Explainable AI and the brain

Characterizing heterogeneity in diverse clinical cohorts

Esten H. Leonardsen

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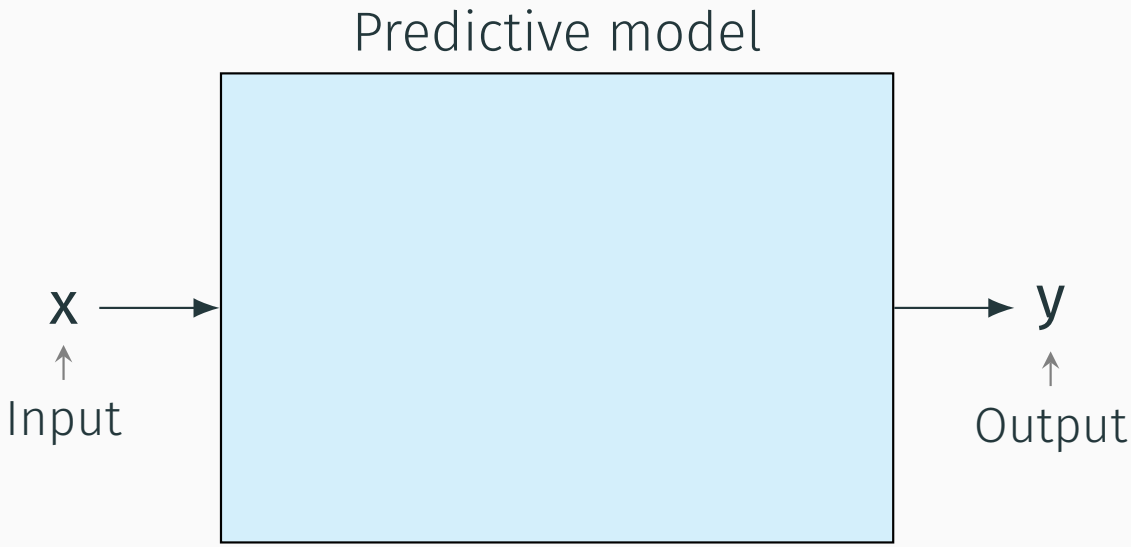
Outline

1. Theoretical background
    a. Artificial neural networks
    b. Explainable AI
2. Explainable AI and dementia
3. Explainable AI and brain age

Artificial neural networks



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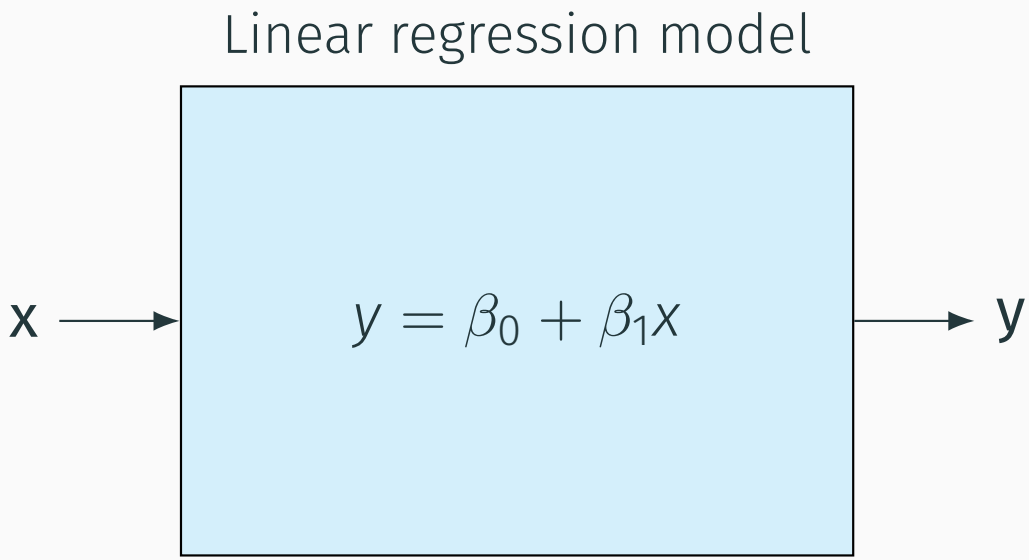

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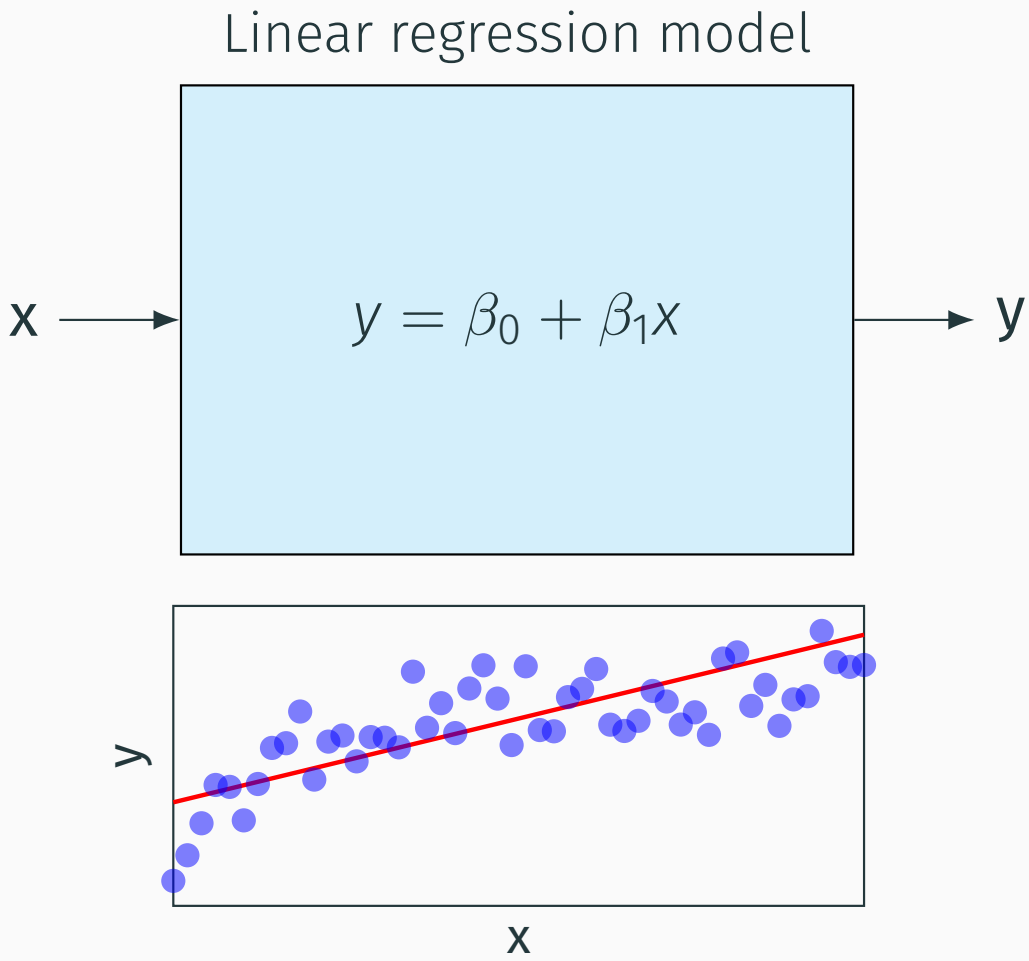

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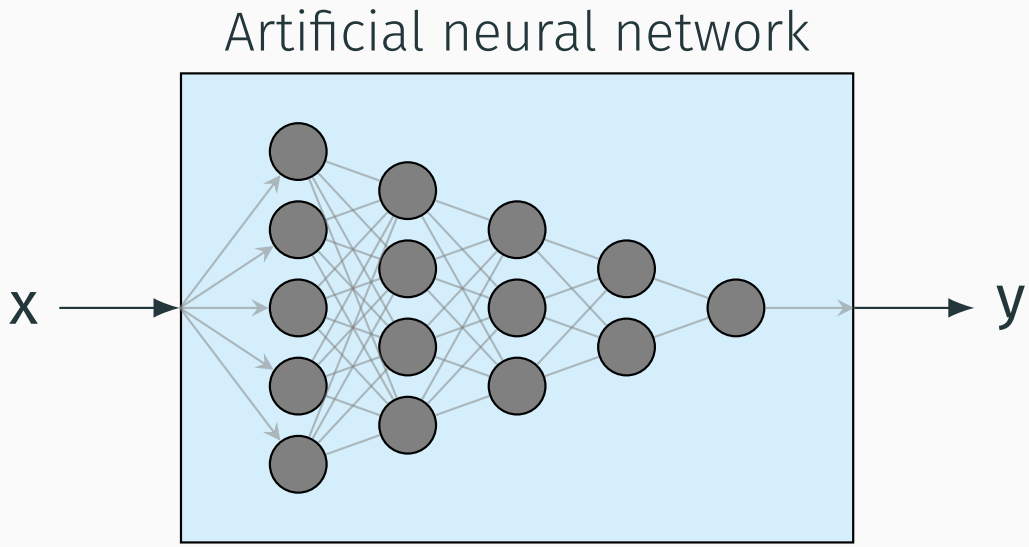

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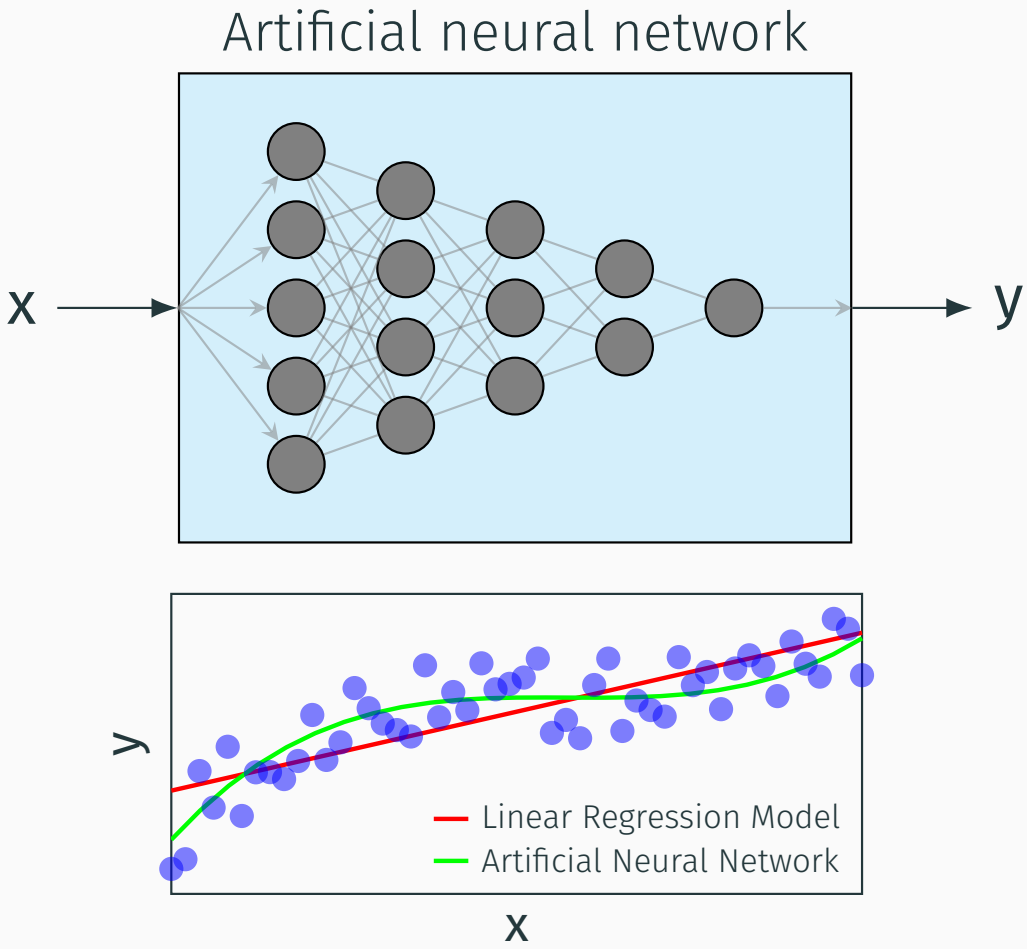

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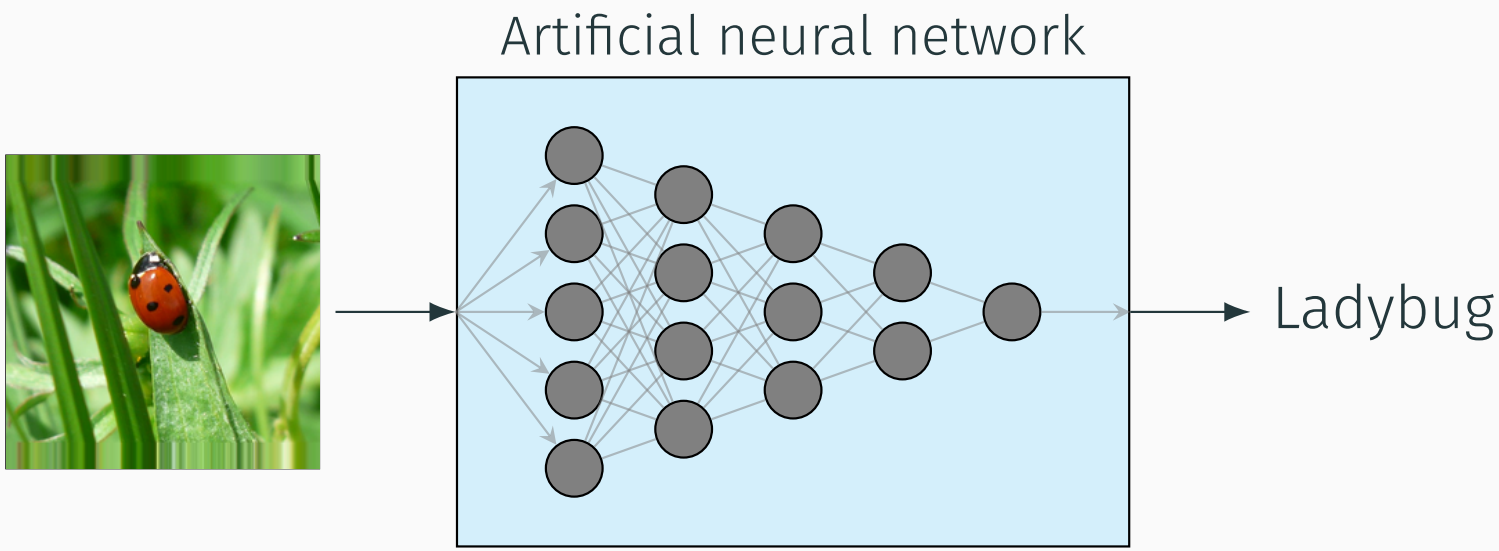
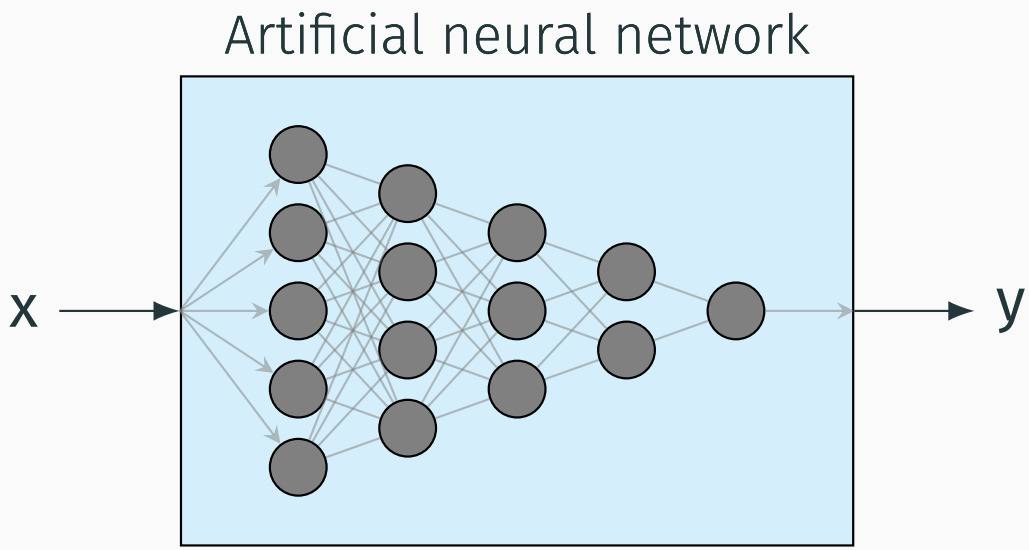


Artificial neural networks: Interpretability



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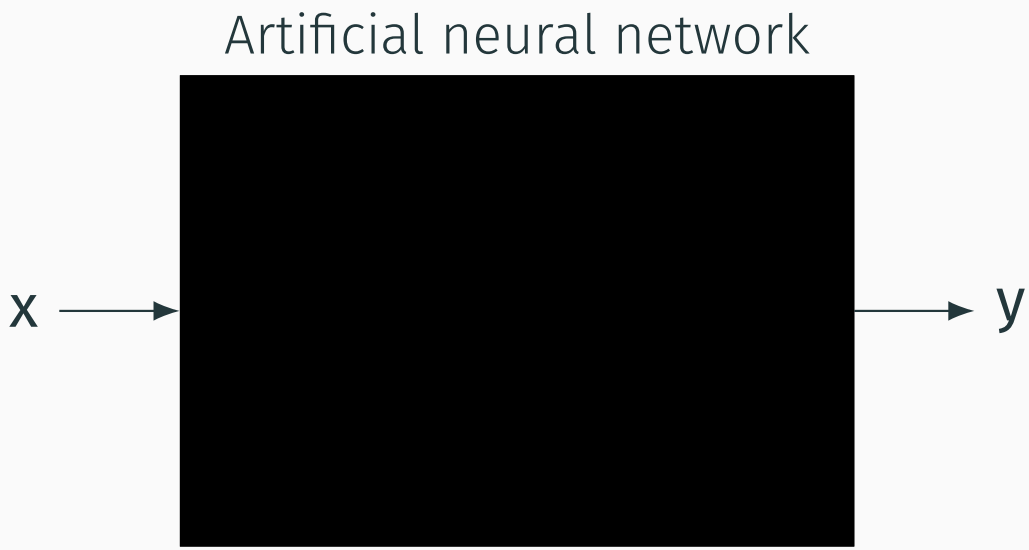

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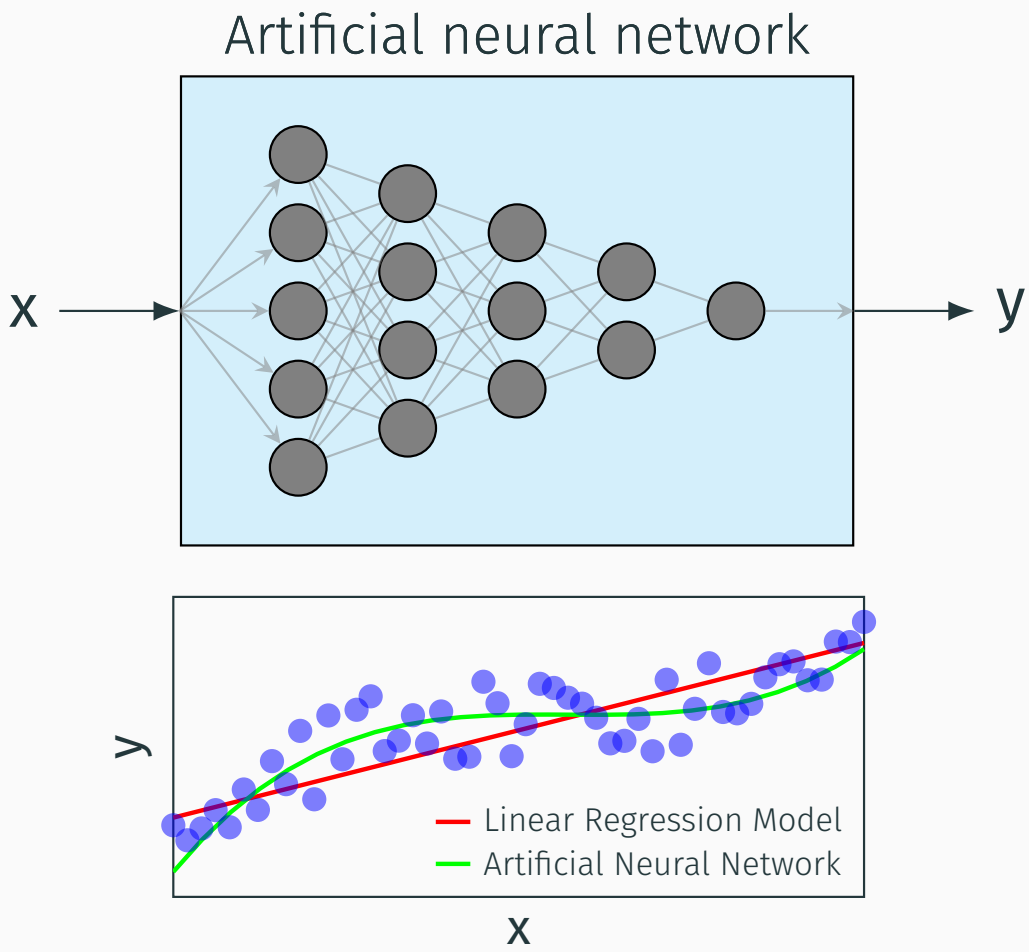

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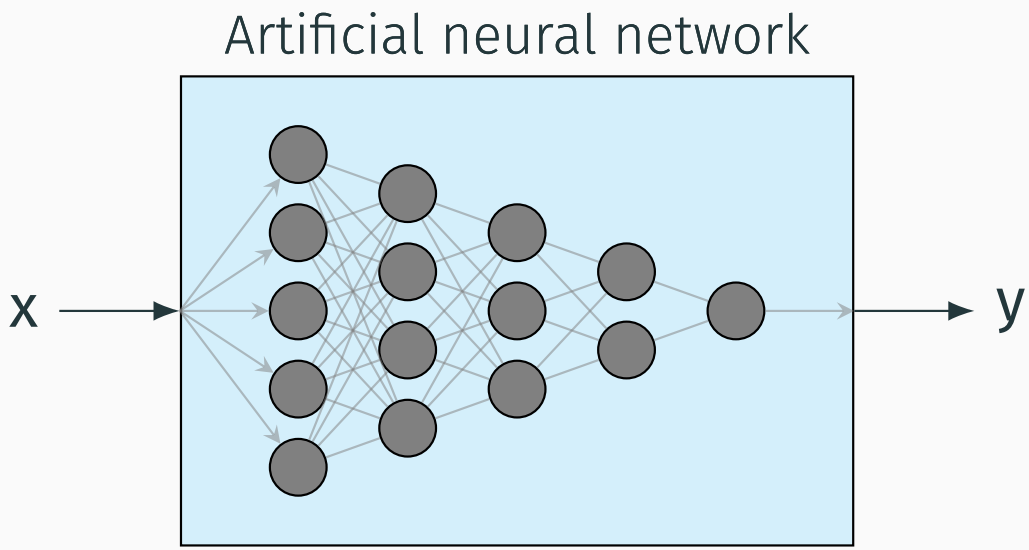

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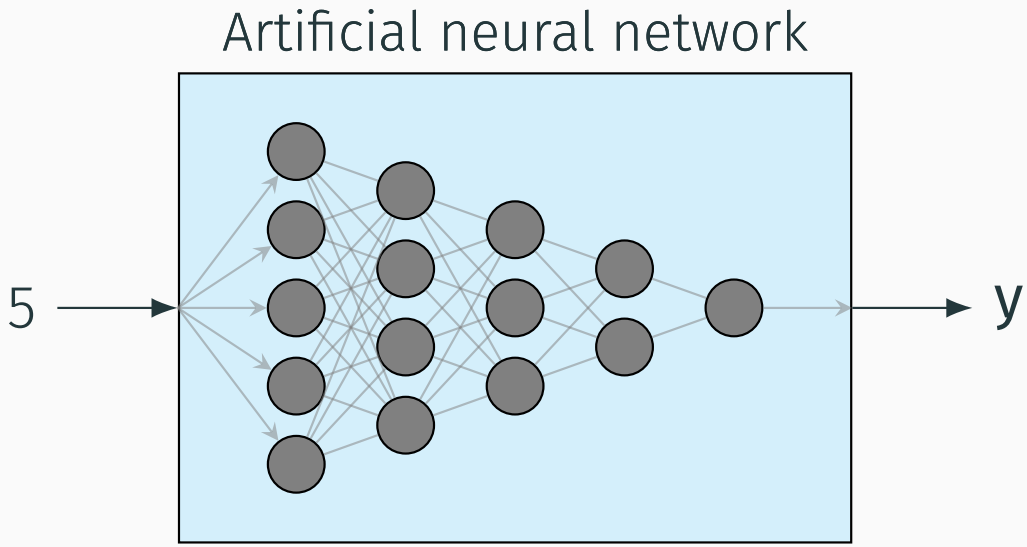

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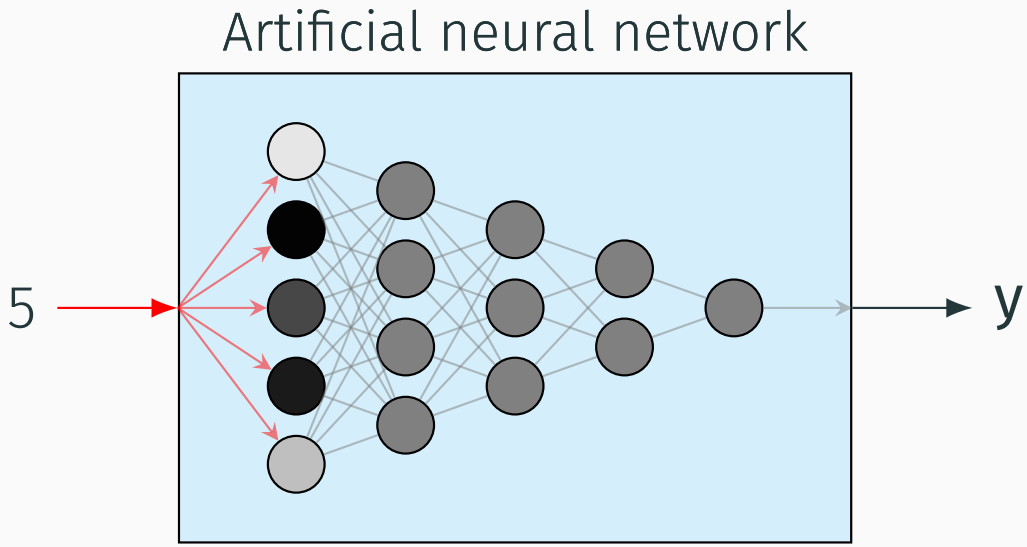

