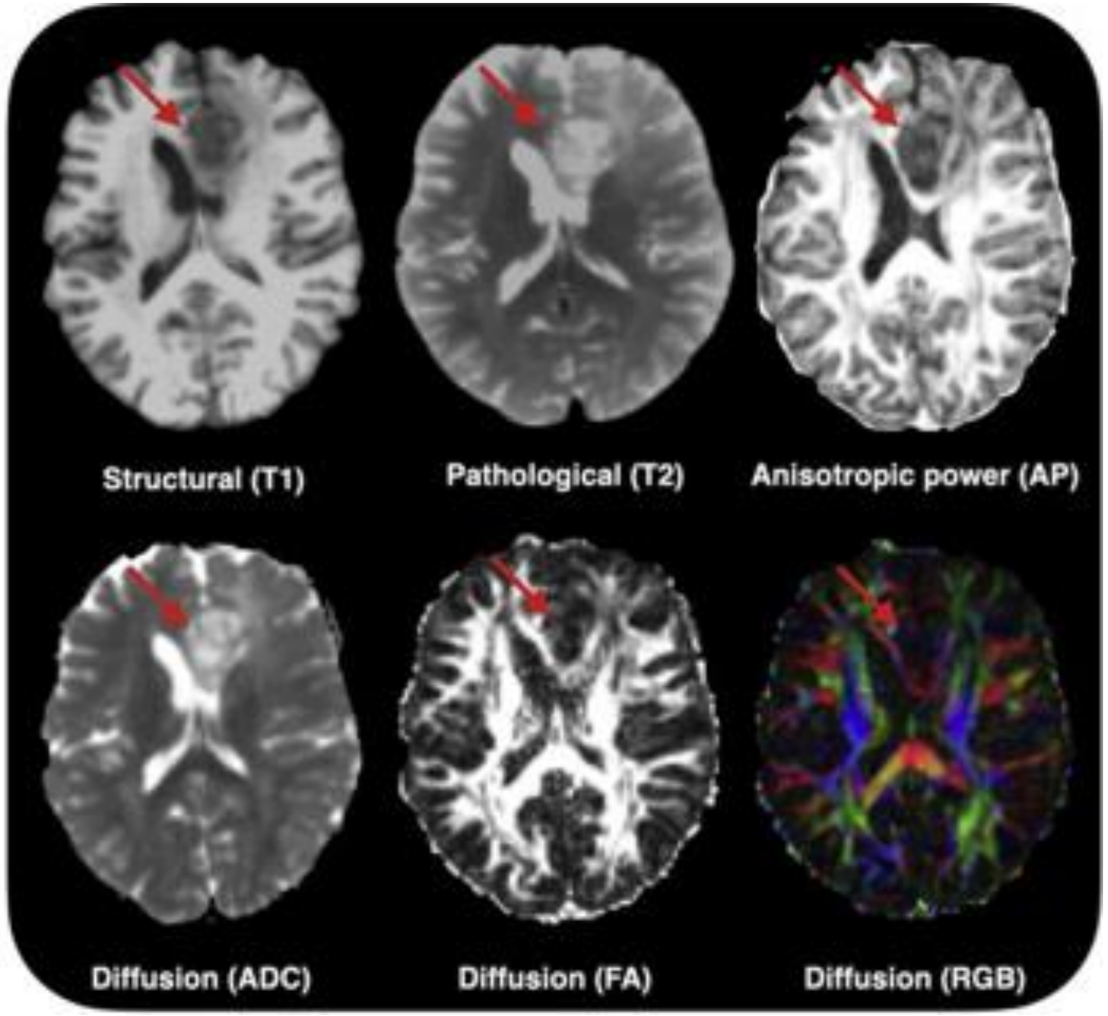
Medical/Bio Research Topics Ⅰ: Week 01 (07.03.2024)

Introduction to the Brain Imaging-based Artificial Intelligence Models

뇌영상 기반 인공지능 모델 소개

Brain Imaging Practices in Radiology

- Precise diagnosis
  - Selecting imaging techniques (e.g., MRI, CT, PET) depending on the suspected condition
  - Identifying abnormalities such as tumors, strokes, hemorrhages, inflammation, and structural anomalies, aiding in the accurate diagnosis of the underlying condition



Brain lesion detection

- Informed prognosis
  - Evaluating disease progression by assessing the extent and severity of brain abnormalities, for example, the size and spread of tumors or the extent of stroke damage
  - Identifying biomarkers that help predict disease progression and outcomes, particularly in degenerative diseases and brain injuries
  - Monitoring changes in the brain over time by regular imaging, helping to predict how a patient is responding to treatment and adjust prognosis accordingly

- Effective treatment planning
  - Guiding surgery or other interventions by providing detailed maps of the brain to ensure that treatments target the correct areas while avoiding critical structures
  - Delineating tumor boundaries and planning targeted radiation therapy, minimizing exposure to healthy brain tissue, in oncology
  - Evaluating whether certain treatments are viable options based on the location, size, and nature of brain lesions

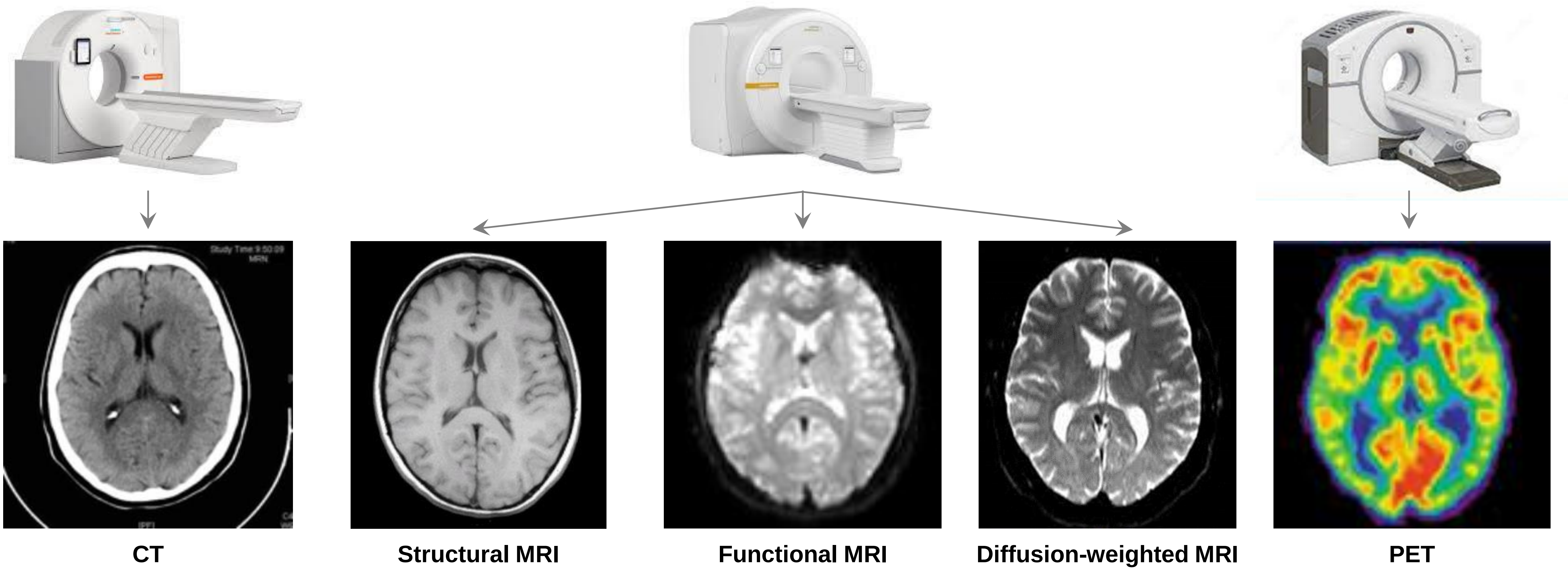
- Ongoing management
  - Assessing the effectiveness of treatments, such as the shrinkage of tumors in response to chemotherapy or changes in inflammatory markers after medication adjustments
  - Detecting complications arising from the disease or treatment, such as bleeding post-surgery or radiation-induced changes, allowing for timely intervention
  - Regular imaging for long-term surveillance to detect recurrence or manage chronic diseases effectively

- General process for brain imaging in radiology
  - Referral
    - From a healthcare provider, who identifies the need for brain imaging based on the patient's symptoms, medical history, and physical examination
    - Choice of modality, often in consultation with a radiologist
  - Preparation
    - Patient instructions, such as fasting or withholding certain medications
    - Safety screening, particularly for contraindications to MRI, such as implanted metal devices or claustrophobia
    - Contrast agent, which may be administered to enhance the visibility of certain structures or abnormalities

- Imaging procedure
  - Positioning on the scanning table, ensuring comfort and the correct posture for optimal imaging of the brain
  - Scanning in the imaging device (e.g., the gantry of a CT scanner or the bore of an MRI machine) for the duration which can vary from a few minutes to an hour, depending on the modality and the extent of imaging required
  - Monitoring throughout the procedure
- Post-procedure
  - Immediate care, especially if a contrast agent was used
  - Instructions, such as hydration to help eliminate a contrast agent

- Analysis and reporting
  - Processing for optimal visualization, including adjustments of brightness, contrast, and in some cases, 3D reconstructions
  - Image review to identify any abnormalities or relevant findings
  - Reporting of the findings, interpretations, and any recommended further imaging or evaluations
  - Communication back to the referring provider, who will discuss the results with the patient and plan any further treatment or investigation needed
- Collaboration and follow-up
  - Interdisciplinary collaboration with other specialists (e.g., neurologists, neurosurgeons) in complex cases to provide a comprehensive interpretation of the imaging results
  - Follow-up imaging recommended to monitor changes over time or to investigate any anomalies further

Brain Imaging



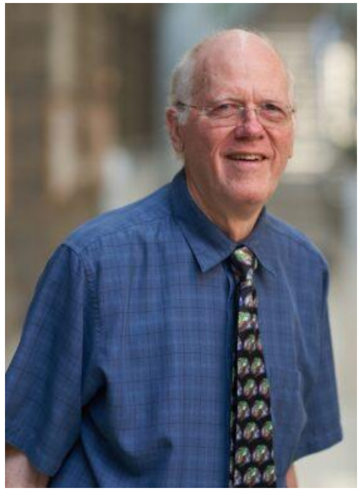
CT, Computed Tomography (컴퓨터단층촬영)
MRI, Magnetic Resonance Imaging (자기공명영상)
PET, Positron Emission Tomography (양전자방출단층촬영)

- Computed Tomography (CT)
  - Uses X-rays to create detailed cross-sectional images of the brain
  - Fast and widely available, making it a first-line imaging technique in emergencies
- Magnetic Resonance Imaging (MRI)
  - Uses a magnetic field and radio waves to produce detailed images of the brain
  - Does not use ionizing radiation

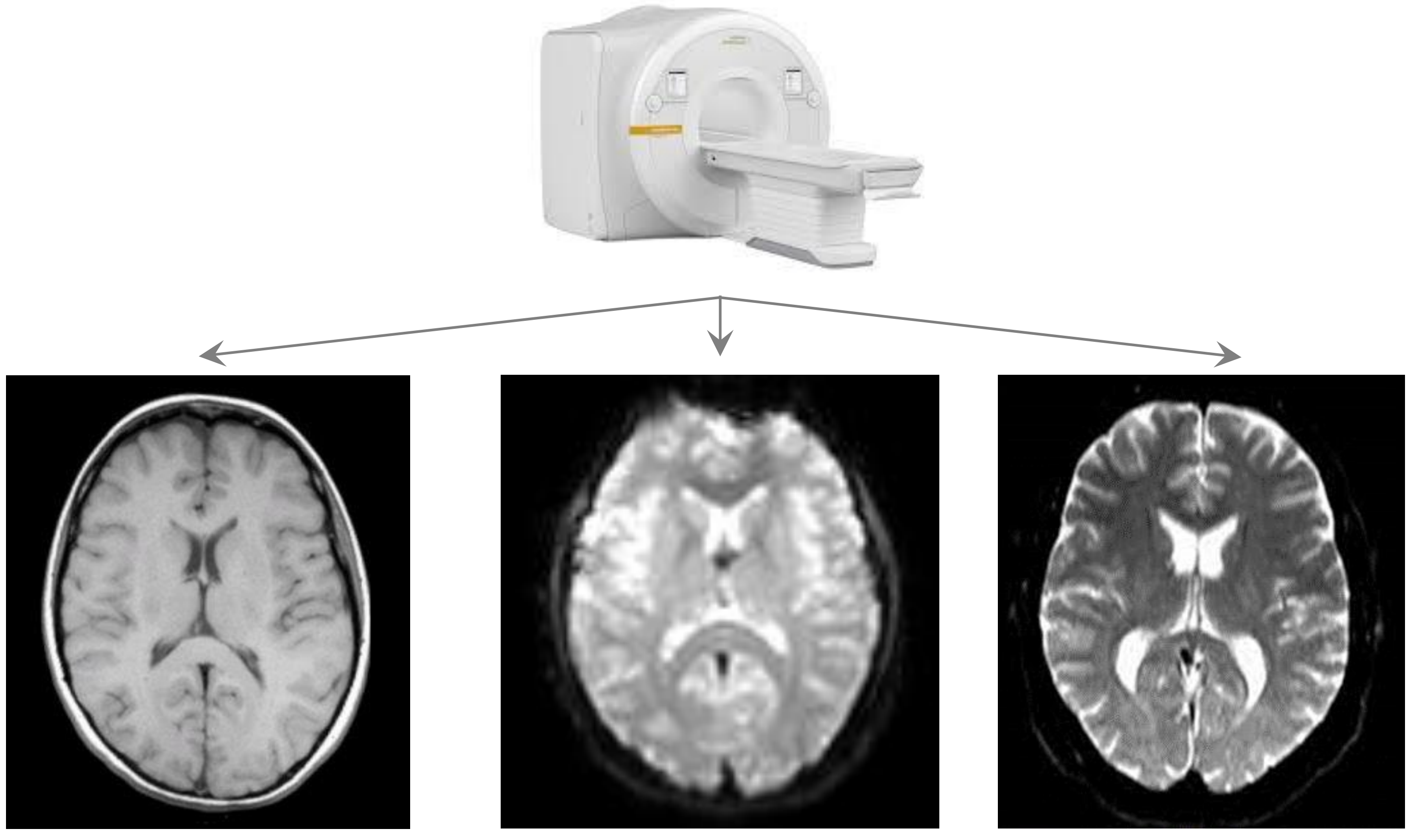
- Positron Emission Tomography (PET)
  - Involves the injection of a radioactive tracer into the bloodstream, which is then taken up by active brain tissue
  - Visualizes metabolic activity within the brain by detecting the radiation emitted by the tracer
- The choice of imaging techniques depends on:
  - Patient's condition
  - Specific clinical question to be answered
  - Imaging facilities available

MRI

- "*A workhorse technology because of the diversity of information attainable using the same scanner to acquire images*" (D.C. Van Essen)



