Geometric Fragility in Alzheimer's Disease: Probing the Loss of Hippocampal Hierarchical Abstraction via Contrastive Point Cloud Modeling

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Abstract

While human spatial cognition relies on hierarchical abstraction to integrate local features, Alzheimer's disease (AD) pathology is often reduced to local volumetric atrophy. We propose geometric fragility as a distinct failure of global topological integrity within the hippocampus rather than mere accumulation of local errors. Using a texture-invariant point cloud framework, we contrasted local feature aggregation with global hierarchical attention as computational probes for structural perception. The global paradigm demonstrated enhanced diagnostic sensitivity and cognitive resilience under simulated neuronal sparsity, maintaining structural recognition where local models suffered pattern collapse. Global modeling effectively unfolded the pathological manifold, revealing a linear trajectory of geometric degradation consistently correlated with cognitive decline. These findings characterize AD progression as systemic topological dissolution and suggest biomarkers should prioritize hierarchical shape abstraction to map the continuous transition from healthy cognition to dementia. This brain-inspired computational framework offers a human-centric perspective on neurodegenerative diagnosis.

Keywords: Geometric Fragility, Hierarchical Abstraction, Hippocampal Topology, Cognitive Resilience, Manifold Unfolding

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