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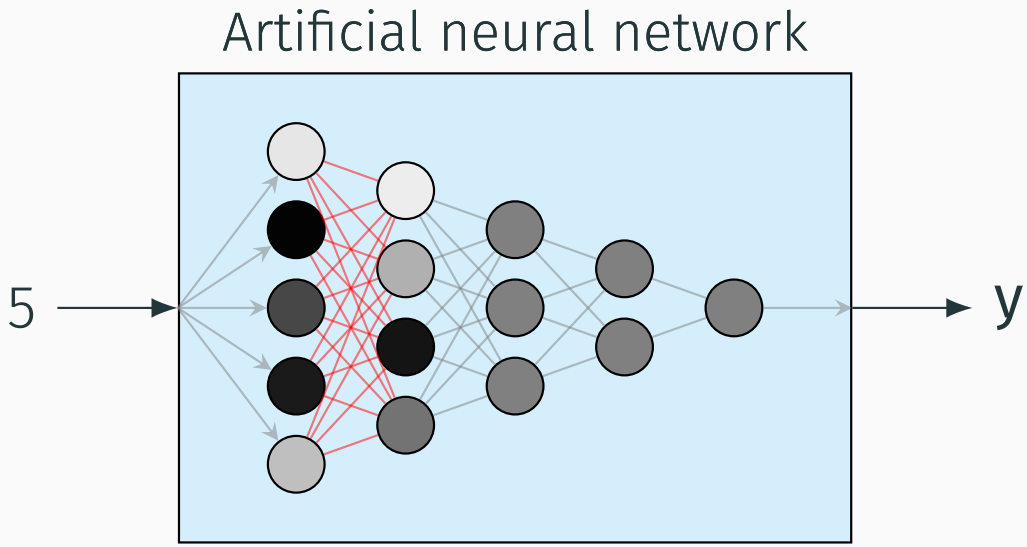

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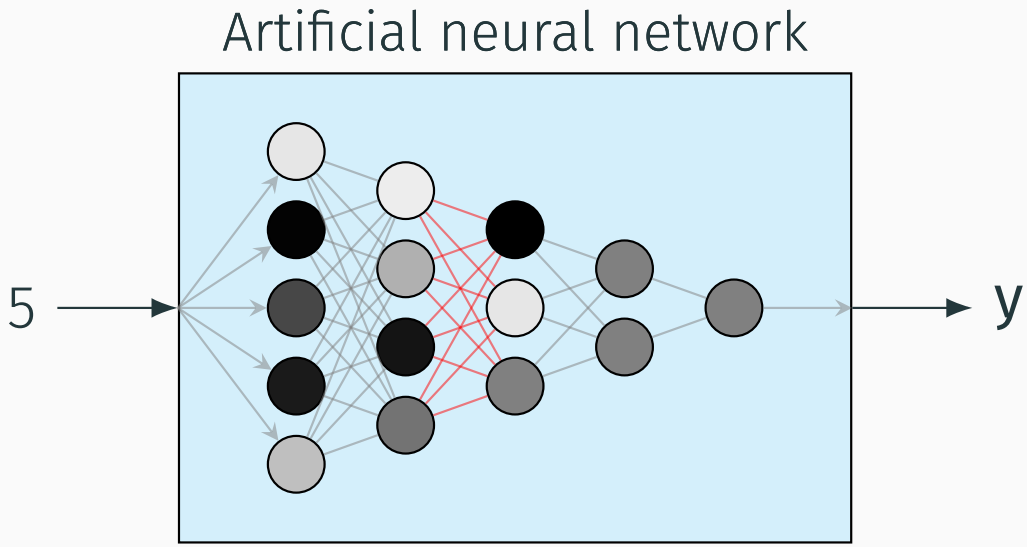

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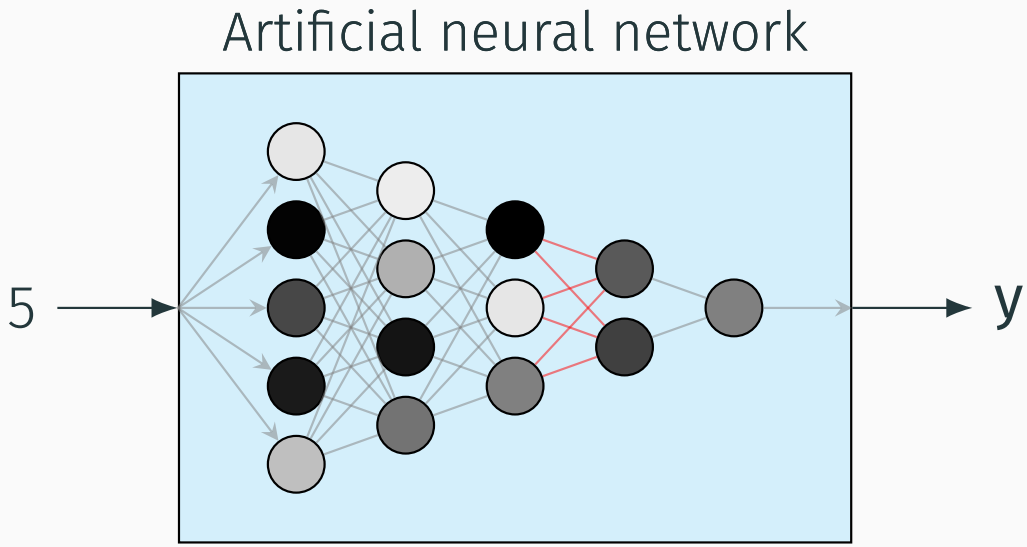

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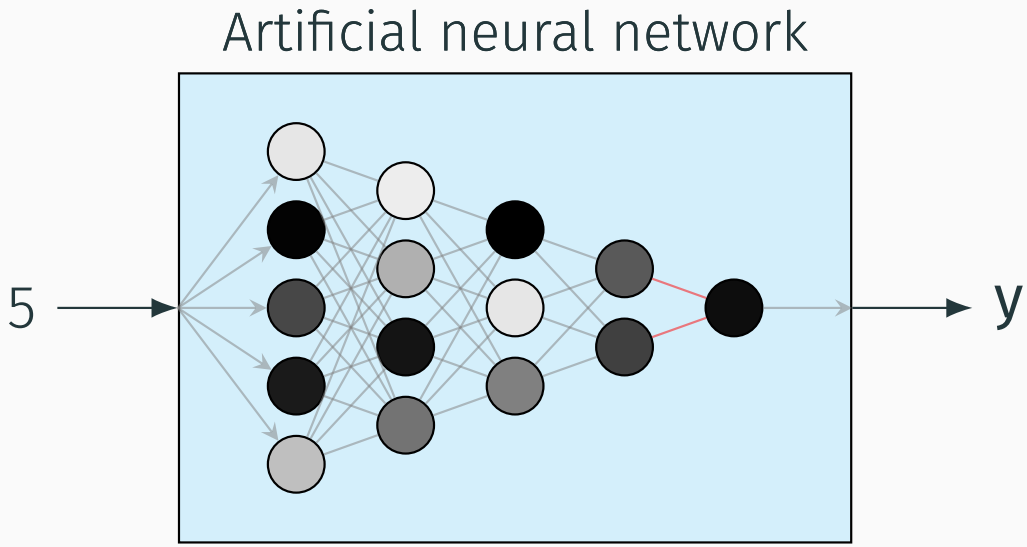

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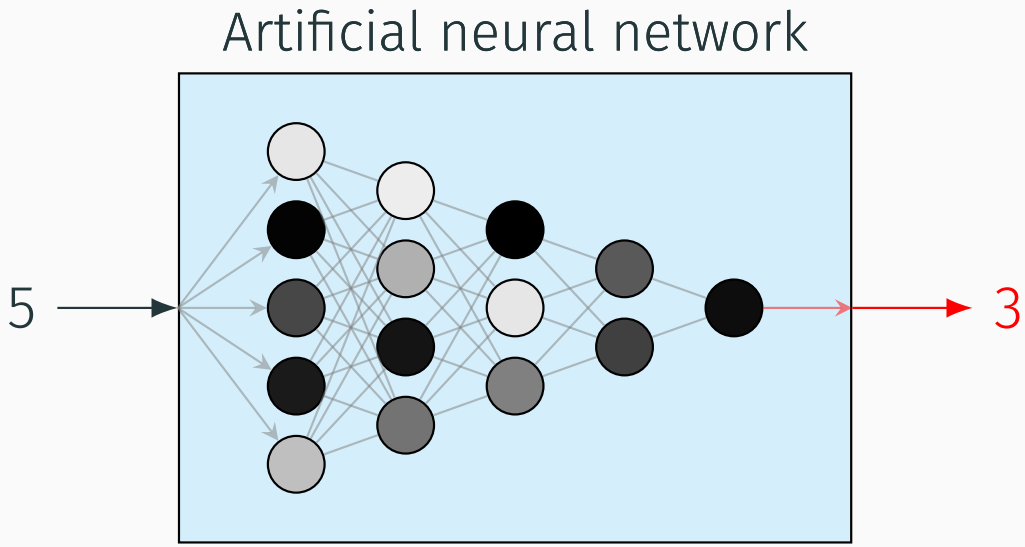

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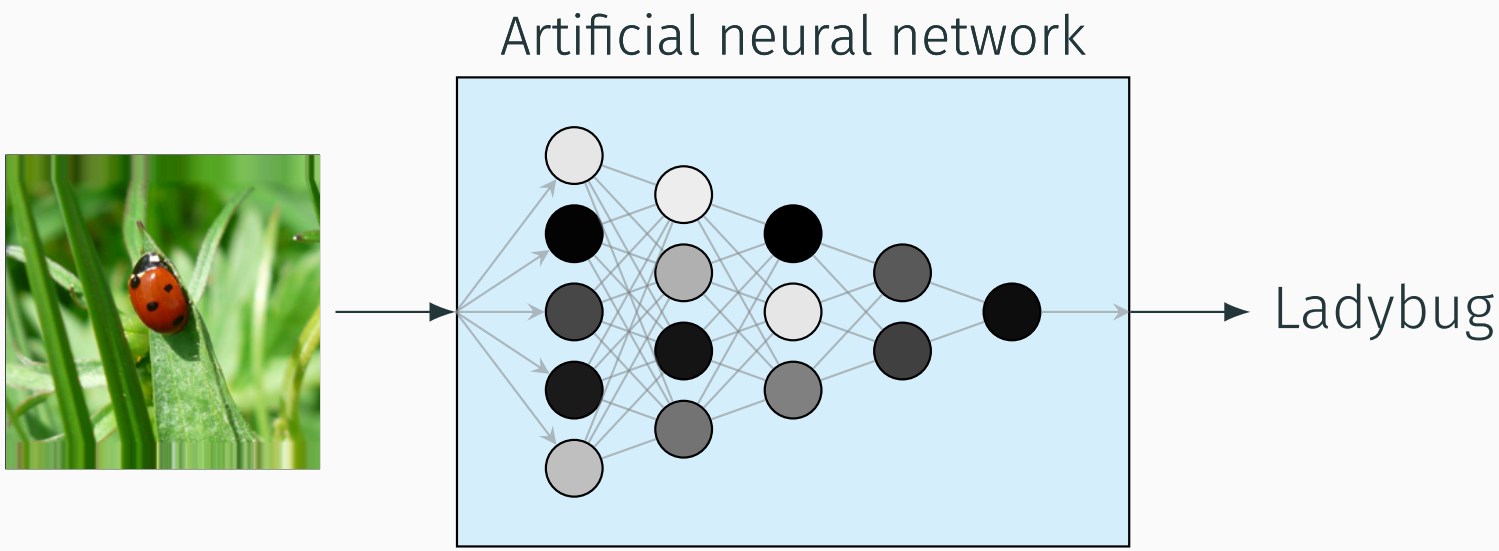

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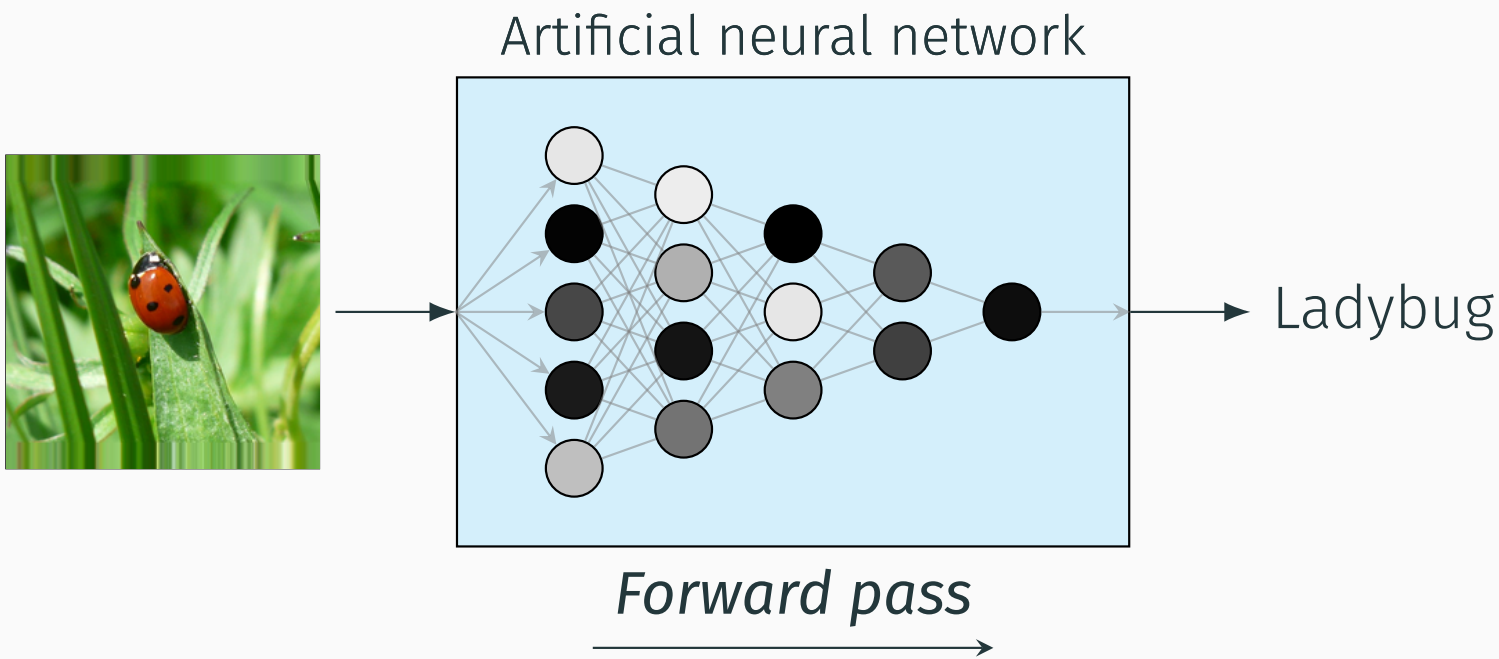

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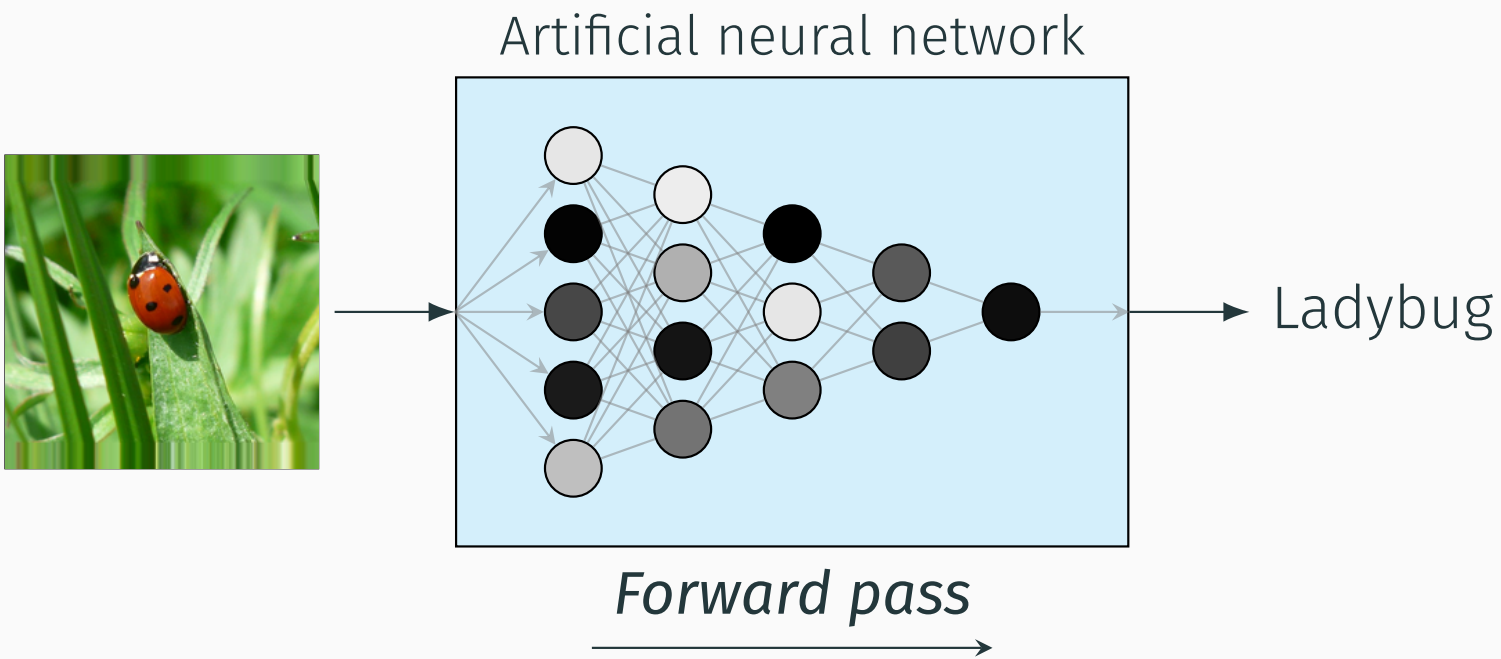

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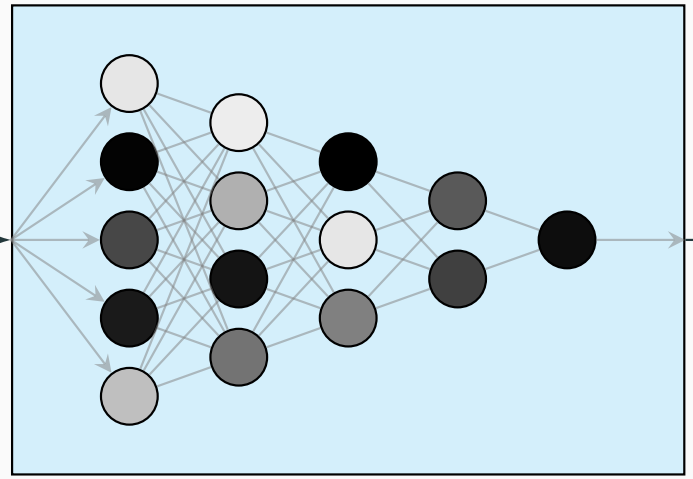

Ladybug

Backward pass

$$R_j^{i-1} = \sum_k \frac{n_j^{(i-1)} w_{jk}^{(i-1)}}{\sum_l n_l^{(i-1)} w_{lk}^{(i-1)}} R_k^i$$

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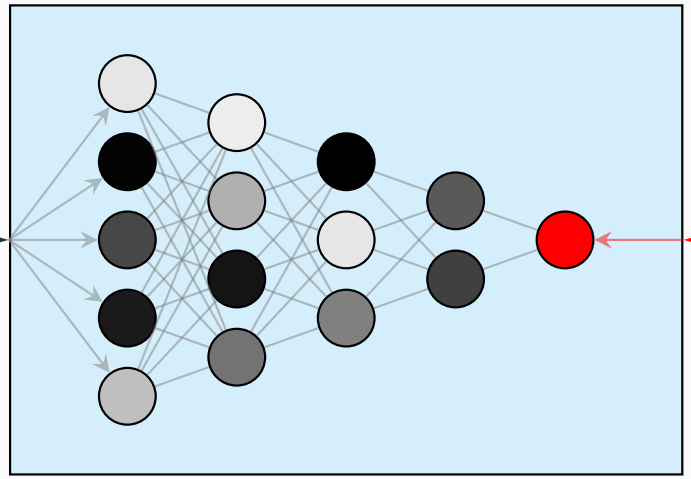

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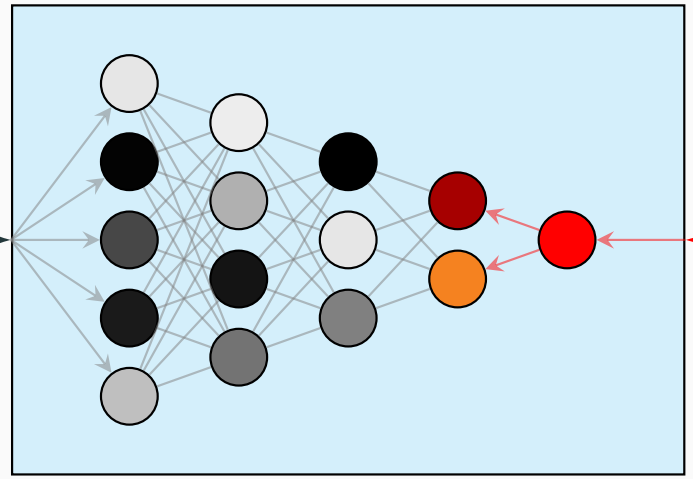

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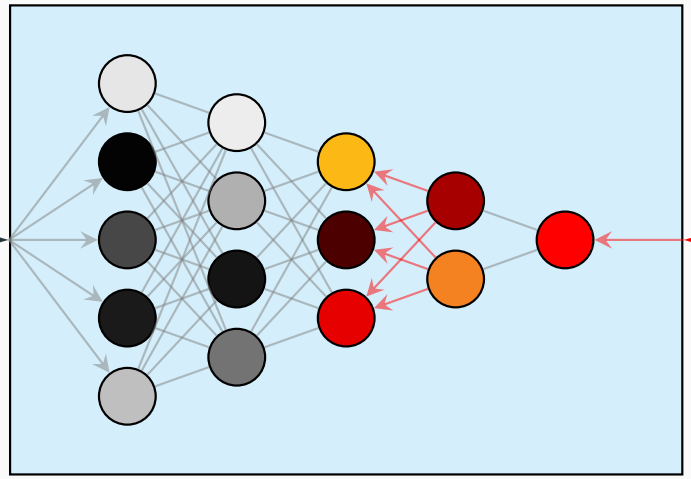

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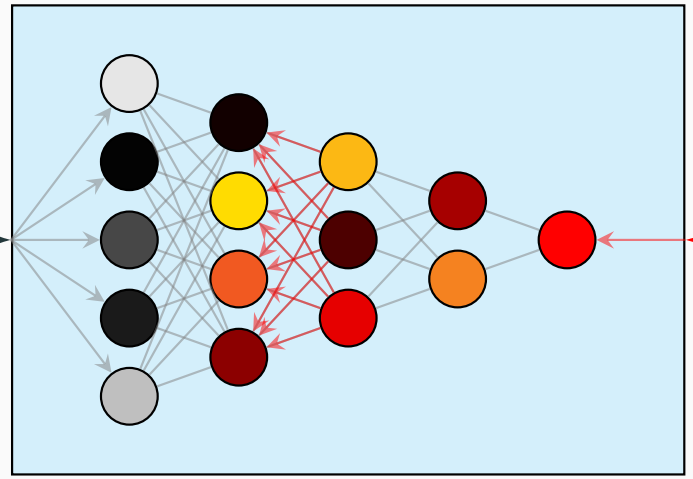

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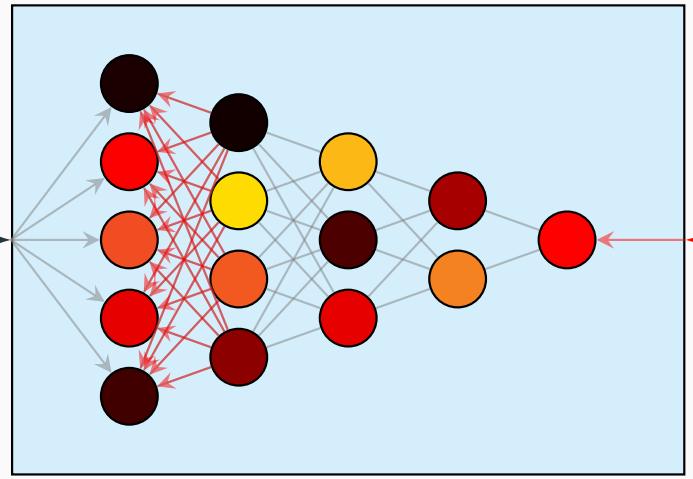

