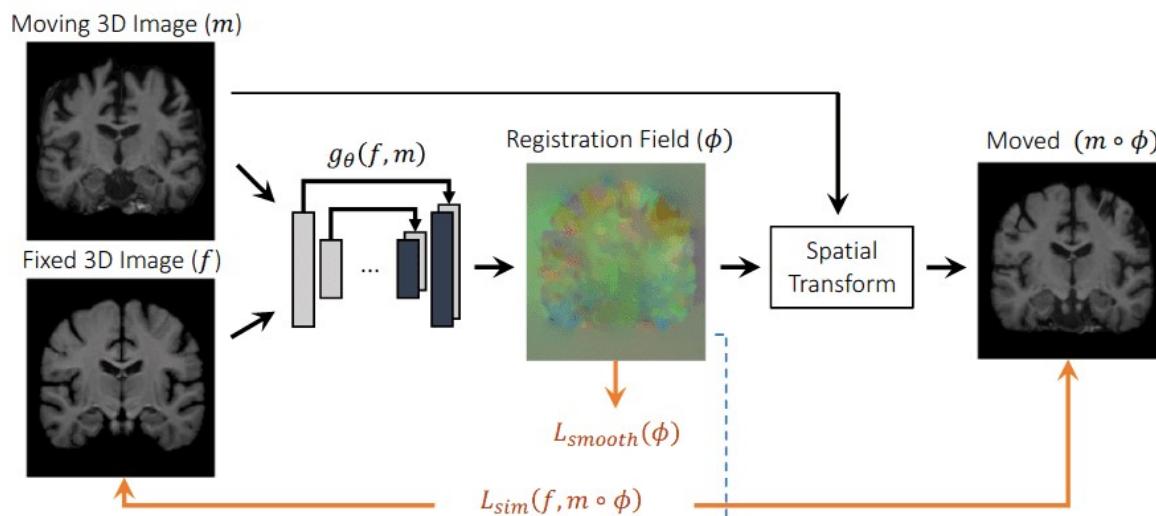
- Benign or malign tumor
- Inflammatory or not inflammatory lesion (pre-identified)
- Absent/present or normal/abnormal
- Etc.



Localize and assign to: « benign », « primary malignant », or « metastatic malignant »

REGISTRATION

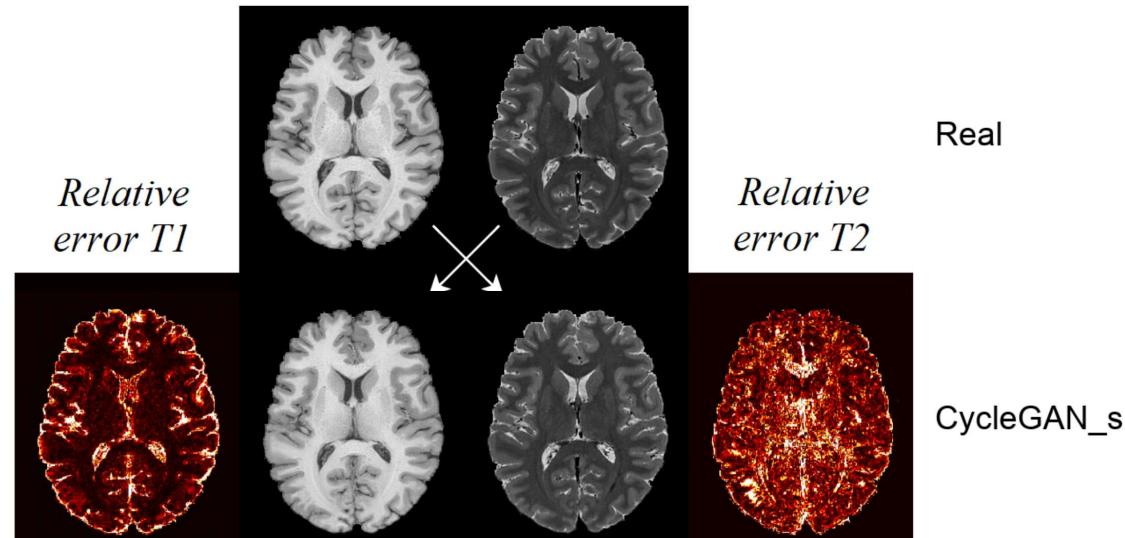
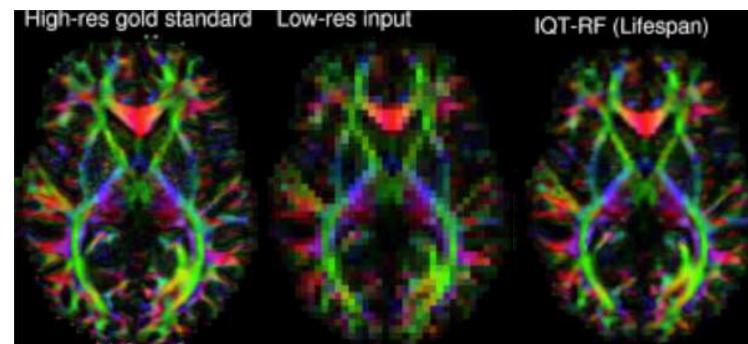
- Alignment to the same coordinate space
 - Find the transformation (rigid, affine, non-linear) to align two images (fixed, moving)
 - Two images of different modalities
 - Motion correction