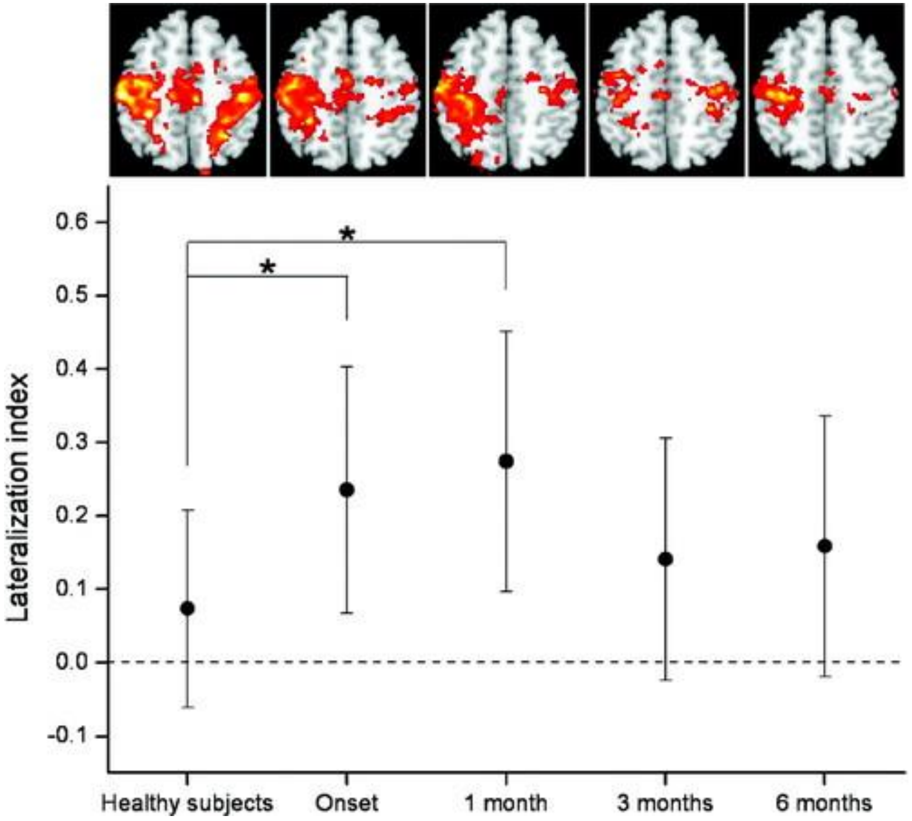
- Three main types of MRI
  - Structural MRI
  - Functional MRI
  - Diffusion-weighted MRI

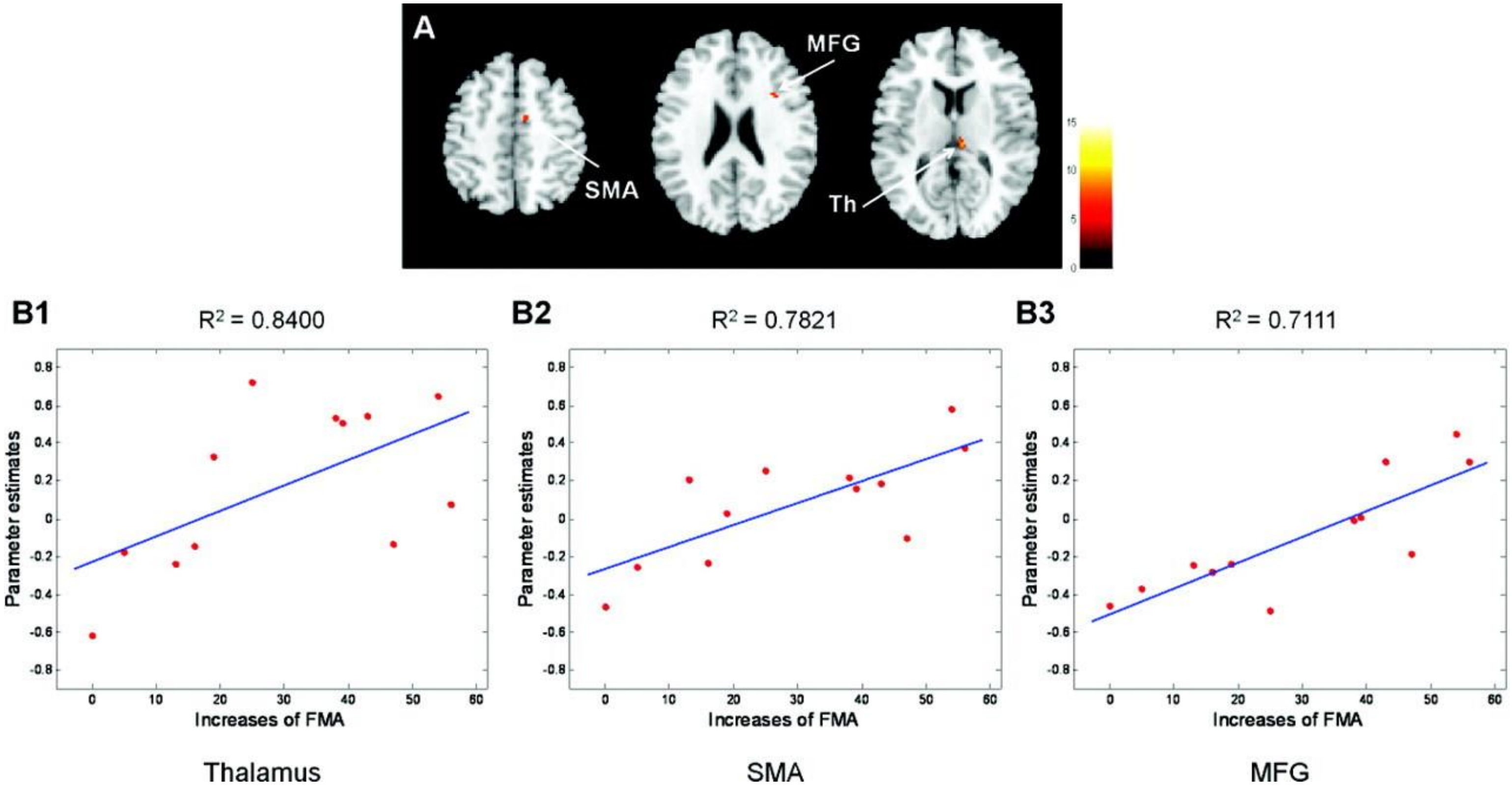


Structural MRI | Functional MRI | Diffusion-weighted MRI

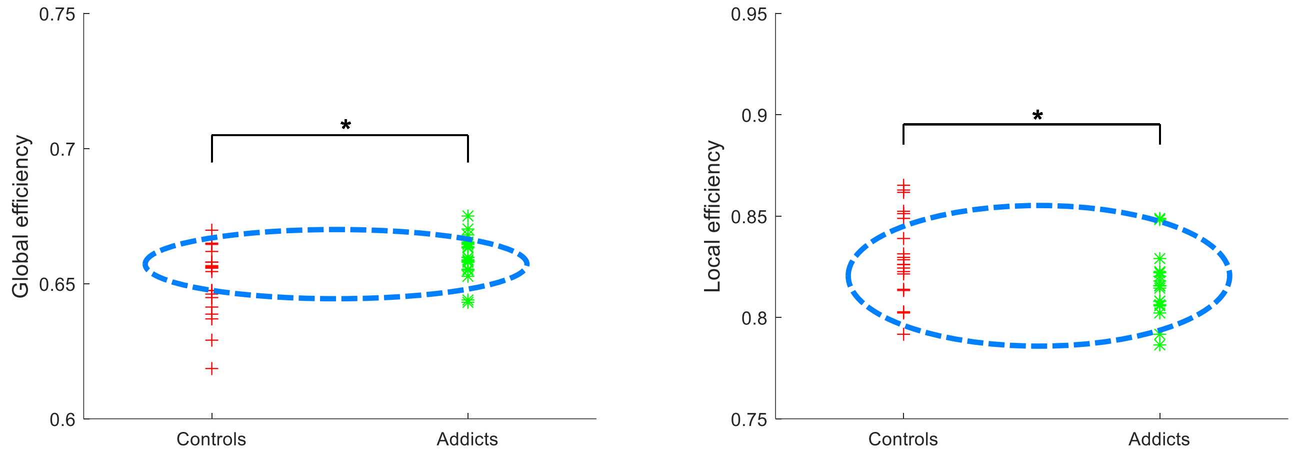
Clinical MRI Studies

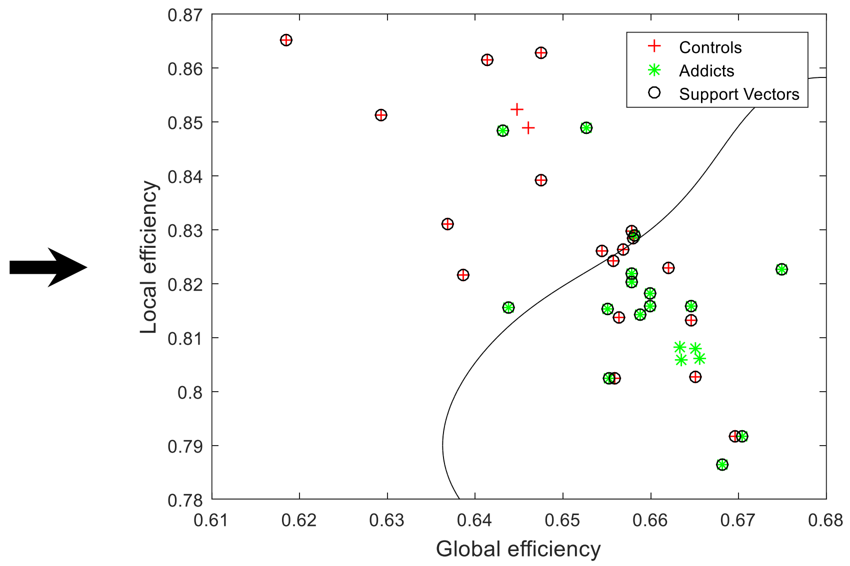
- Brain changes in recovery after stroke [Park et al, 2011]




A
MFG
SMA
Th
B1
R² = 0.8400
Parameter estimates
Increases of FMA
Thalamus
B2
R² = 0.7821
SMA
B3
R² = 0.7111
MFG

- Classification beyond describing group differences



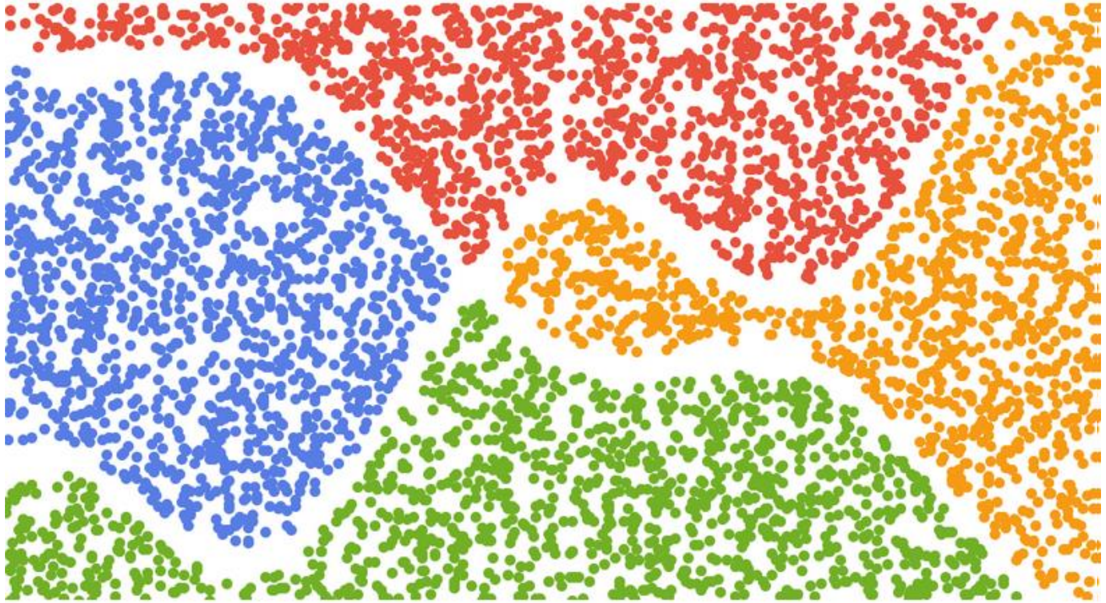


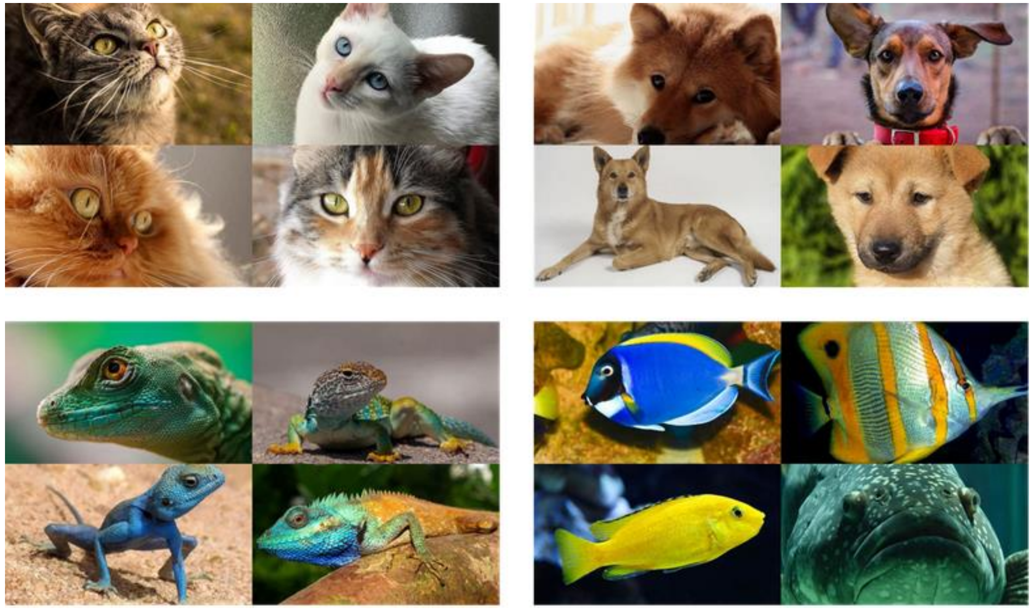
Machine Learning

[https://reference.wolfram.com/language/guide/MachineLearning.html]