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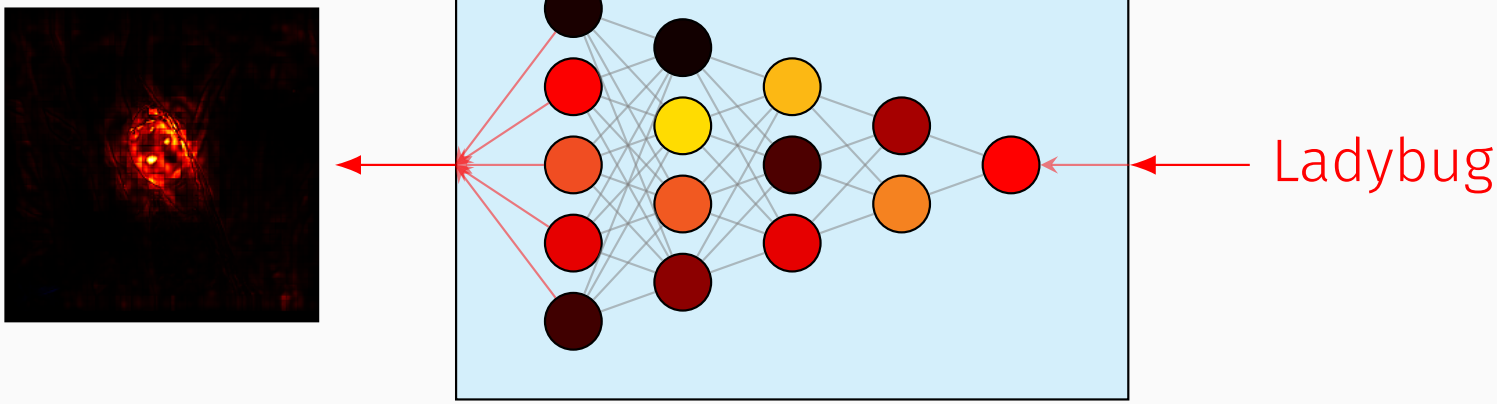

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Artificial neural networks: Explainability

Reasons to use explainable AI:

- Sanity check models
- Building trust among users

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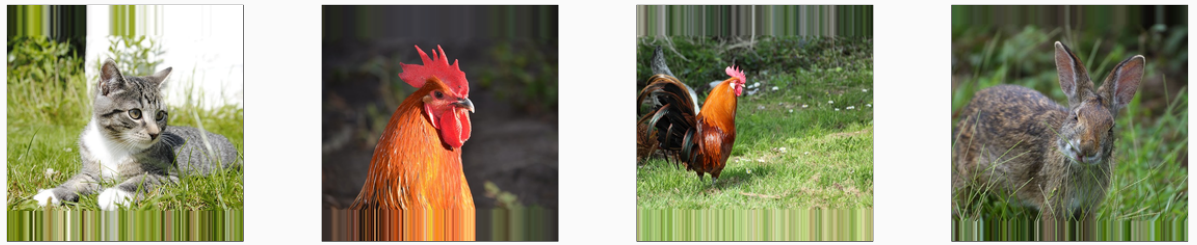
Reasons to use explainable AI:

- Sanity check models
- Building trust among users
- Scientific discovery
- Characterize heterogeneity in groups we consider (somewhat) homogeneous

Explainable AI: The central idea

Animals



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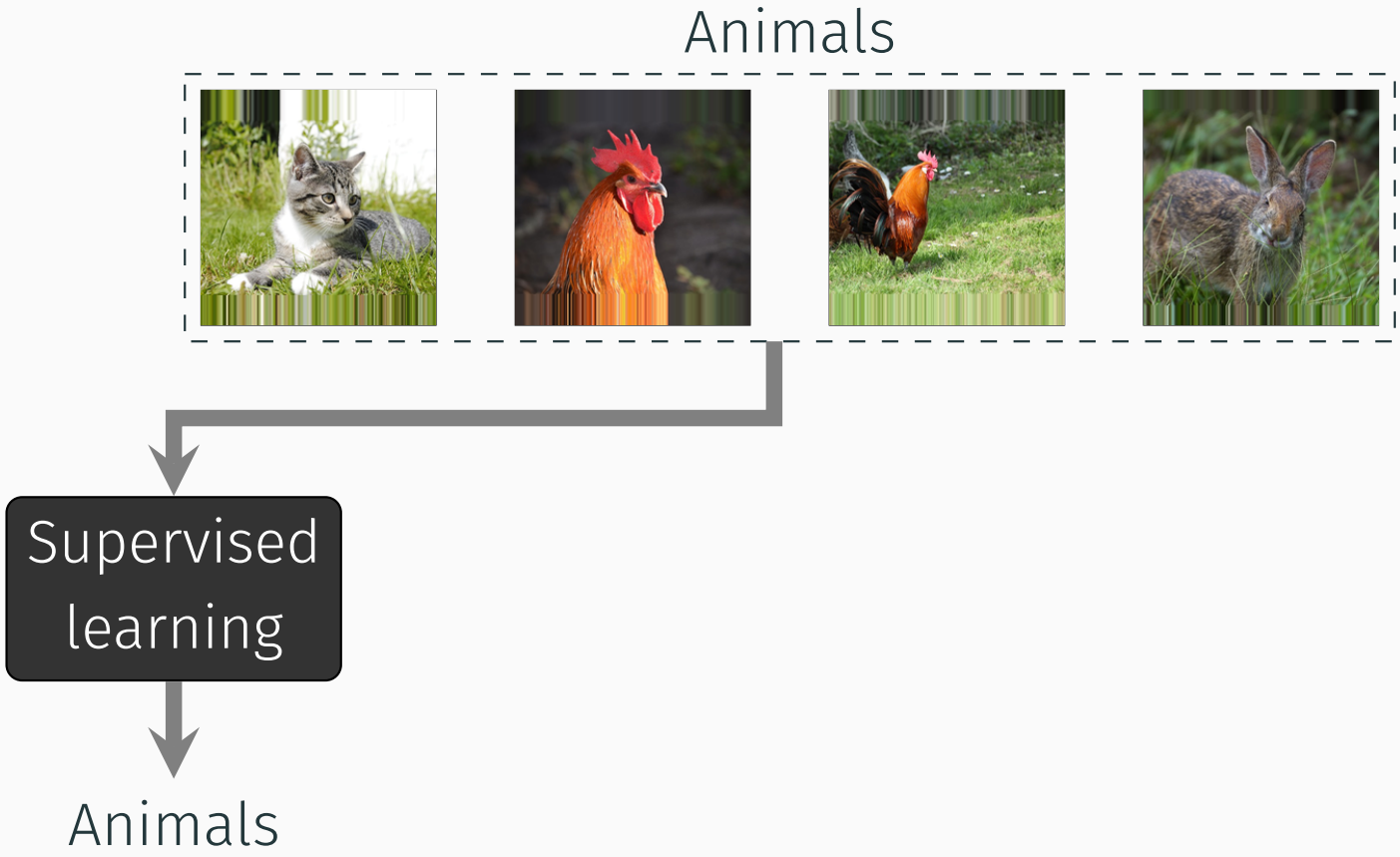

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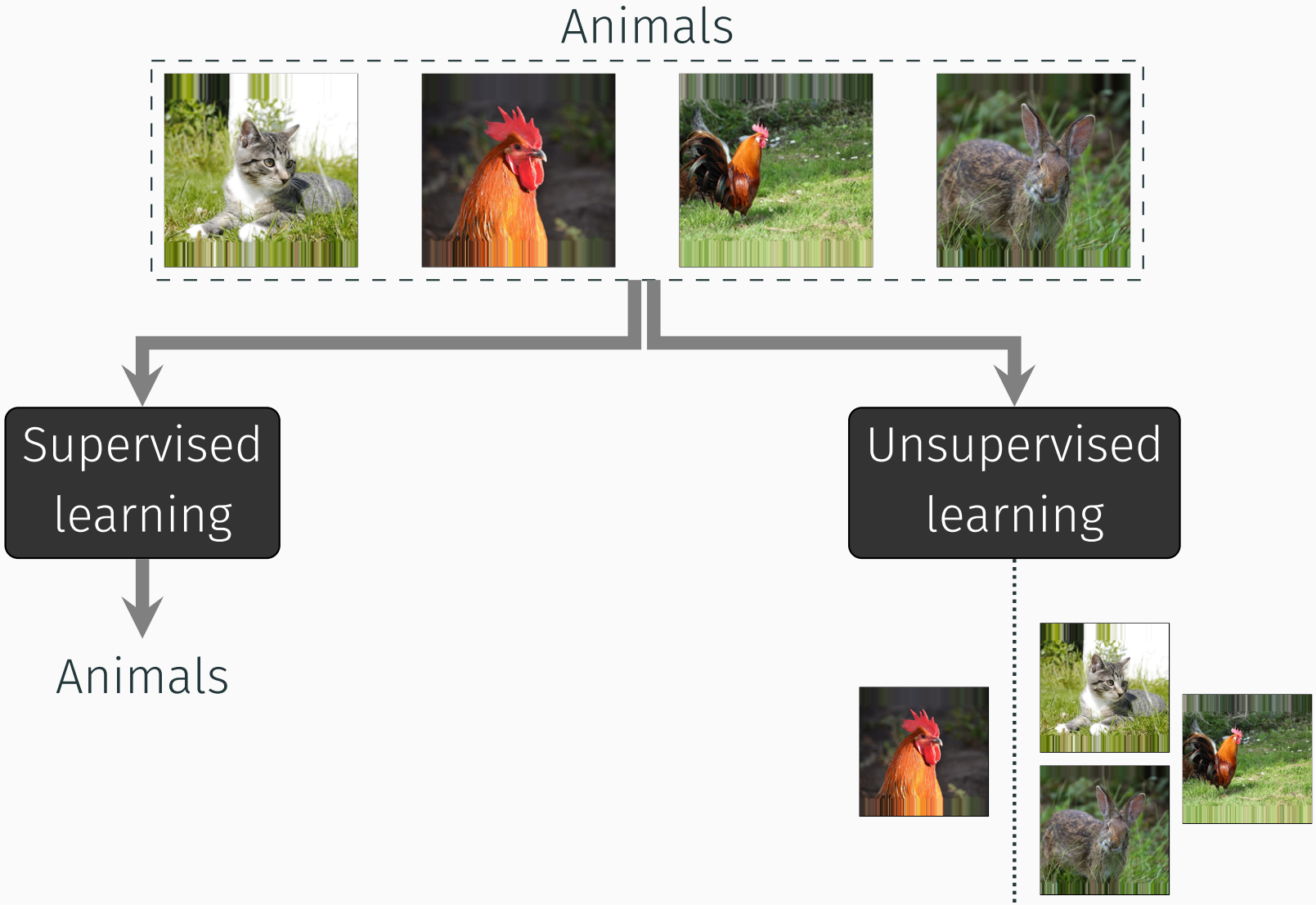

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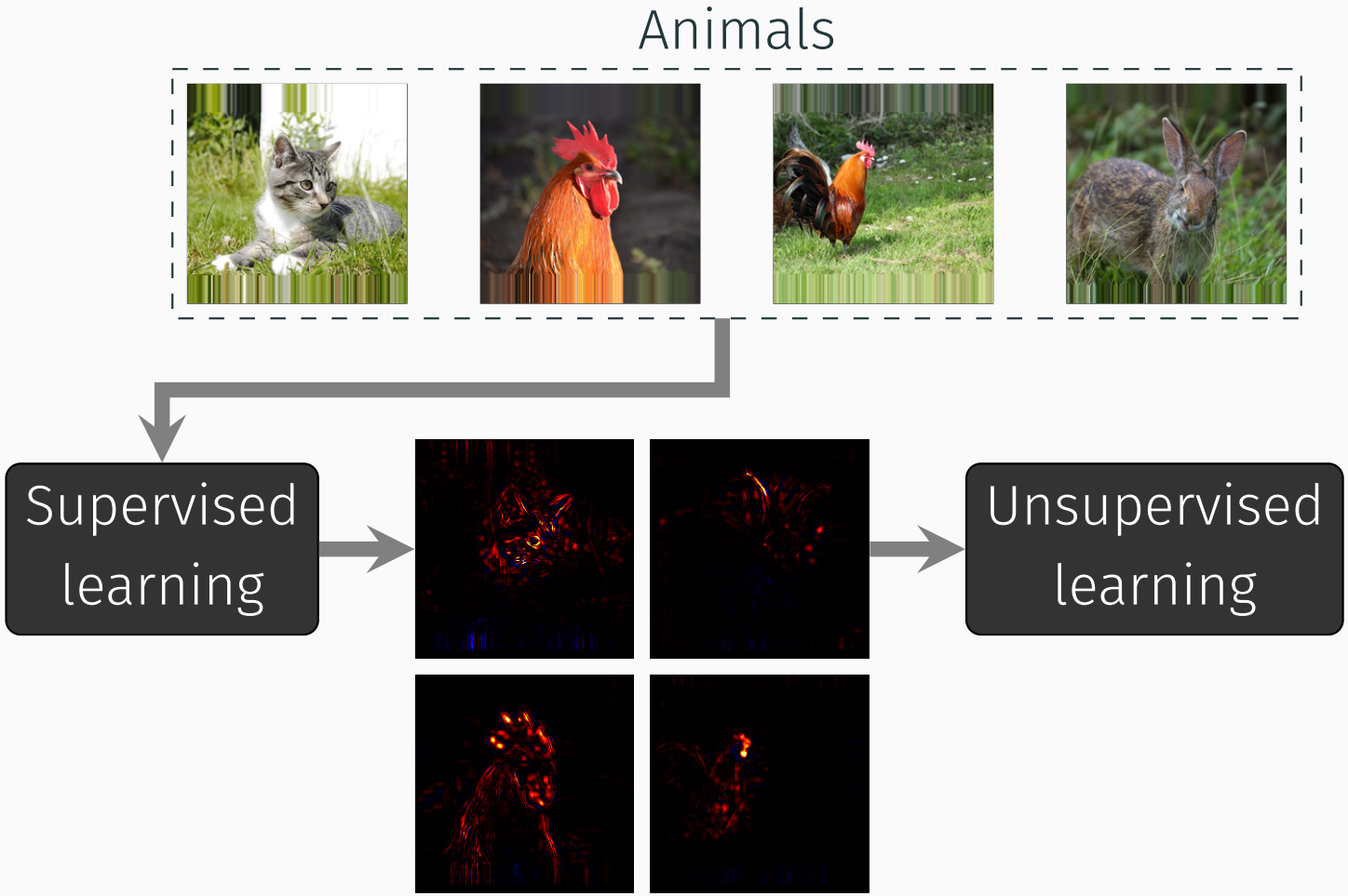

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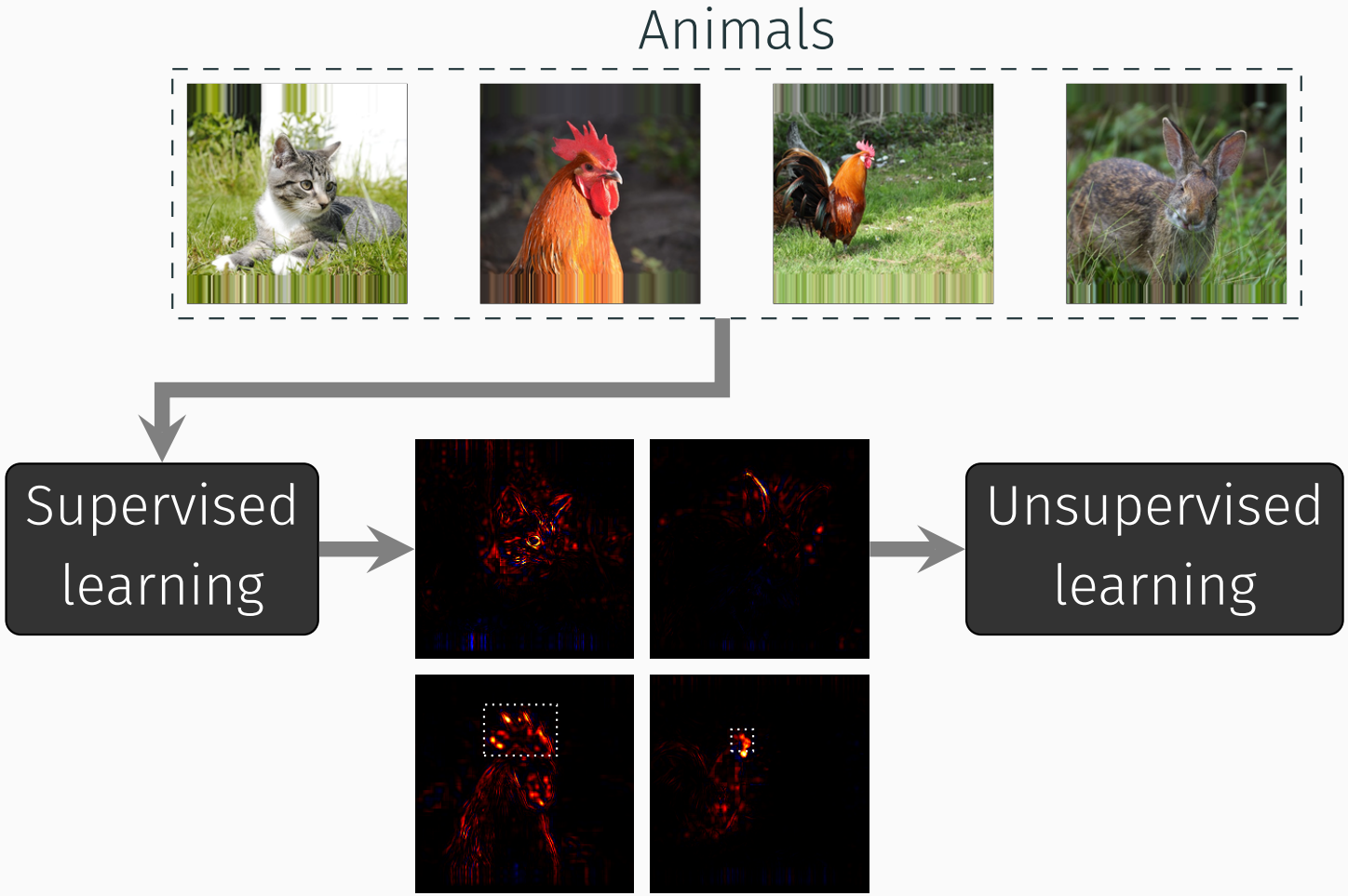
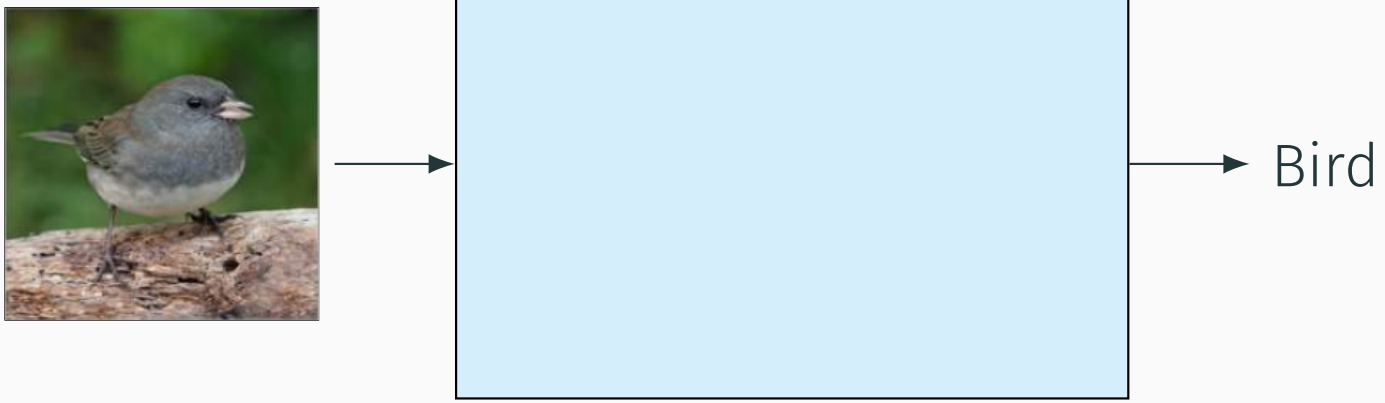


Explainable AI: Caveats



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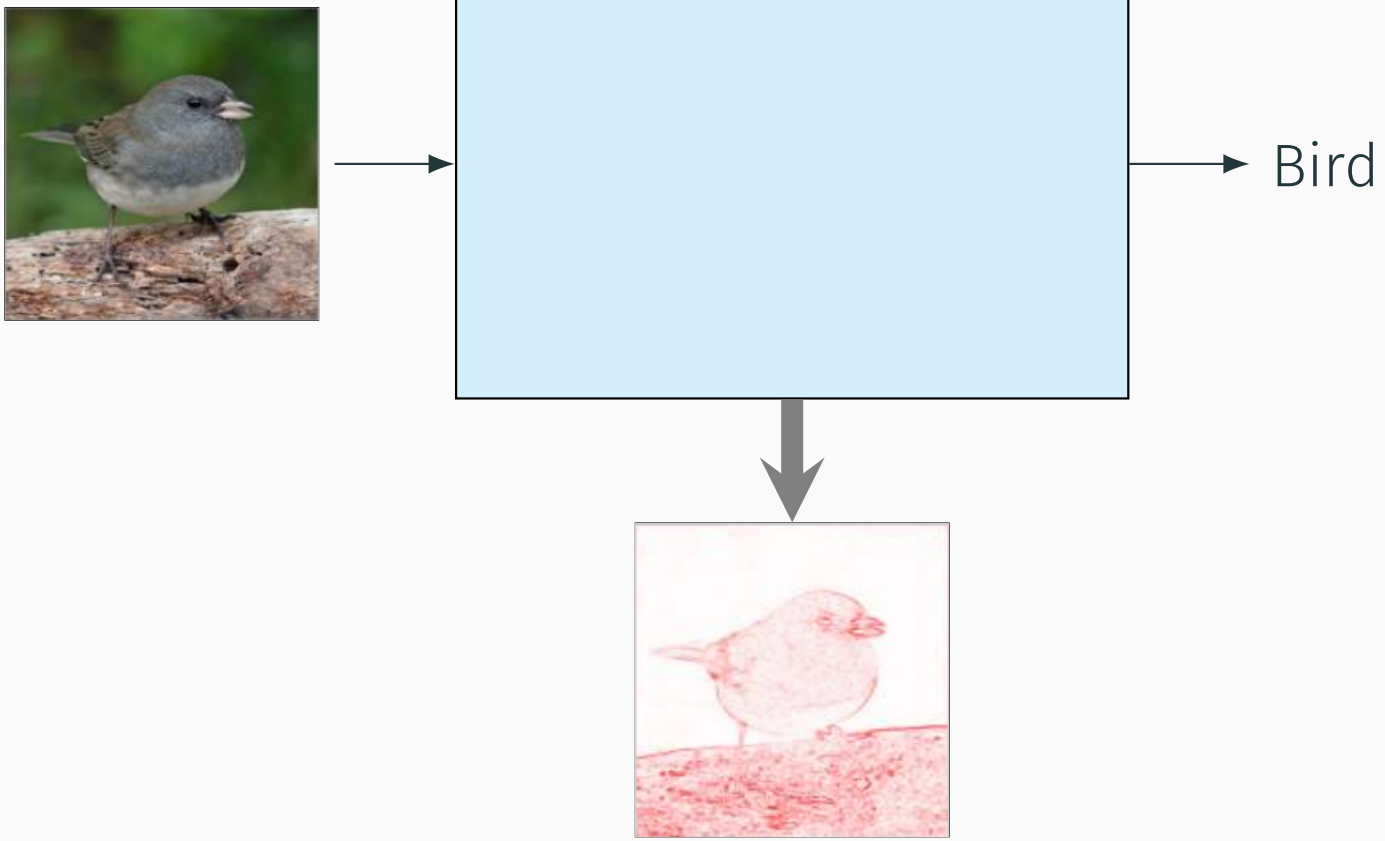

Explainable AI: Caveats

Explainable AI and dementia predictions

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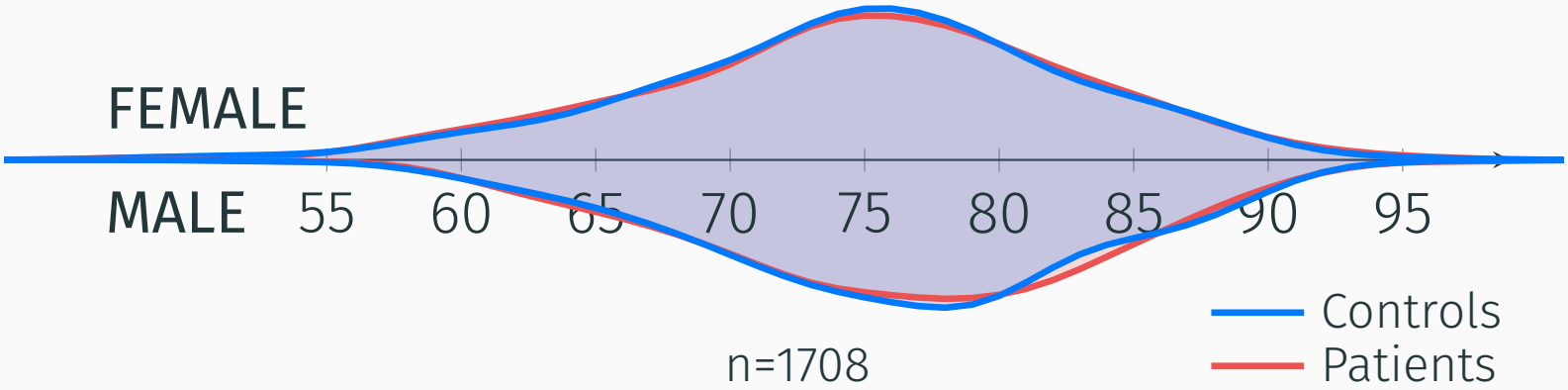
Explainable dementia classification: Dataset