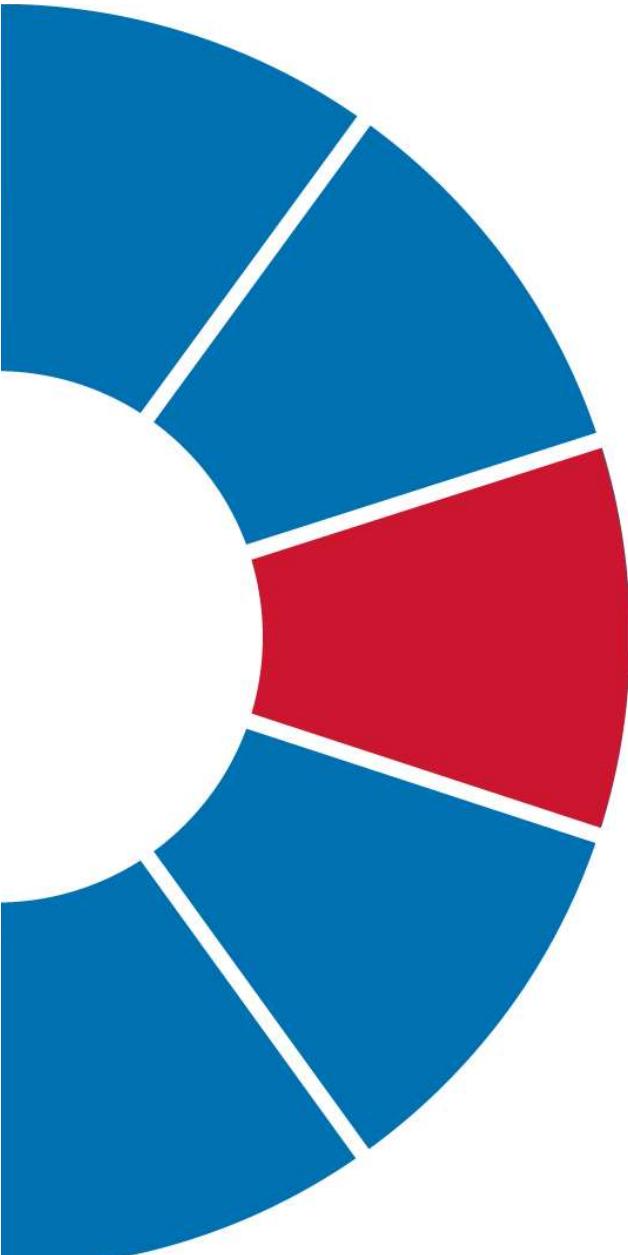


Sources: Philipp Glira, Youtube; Balakrishnan, et al., TMI 2018; Yoder, Basic PET Data Analysis Techniques book, 2013

SYNTHESIS/RECONSTRUCTION

- Creating new images using existing ones
 - Super-resolution
 - Image translation (ex: CT-> MRI)
 - Synthetic data generation (ex. with GANs, VAEs)
 - Etc.