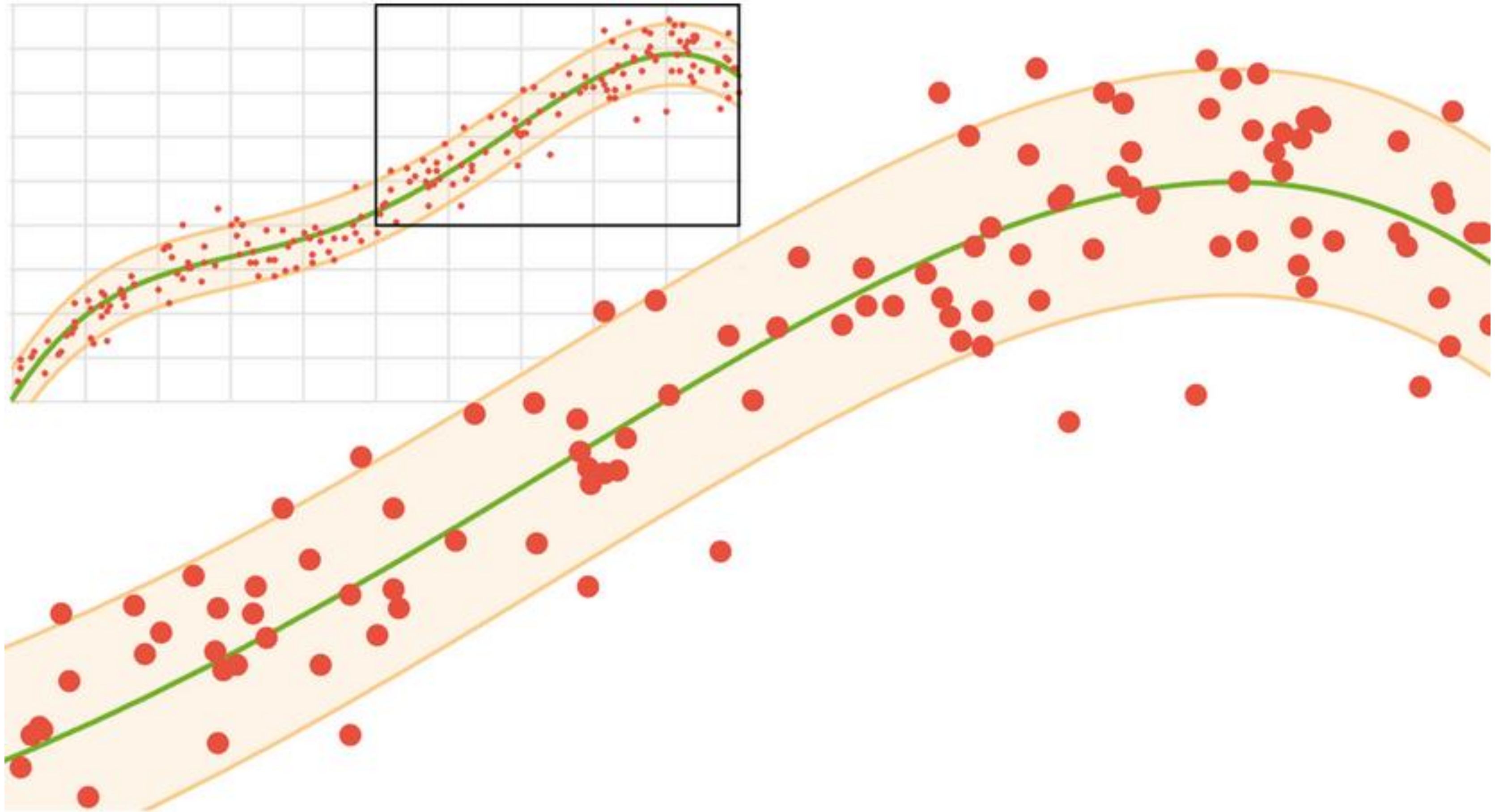
- Algorithms that have been developed with the specific purpose of analyzing patterns and leveraging correlation within real-world measurements in order to turn data into applications

- Supervised machine learning: classification

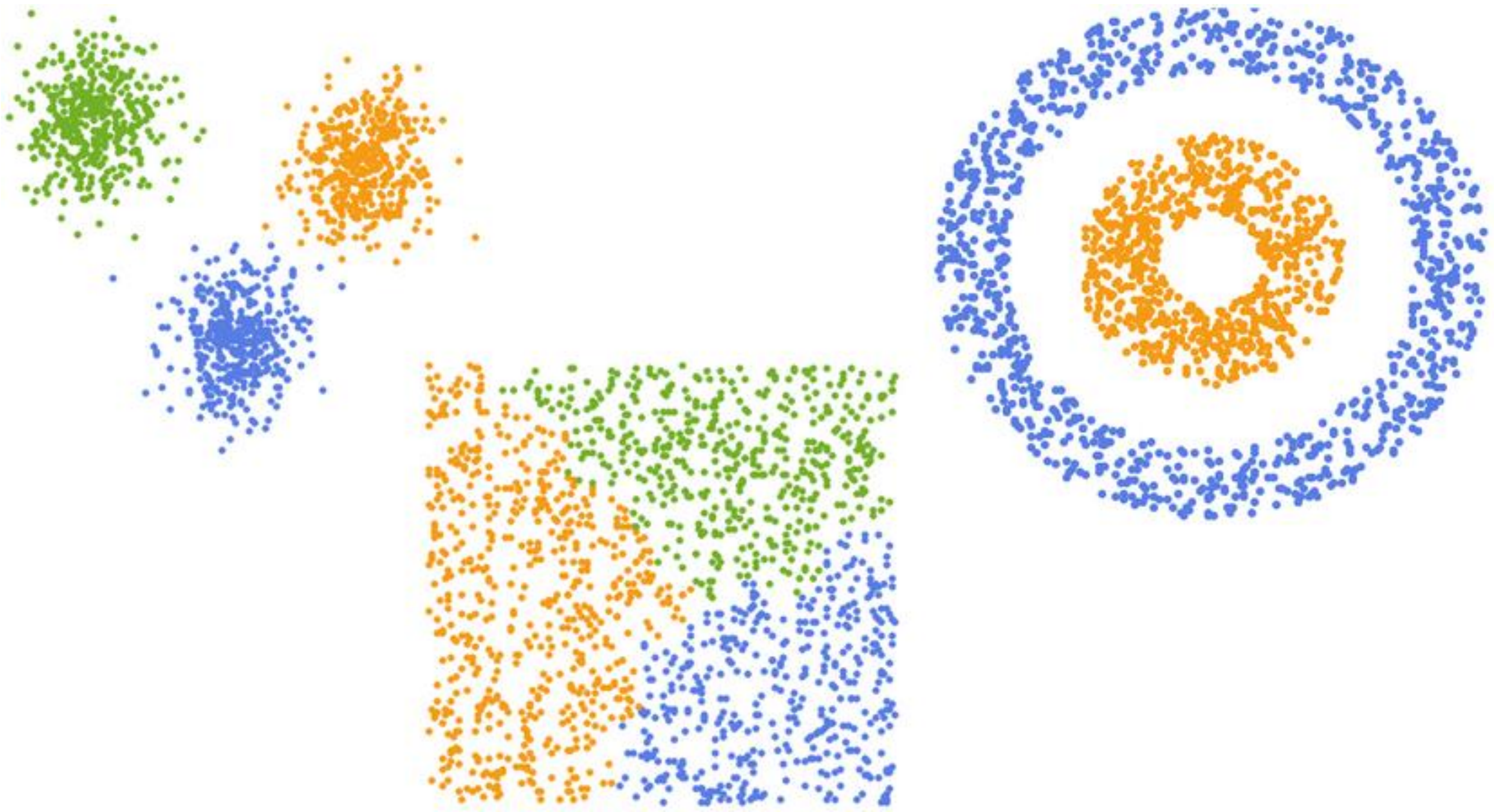




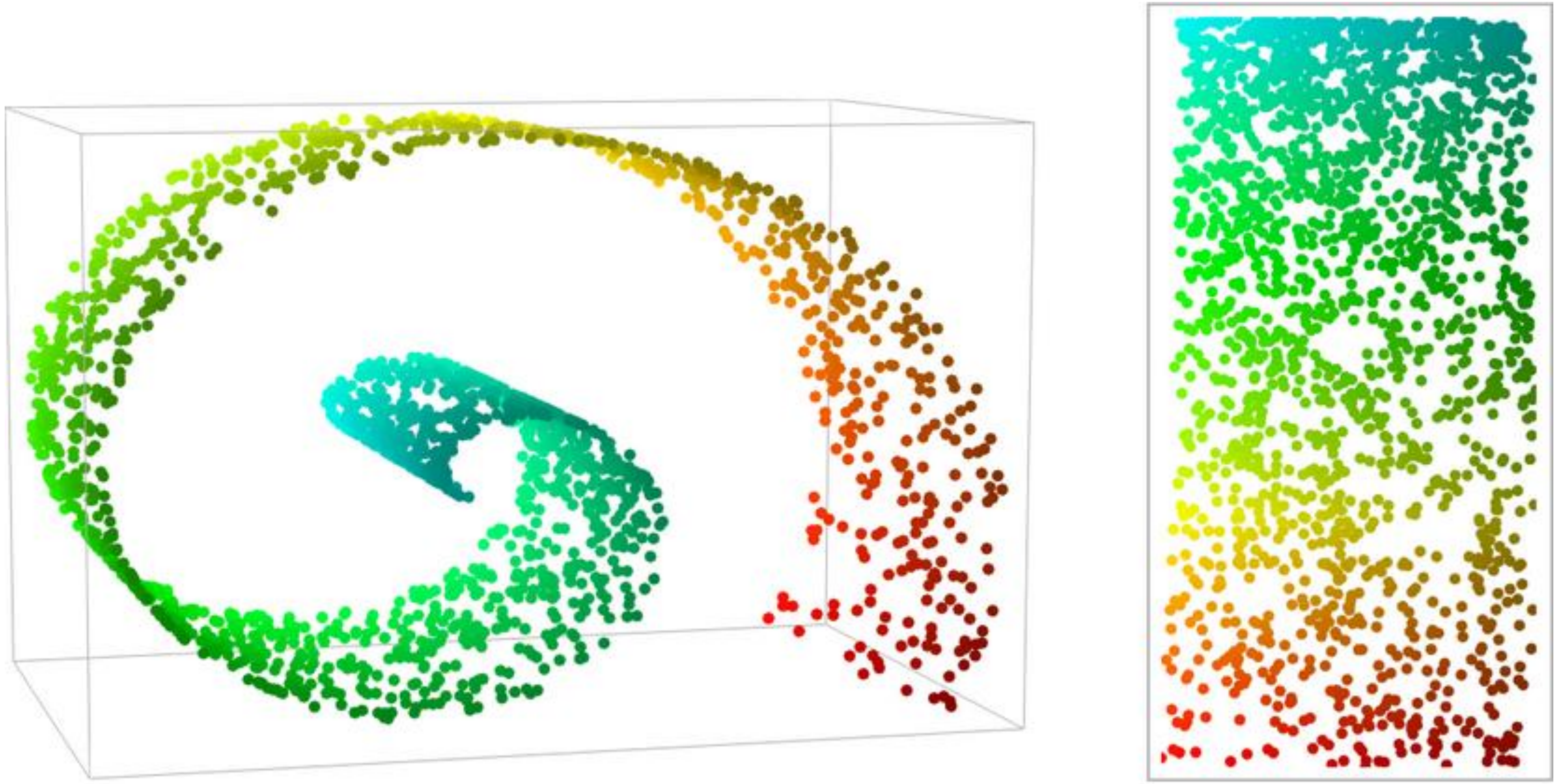
- Supervised machine learning: regression