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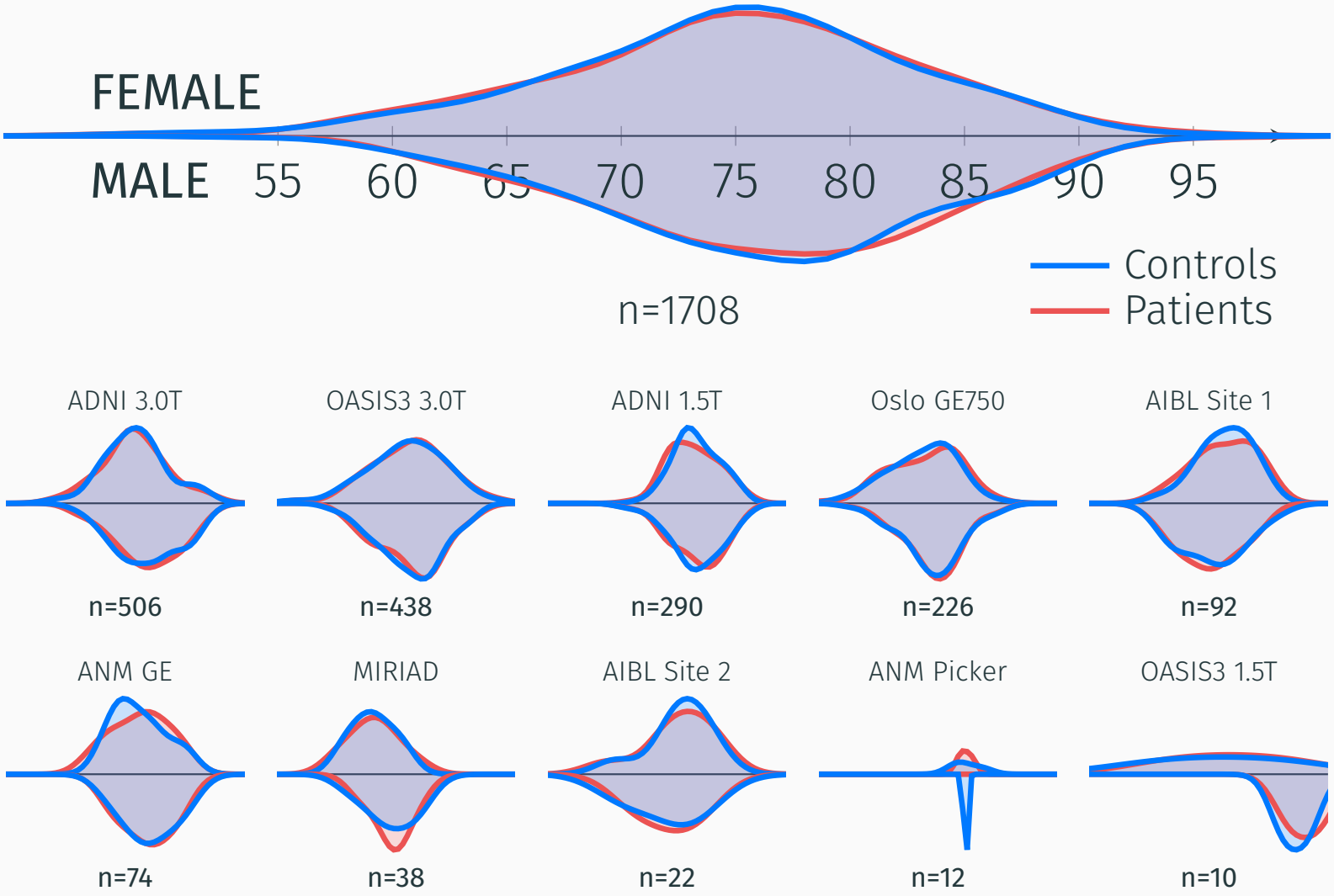
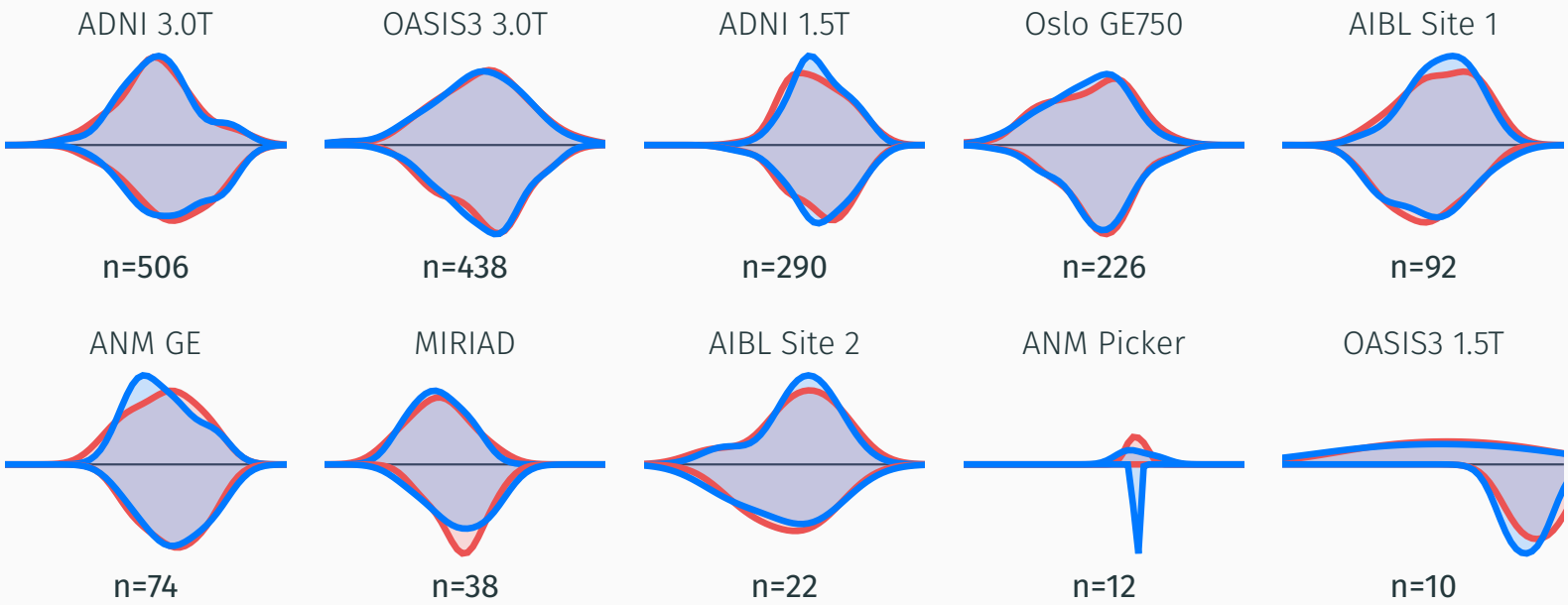


Explainable dementia classification: Dataset

ADNI:
Probable
Alzheimer's disease

OASIS3:
Dementia

Oslo:
Alzheimer's disease,
Vascular dementia,
Unspecified dementia



Explainable dementia classification: Modelling

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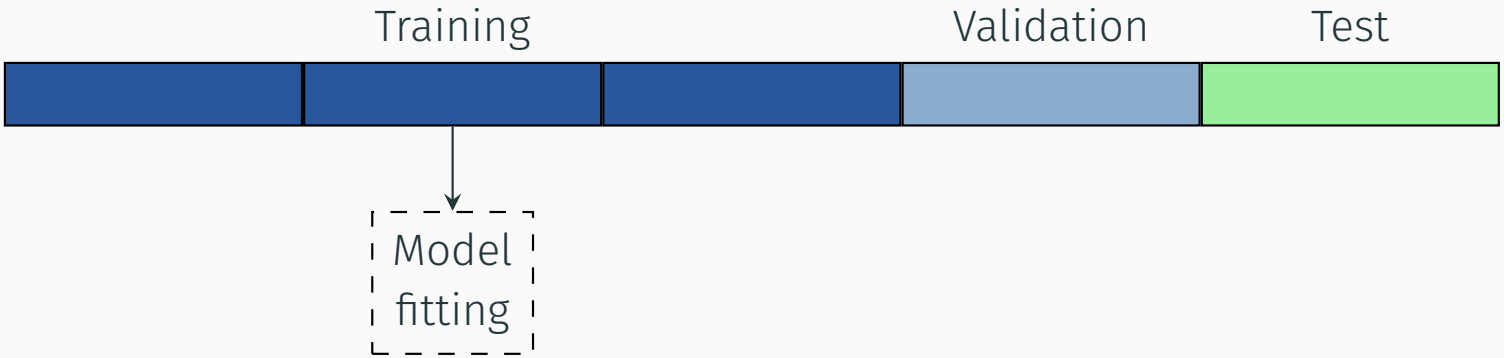

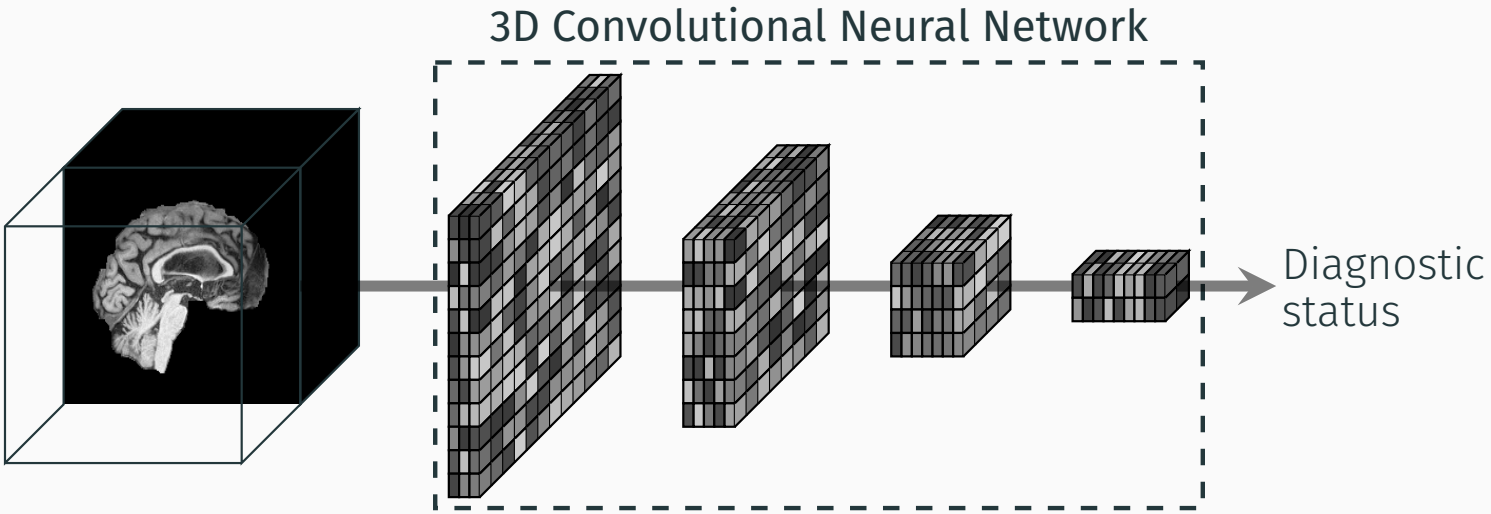

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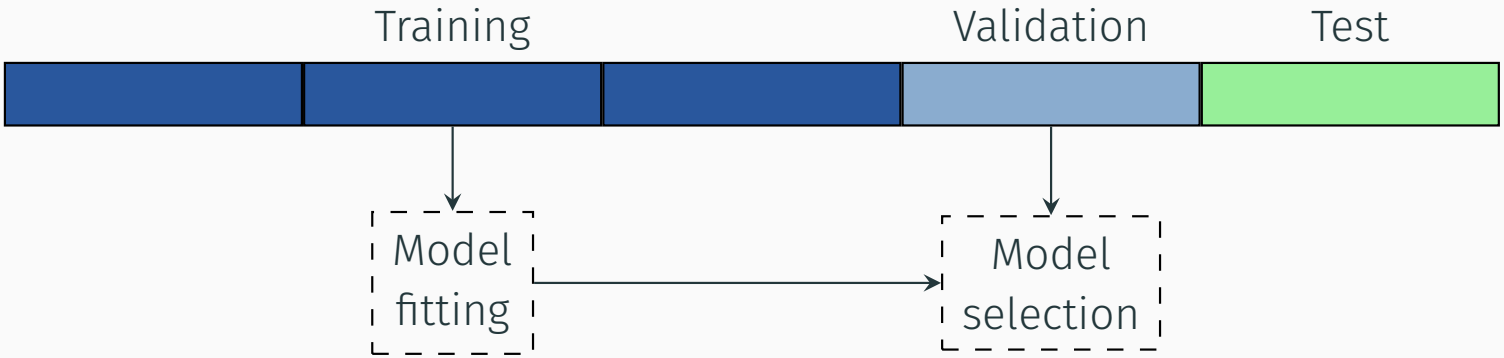

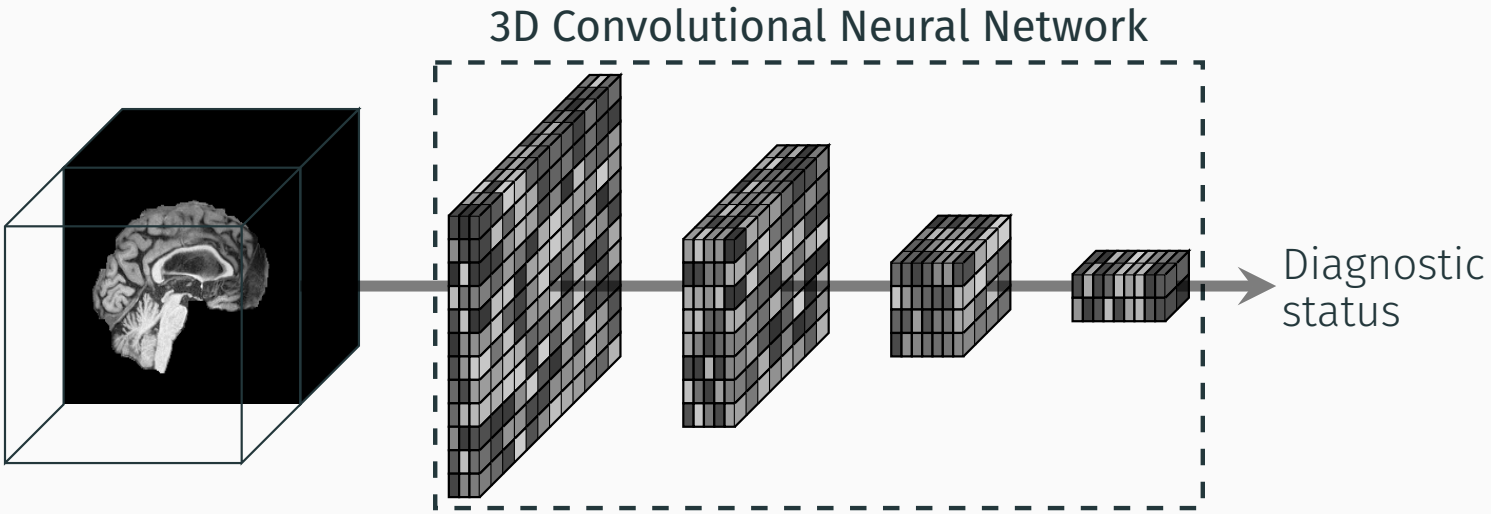

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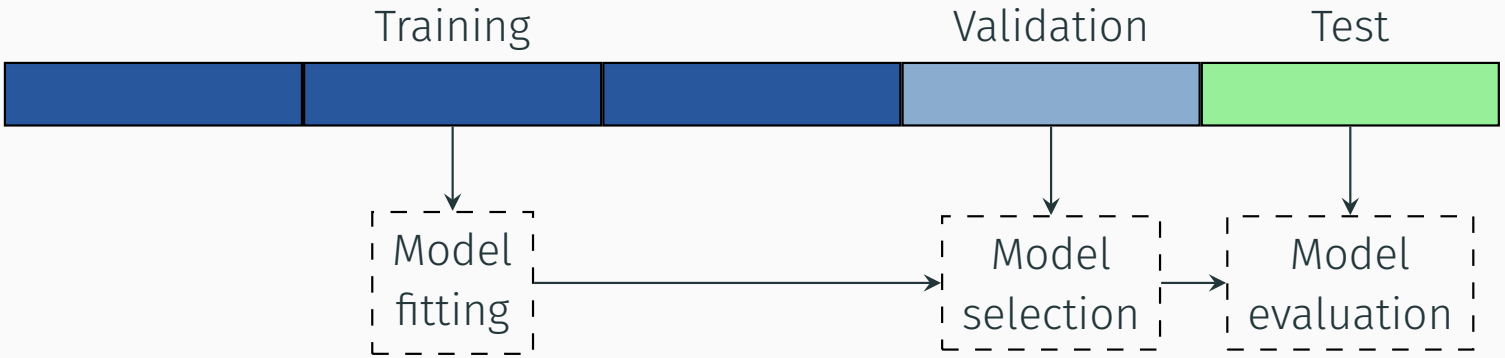

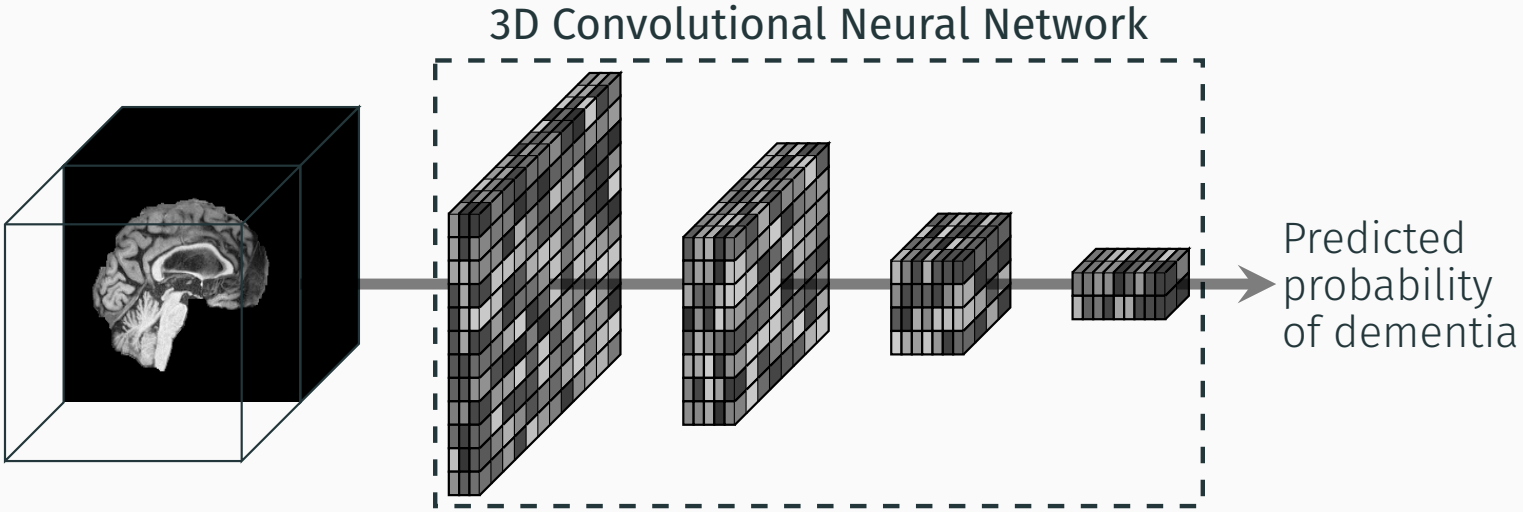

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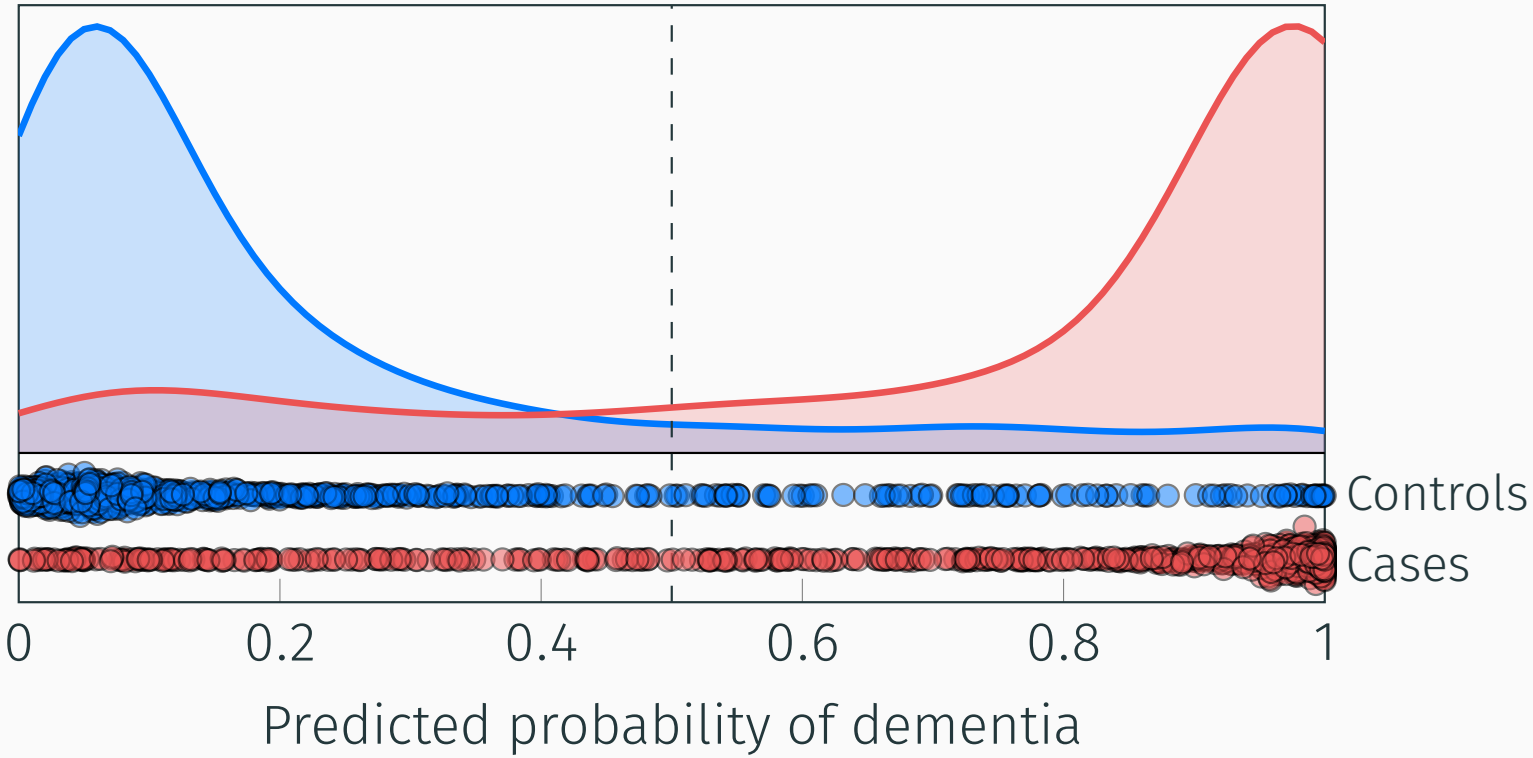
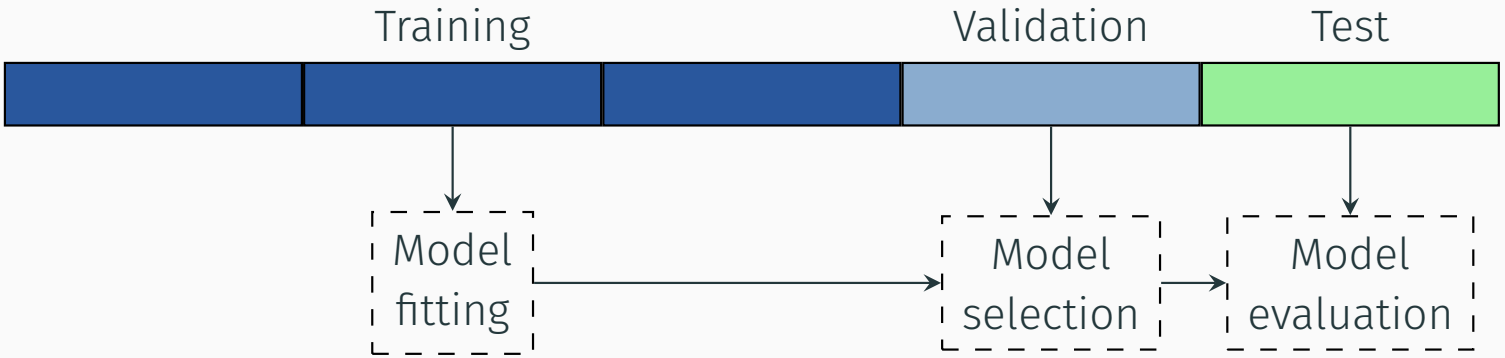
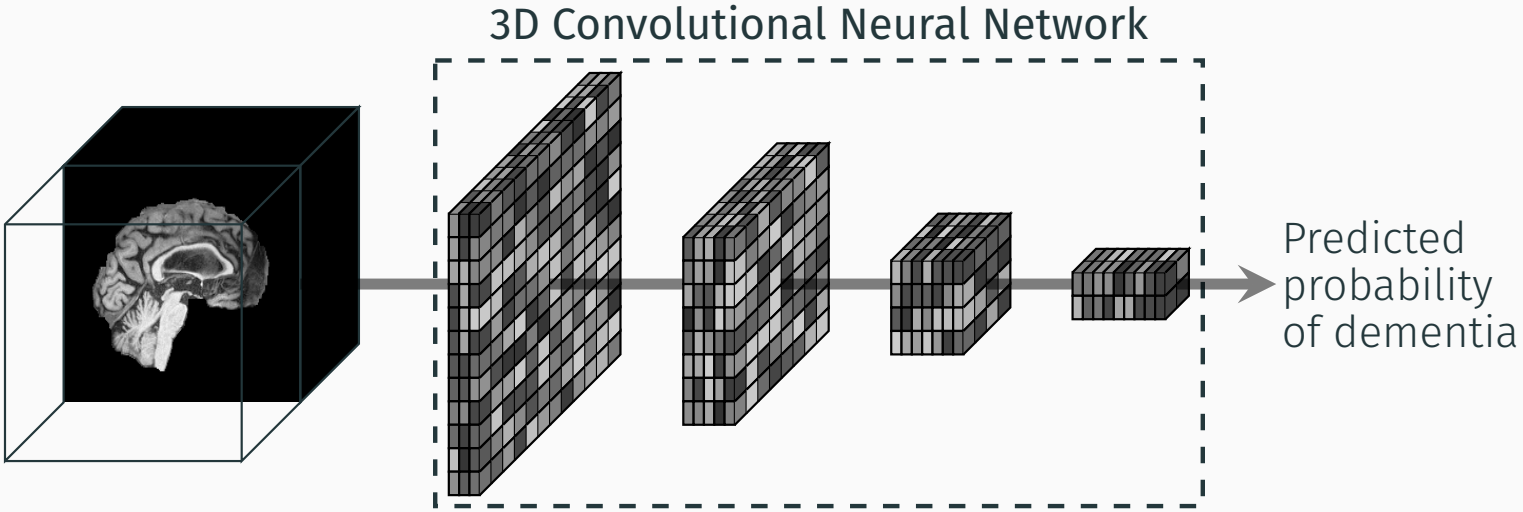