Diffusion MRI & in developing human brains

THE BRAIN

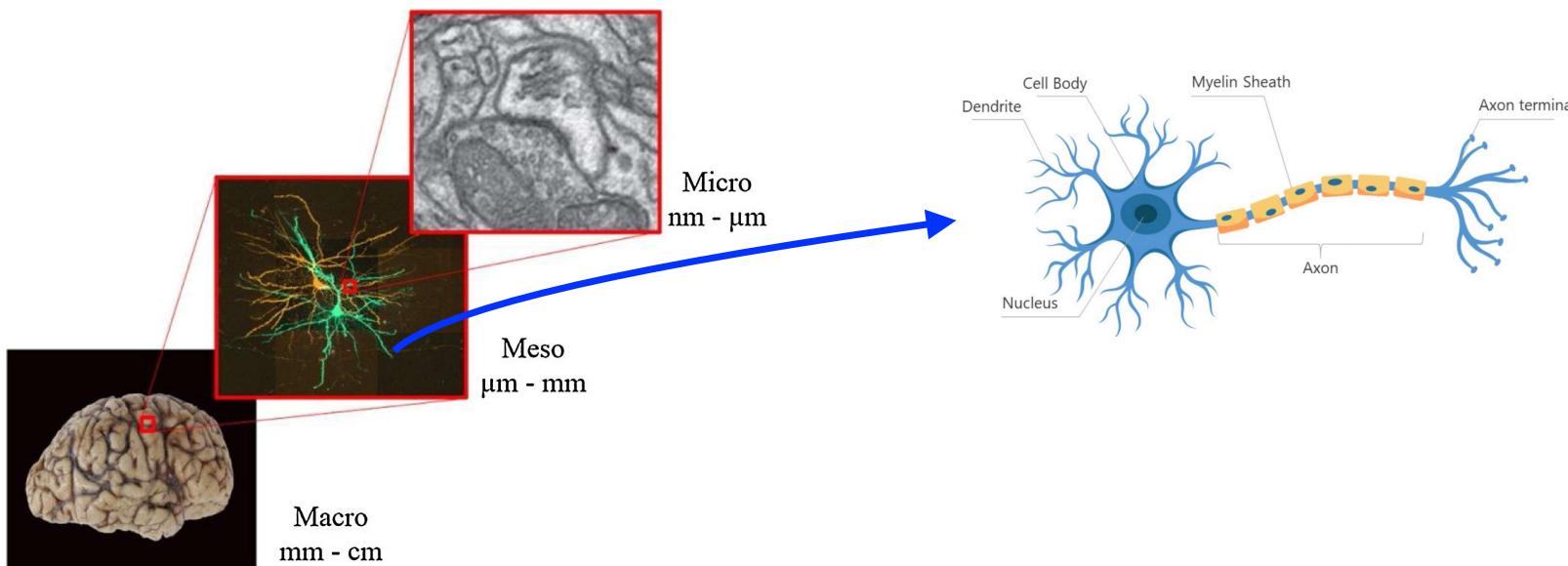
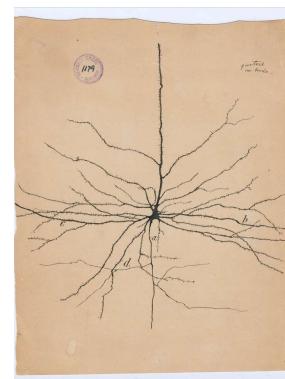
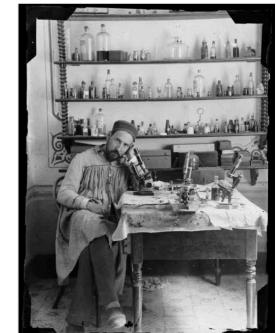
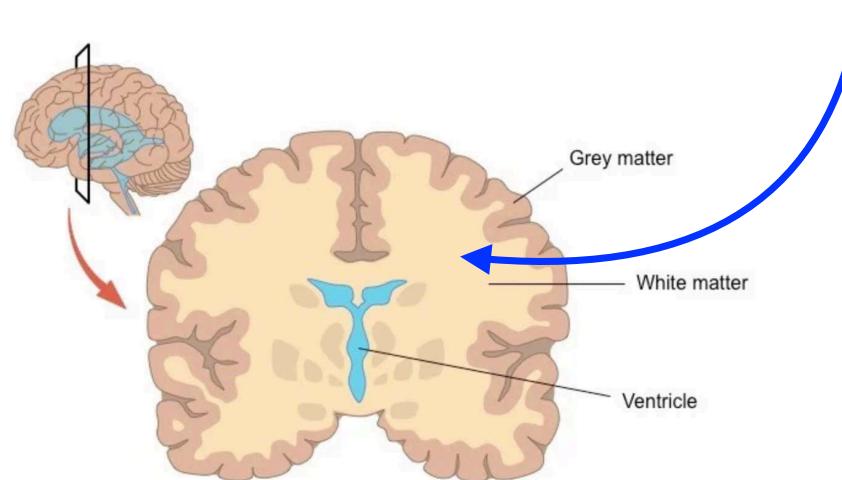


