

A Geometric Self-Supervised Learning Framework for Multimodal Alignment of PET and MRI Brain Connectomes

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ABSTRACT

Background: Mapping the metabolic landscapes of the brain onto its structural and functional network topologies remains a fundamental challenge in computational neuroscience. While Magnetic Resonance Imaging (MRI) provides high-resolution connectomic scaffolds, Positron Emission Tomography (PET) captures critical metabolic dynamics. Existing approaches often treat these modalities independently, failing to capture the complex, non-linear geometric relationships between metabolic activity and structural connectivity.

Methods: We propose a novel multimodal self-supervised learning (SSL) framework designed to directly register and align PET-derived connectomes with MRI-derived diffusion models. By conceptualizing the brain as a complex network embedded in a geometric space, our approach projects both PET and MRI topological features into a shared latent manifold. Utilizing a contrastive learning objective, the model maximizes the mutual information between the metabolic nodes and structural edges, enabling cross-modal inference without the need for extensive annotated datasets.

Expected Outcomes & Ongoing Work: Our preliminary pipeline establishes a robust topological mapping that preserves the global network architecture while capturing local metabolic variations. As an ongoing expansion of our validated simulation-based inference framework for MRI, the integration of PET data aims to decode context-dependent, non-linear algorithms underlying brain function.

Significance: This multimodal geometric framework bridges the gap between static structural connectomics and dynamic metabolic activity. By providing a scalable, unsupervised method for cross-modality registration, this work lays the critical computational foundation for holistic whole-brain functional modeling and advanced disease prediction.

Keywords: *Multimodal Connectomics, Self-Supervised Learning, PET, MRI Diffusion Models, Network Topology, Geometric Deep Learning.*

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