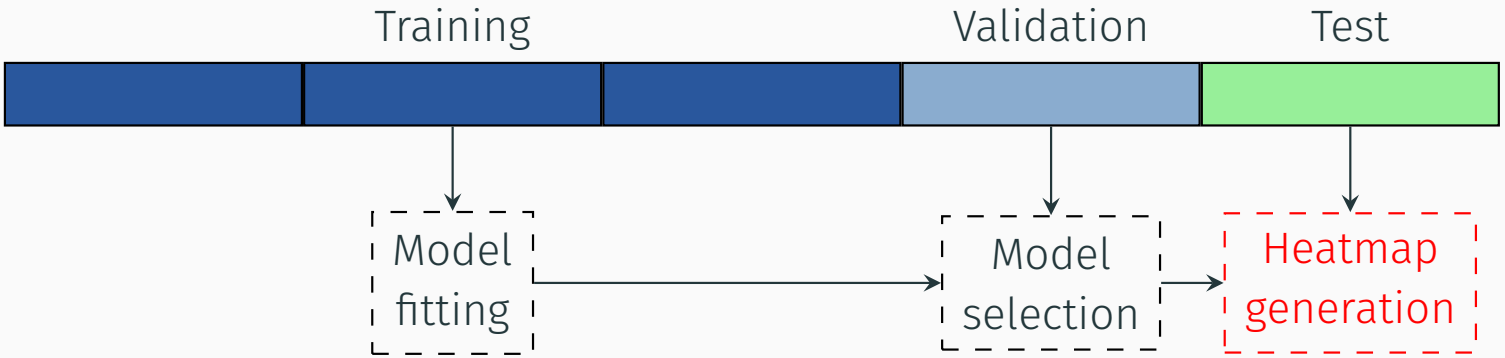
AUC=0.91, balanced accuracy=85%

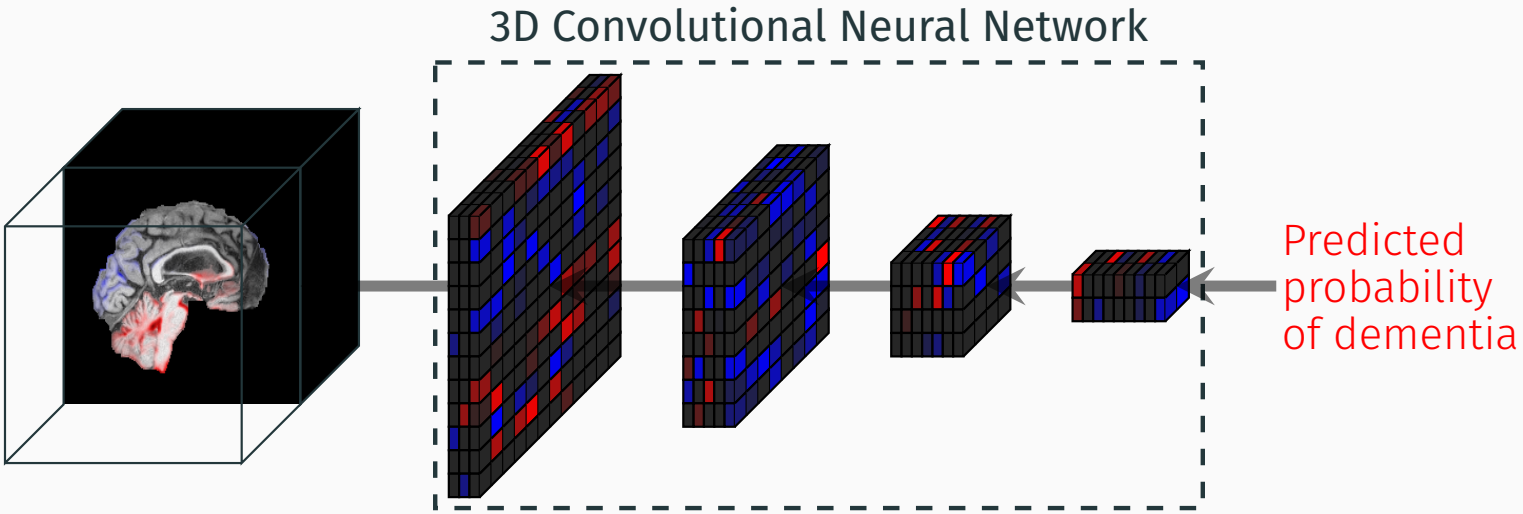
Explainable dementia classification: Modelling



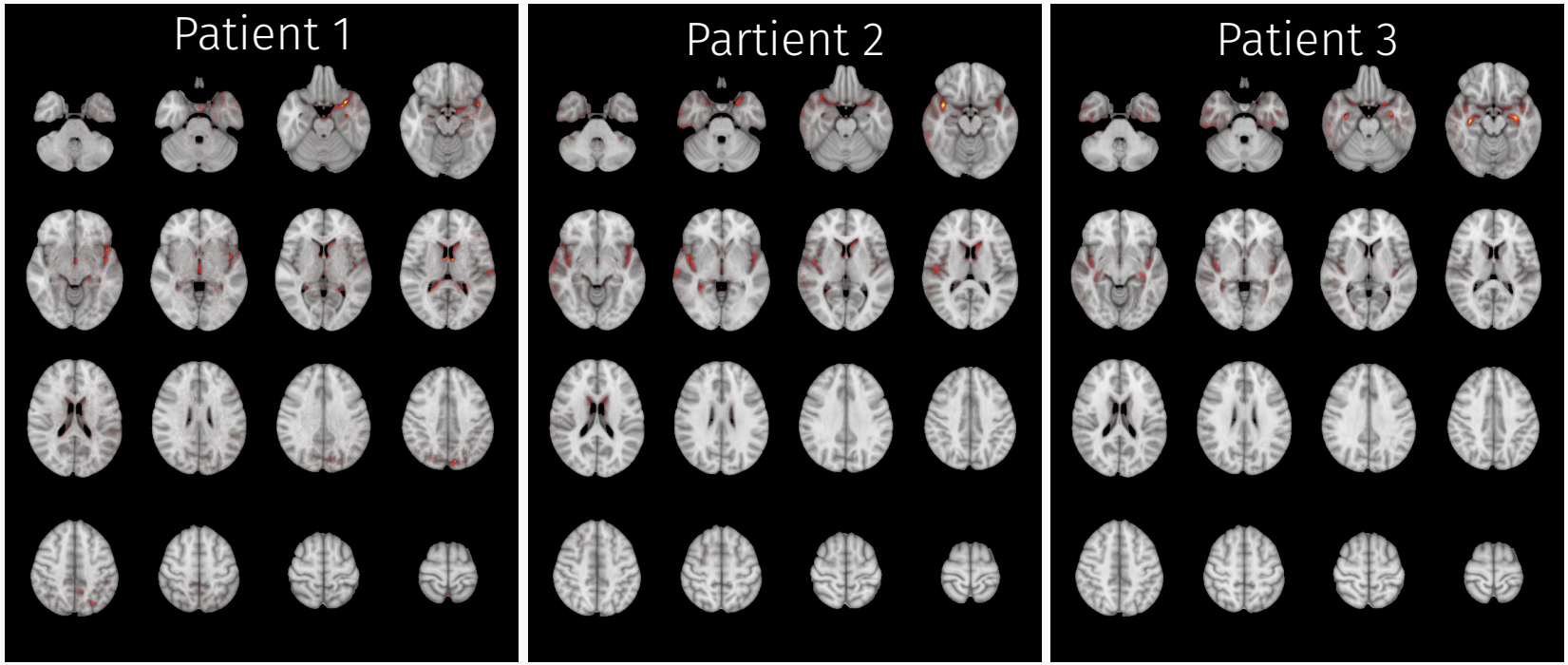


Explainable dementia classification: Modelling



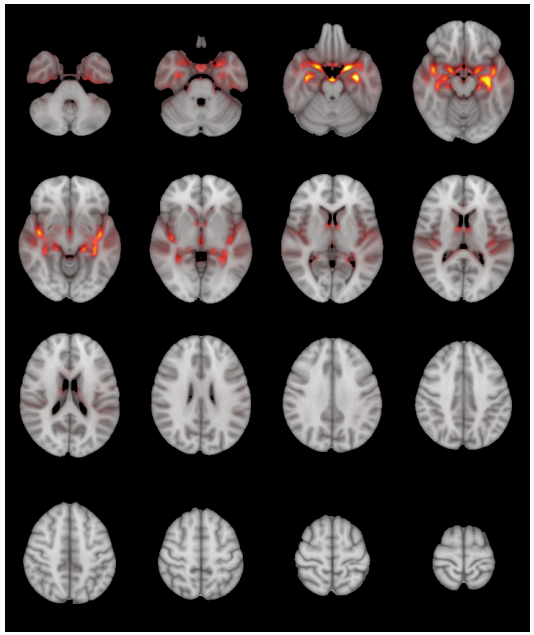


Explainable dementia classification: Modelling



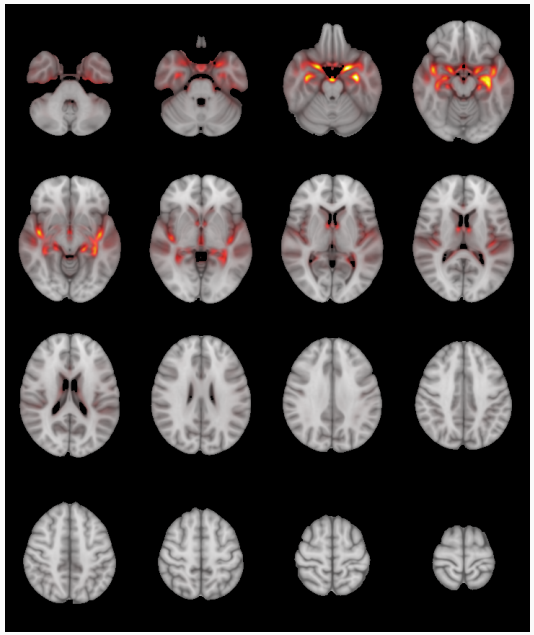
Explainable dementia classification: Validation

Explainable AI

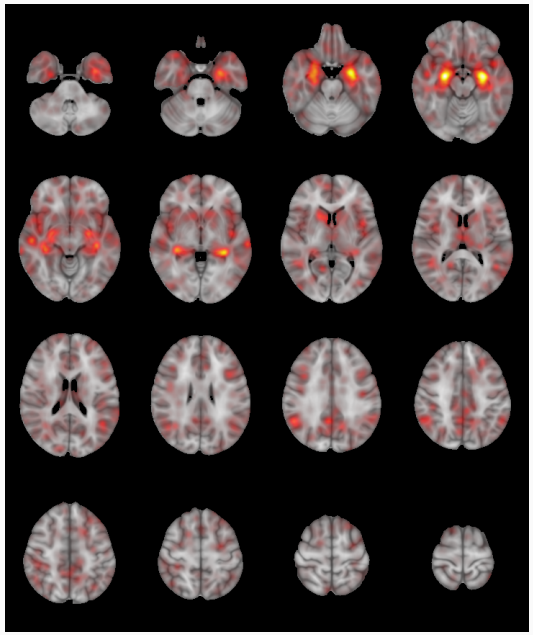


Explainable dementia classification: Validation

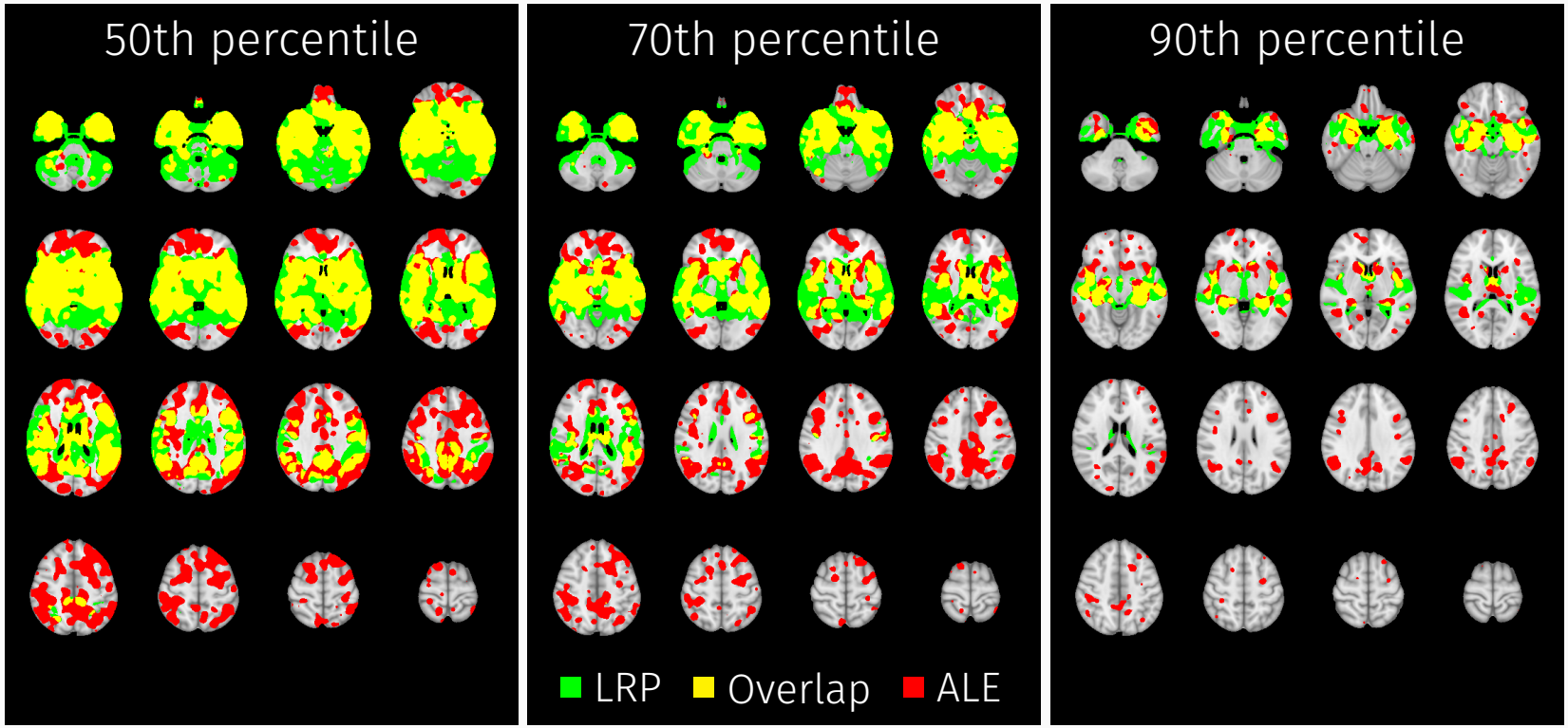
Explainable AI



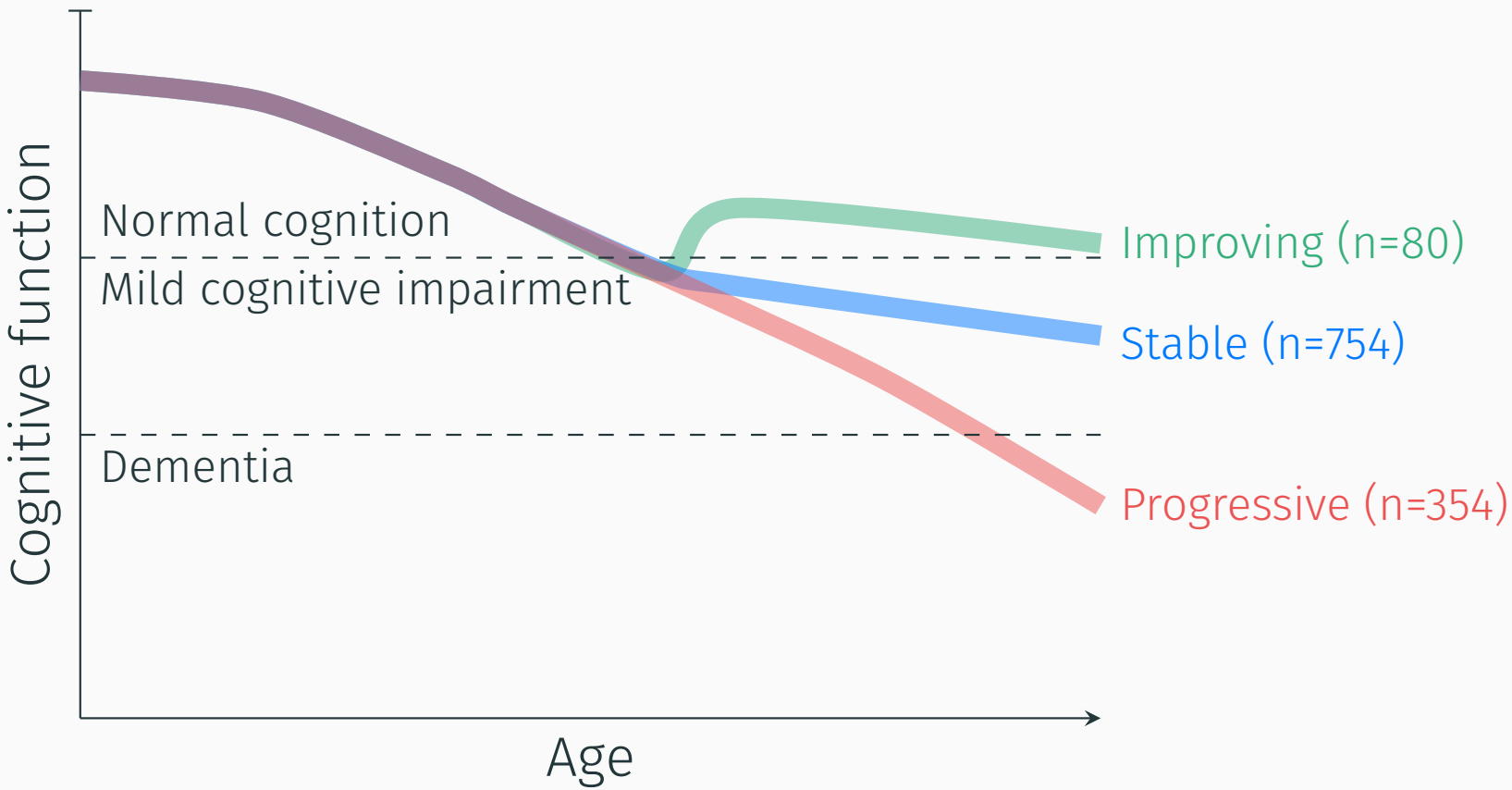
Human researchers



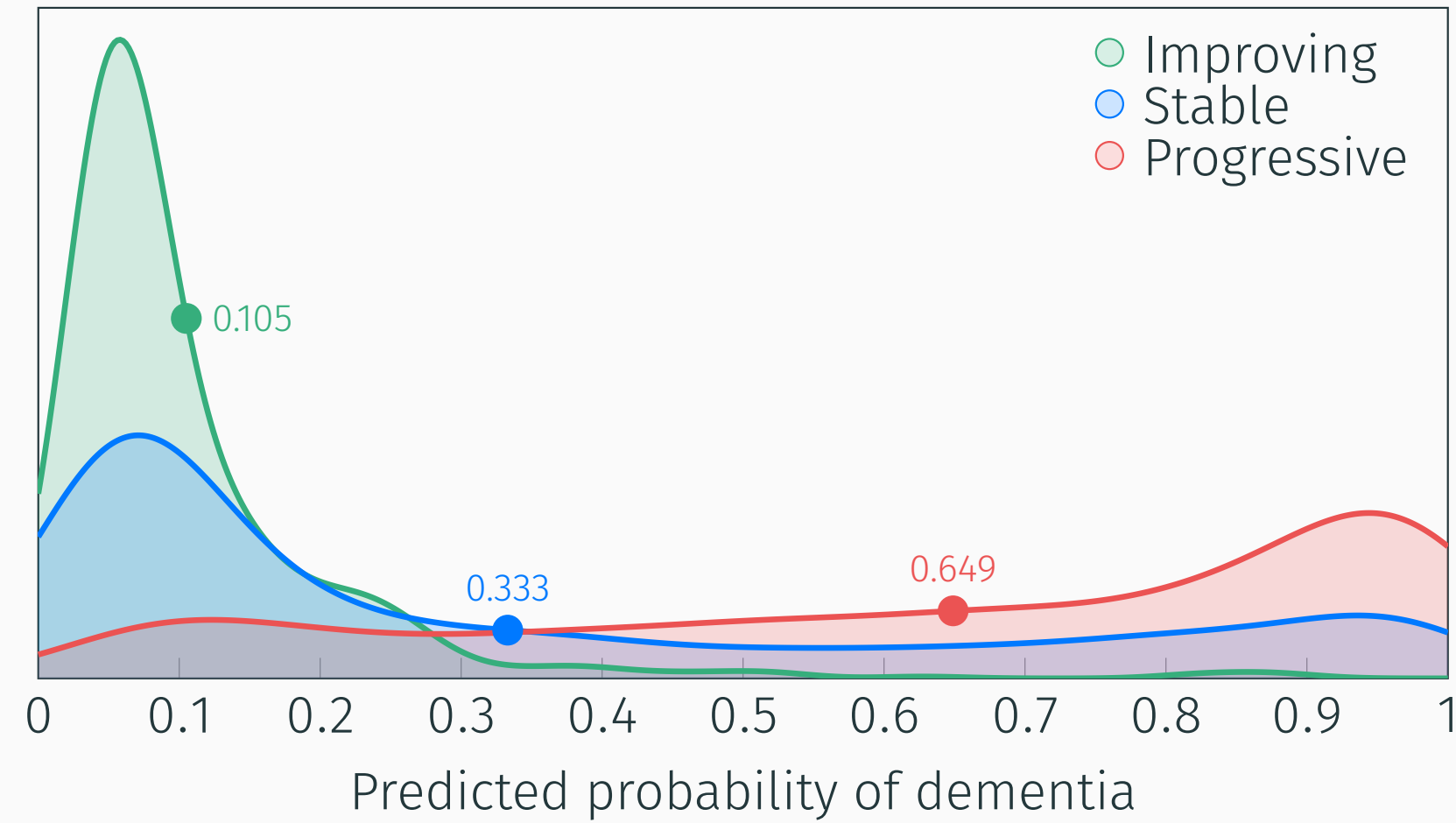
Explainable dementia classification: Validation



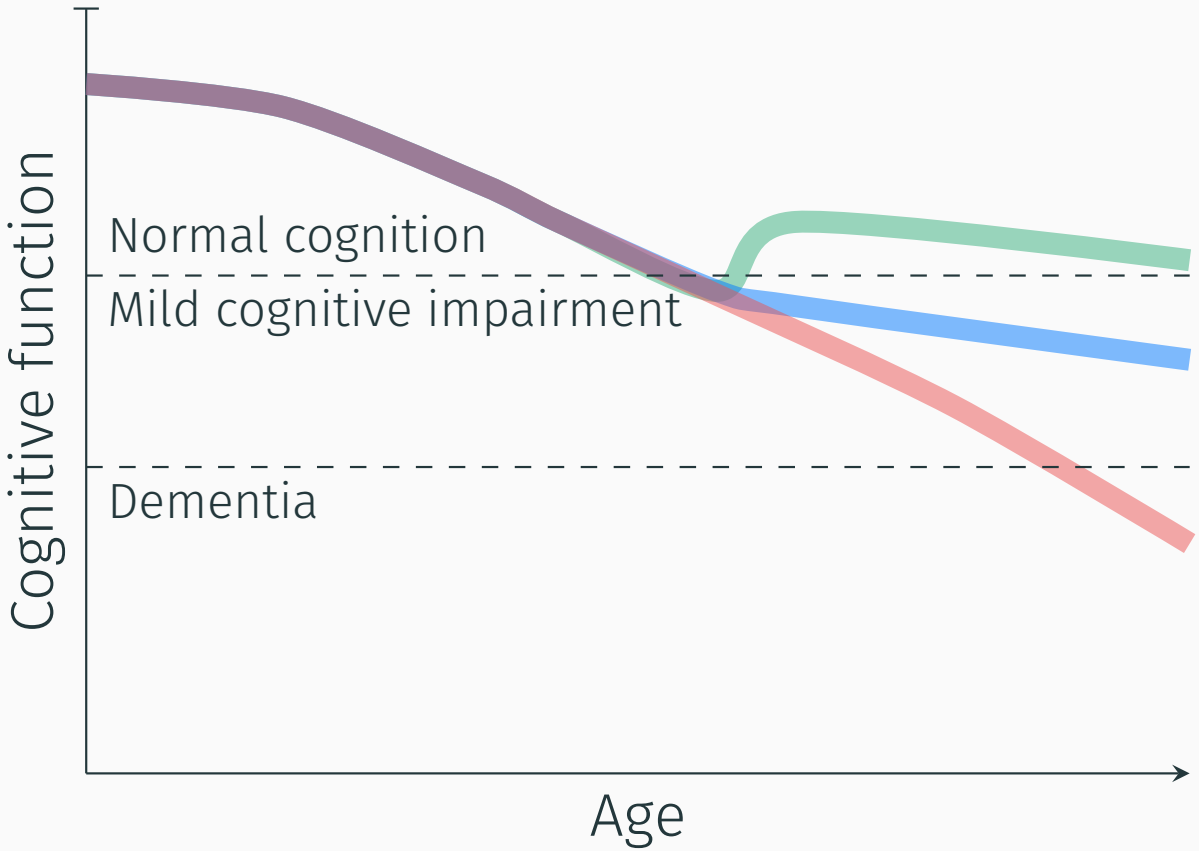
Explainable dementia classification: Application