- Unsupervised machine learning: cluster analysis

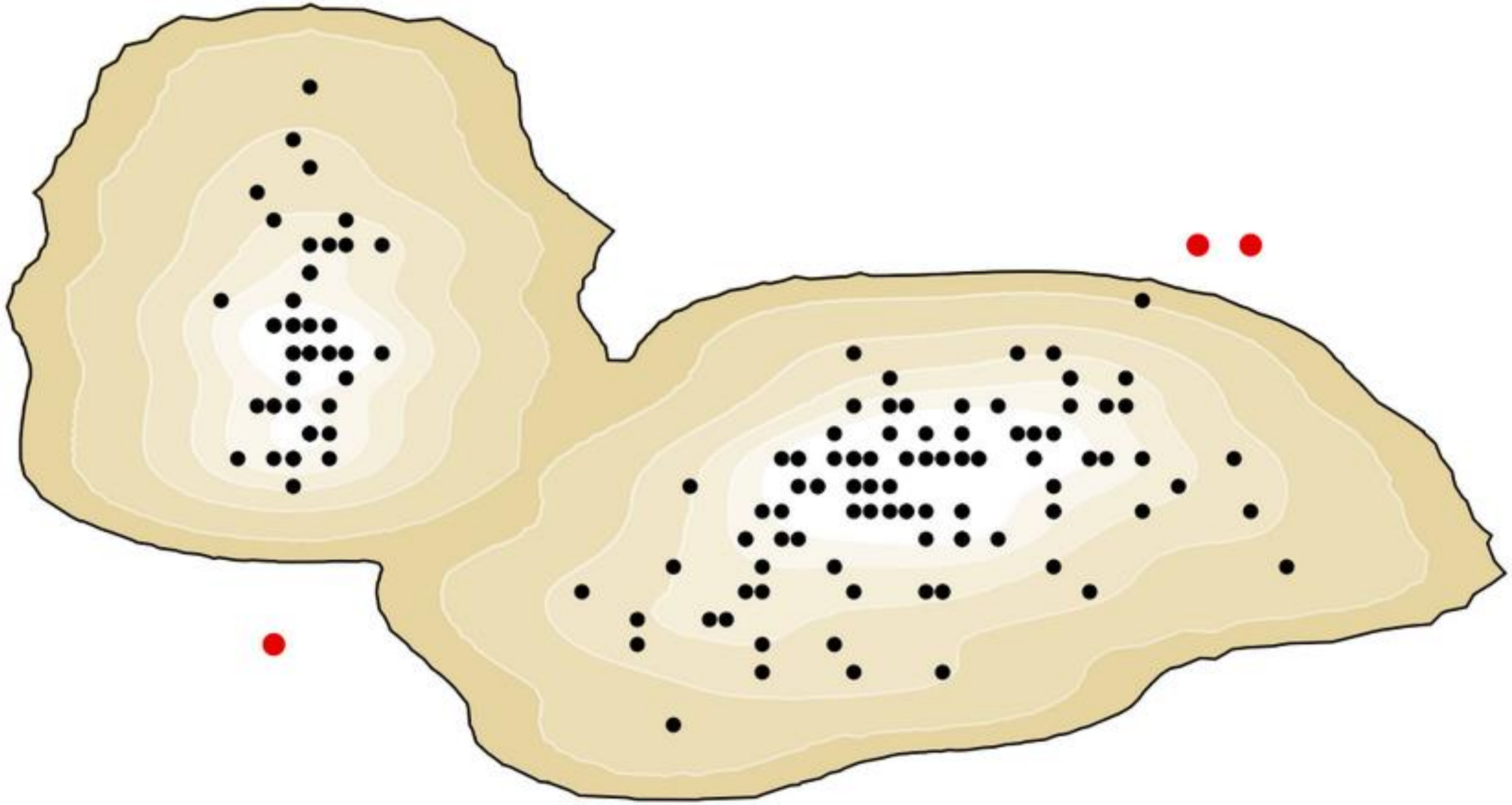


- Unsupervised machine learning: dimensionality reduction

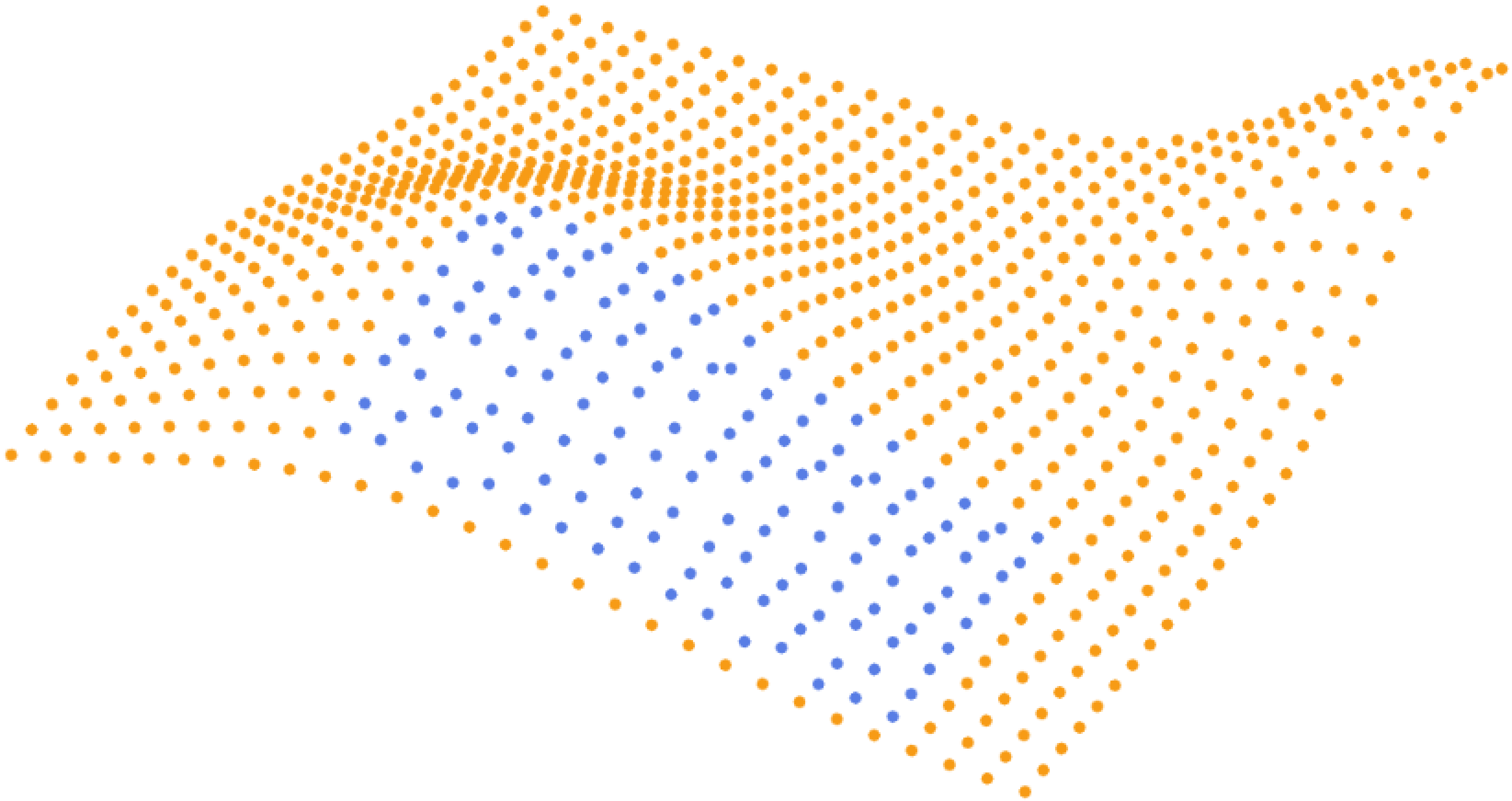


DimensionReduce

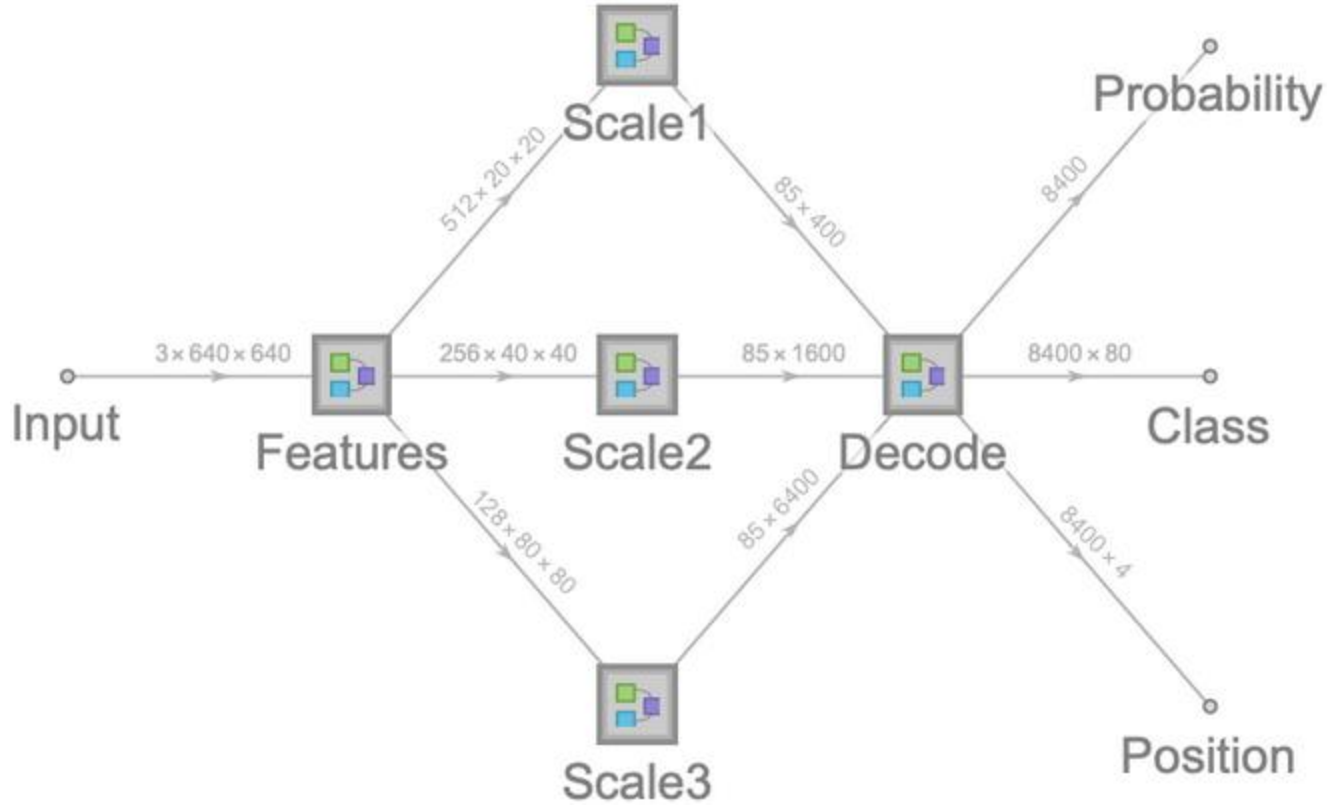
- Unsupervised machine learning: anomaly detetion



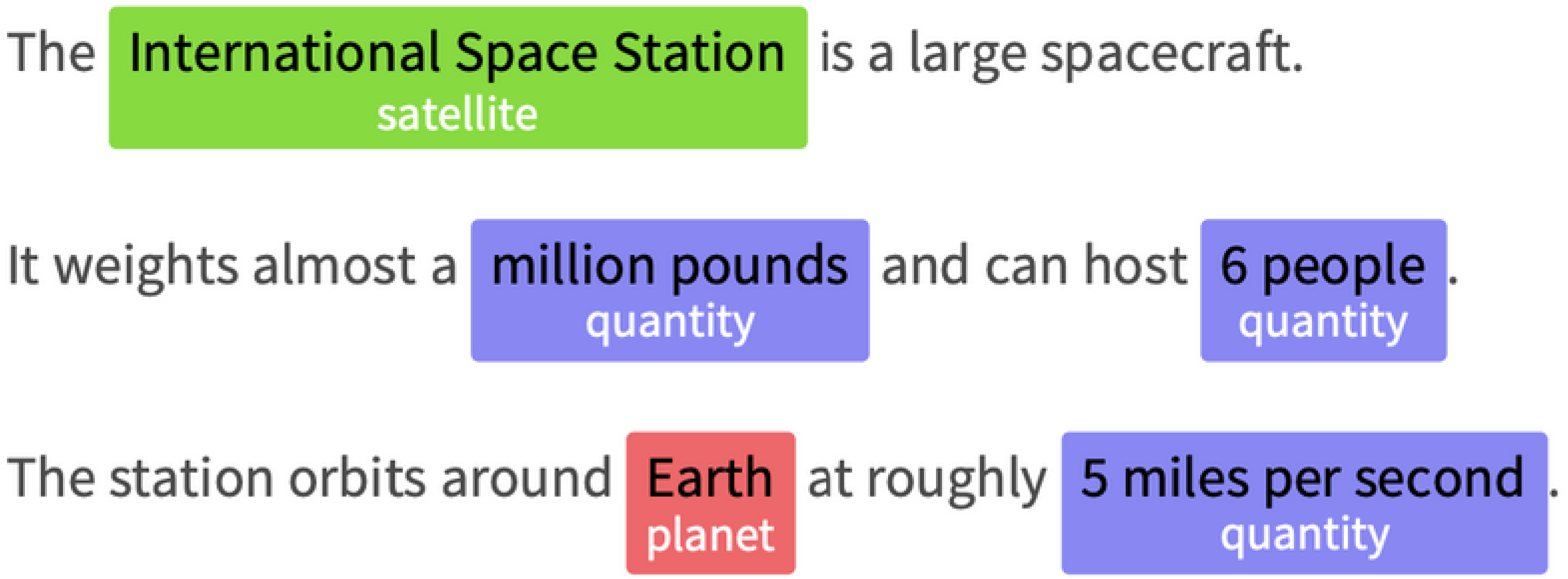
- Unsupervised machine learning: missing data imputation



