MAPS: A Dataset for Controlled Probing of Representational Topology in Vision Models

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Introduction

Neural activity is often low-dimensional and can exhibit topologies such as tori or spheres [1–2], but the topological structure of sensory representations during naturalistic stimulation remains poorly understood [3].

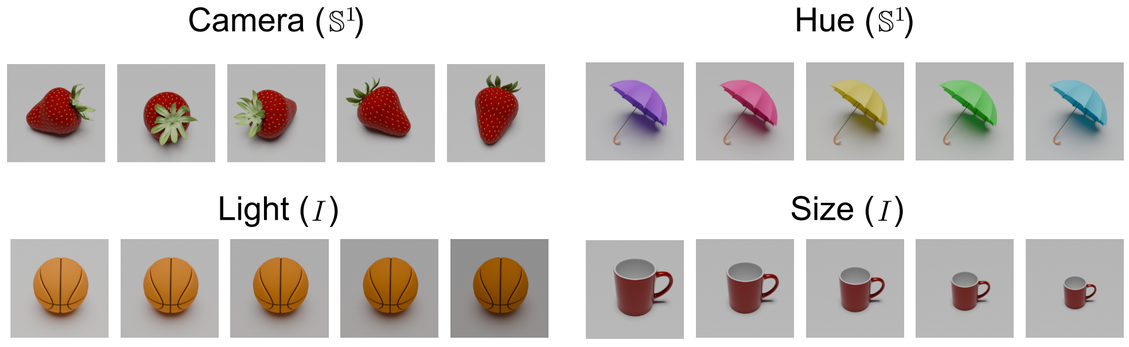
Here, we introduce MAPS (Manifolds of Artificial Parametric Scenes), a high-resolution dataset of controlled stimuli for probing representational topology in vision models.

Using MAPS and topological data analysis in ResNet-50, we show that early-layer activity patterns preserve topological structure present in the input space.

MAPS: A synthetic dataset for probing vision models

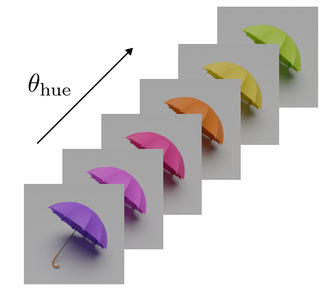
We created MAPS by importing 10 different 3D object models into Blender and generating controlled image sets with systematic variations in camera, hue, light, and size.

Each transformation defines its own underlying topology, and their combination forms a product manifold in the joint parameter space.

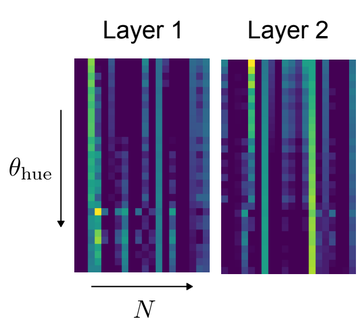


Pipeline: Extracting the topology from ANN activations

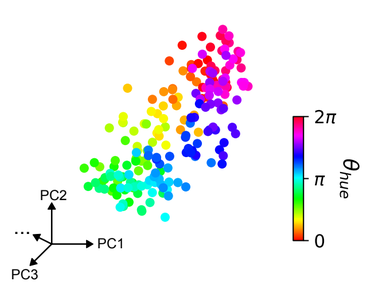
Using MAPS, we analyze the topology of image transformations by generating transformed images, extracting ANN activations across layers, and computing persistence diagrams on those activations. Here, we will generate parametric images for the umbrella class.



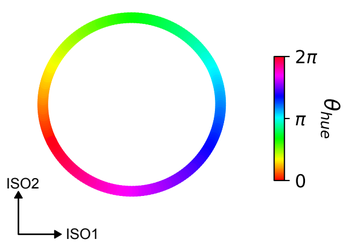
1. Render images of an object across a parametric transformation.



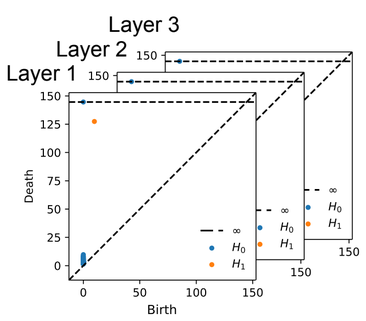
2. Extract activations for the images across layers of a model.



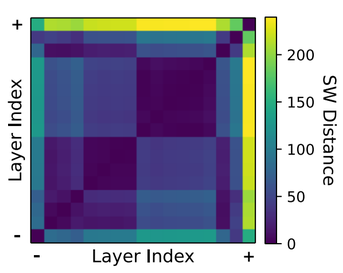
3. Reduce dimensionality using PCA (we retain first 10 components).