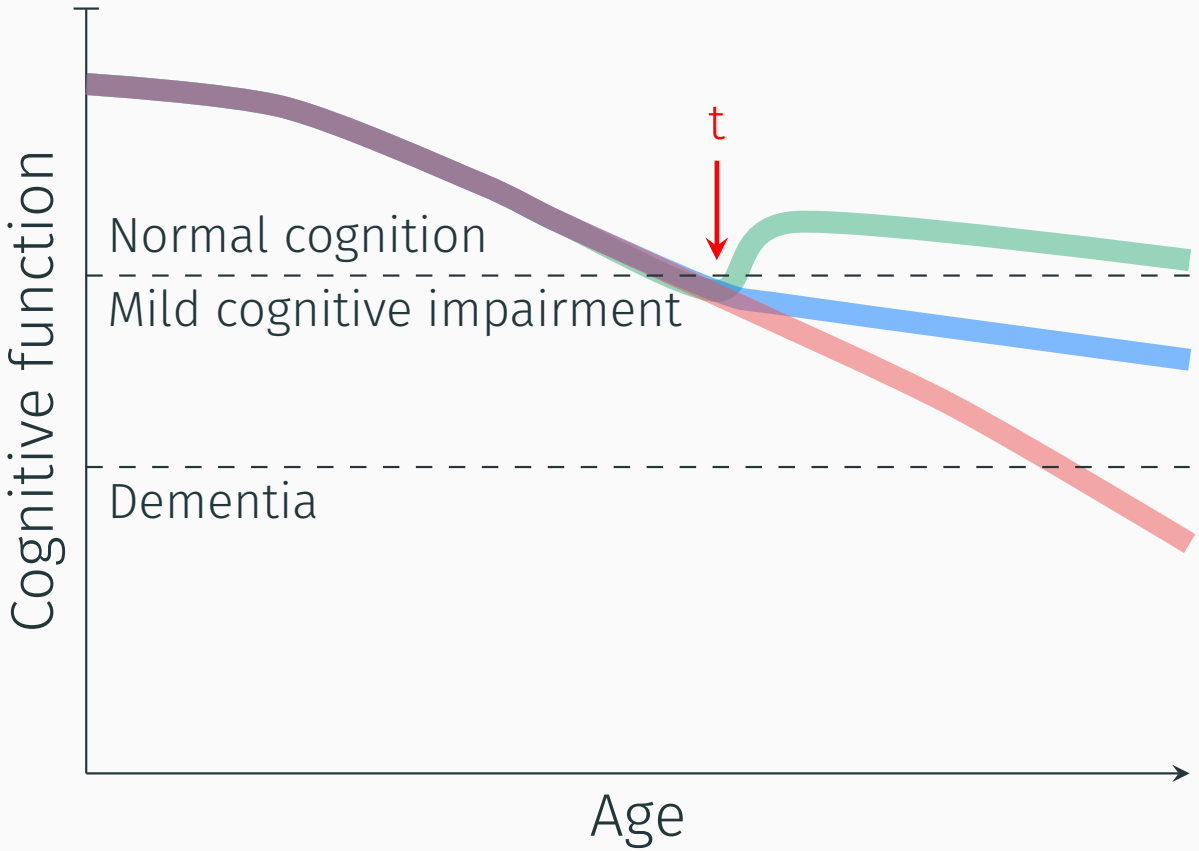
Explainable dementia classification: Application



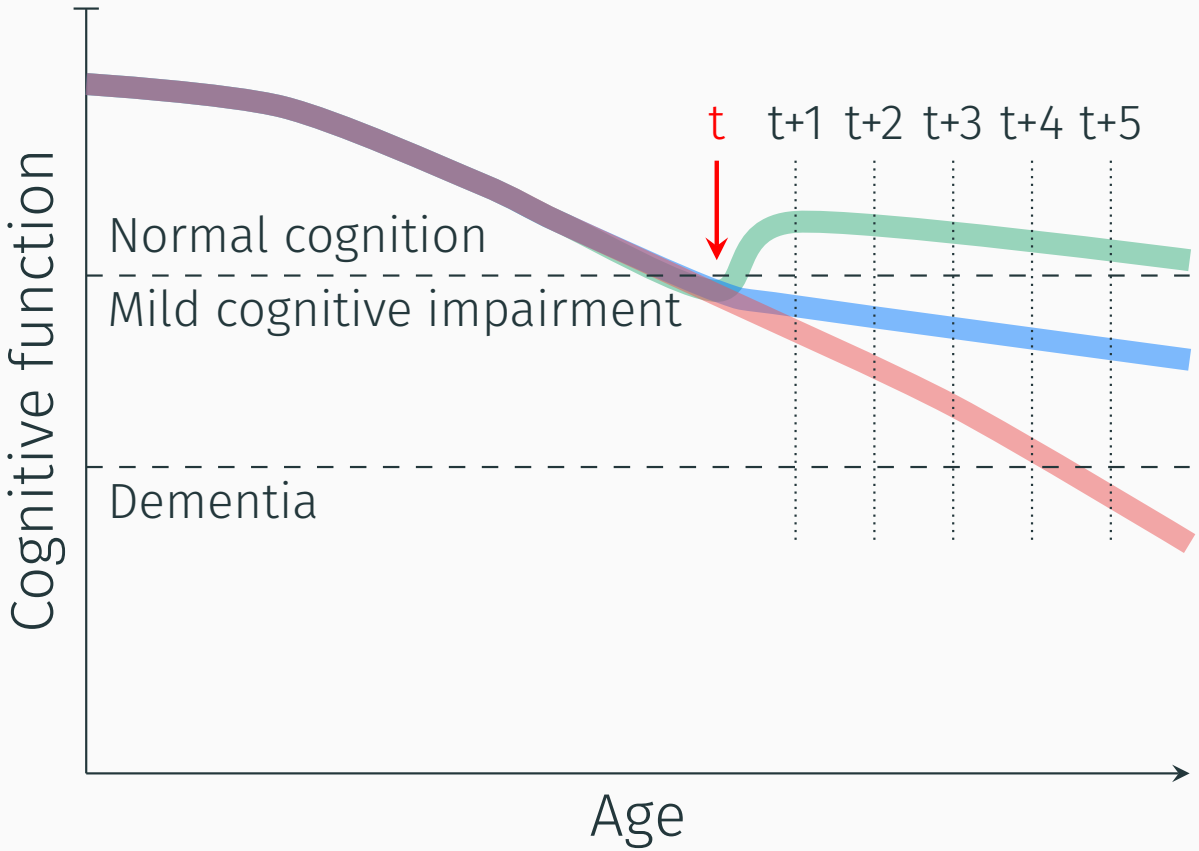
Explainable dementia classification: Application



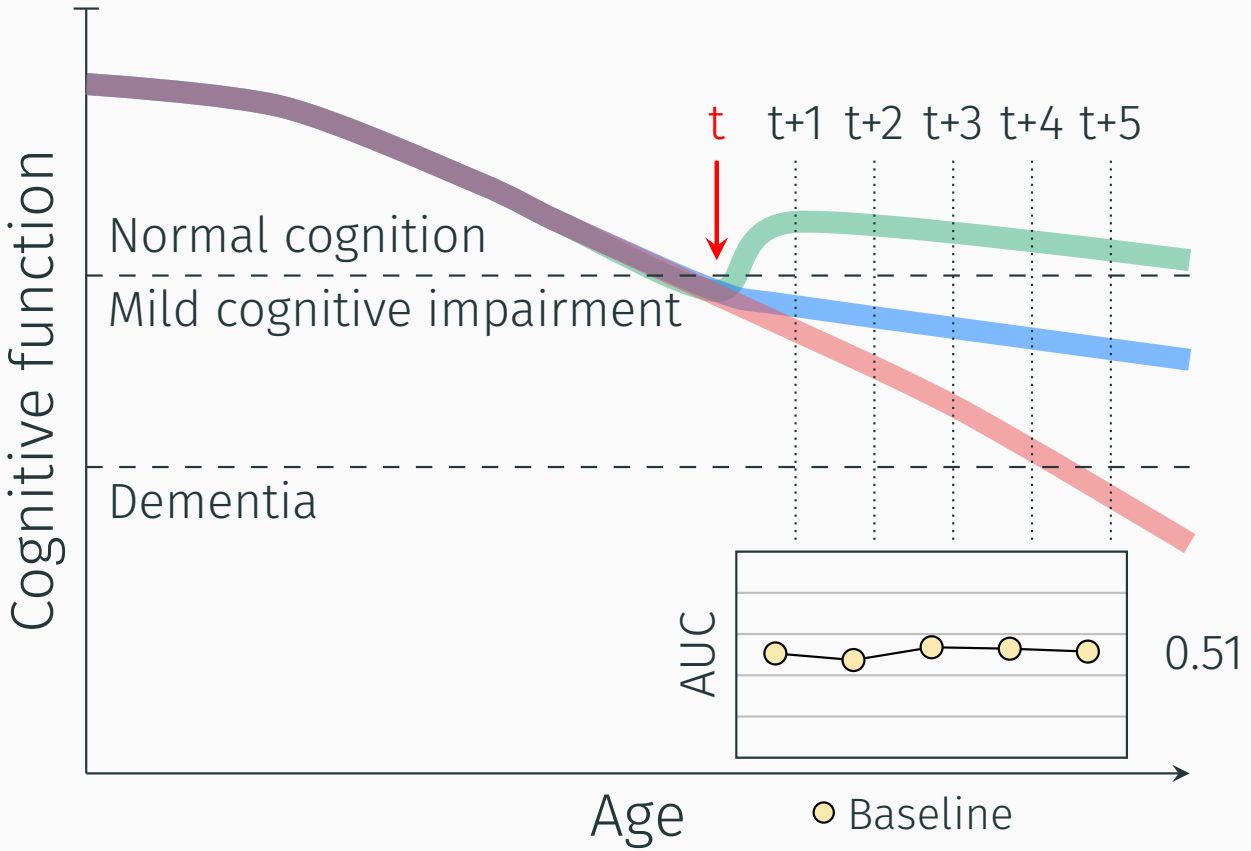
Explainable dementia classification: Application



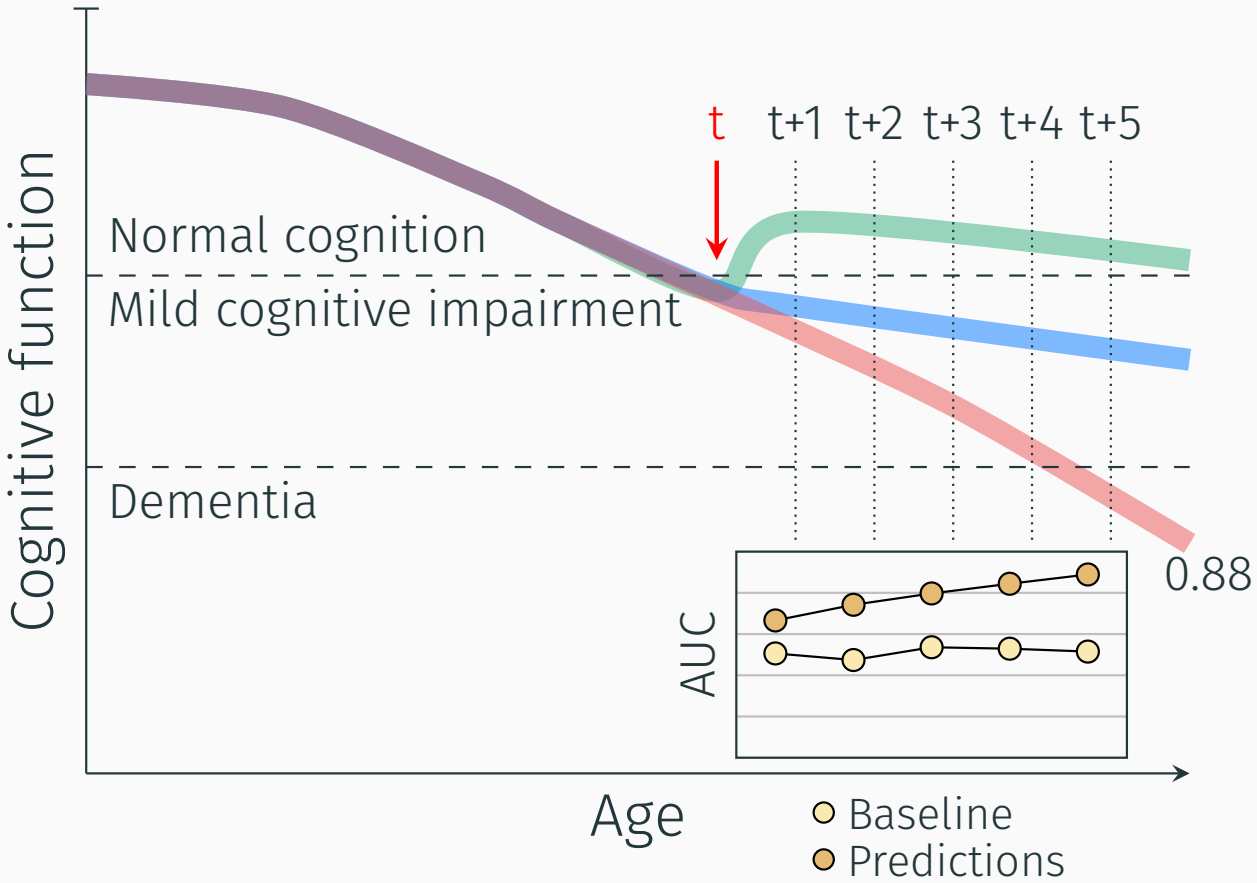
Explainable dementia classification: Application



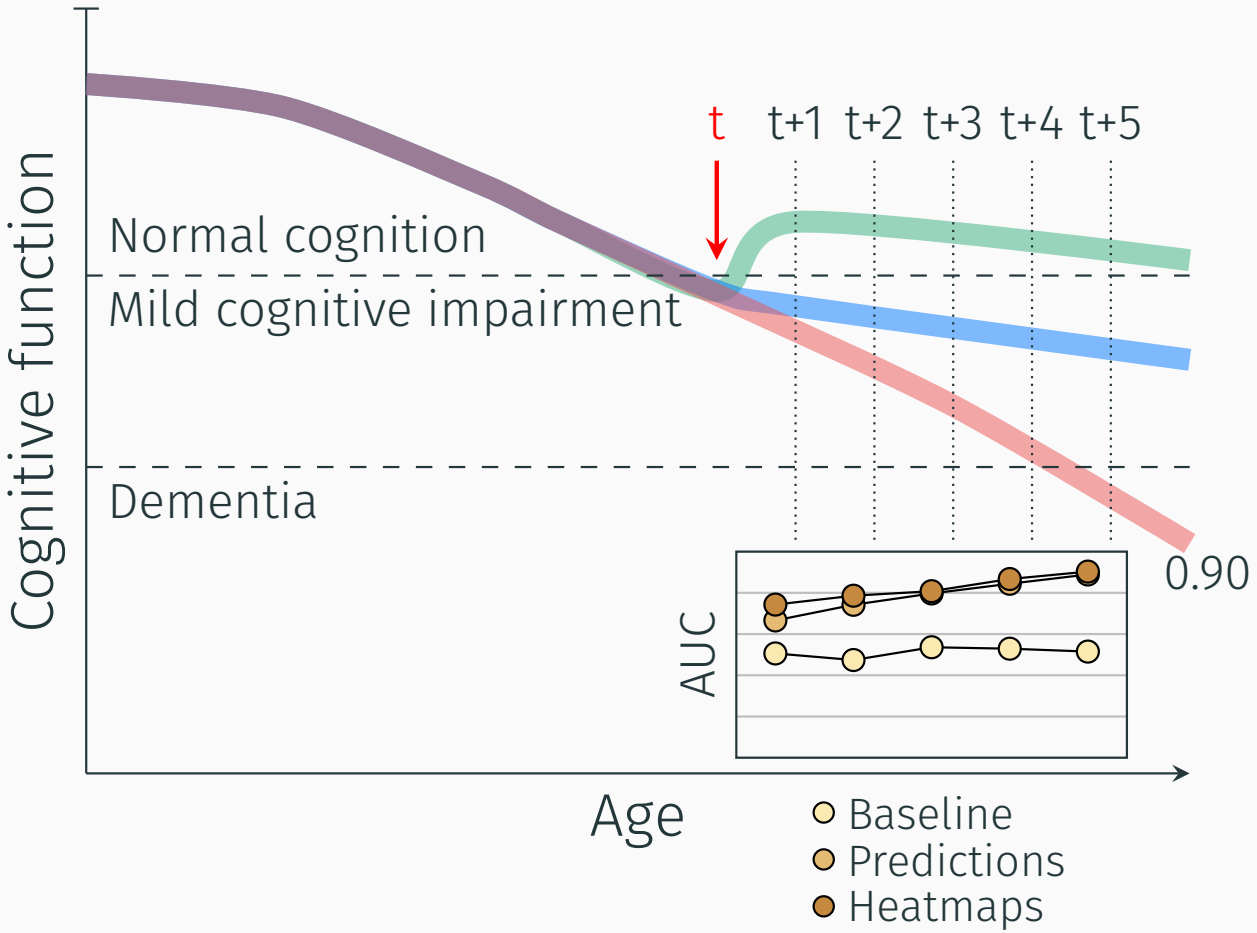
Explainable dementia classification: Application



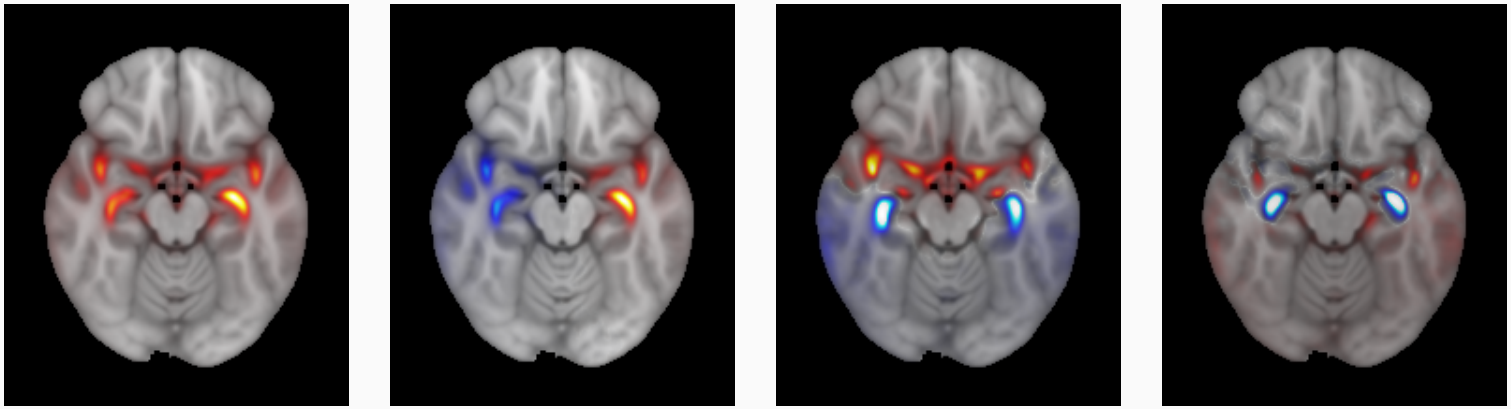
Explainable dementia classification: Application



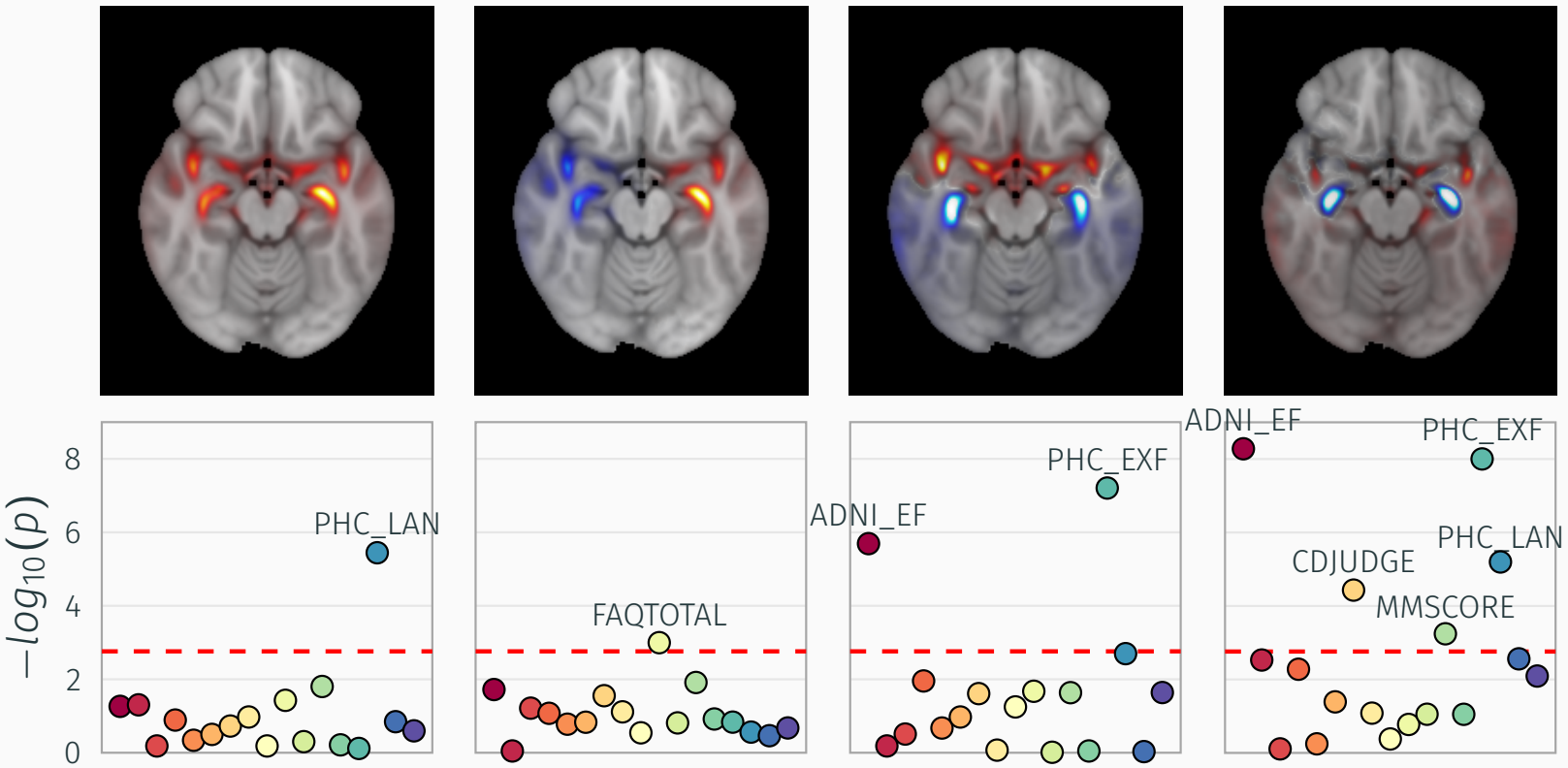
Explainable dementia classification: Application



Explainable dementia classification: Application



Explainable dementia classification: Application



Explainable dementia classification: Application

We used explainable AI to generate heatmaps characterizing the manifestation of dementia-related aberrations in individual brains

- Information in the heatmaps allowed us to predict progression from mild cognitive impairment to dementia with an AUC of 0.9 after 5 years
- Distinct patterns in the heatmaps were associated with decline in various cognitive domains

Explainable AI and brain age predictions

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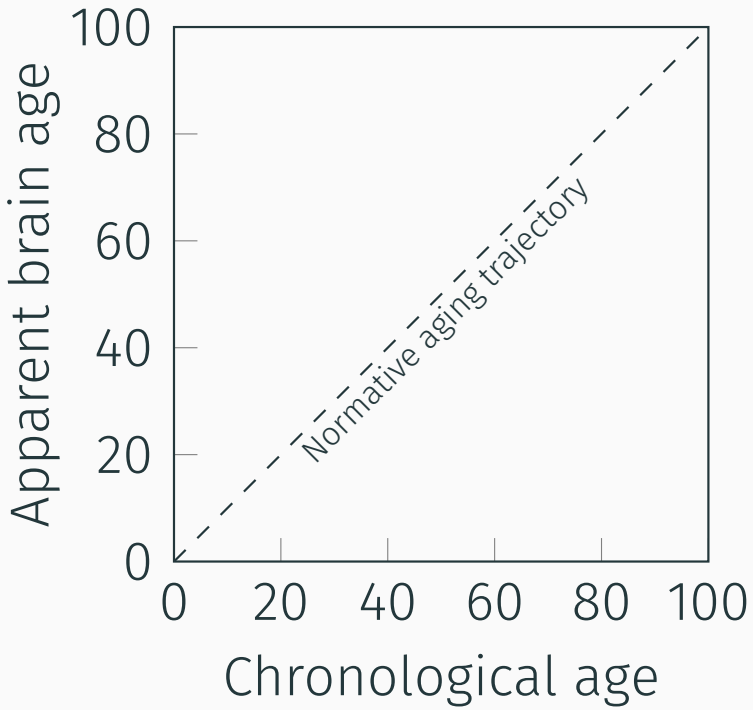
Explainable brain age: Motivation