Figure from Bennett et al.,
Neuroscience & Biobehavioral
Reviews 2018



DIFFUSION MRI



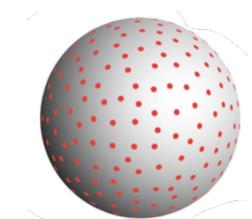
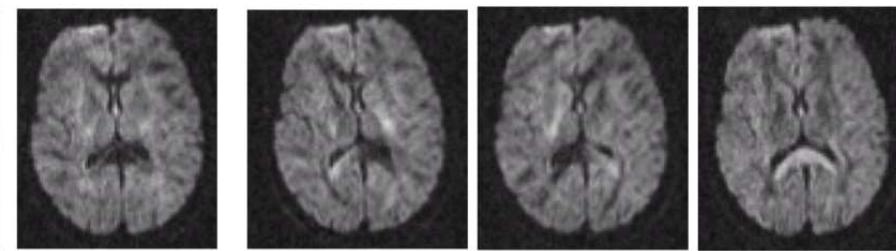
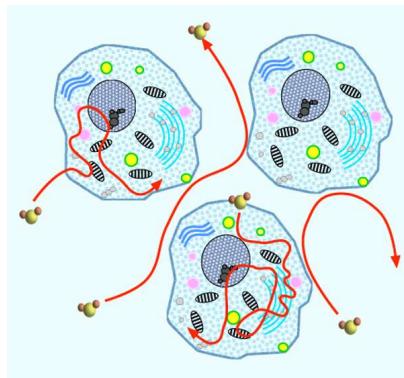
Robert Brown (1773-1858)



Albert Einstein (1879-1955)



