

Scanner-aware Causal Harmonization Of ADNI MRI For Alzheimer's Disease Detection

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1. Background & Motivation

- Scanner and acquisition variability in ADNI MRI introduces structured vendor-specific bias.
- These scanner effects can obscure subtle disease-related changes and hurt reproducibility.
- Conventional statistical and deep learning methods only partially mitigate scanner effects and may overfit to vendor signatures.
- Foundation vision-language models such as CLIP have strong representational power, but they need adaptation for MRI harmonization.
- Goal:** learn scanner-agnostic, anatomy-driven representations for Alzheimer's disease detection.

2. ADNI Data & Experimental Setup

ADNI T1-weighted MRI

GE Philips Siemens

Central Axial (± 2) Coronal Sagittal

- Dataset:** ADNI T1-weighted MRI.
- Scanner vendors:** GE, Philips, Siemens.
- Per subject,** 5 diagnostically informative slices were used: central axial with adjacent slices, plus central coronal and sagittal views.
- Preprocessing:** min-max normalization and 240×240 resizing.
- Task:** CN vs AD classification.
- Evaluation:** 5-fold cross-validation.

3. Key Contributions

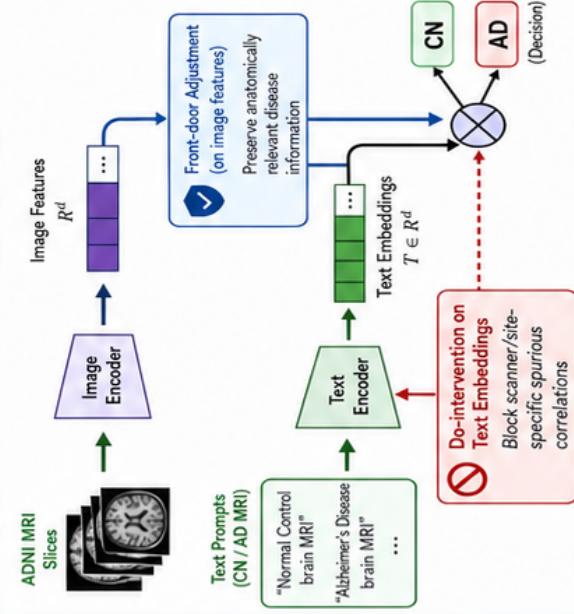
- Introduces CausalCLIP for scanner-aware harmonization of ADNI MRI.
- Uses causal adaptation to suppress scanner/site confounding while preserving disease-relevant anatomy.
- Produces more scanner-invariant and disease-discriminative embeddings for AD detection.

6. Conclusion

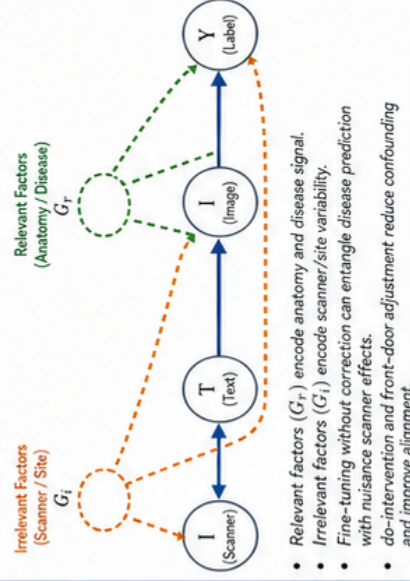
This study presents the first application of a foundation vision-language model for MRI scanner harmonization in AD research.

CausalCLIP disentangles disease-relevant anatomy from scanner-related variability.

4. Method Overview: CausalCLIP for ADNI MRI



Causal Perspective



- Relevant factors (G_r) encode anatomy and disease signal.
- Irrelevant factors (G_i) encode scanner/site variability.
- Fine-tuning without correction can entangle disease prediction with nuisance scanner effects.
- do-intervention and front-door adjustment reduce confounding and improve alignment.

Why Causal Harmonization?

- Prevents over-reliance on scanner-specific signatures.
- Encourages scanner-invariant, anatomy-driven features.
- Improves generalization across MRI vendors.

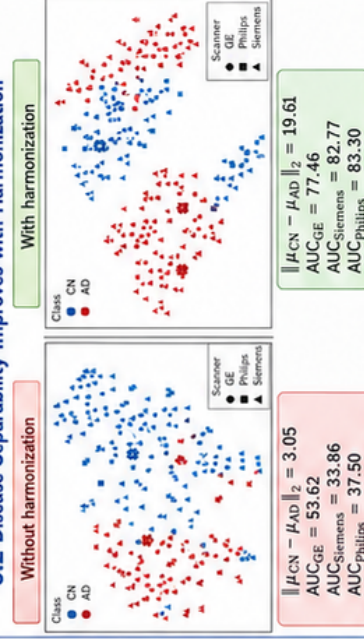
5. Results

5.1 Overall Performance (AUC)

Vendor	AUC (Mean $\pm$ SE)
GE	77.46 $\pm$ 0.11
Philips	83.30 $\pm$ 0.06
Siemens	82.77 $\pm$ 0.07
Overall mean	80.41 $\pm$ 0.05

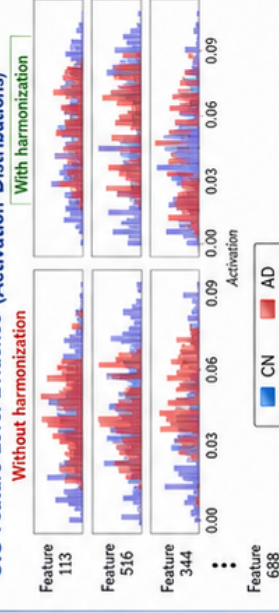
★ Best overall mean AUC: 80.41 $\pm$ 0.05

5.2 Disease Separability Improves with Harmonization



t-SNE projections of slice-level CLIP embeddings. Harmonization yields much stronger CN-AD separation and better vendor-specific AUCs.

5.3 Feature-Level Evidence (Activation Distributions)



Histograms of selected CLIP embedding dimensions across GE (blue), Philips (green) and Siemens (red) scanners (overlaid). After harmonization, scanner-dependent shifts are reduced while CN-AD separation is preserved.

7. Take-Home Message



Causal harmonization helps CLIP focus on Alzheimer's disease biology rather than scanner identity, improving robustness across ADNI MRI vendors.