Generated by Dall-E 3

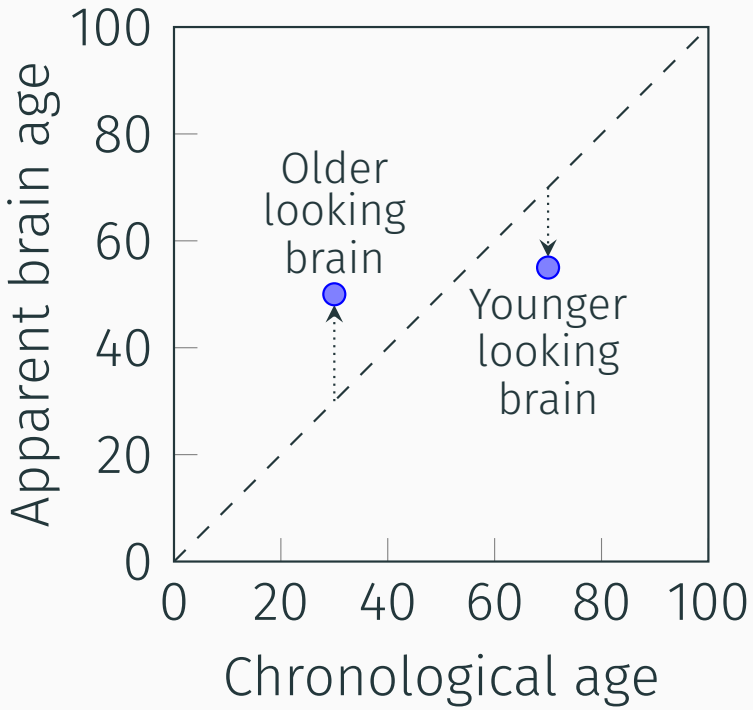
Explainable brain age: Motivation

Generated by Dall-E 3

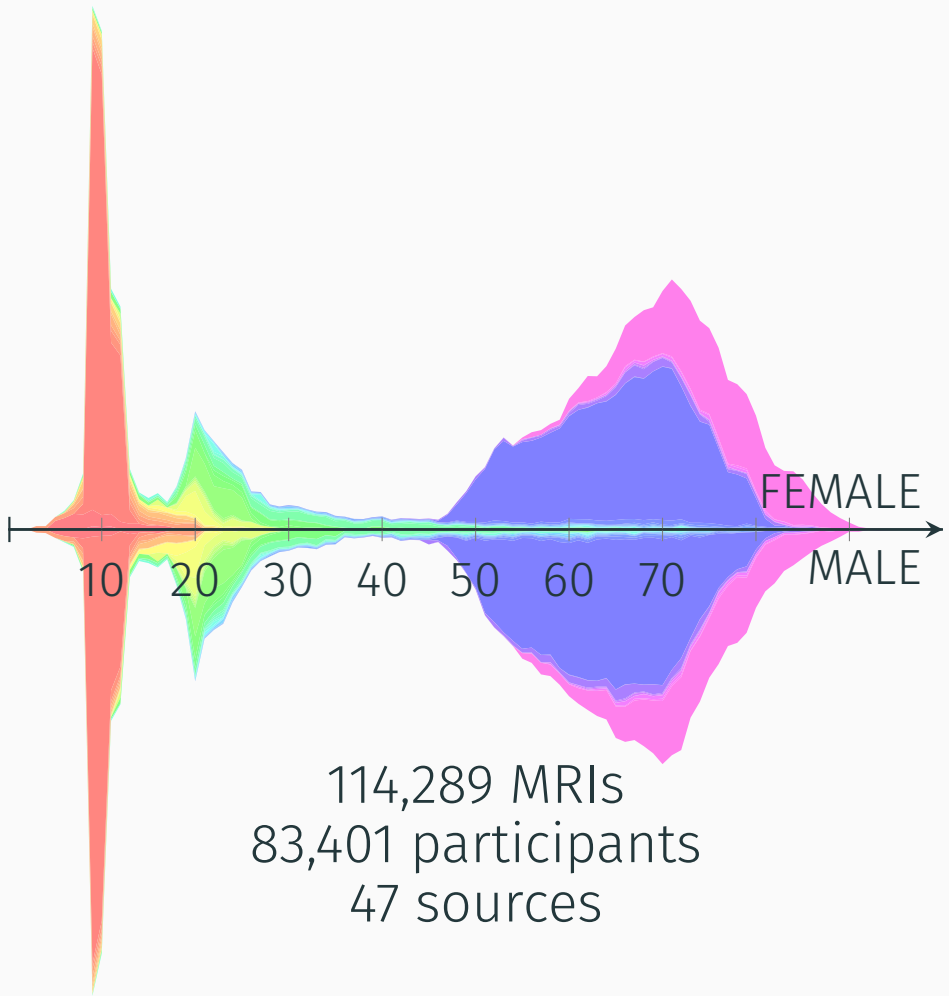


Explainable brain age: Motivation

Generated by Dall-E 3



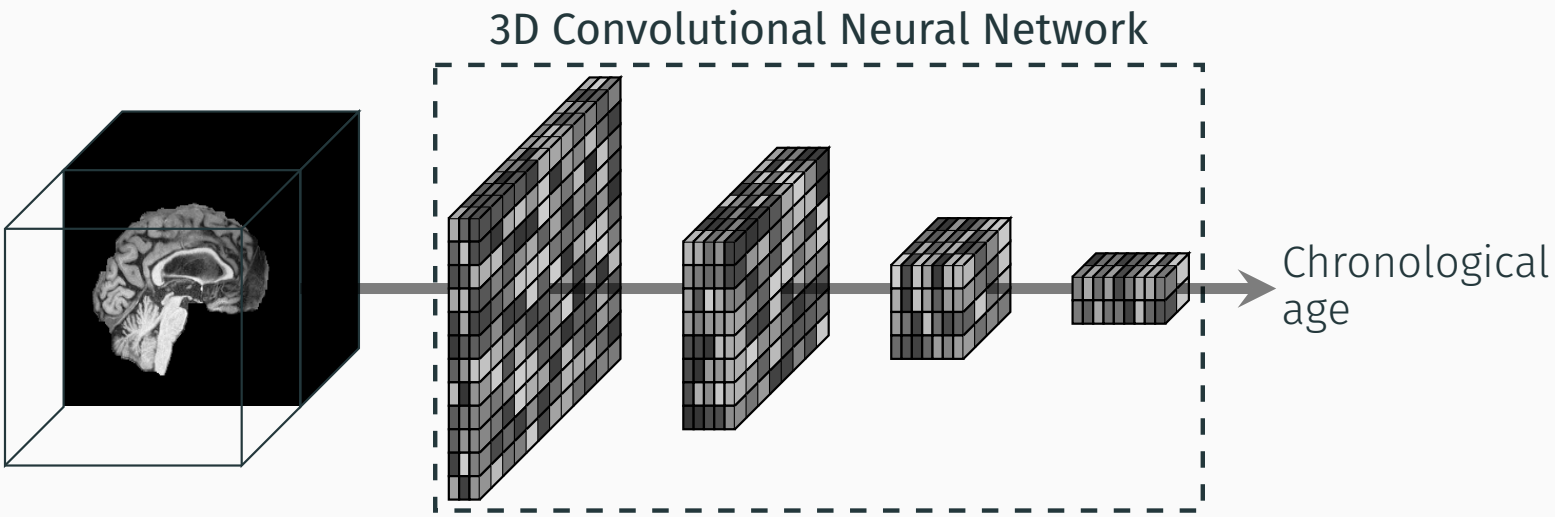
Explainable brain age: Motivation



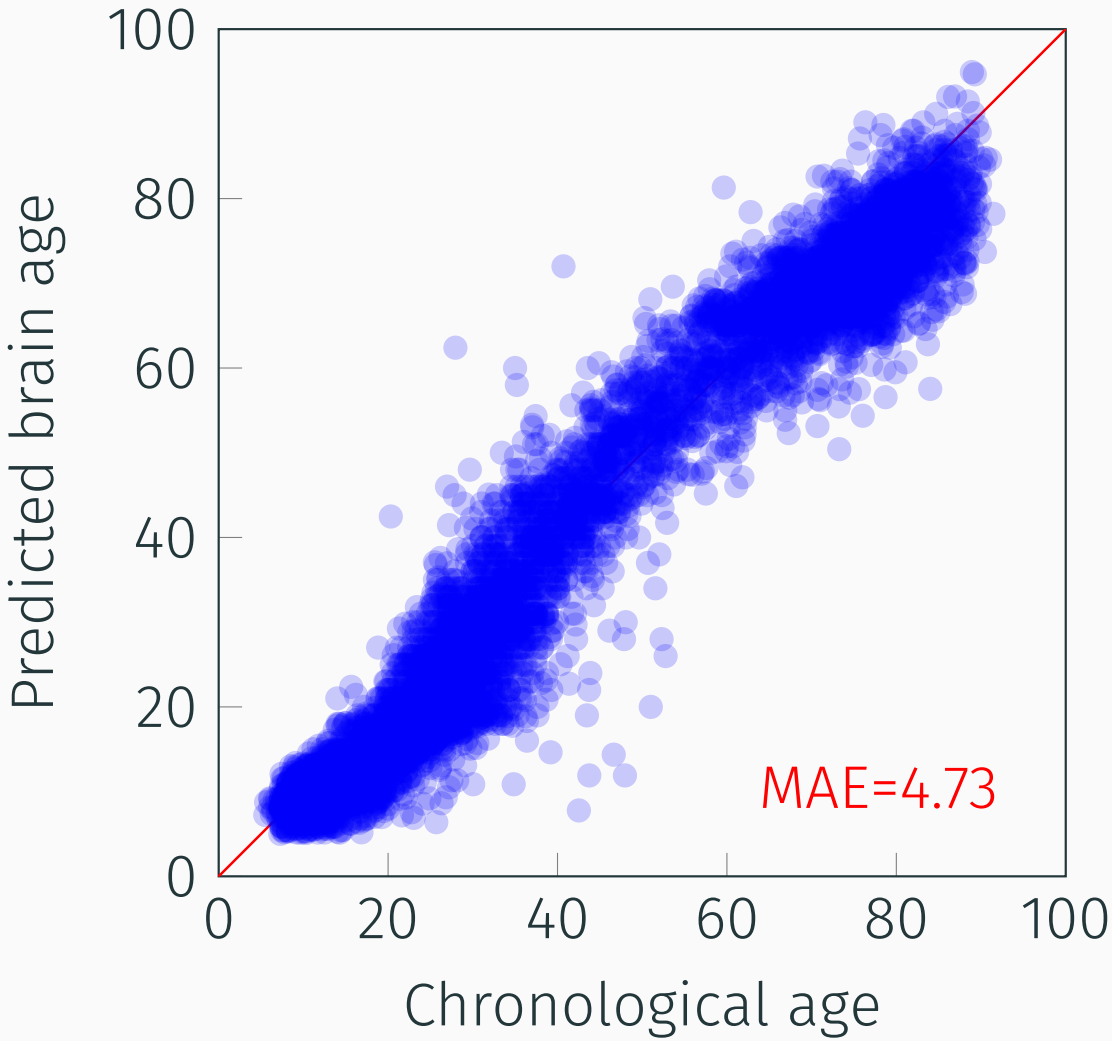
114,289 MRIs
83,401 participants
47 sources

- ds002424
- HBN
- ABCD
- QTAB
- PING
- ADHD200
- PNC
- ABIDE-II
- ds000119
- ABIDE-I
- BRAINMINT
- SLIM
- QTIM
- Beijing
- AOMIC-PIOP2
- ds000202
- AOMIC-PIOP1
- AOMIC-ID1000
- CoRR
- HCP
- FCON1000
- ds000171
- TOP
- SCZ-Z
- NIMH
- NKI-RS
- MPI-LEMON
- ds003592
- ds004302
- ds000222
- SALD
- IXI
- DLBS
- Cam-CAN
- StrokeMRI
- PPMI
- UKBB
- Tao-Wu
- ds000245
- OASIS3
- Demgen
- NEUROCON
- MIRIAD
- ds004392
- AIBL
- ANM
- ADNI

Explainable brain age: Motivation



Explainable brain age: Motivation



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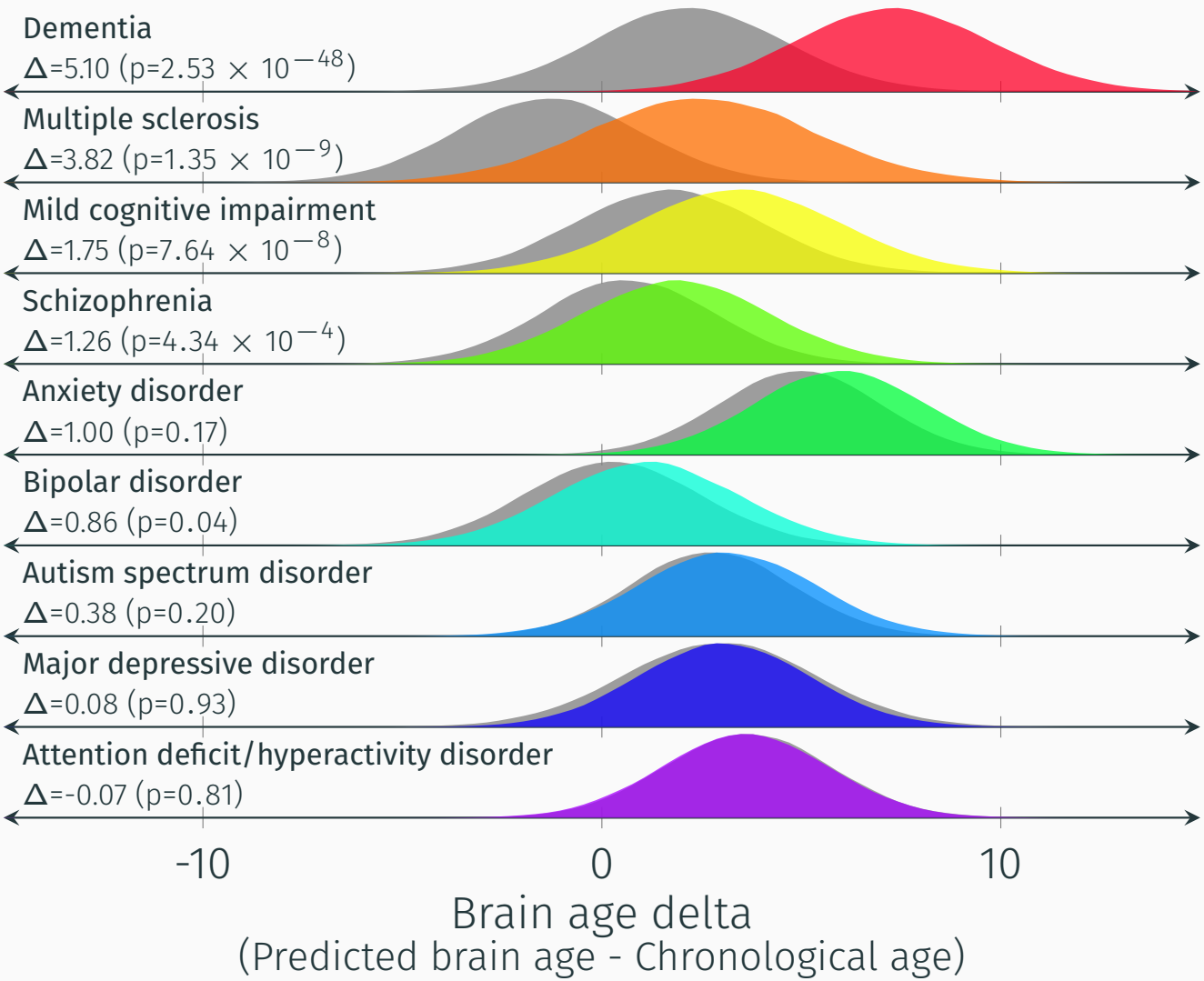
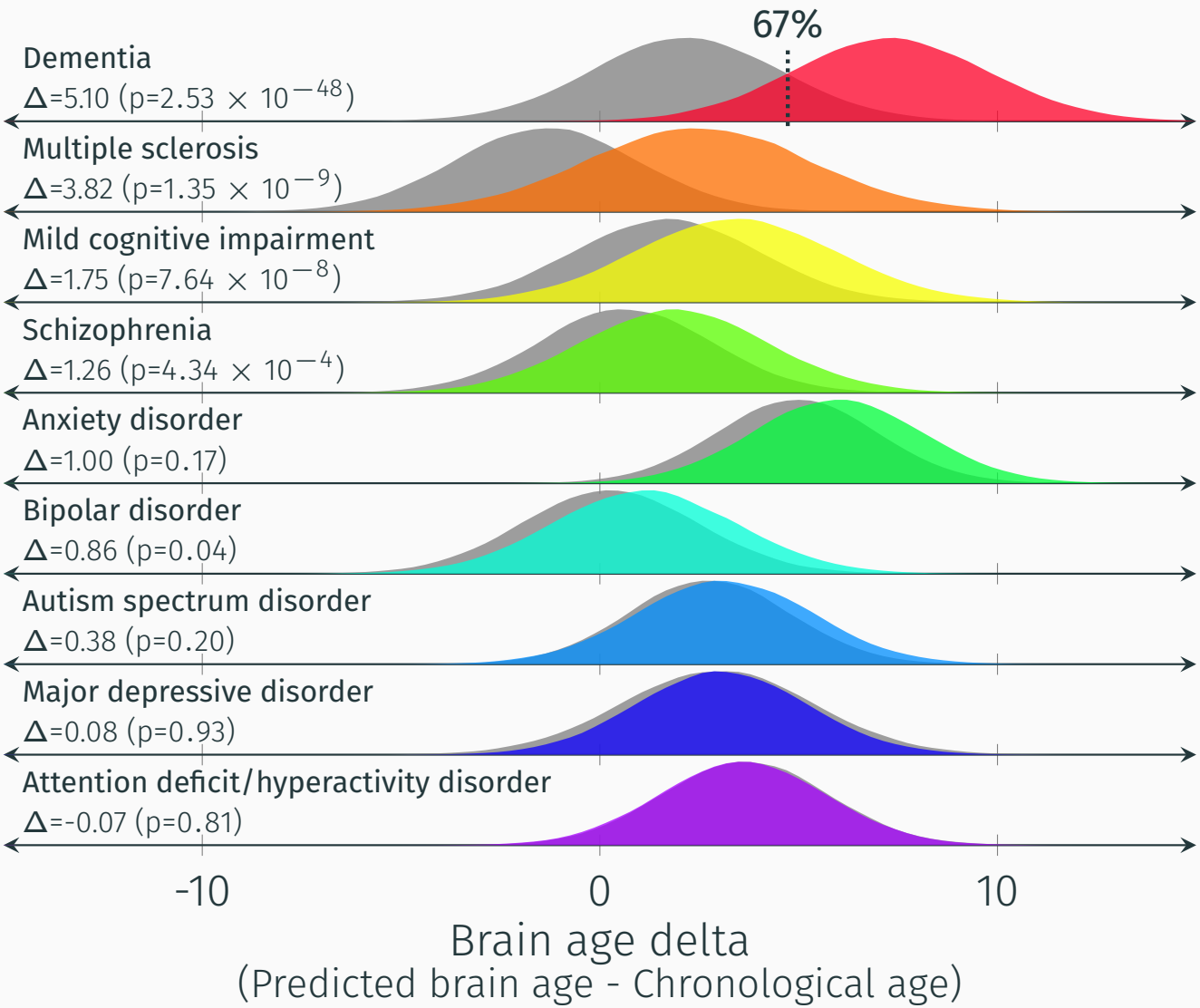
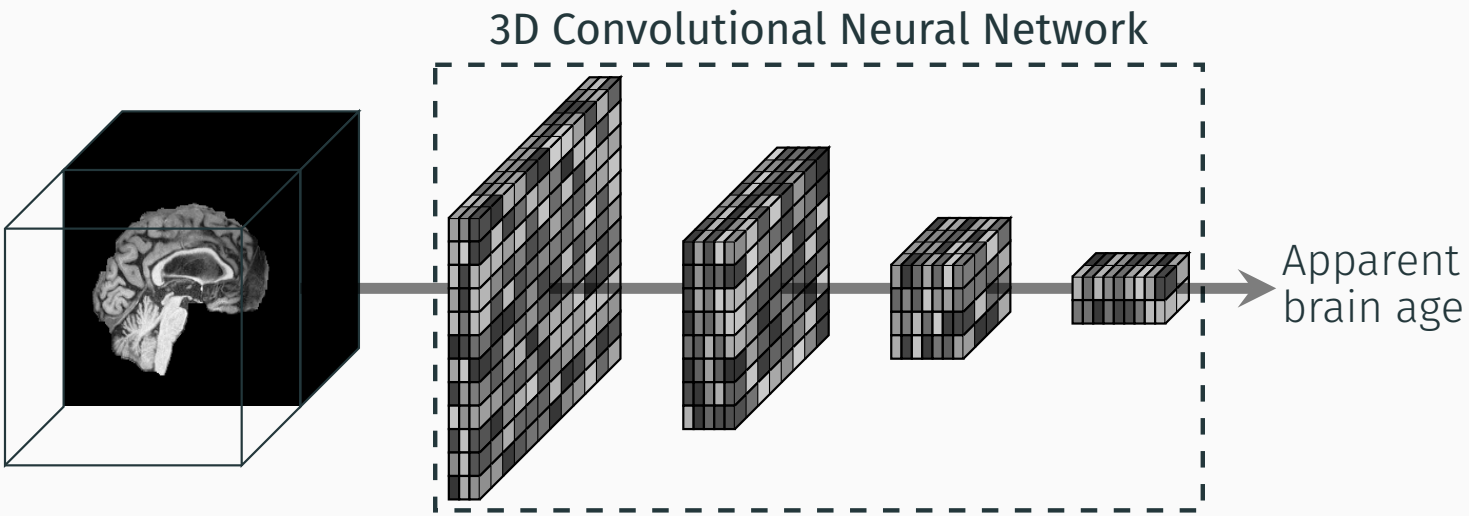