- Principle
 - Water molecules displacement ~ Anatomy

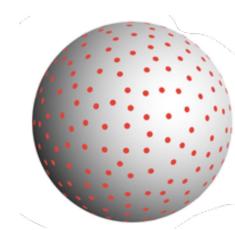


Sources: FSL; Avram et al., PhD thesis, 2011

DIFFUSION WEIGHTED IMAGING

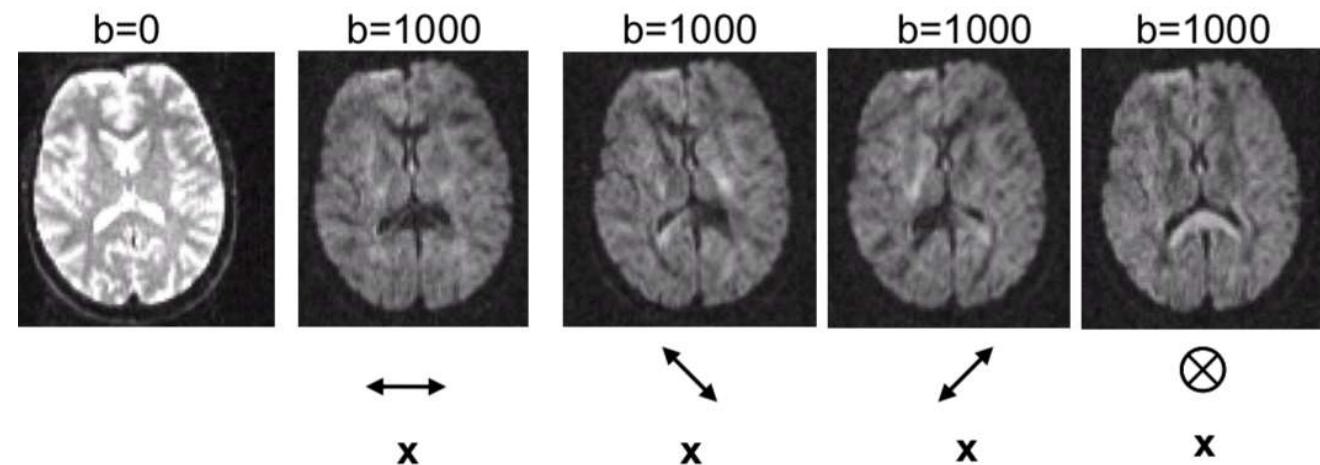
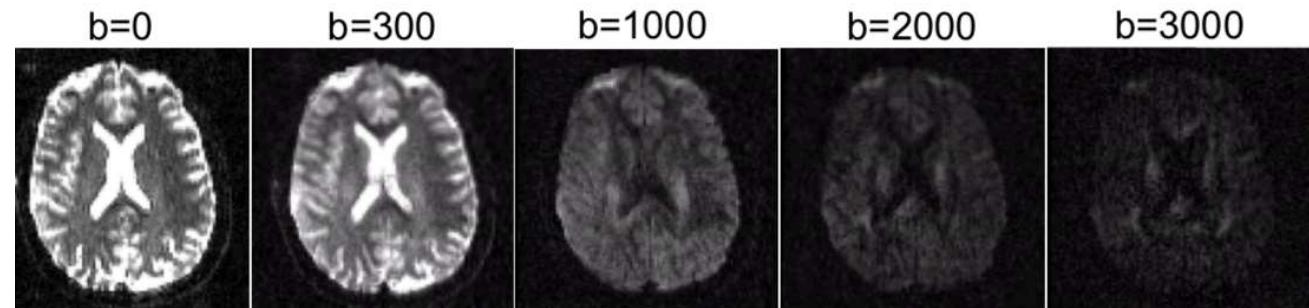
■ Two important parameters

- Number of gradient directions (angular dimension)
- b-value

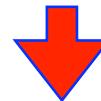
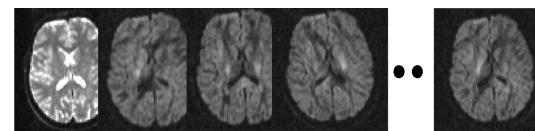
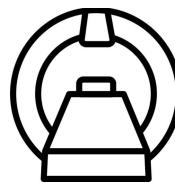


$$b$$
$$\frac{S_g}{S_0} = \exp \left[-\gamma^2 G^2 \delta^2 \left(\Delta - \frac{\delta}{3} \right) D \right]$$

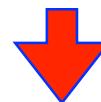
b value $\sim G^2 \cdot \text{DiffTime}$ (units in s/mm²)



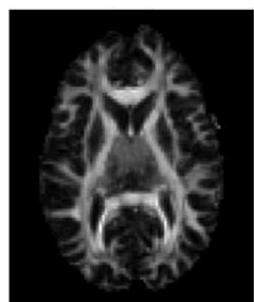
DIFFUSION MODELS



Quality control & preprocessing



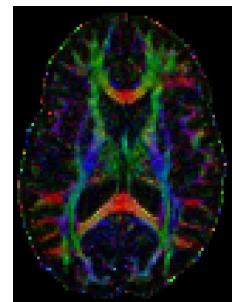
Model fitting



Fractional Anisotropy
(FA)



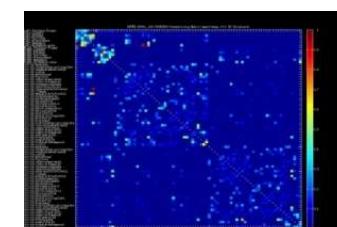
Mean Diffusivity
(MD)



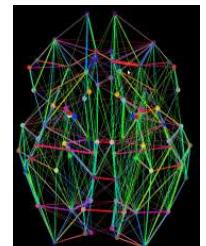
Color FA



Tractography



Connectomes



Graphs

THE RAPID CHANGE OF DEVELOPING BRAINS