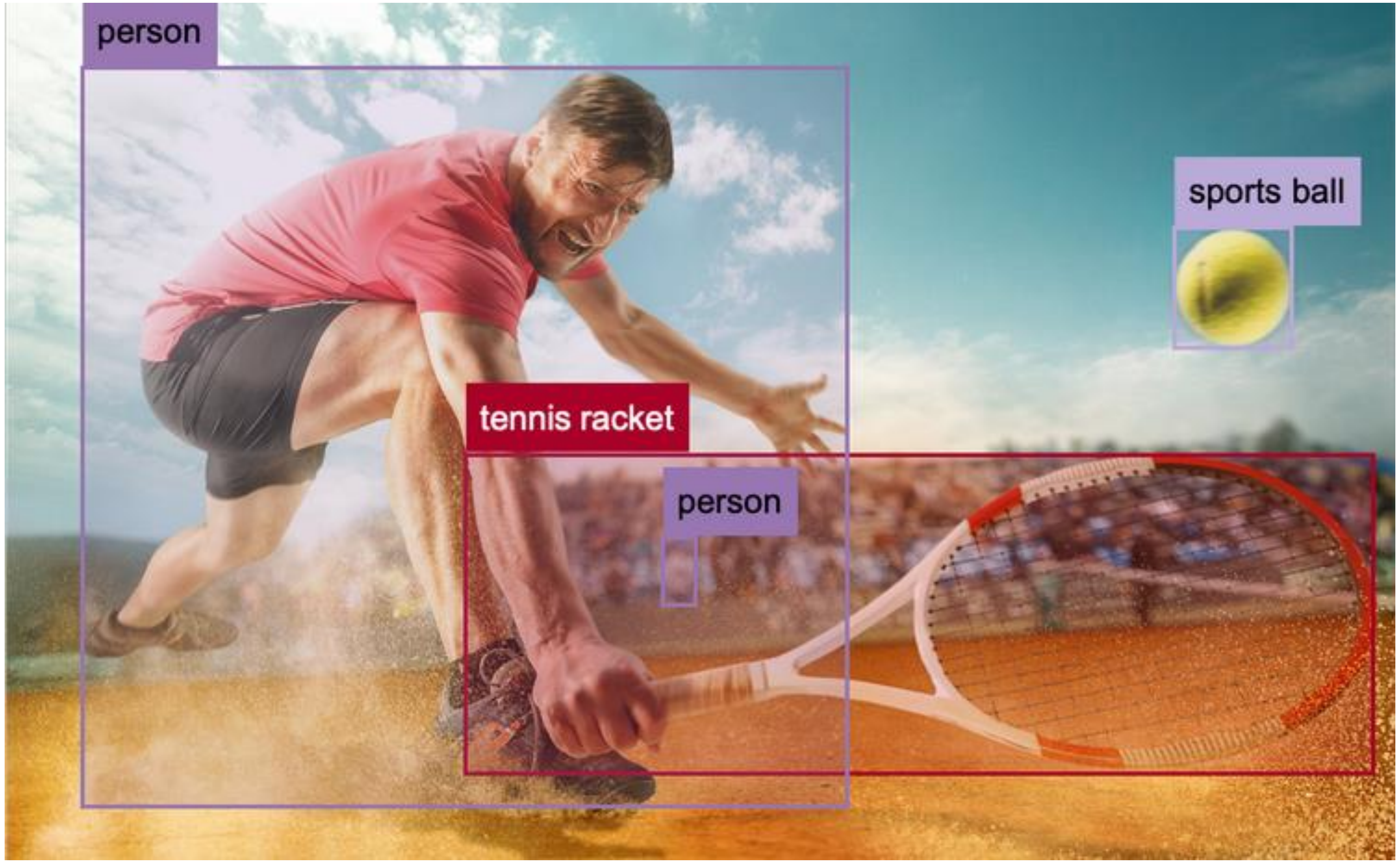
- Neural networks



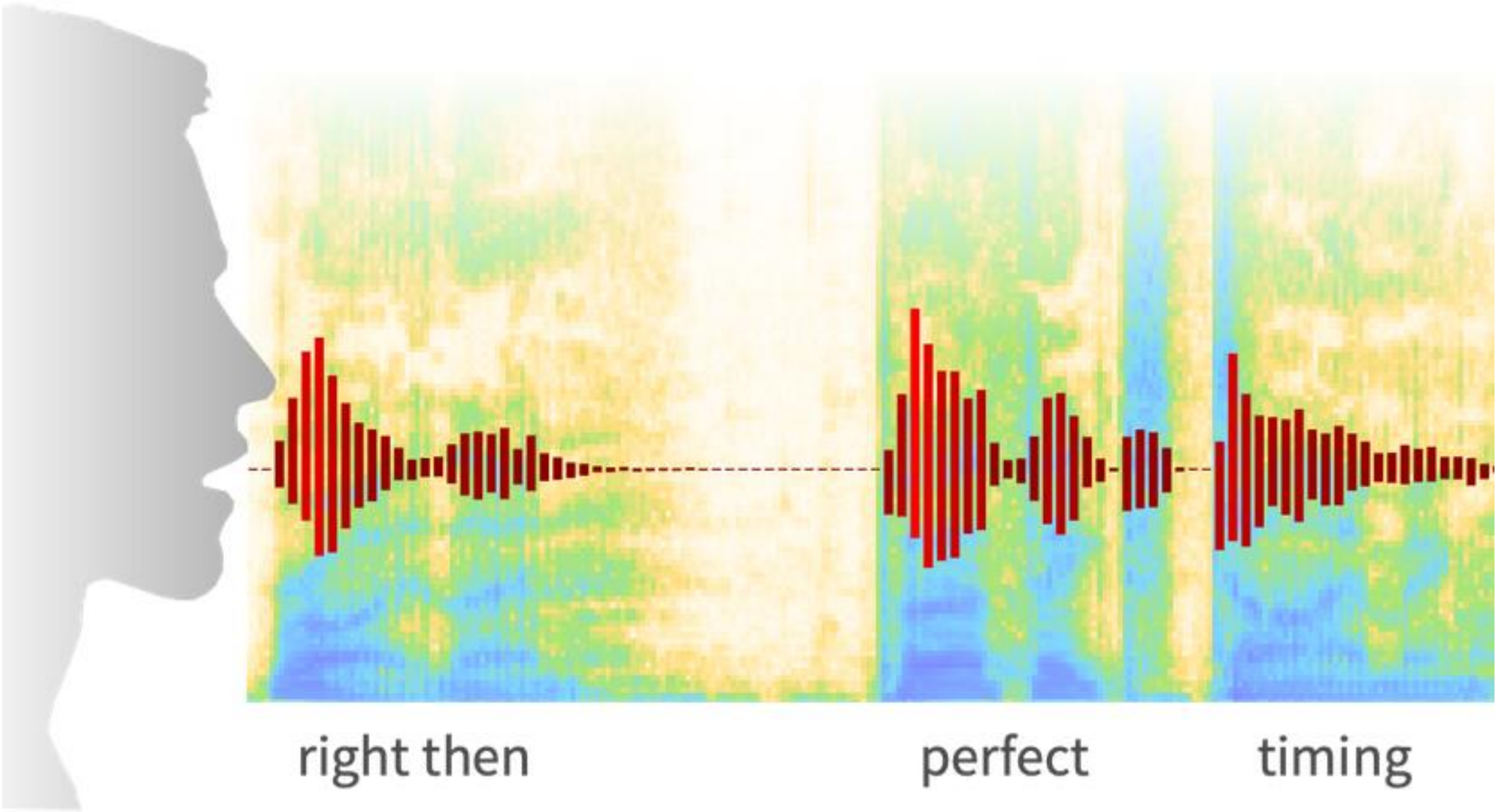
- Natural language processing



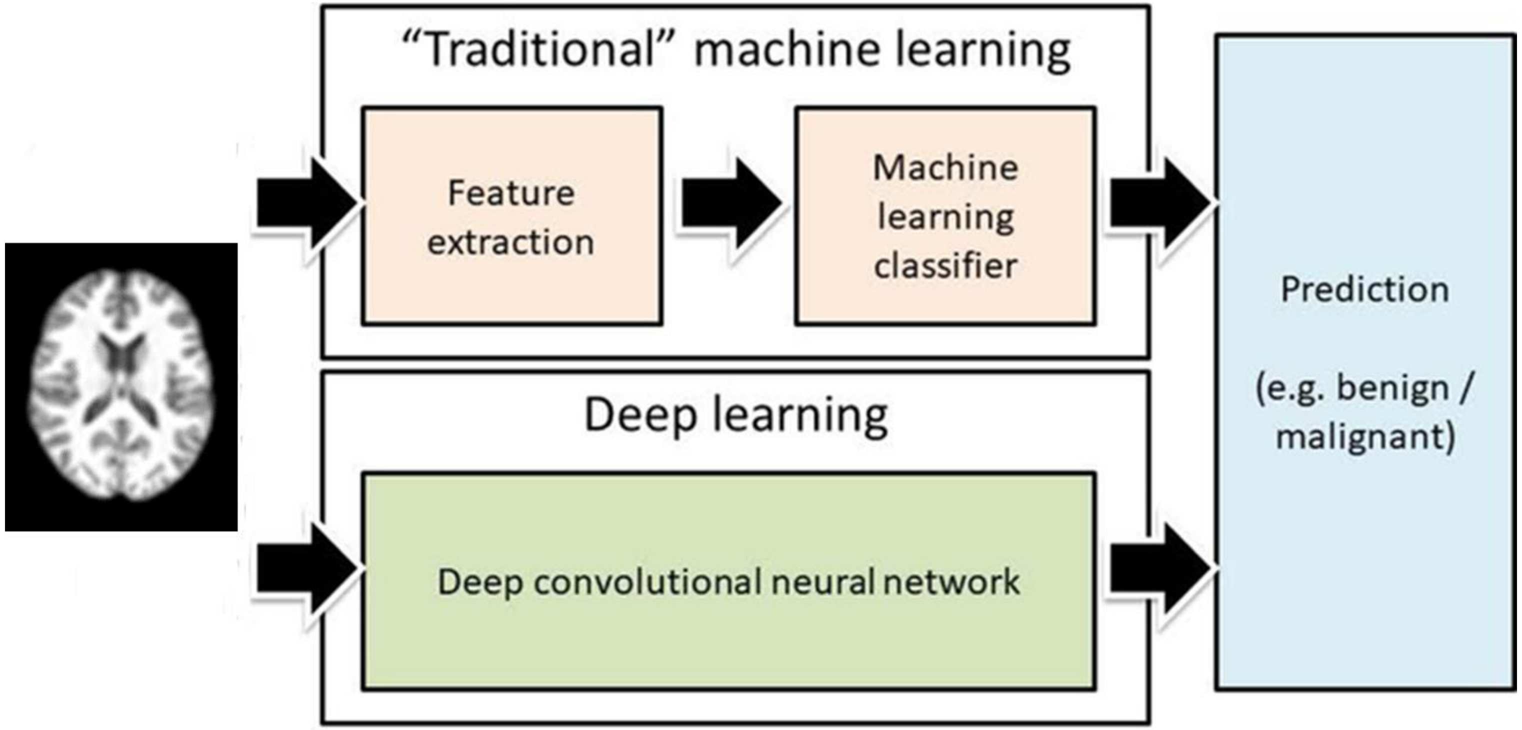
- Computer vision



- Speech computation



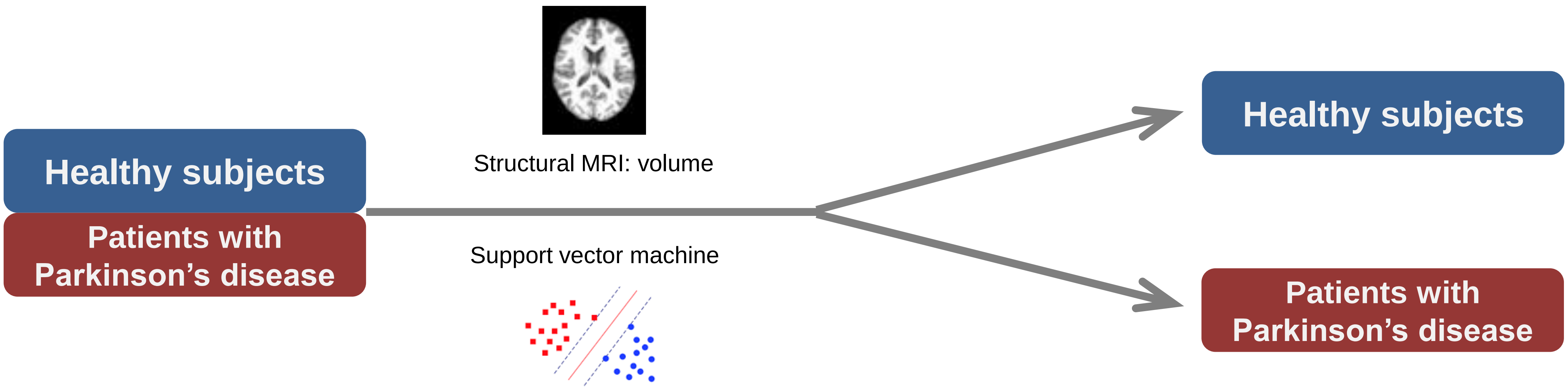
MRI Machine Learning Studies



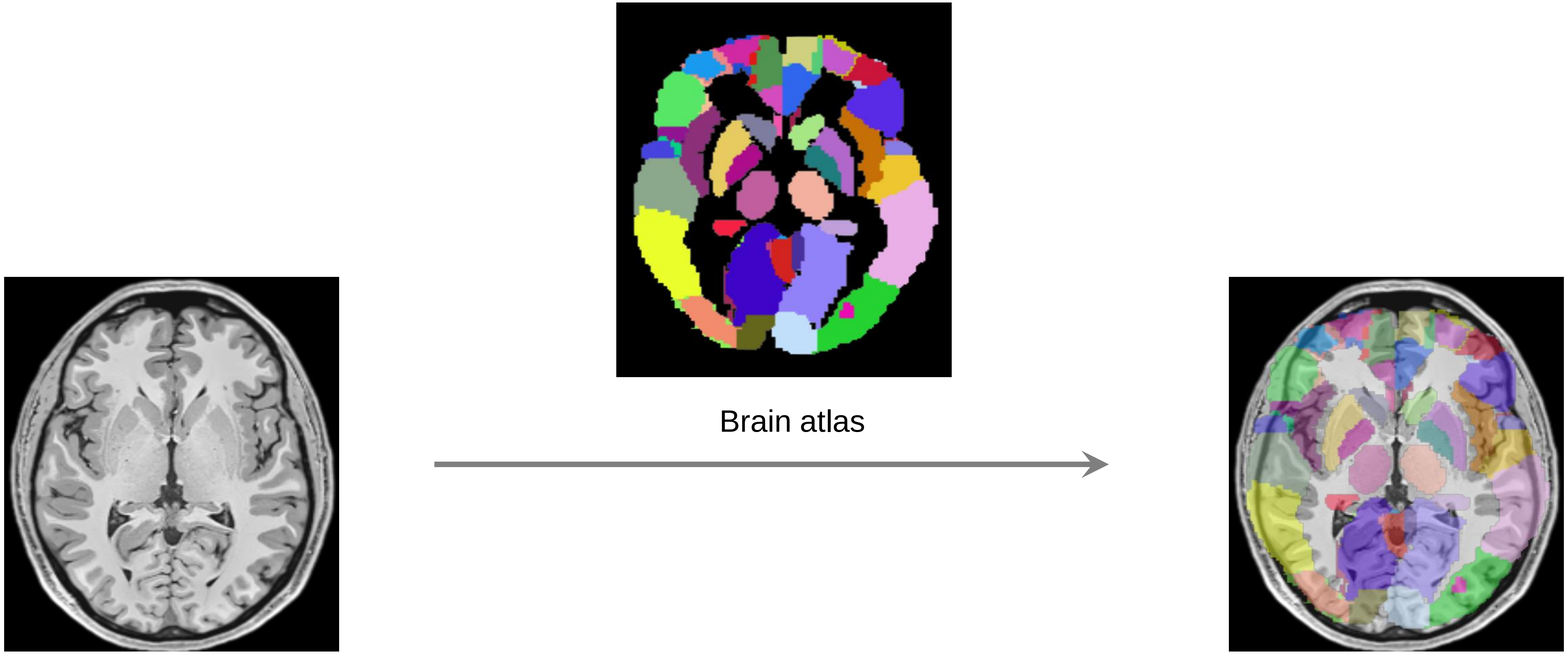
[Mazurowski et al., 2018]

Difference between traditional machine learning and deep learning

- Classification



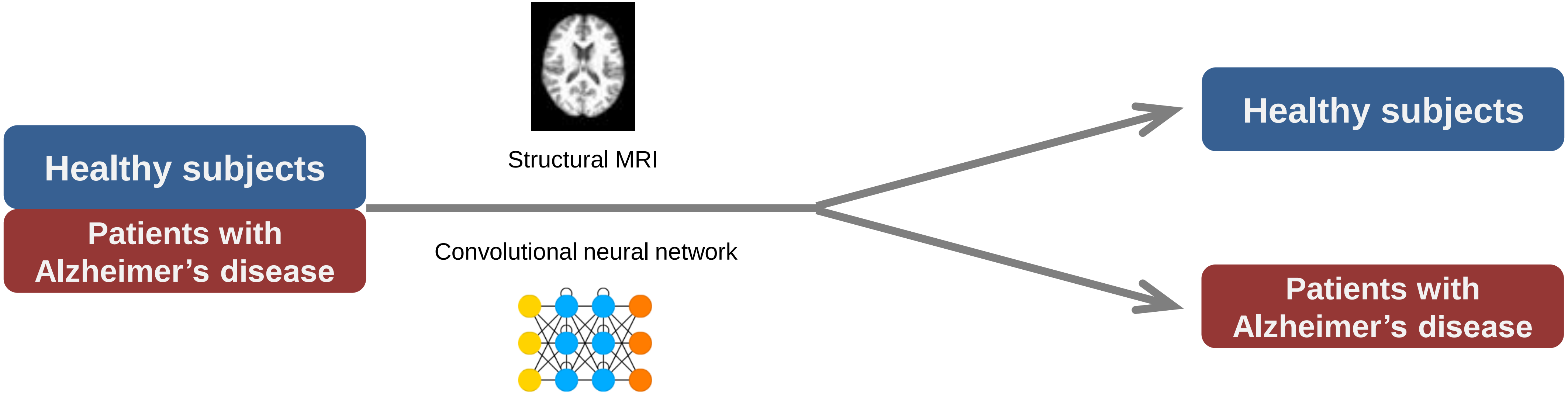
[Park et al., 2020]



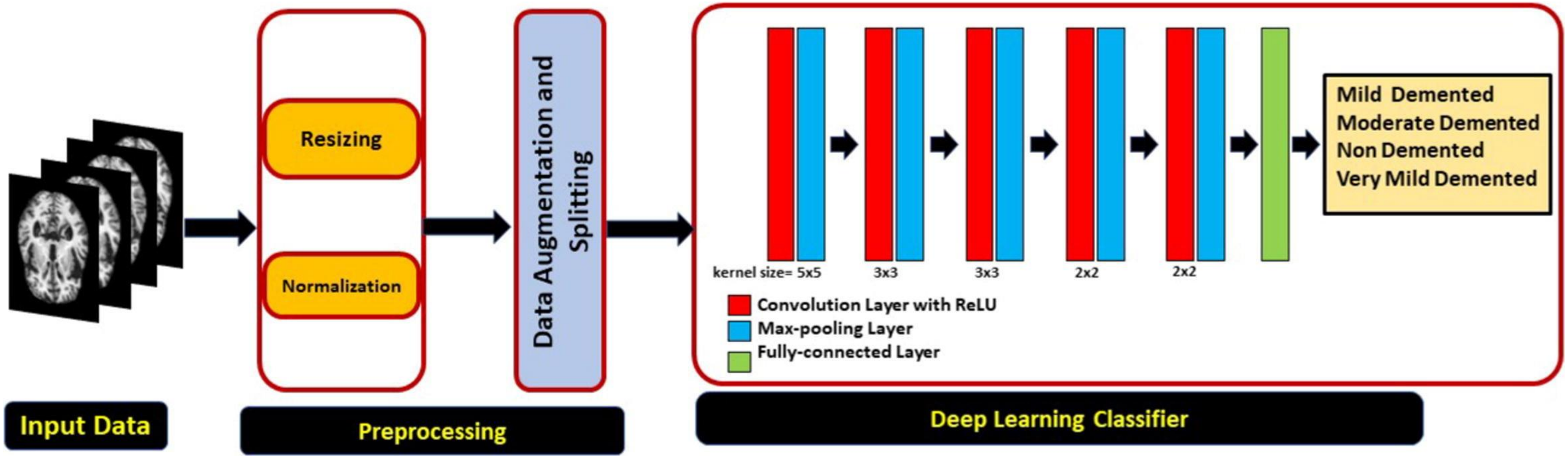
Features

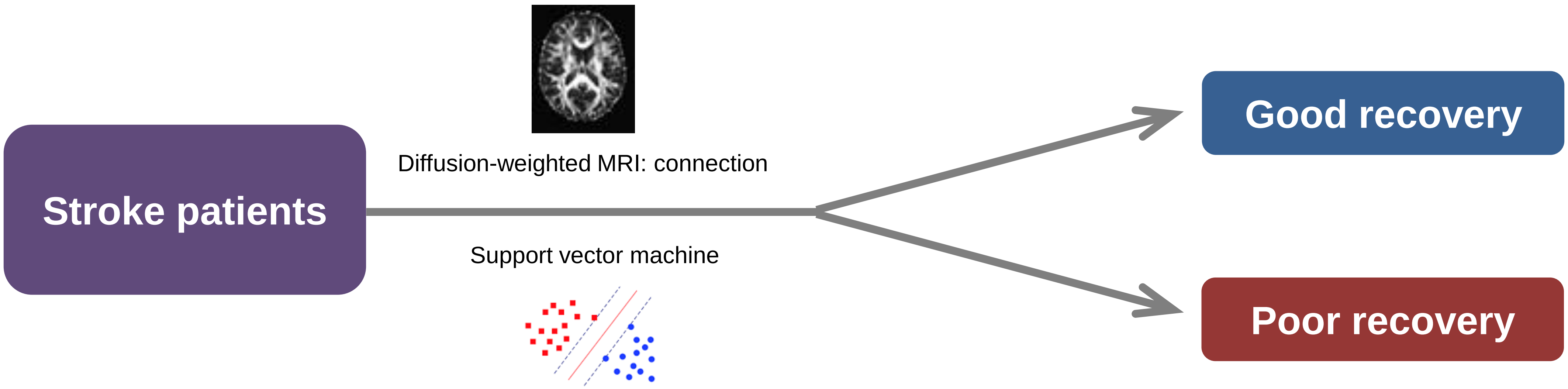
Samples

	Brain area 1 volume	Brain area 2 volume	Brain area 3 volume	…
Subject 1	-	-	-	-
Subject 2	-	-	-	-
Subject 3	-	-	-	-
⋮	-	-	-	-