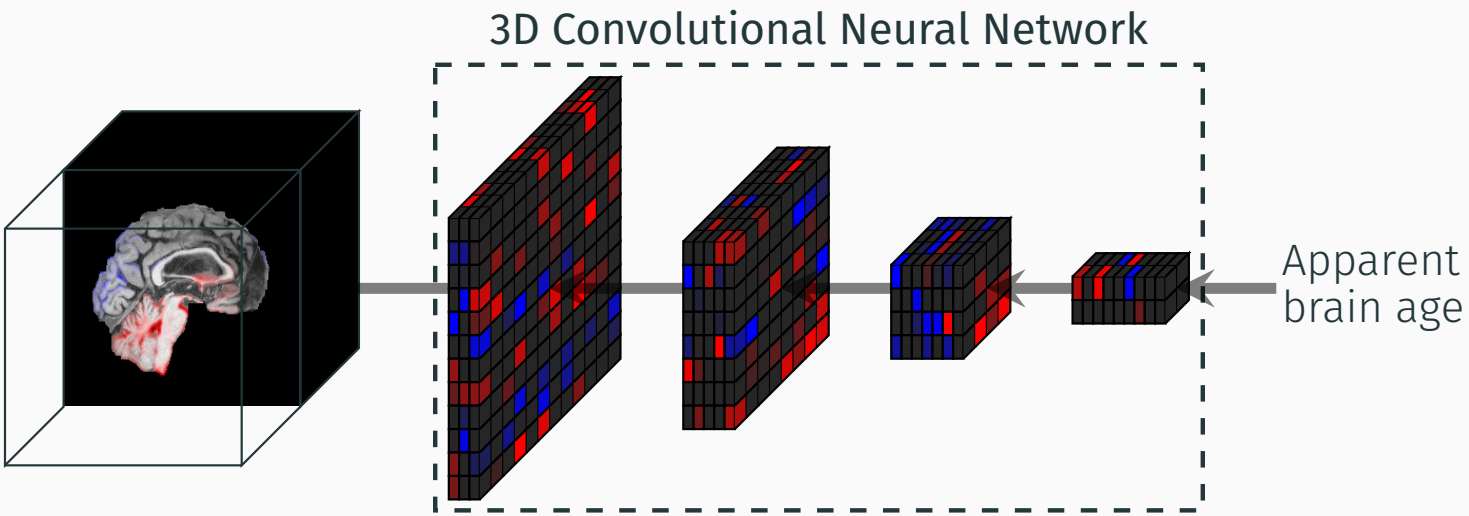
Explainable brain age: Motivation



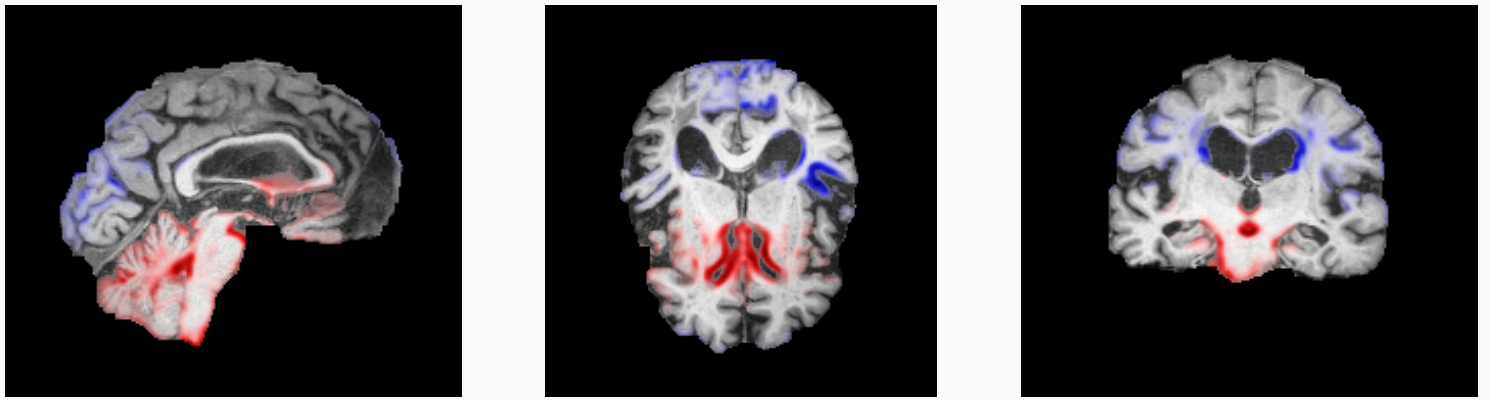
Explainable brain age: Methods



Explainable brain age: Methods



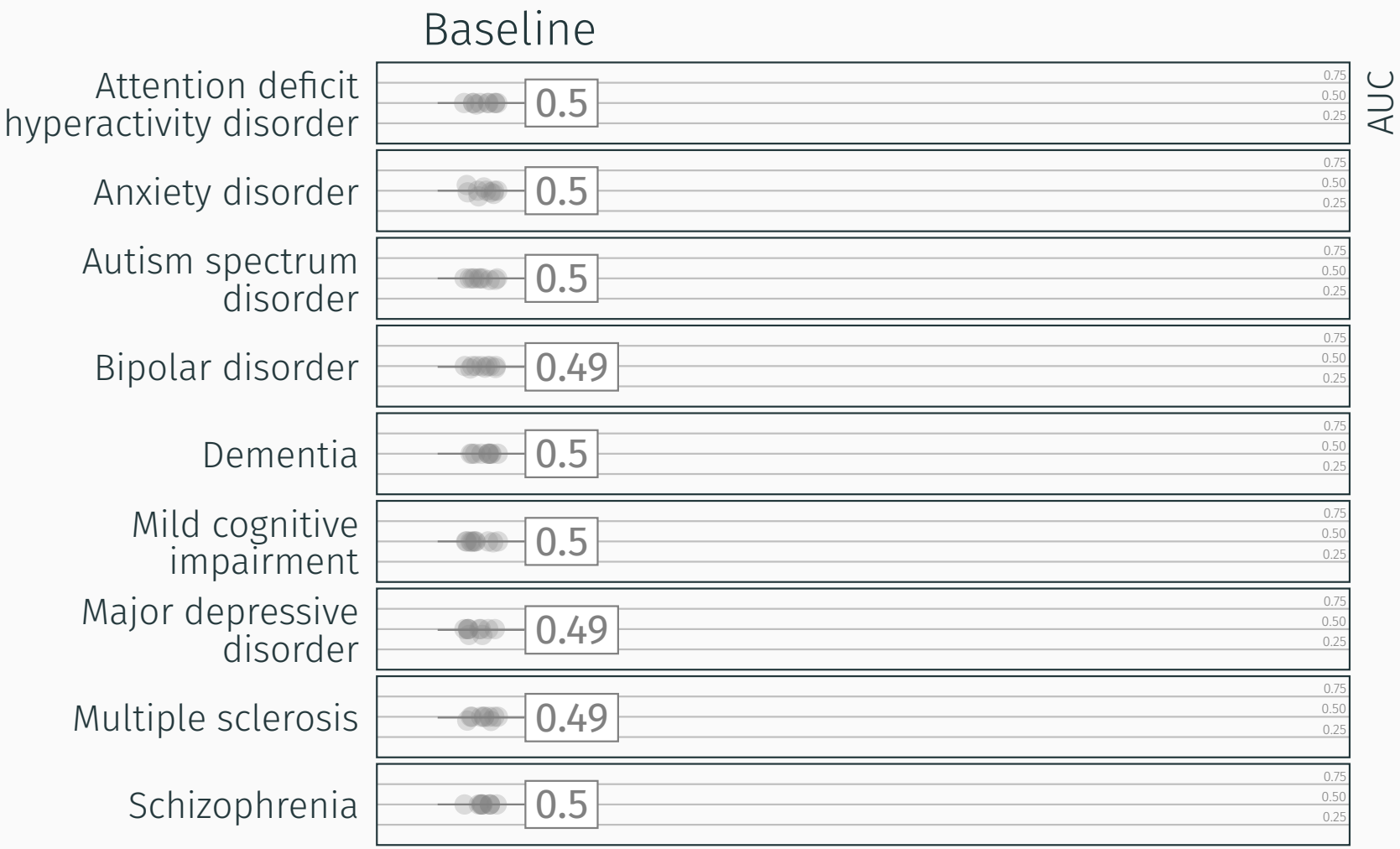
Explainable brain age: Methods



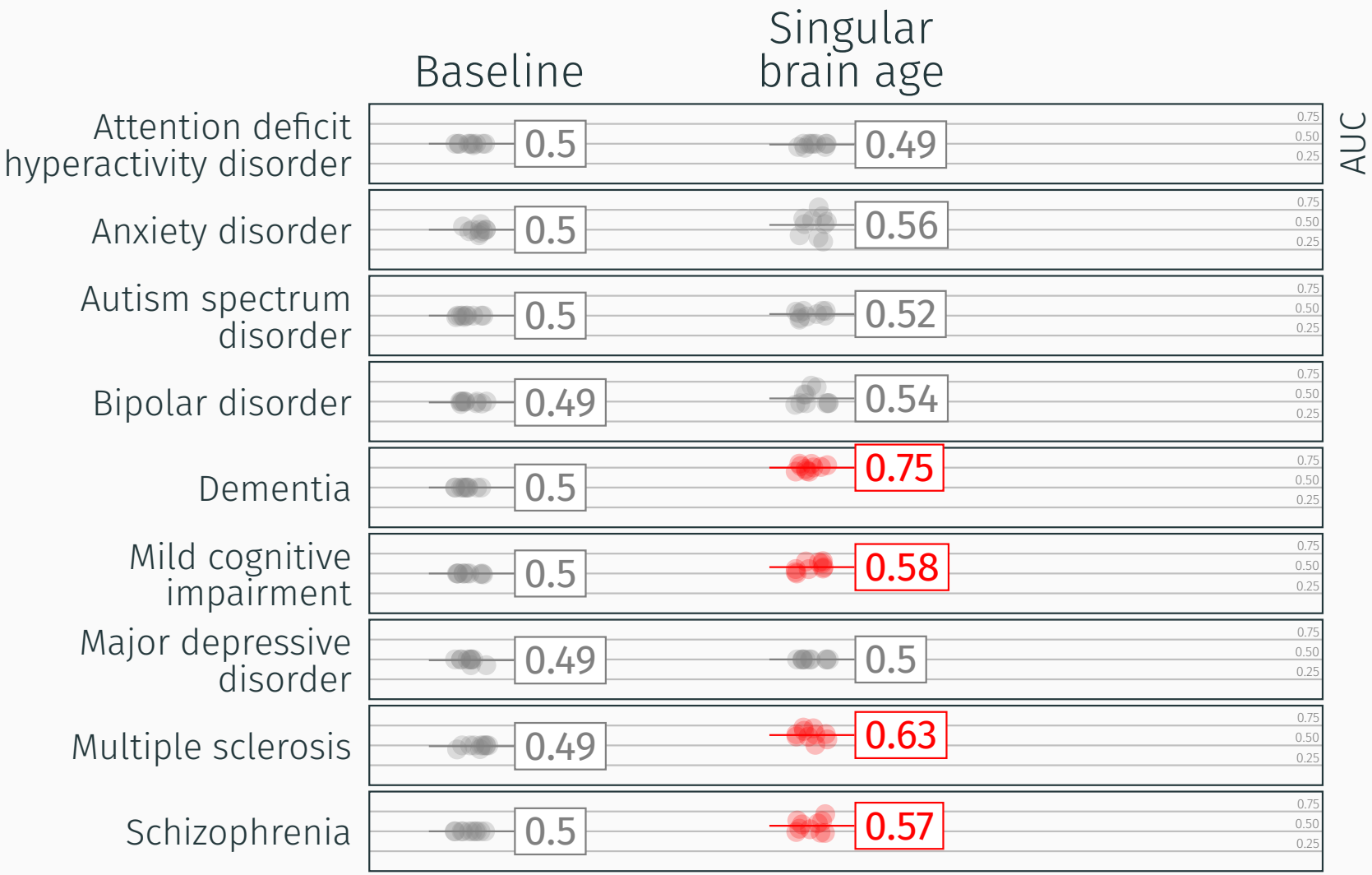
Younger appearing

Older appearing

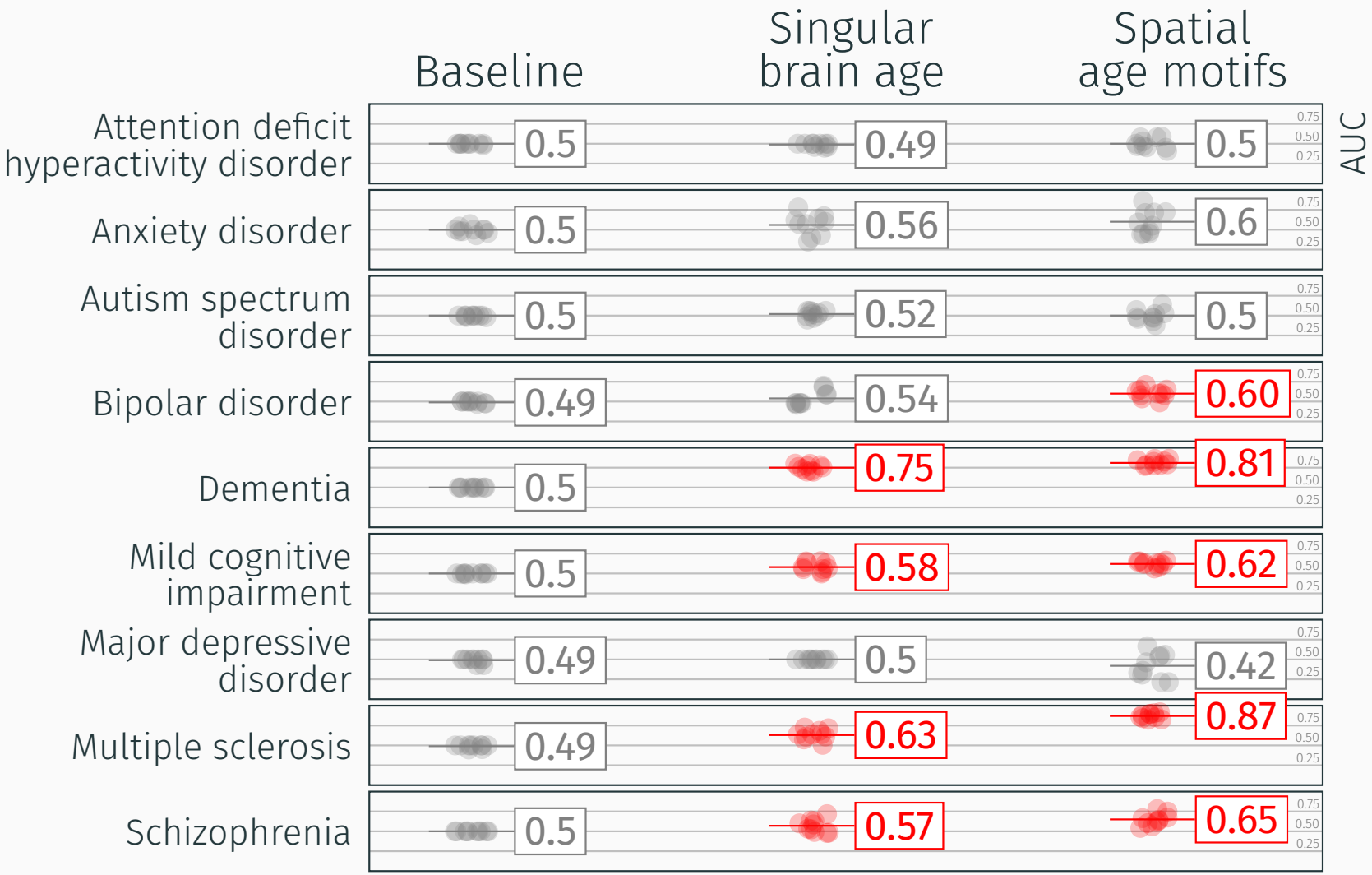
Explainable brain age: Results



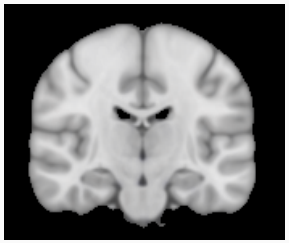
Explainable brain age: Results



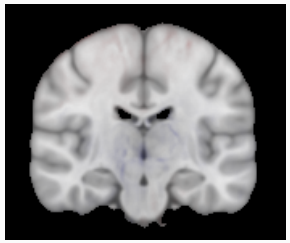
Explainable brain age: Results



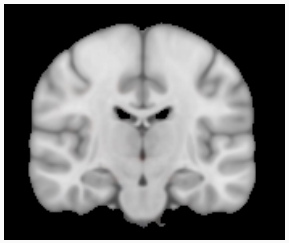
Explainable brain age: Results



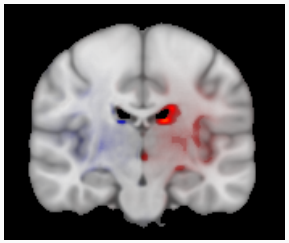
Attention deficit hyperactivity disorder



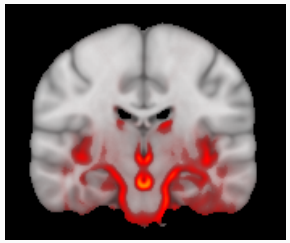
Anxiety disorder



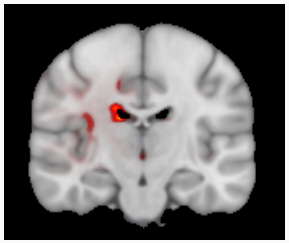
Autism spectrum disorder



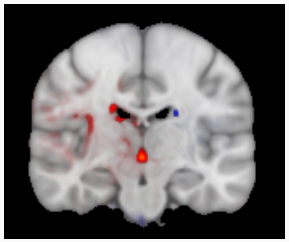
Bipolar disorder



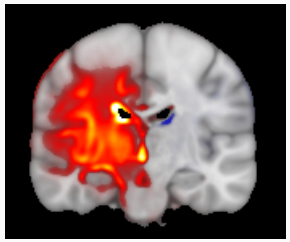
Dementia



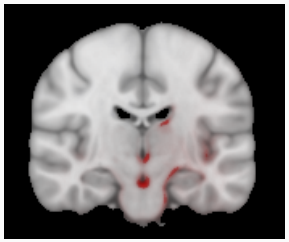
Schizophrenia



Major depressive disorder

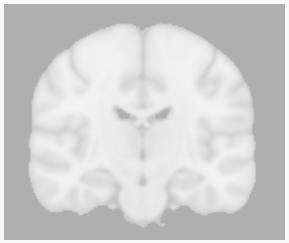


Multiple sclerosis

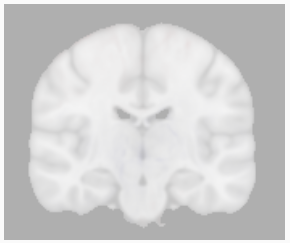


Mild cognitive impairment

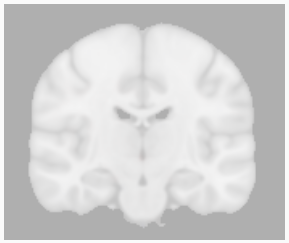
Explainable brain age: Results



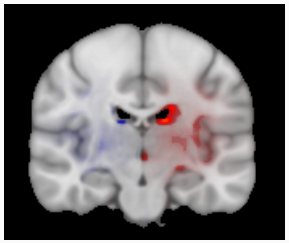
Attention deficit hyperactivity disorder



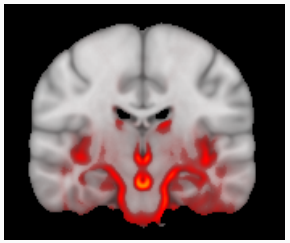
Anxiety disorder



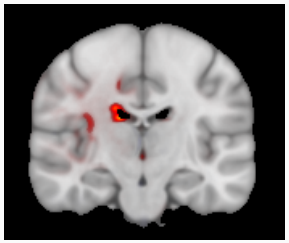
Autism spectrum disorder



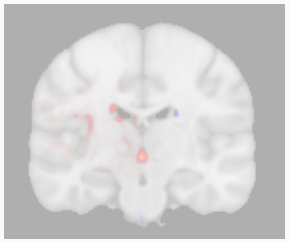
Bipolar disorder



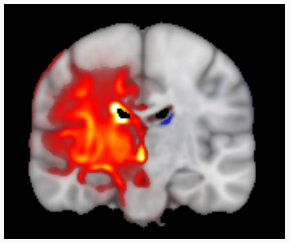
Dementia



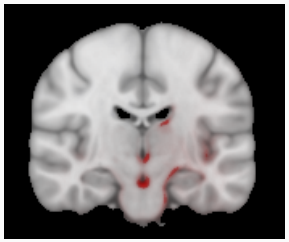
Schizophrenia



Major depressive disorder

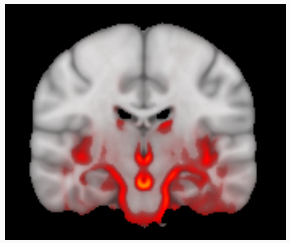


Multiple sclerosis



Mild cognitive impairment

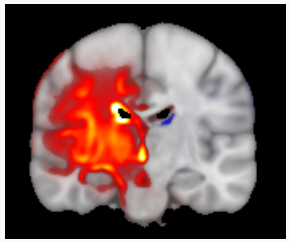
Explainable brain age: Results



Dementia

- Temporal pole
- Left amygdala
- Parahippocampal gyrus

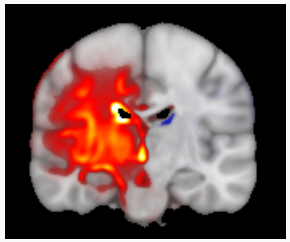
Explainable brain age: Results



Multiple sclerosis

- Right pallidum
- Right thalamus
- Right putamen

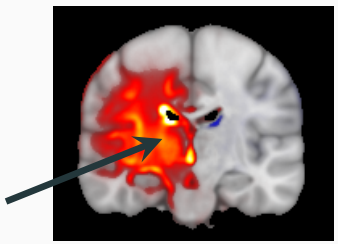
Explainable brain age: Results



Multiple sclerosis

- Right pallidum
- Right thalamus
- Right putamen

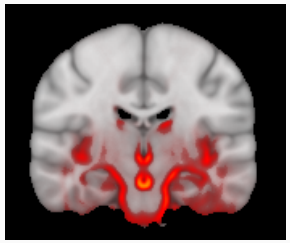
Explainable brain age: Results



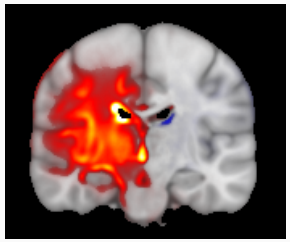
Multiple sclerosis

- Right pallidum
- Right thalamus
- Right putamen

Explainable brain age: Results

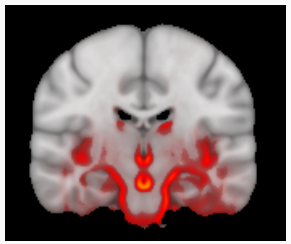
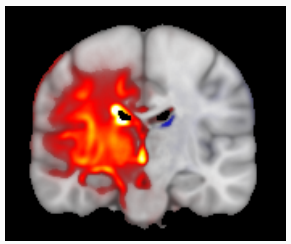


Dementia

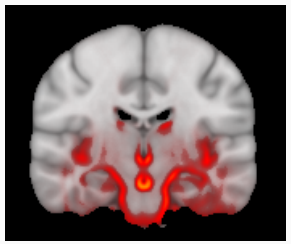


Multiple sclerosis

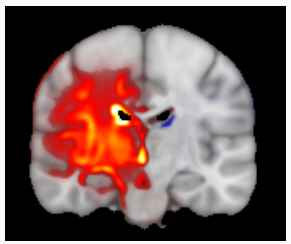
Explainable brain age: Results

	AUC	
	Singular brain age	Spatial age motifs
 Dementia	0.75	0.81
 Multiple sclerosis	0.63	0.87

Explainable brain age: Results



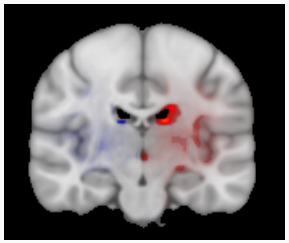
Dementia



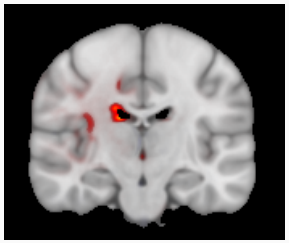
Multiple sclerosis

	AUC	
	Singular brain age	Spatial age motifs
Dementia	0.75	0.81 (+0.06)
Multiple sclerosis	0.63	0.87 (+0.24)

Explainable brain age: Results

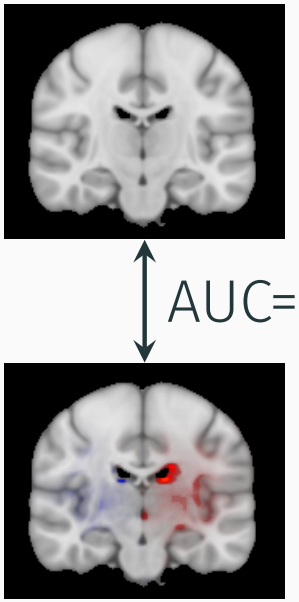


Bipolar disorder



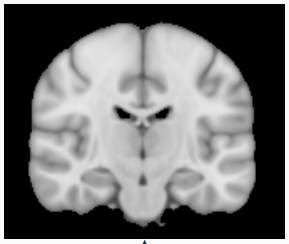
Schizophrenia

Explainable brain age: Results

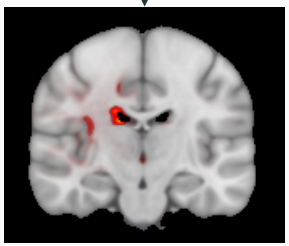


AUC=0.60

Bipolar disorder

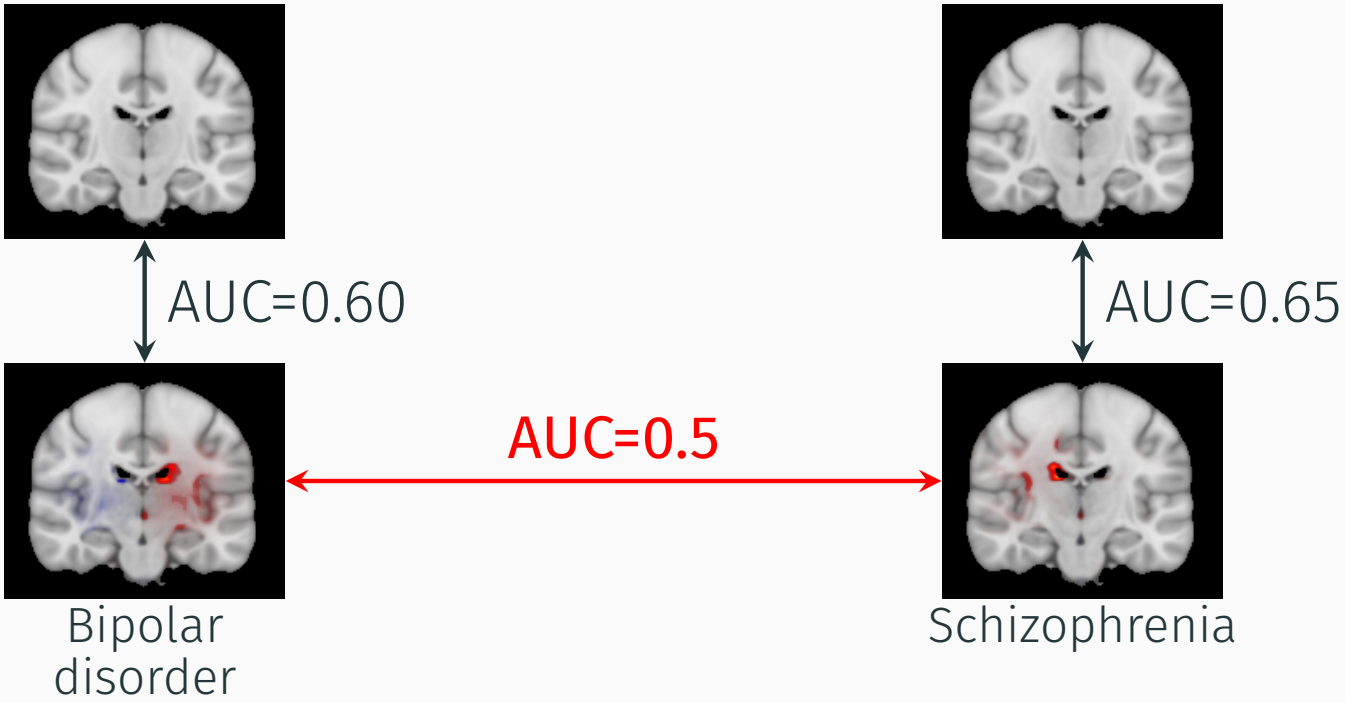


AUC=0.65



Schizophrenia

Explainable brain age: Results



Explainable brain age: Results

We used explainable AI to generate heatmaps characterizing how different regions of the brain looked younger or older than expected in individual participants

- Spatial information about deviant aging allowed us improve case-control classification in multiple disorders
- Triangulation between average heatmaps in different disorders revealed both common and disorder-specific patterns
- **Results exposed weaknesses of the methodology, emphasizing the importance of rigorous validation**