4. For visualization,we use isomap from the 10 PCA dimensions.



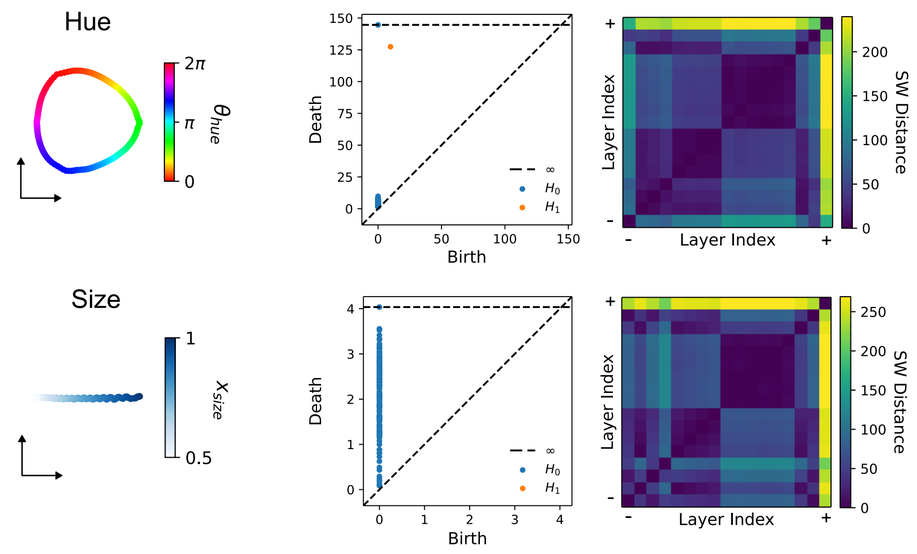
5. For each layer, generate the persistence diagram using the 10 PCA dimensions.



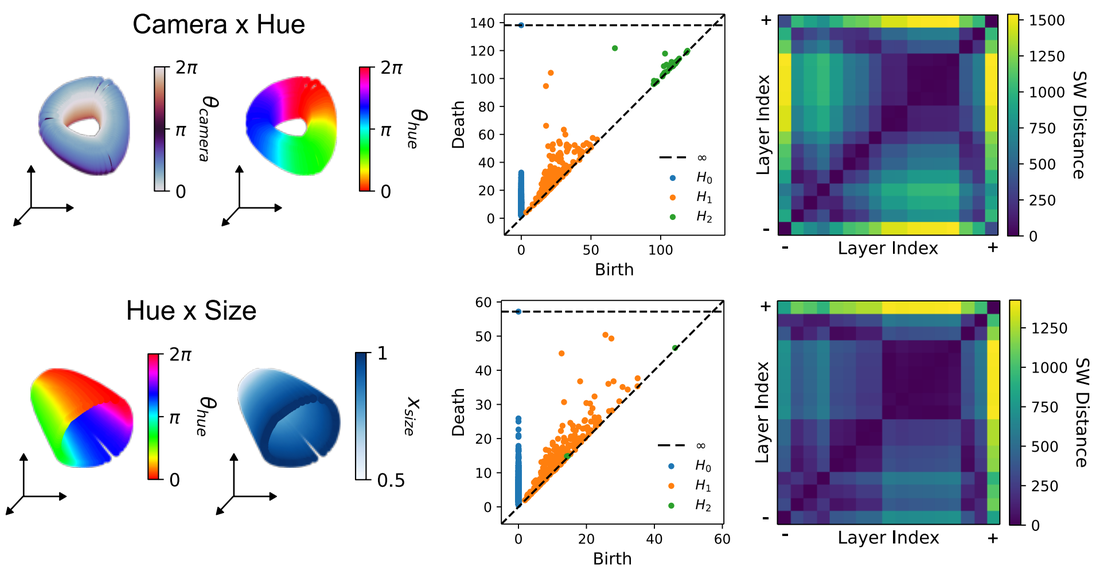
6. Calculate the distance matrix using the Sliced-Wasserstein (SW) between persistence diagrams.

The topology of transformations on ResNet-50

Early ResNet-50 layers reflect the underlying structure of the transformations, showing a hue ring and a linear manifold for size.



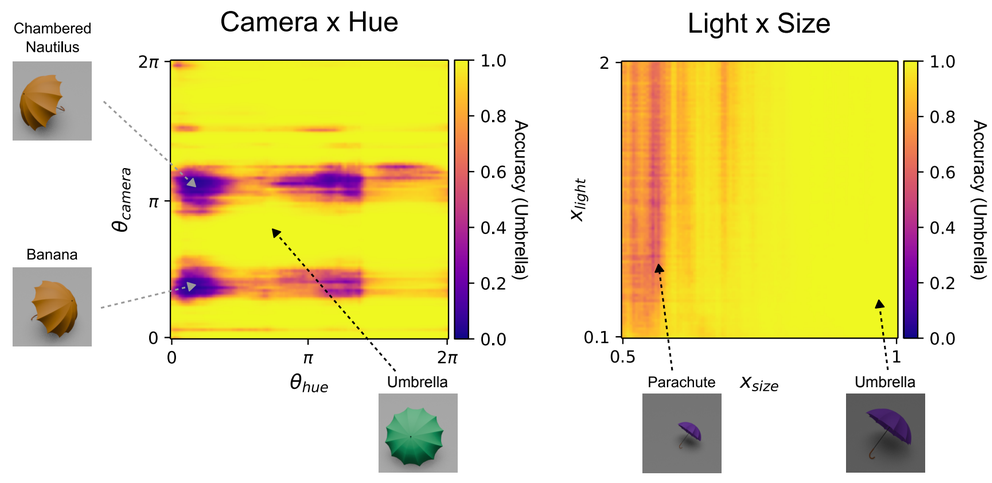
When transformations are combined, the activation patterns reveal the topological structure of the joint parameter space.



Conclusions

MAPS provides a controlled testbed to reveal how deep networks preserve and transform the underlying topology of individual and combined visual transformations.

In future work, we aim to link topology and geometry changes with prediction accuracy across the parameter space to understand their impact on model performance.



References

[1] Perich et al., 2025 [2] Gardner et al., 2022 [3] Singh et al., 2008

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