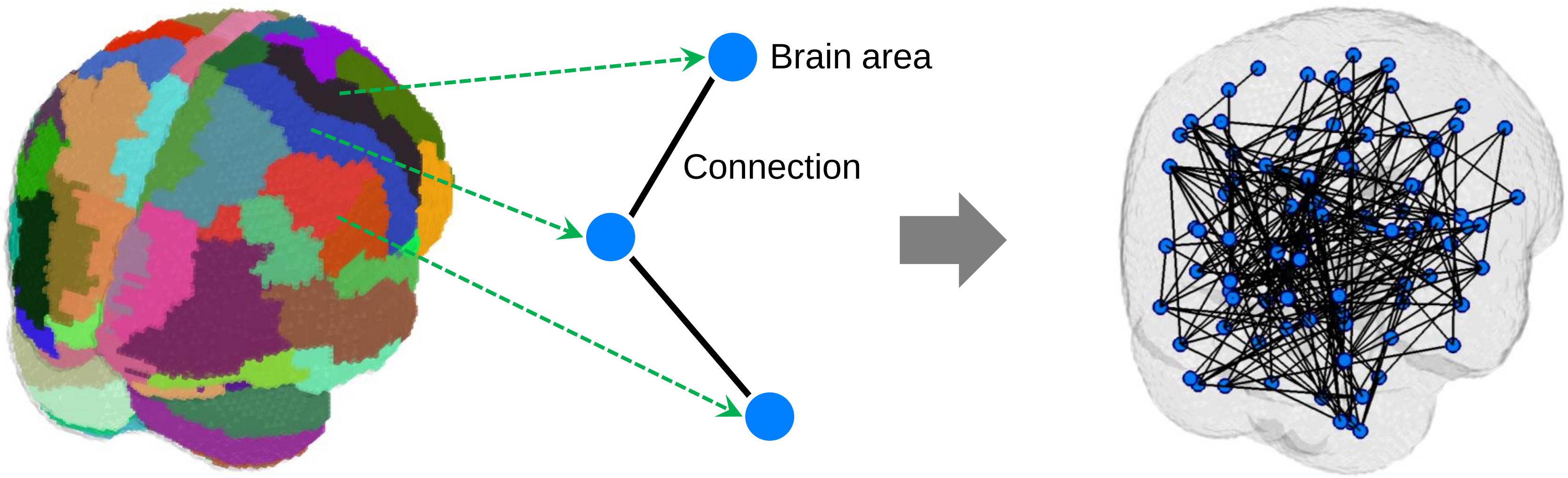


[EL-Geneedy et al., 2023]


Resizing
Normalization
Data Augmentation and Splitting
kernel size= 5x5
3x3
3x3
2x2
2x2
Mild Demented
Moderate Demented
Non Demented
Very Mild Demented
Convolution Layer with ReLU
Max-pooling Layer
Fully-connected Layer
Input Data
Preprocessing
Deep Learning Classifier



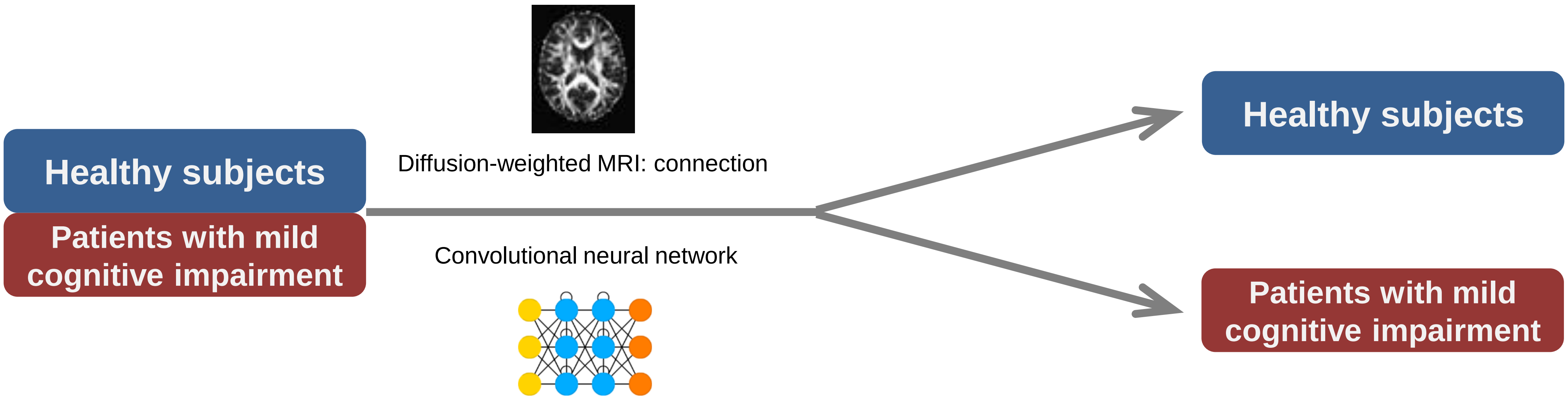
[Koch et al., 2021]



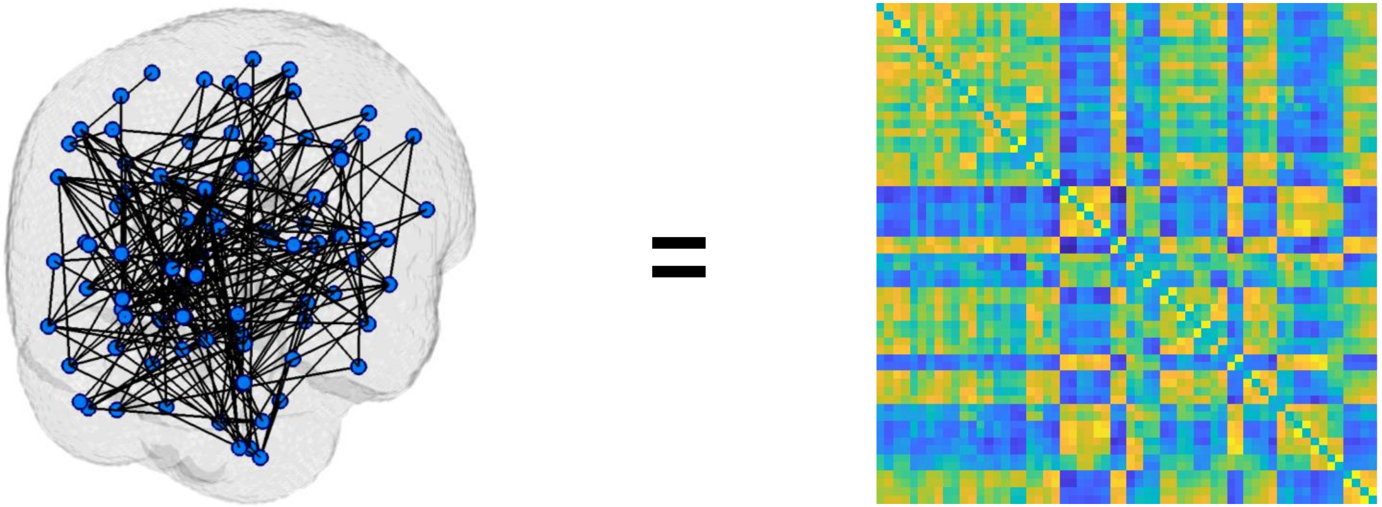
Features

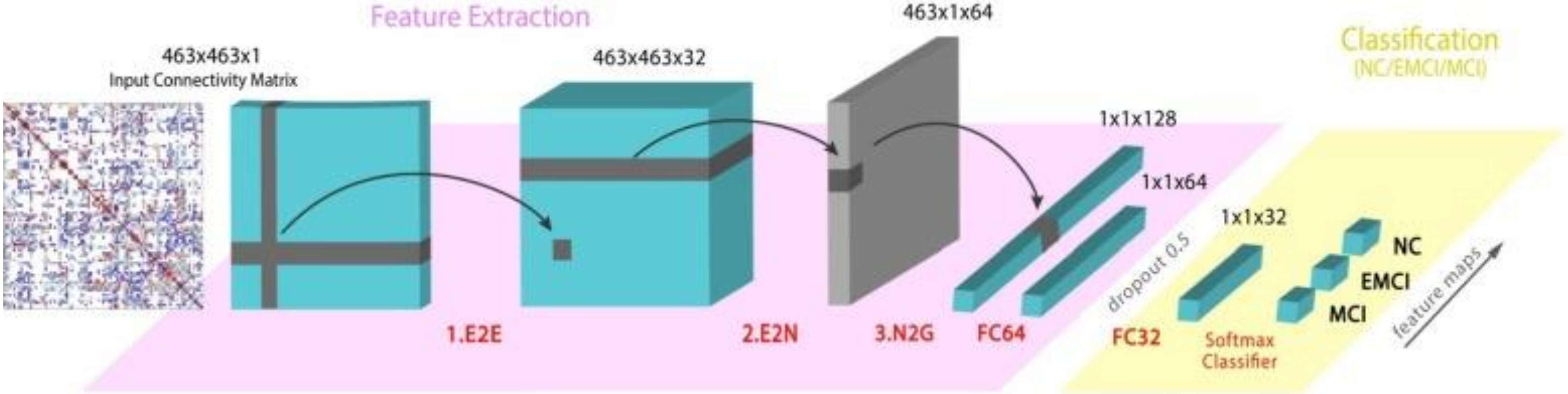
Samples

	Brain areas 1 – 2 connection	Brain areas 1 – 3 connection	Brain areas 1 – 4 connection	…
Subject 1	-	-	-	-
Subject 2	-	-	-	-
Subject 3	-	-	-	-
⋮	-	-	-	-

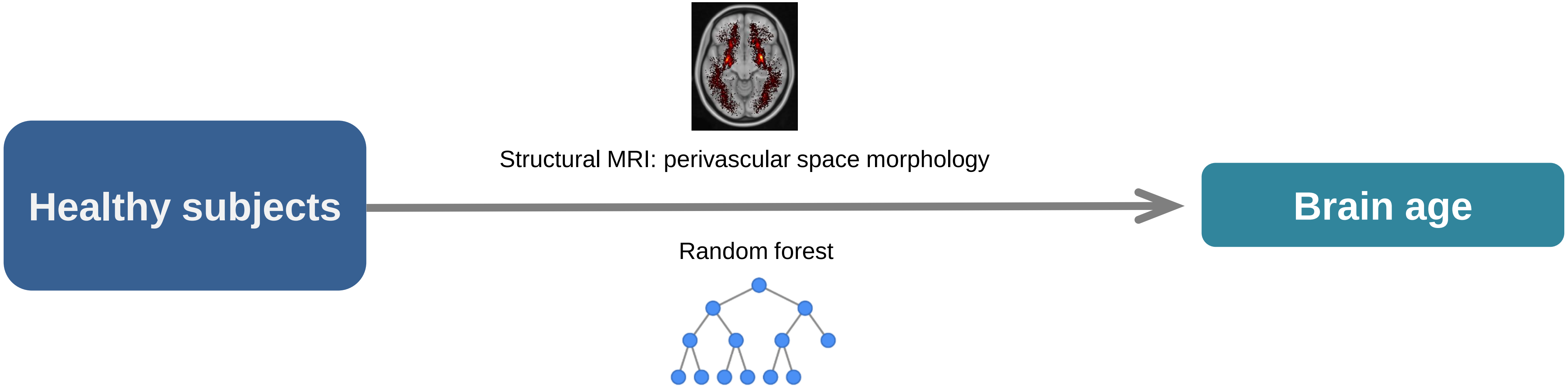


[Kolahkaj et al., 2023]

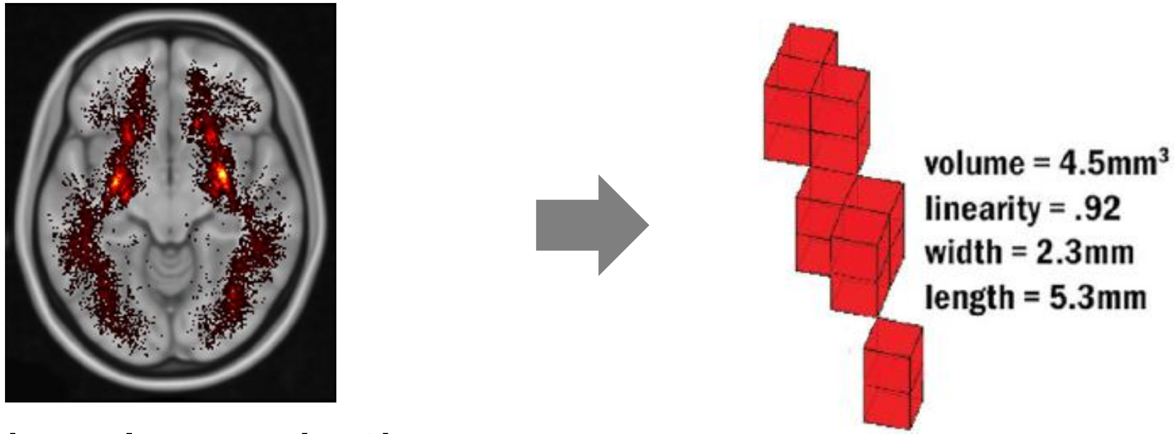



Feature Extraction
463x463x1
Input Connectivity Matrix
463x463x32
463x1x64
1x1x128
1x1x64
1x1x32
Classification
(NC/EMCI/MCI)
1.E2E
2.E2N
3.N2G
FC64
dropout 0.5
FC32
Softmax
Classifier
NC
EMCI
MCI
feature maps

- Regression



[Park et al., 2023]

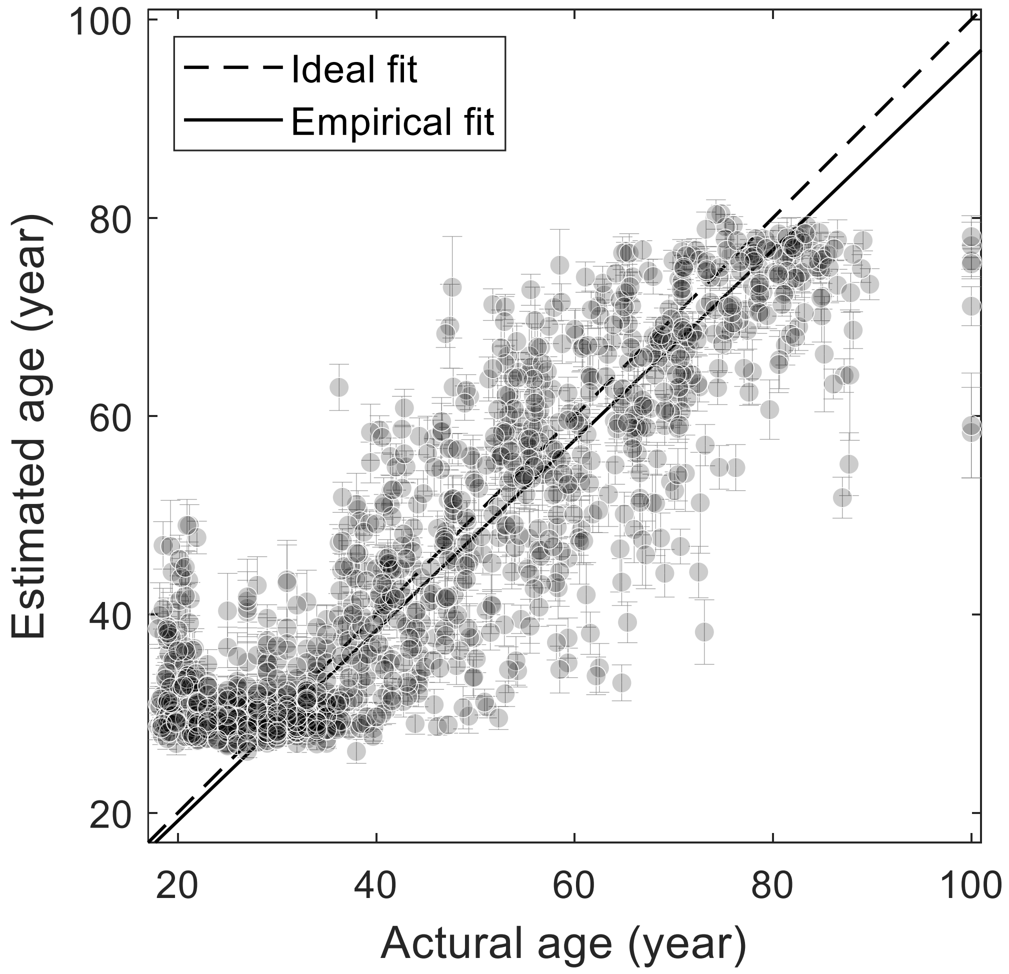


Perivascular space (PVS)

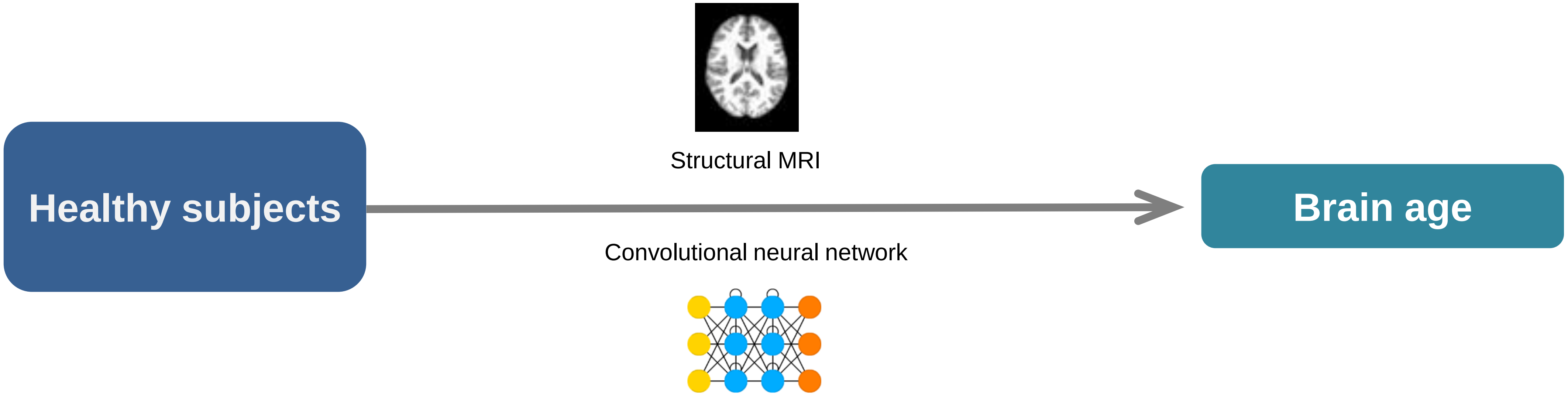
Features

Samples

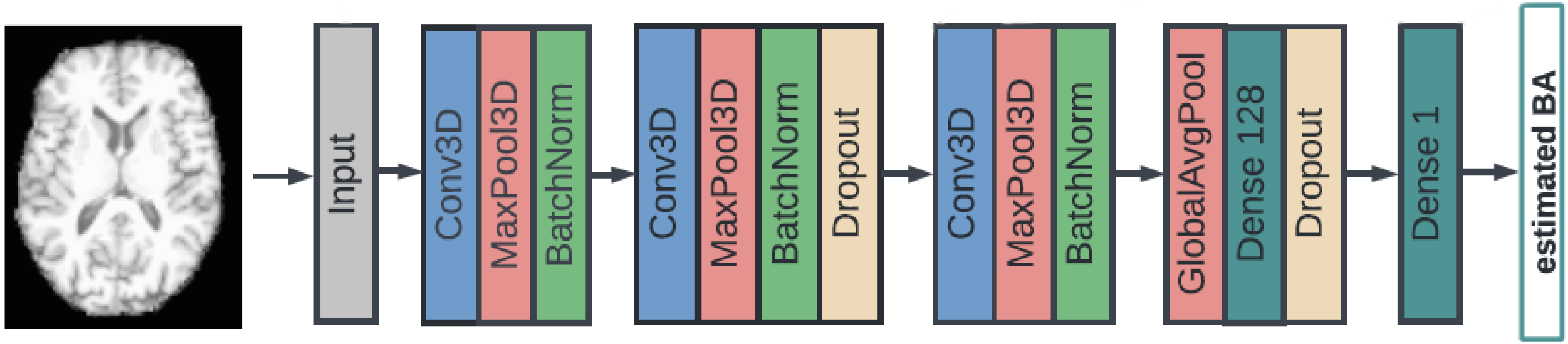
	Brain area 1 PVS volume	Brain area 1 PVS linearity	Brain areas 1 PVS width	…
Subject 1	-	-	-	-
Subject 2	-	-	-	-
Subject 3	-	-	-	-
⋮	-	-	-	-

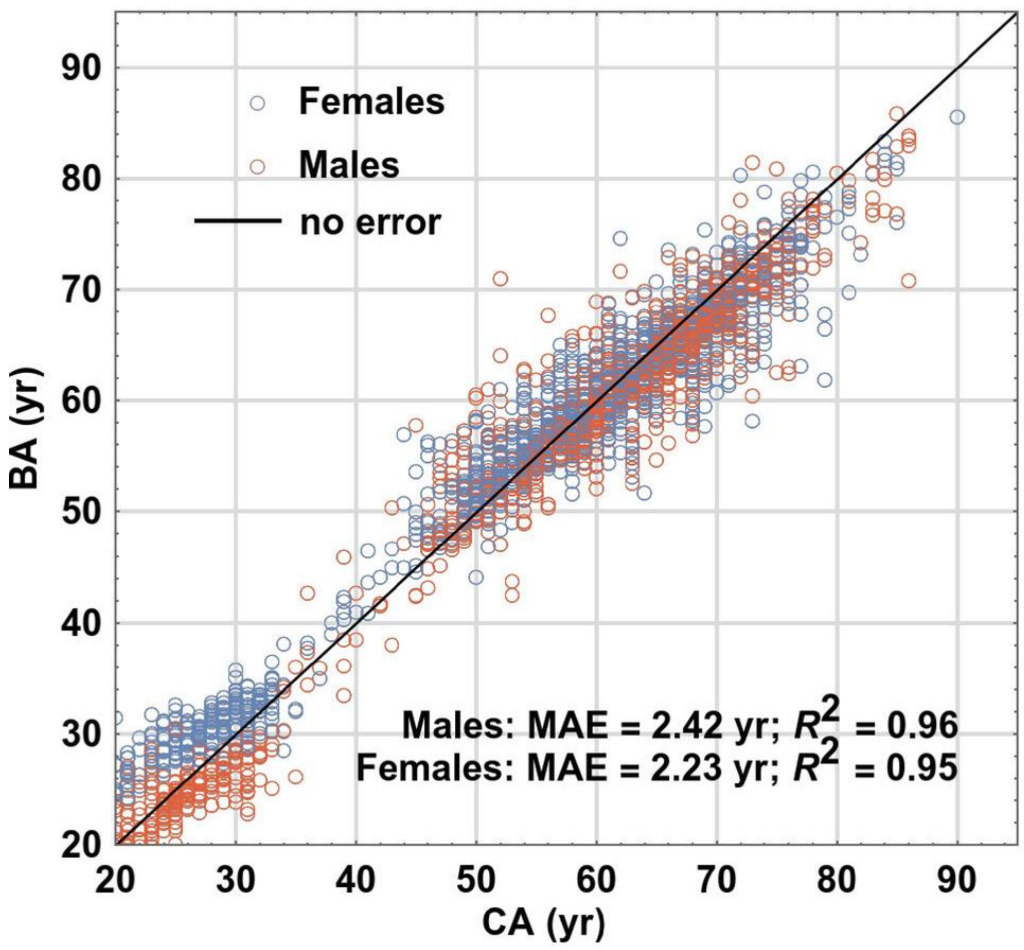


Actual age (chronological age) vs. estimated age (brain age)



[Yin et al., 2023]


Input
Conv3D
MaxPool3D
BatchNorm
Conv3D
MaxPool3D
BatchNorm
Dropout
Conv3D
MaxPool3D
BatchNorm
GlobalAvgPool
Dense 128
Dropout
Dense 1
estimated BA



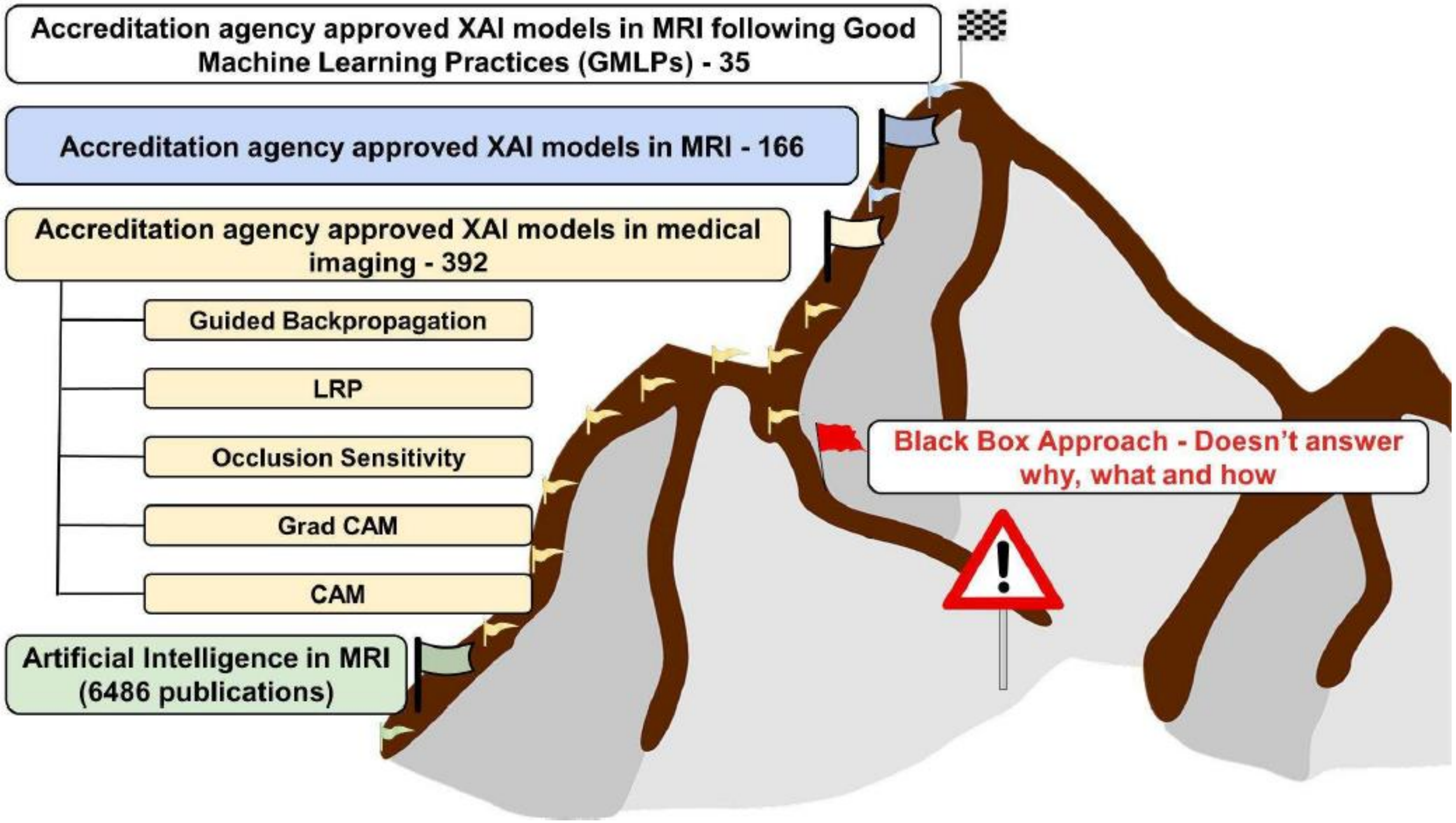
Actual age (chronological age) vs. estimated age (brain age)

Demands for MRI Machine Learning

- Good Machine Learning Practices (GMLPs)
- Explainable artificial intelligence (XAI)
  - For visualizing and interpreting machine learning predictions
  - Article 15 GDPR (General Data Protection Regulation) [https://gdpr-info.eu/art-15-gdpr]: right of access by the data subject
    - Patients have the right to request an explanation for how a given diagnosis was reached

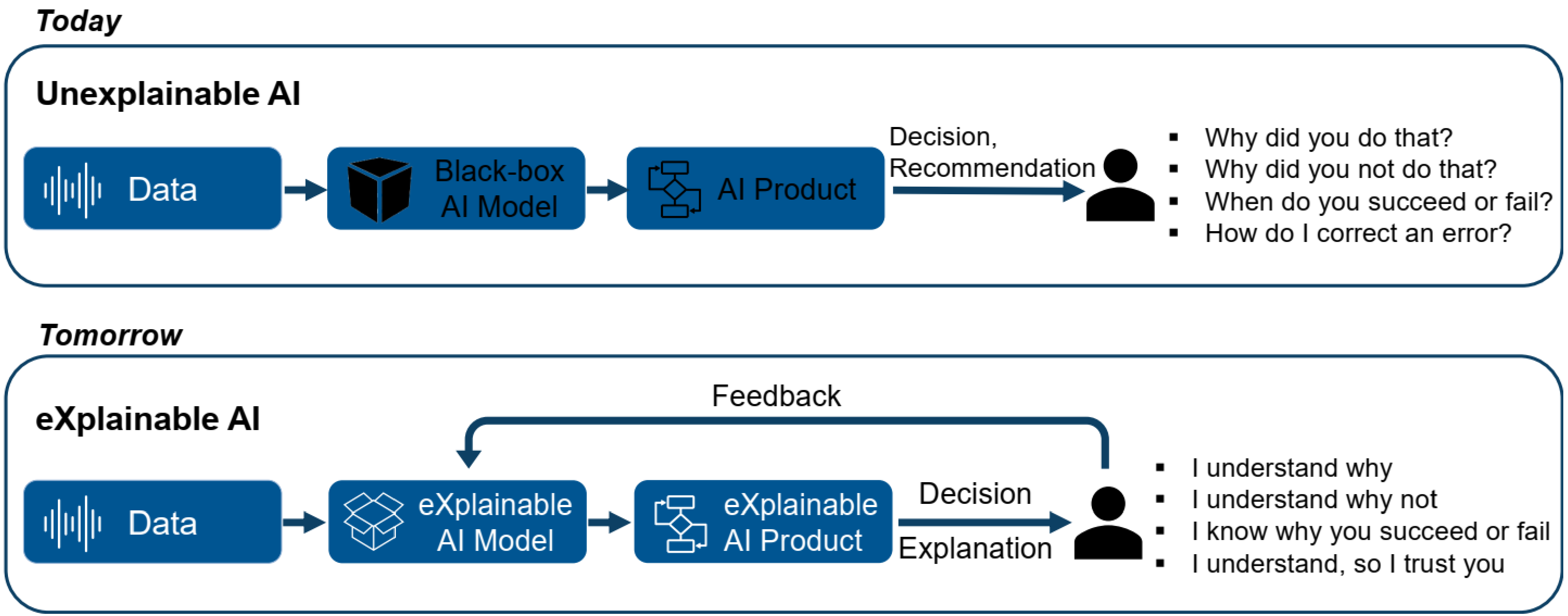
Checklist of GMLPs for brain MRI		
1.	Are neuroradiologists, neuroimaging scientists, MR technician and data scientist working together throughout the whole life cycle of the product?	
2.	Is the patient's personal information anonymous in the brain MR images?	
3.	Is the metadata being filled for each patient scan with proper details of all parameters?	
4.	Does training and testing MR datasets contain different scans? There shouldn't be any common scan in both datasets.	
5.	Does reference MR dataset for validation of model have completely unique scans with same parameters as training and testing dataset?	
6.	Are you using the model for segmenting brain structures from the specific contrast for which it has been trained for? If so, don't use it for other contrasts.	
7.	Is the output of the model accepted and readable by the neuroradiologist?	
8.	Has the model been tested in the neuroradiology department under the supervision of an expert neuroradiologist before deployment?	
9.	Are the precautions and potential dangers of using the model explicitly mentioned?	
10.	Is the model being updated frequently for incorporating the changes in the new scans that may occur naturally?	

[https://doi.org/10.48550/arXiv.2301.01241]



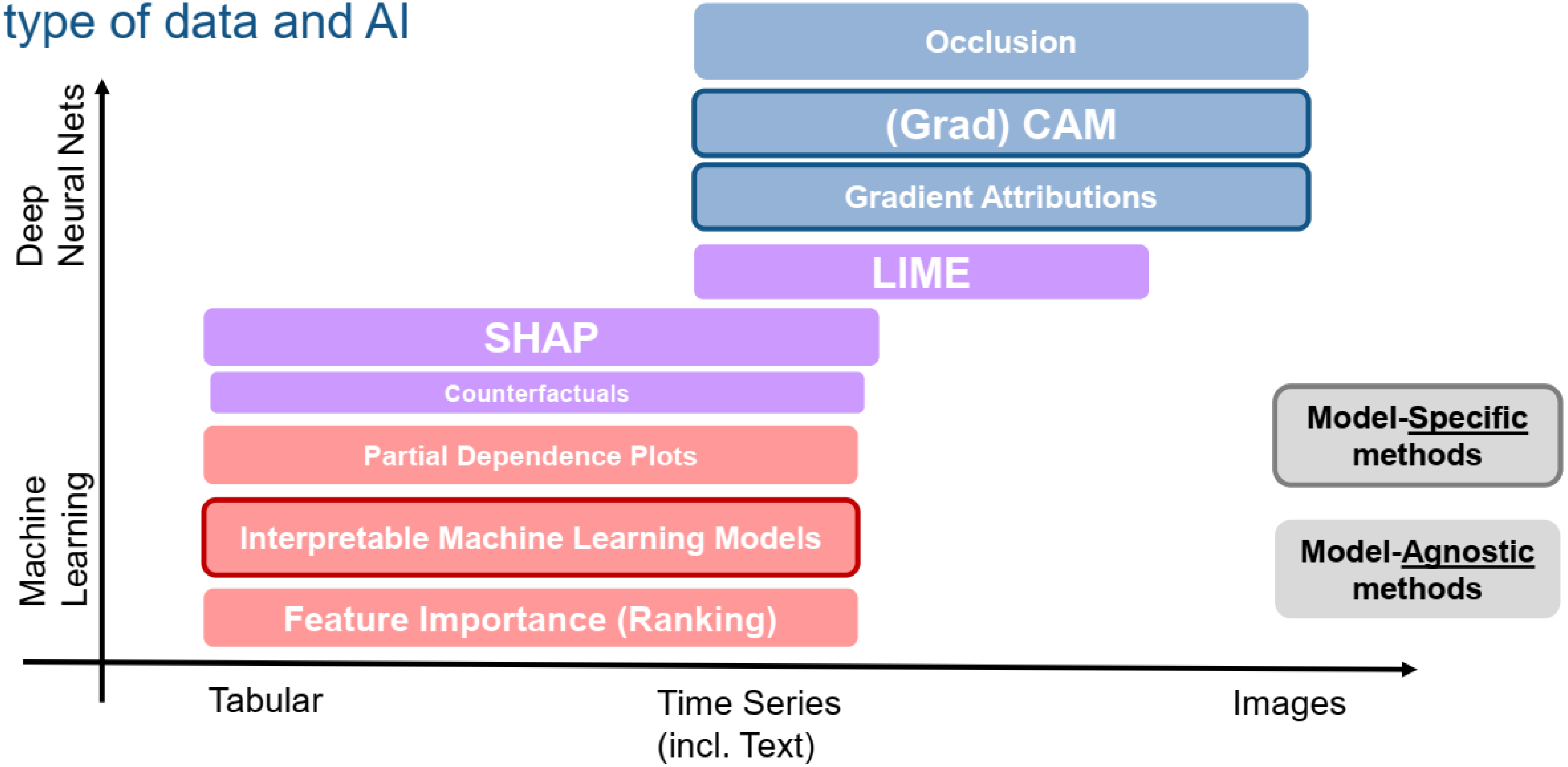
[https://doi.org/10.48550/arXiv.2301.01241]

Publications of MRI machine learning

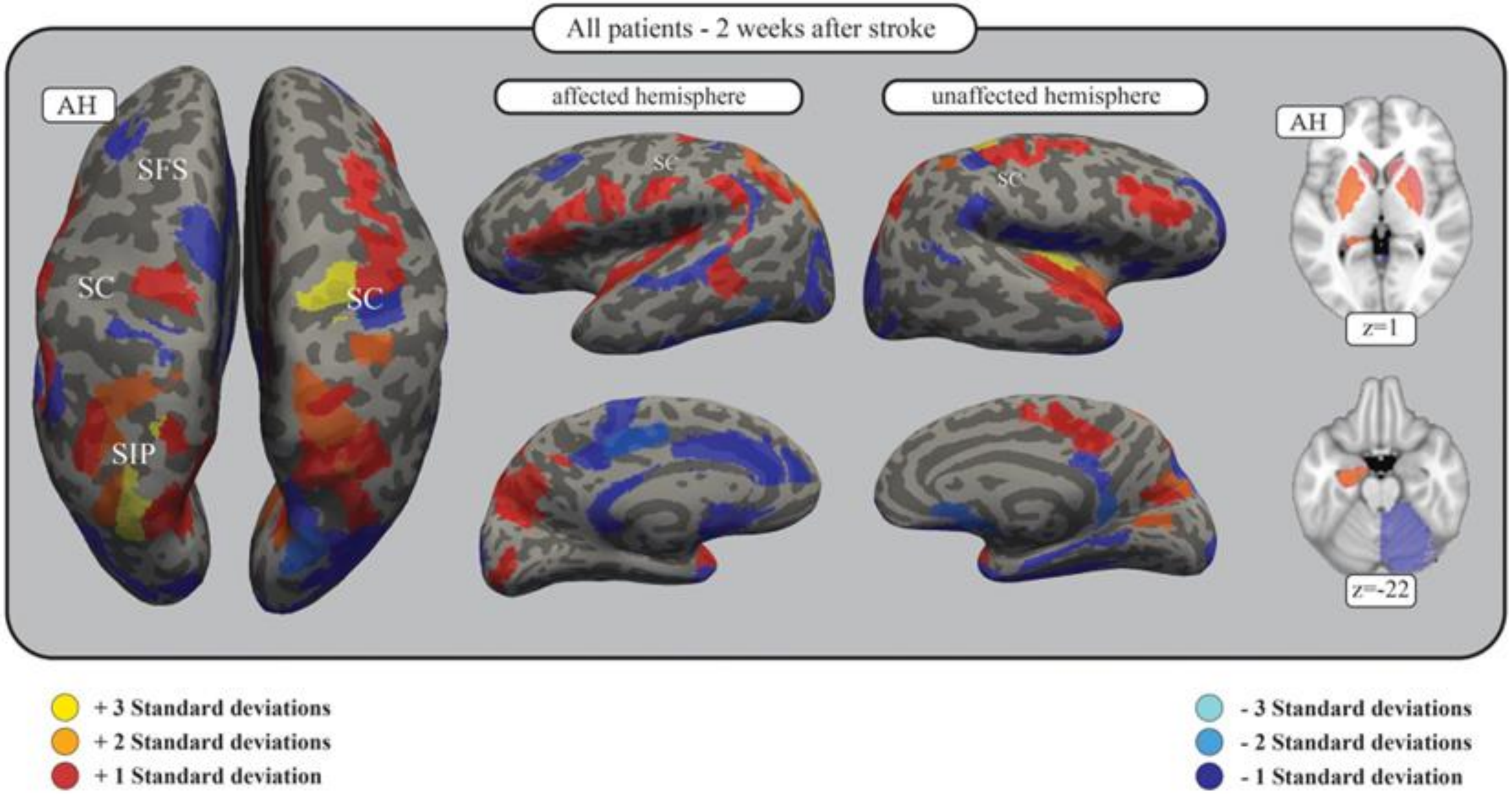


[MathWorks Online Seminar: eXplainable AI and AI V&V]]

Wide range of techniques with varying applicability depending on type of data and AI

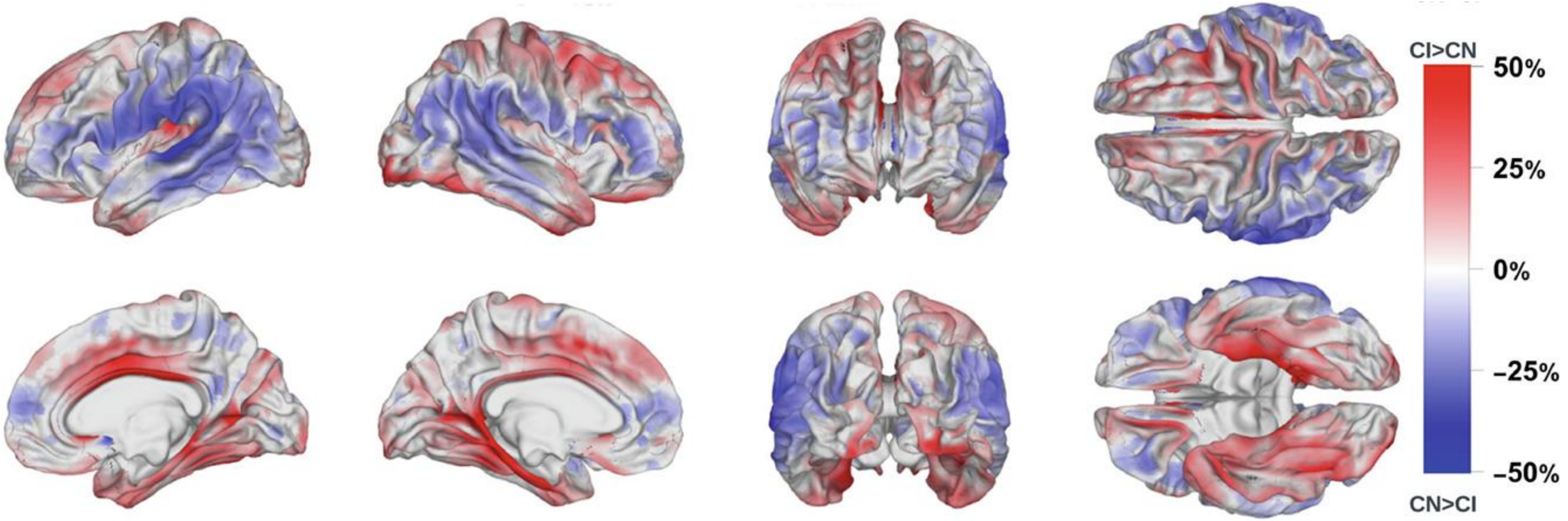


[MathWorks Online Seminar: eXplainable AI and AI V&V]]



[Koch et al., 2021]]

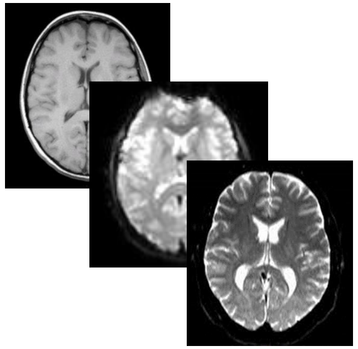
Brain areas contributing to predictions



[Yin et al., 2023]]

Brain areas contributing to predictions

Summary: MRI Data Analytics



Data

Tools

MATLAB

python

R

Domain knowledge